Leafy Spurge Control with Herbicides in North Dakota: 20-Year Summary

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Abstract

Leafy spurge (*Euphorbia esula* L.) control by herbicides can vary from year to year due to changing environmental conditions. Data from leafy spurge control experimental and demonstrational plots with 2,4-D [(2,4-dichlorophenoxy)acetic acid], dicamba (3,6-dichloro-*o*-anisic acid), picloram (4-amino-3,5,6-trichloropicolinic acid) and glyphosate [*N*-(phosphonomethyl)glycine] were combined from 1963 through 1982. The amine and ester formulations of 2,4-D provided similar leafy spurge control. 2,4-D at rates up to 4.5 kg/ha provided less than 40% control after 1 year, and annual (spring or fall) or biannual (spring and fall) 2,4-D applications did not increase leafy spurge control. Dicamba was most effective as a liquid formulation when spring applied and as a granular formulation when fall applied. Dicamba at 9.0 kg/ha was required for satisfactory leafy spurge control for 1 year. Picloram at 2.2 kg/ha gave over 90% control of leafy spurge for 2 growing seasons regardless of formulation or time of application. Synergistic weed control was observed when 2,4-D at 1.1 kg/ha or less was applied with dicamba or picloram at 0.6 kg/ha or less. These synergistic herbicide combinations are economical on many pasture and rangeland sites infested with leafy spurge. Fall-applied glyphosate at 0.8 kg/ha or more gave good control of established leafy spurge for 1 year in shelterbelts and as a spot treatment.

Leafy spurge (*Euphorbia esula* L.) is an introduced perennial weed that infests over 1 million hectares in North America (Dunn 1979). Leafy spurge was discovered in the United States in Newbury, Mass., in 1827 (Britton 1921) and by 1881 had extended west to Michigan (Hanson and Rudd 1933). In 1909 the plant was discovered growing along a Fargo, N. Dak., street (Hanson and Rudd 1933). Leafy spurge has spread via root and seed until it presently occupies nearly 349,000 hectares in North Dakota (Messersmith and Lym 1983). Leafy spurge now is centered in the northern Great Plains and Rocky Mountain areas of the United States and Prairie Provinces of Canada (Noble et al. 1979).

Leafy spurge has not been a problem in crop land due to repeated tillage operations, crop rotation, and the use of herbicides (Derscheid et al. 1960). However, the plant has become a serious problem in range and pastureland where it displaces useful forage and, if left unchecked, will render productive pastures useless. Also, leafy spurge contains a toxin which, when taken internally, is an irritant, emetic, and purgative (Selleck et al. 1962). The toxin causes scours and weakness in cattle and may result in death. Kingsbury (1964) reported inflammation and loss of hair on the feet of horses from walking in freshly mowed stubble during haying. Sheep will graze small plants but large plants are toxic (Johnston and Peake 1960). Most animals will eat the dried plants in hay but avoid eating growing plants (Krockmal 1952). Thus forage is lost due to both weed competition and avoidance of forage in leafy spurge infested areas.

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Herbicides have been the most successful method for leafy spurge control. However, perennial weed control by herbicides can vary from year to year depending on environmental conditions and experimental sites and a variable leafy spurge complex (Ebke and McCarty 1983). Perennial weed infestations also vary in density at various sites. Data obtained by averaging leafy spurge control from several areas and years should provide the best assessment of a herbicide's effectiveness for weed control. Data from experimental and demonstrational plots established by North Dakota State University were summarized for 2,4-D, dicamba, picloram, and glyphosate, which are the primary herbicides currently used for leafy spurge control.

Materials and Methods

Leafy spurge control by 2,4-D [(2,4-dichlorophenoxy) acetic acid], dicamba (3,6-dichloro-*o*-anisic acid), picloram (4-amino-3,5,6-trichloropicolinic acid) and glyphosate [*N*-(phosphonomethyl) glycine] in North Dakota was summarized from sites established between 1963 and 1982. Data were taken from 70 North Dakota Agricultural Experiment Station sites and 68 demonstration sites established by the North Dakota Cooperative Extension Service and summarized across years by herbicide formulations, rates, and season of application. The formulations in this summary included 2,4-D amines and esters, dicamba liquid and 5% granules, picloram liquid and 2% granules, and glyphosate. The liquid formulations were applied in water at 76 to 171 L/ha, except at a few demonstration sites which were treated in higher volumes.

Data for each treatment are means of percent control based on visual or stand count observations. Each plot evaluated was considered an observation. Thus an experiment with 4 replications had 4 observations per treatment, while a demonstration with 2 replications at 12 sites had 24 observations. The data were analyzed using the General Linear Models procedure (SAS Institute 1982). The number of observations per mean is presented in parentheses as an additional guide to the probable reliability of each mean. The data were divided into spring or fall applied treatments. Spring treatments were applied in late May and June, while applications from mid-August through September were considered fall treatments. Experiments containing biannual treatments had herbicides applied twice per year in both the spring and fall. Annual and biannual treatments applied for 2 or more years used only the liquid formulation and did not distinguish between the 2,4-D amine and ester formulations.

Results and Discussion

2,4-D

The 2,4-D amine and ester formulations gave similar leafy spurge control when evaluated 3 and 12 months after spring treatment (Table 1). Leafy spurge control at 3 months after a spring application averaged across 2,4-D at 0.6 through 2.2 kg/ha was 49 and 51% for the amine and ester formulations, respectively. The comparable mean after 12 months was 17 and 22% leafy spurge

Table 1. Leafy spurge control with 2,4-D as amine and ester formulations either spring or fall applied in North Dakota.

Season and rate	Months after treatment 3/9[1] Amine	3/9[1] Ester	12 Amine	12 Ester
(kg/ha)	(%)			
Spring				
0.6	53(16)[2]	48(16)	6(8)	23(4)
0.8	50(8)	55(8)	.....	10(4)
1.1	43(116)	51(81)	5(16)	11(8)
1.7	47(108)	48(92)	.....	30(4)
2.2	51(47)	51(143)	39(44)	38(50)
LSD (0.05) Rate × Form	12		Non-est[3]	
Fall				
1.1	19(24)	19(8)	4(12)	14(8)
2.2	18(14)	21(8)	0(12)	11(8)
4.5	26(12)	15(8)	8(8)	2(12)
LSD (0.05) Rate × Form	12		Non-est	

[1]Spring applied treatments were evaluated at the end of the same summer (3 months) and fall applied treatments were evaluated after the winter (9 months).
[2]Numbers in ( ) are the number of observations in the mean.
[3]Non-estimable due to insufficient number of similar experiments across all means.

control for the amine and ester formulations, respectively. Leafy spurge control was similar for 2,4-D amine and ester formulations when fall applied also. However, spring applications resulted in slightly increased long-term control compared to fall application. Leafy spurge control at 12 months averaged from 2,4-D amine at 1.1 to 2.2 kg/ha was 22 and 2% when spring and fall applied, respectively. No advantage was detected for applying 2,4-D ester or amine at greater than 0.8 kg/ha. However, the authors suggest using both formulations of 2,4-D at 1.1 to 1.7 kg/ha until enough additional observations are obtained to demonstrate that lower 2,4-D rates will provide consistent leafy spurge control and improved forage production.

Biannual 2,4-D applications generally did not provide greater leafy spurge control than the initial treatment (Table 2). Leafy

Table 2. Leafy spurge control with 2,4-D, dicamba or picloram applied both spring and fall for several growing seasons in North Dakota.

Herbicide and rate	Months after first treatment 3	12	15	24	27
(kg/ha)	(%)				
2,4-D					
1.1	48(197)[1]	38(50)	43(47)	65(28)	.....
1.7	47(108)	65(54)	50(35)	49(28)	.....
2.2	50(190)	45(78)	58(102)	72(8)	55(12)
LSD (0.05)	13	28	Non-est[2]	Non-est	Non-est
Dicamba					
0.6	47(34)	49(14)	39(14)	45(12)	52(8)
1.1	50(34)	57(18)	55(10)	58(12)	68(8)
LSD (0.05)	20	4	Non-est	Non-est	Non-est
Picloram					
0.3	56(41)	67(18)	69(10)	72(18)	82(14)
0.6 (Spring applied only)	58(62)	72(18)	87(10)	81(8)	86(8)
LSD (0.05)	16	12	11	Non-est	Non-est

[1]Numbers in ( ) are the number of observations in the mean.
[2]Nonestimable due to insufficient number of similar experiments across all means.

spurge control averaged from 2,4-D at 1.1 through 2.2 kg/ha was 48% after 1 treatment (3 months) and 62% after 4 treatments (24 months). Generally leafy spurge control was not enhanced by increasing the 2,4-D rate from 1.1 to 1.7 or 2.2 kg/ha in a biannual treatment program.

Both annual and biannual 2,4-D treatments provided similar leafy spurge control after 3 months (Table 1, 2). Leafy spurge control at 12 months declined substantially following a single 2,4-D application, while biannual 2,4-D treatments maintained the initial level of weed control. However, Bybee and Messersmith (1976) reported that leafy spurge reestablished to the original density within 1 year after discontinuation of treatments that had been applied biannually for 4.5 years. Both annual and biannual 2,4-D applications should eliminate seed production and greatly reduce or prevent a leafy spurge stand from expanding until treatments are discontinued. Annual 2,4-D applications for leafy spurge control provide nearly a 40% increase in forage production over untreated areas (Lym and Messersmith 1983), and presumably biannual 2,4-D applications would provide a similar increase in forage production.

Dicamba

Leafy spurge control with dicamba has included the liquid and granular formulations alone, dicamba in combination with 2,4-D and dicamba biannual treatments. Leafy spurge control with spring applied dicamba increased as the application rate increased regardless of formulation (Table 3). Control with dicamba liquid

Table 3. Leafy spurge control with dicamba spring applied as liquid and granular formulations in North Dakota.

Rate	Formulation	Months after treatment 3	12	15	24	27
(kg/ha)		(%)				
0.6	Liquid	47(34)[1]	18(8)	...	...	...
1.1	Liquid	50(34)	8(32)	4(20)	3(10)	...
1.1	5% Granule	10(7)	10(7)	5(3)	...	...
2.2	Liquid	42(16)	21(12)	...	14(10)	...
2.2	5% Granule	24(7)	37(12)	8(3)	...	...
4.5	Liquid	79(85)	64(58)	57(54)	10(4)	64(28)
4.5	5% Granule	59(8)	53(18)	21(14)	9(12)	3(8)
6.7	Liquid	82(17)	69(17)	53(33)	22(6)	...
9.0	Liquid	93(25)	80(47)	65(41)	35(16)	12(8)
9.0	5% Granule	92(8)	78(20)	53(14)	34(12)	10(19)
13.4	Liquid	100(8)	96(8)	78(7)	...	...
13.4	5% Granule	97(8)	94(8)	75(8)	...	...
LSD (0.05)		13	12	11	Non-est[2]	Non-est

[1]Numbers in ( ) are the number of observations in the mean.
[2]Non-estimable due to insufficient number of similar experiments across all means.

averaged 47% at 0.6 kg/ha and 100% at 13.4 kg/ha when evaluated 3 months after treatment. Dicamba spring-applied generally provided better control as the liquid than granular formulation at comparable rates. Leafy spurge control, averaged across dicamba at 1.1 through 13.4 kg/ha, with the liquid and granular formulations was 74 and 56% at 3 months and 51 and 32% at 15 months, respectively.

Dicamba granules provided better long-term leafy spurge control than the liquid formulation when fall applied at similar rates (Table 4). The mean across dicamba at 4.5 through 9.0 kg/ha was 62 and 38% leafy spurge control for the granular and liquid formulations, respectively, after 12 months. Leafy spurge control averaged 62 and 71% at 12 months for fall applied granules and spring applied liquid formulations of dicamba, respectively, at 4.5 to 9.0 kg/ha (Table 3, 4). In general dicamba must be applied at 9.0 kg.ha or more as a liquid formulation in the spring and granular formulation in the fall to obtain good leafy spurge control for at least 12 months in North Dakota.

Dicamba at 0.6 kg/ha applied biannually maintained leafy spurge control from 47% at 3 months to 52% at 27 months, while similar treatments with dicamba at 1.1 kg/ha increased leafy spurge control slightly from 50 to 68%, respectively (Table 2). Biannual applications of dicamba at 1.1 kg/ha meant that a total of

Table 4. Leafy spurge control with dicamba fall applied as liquid and granular formulations in North Dakota.

Rate	Formulation	Months after treatment 9	12	21	24
(kg/ha)		(%)			
0.6	Liquid	35(10)[1]	31(8)	8(4)	...
1.1	Liquid	29(23)	7(16)	9(5)	...
4.5	Liquid	90(10)	30(6)	18(5)	...
4.5	5% Granule	80(18)	44(8)	34(7)	31(4)
6.7	Liquid	88(14)	28(8)	63(3)	...
6.7	5% Granule	84(18)	66(8)	68(7)	58(4)
9.0	Liquid	97(14)	55(10)	53(9)	97(4)
9.0	5% Granule	98(14)	77(15)	62(7)	83(4)
11.2	Liquid	98(3)	...	85(3)	...
LSD (0.05)		7	24	17	Non-est[2]

[1]Numbers in ( ) are the number of observations in the mean.
[2]Non-estimable due to insufficient number of similar experiments across all means.

5.5 kg of dicamba had been applied to these plots in 27 months, and the control of 68% at 27 months was similar to the 64% with dicamba at 4.5 kg/ha applied once (Table 3). Thus, an advantage was not detected for applying dicamba at lighter rates twice yearly for several years compared to a larger rate applied once.

Leafy spurge control with a single treatment was better with dicamba plus 2,4-D than dicamba alone at similar dicamba rates after 3 months, but control generally was similar after 12 months (Table 5). When averaged across dicamba at 0.6 through 2.2 kg/ha, leafy spurge control after 3 months was 47% with dicamba alone compared to 91% with dicamba plus 2,4-D. The comparable means after 9 months were 51 and 59% control, respectively. There was an initial top growth control advantage with dicamba plus 2,4-D, but the plants recovered by the following growing season.

Dicamba plus 2,4-D as biannual treatments for 2 years improved leafy spurge control over either herbicide used alone at similar rates. Leafy spurge control at 27 months from biannual applications of 2,4-D alone at 2.2 kg/ha was 55% (Table 2) and with dicamba alone at 0.6 kg/ha was 33% (Table 5), but control

Table 5. Leafy spurge control with dicamba plus 2,4-D and picloram plus 2,4-D combination treatments in North Dakota.

Herbicides and rate		Months after first treatment 3	9	12	15	21	24	27
(kg/ha)					(%)			
Single treatment[1]								
Dicamba + 2,4-D								
0.6	0	47(20)[1]	35(11)	24(16)	...	...	...	...
0.6	1.7	89(3)	38(4)	22(7)	5(3)	22(3)	...	...
1.1	0	50(34)	29(33)	8(48)	4(20)	9(5)	3(10)	...
1.1	3.4	92(3)	61(3)	30(3)	3(3)	22(3)	...	...
2.2	0	43(16)	90(3)	21(12)	...	33(3)	14(10)	...
2.2	6.7	...	77(3)	...	...	33(3)	...	...
LSD (0.05)		18	17	4	Non-est[3]	Non-est	Non-est	
Picloram + 2,4-D								
0.14	0	29(4)	...	38(4)	...	...	...	...
0.14	0.14	98(4)	...	28(4)	...	...	...	...
0.3	0	56(41)	20(20)	22(37)	5(19)	...	...	...
0.3	1.1	68(20)	39(8)	64(8)	18(8)	...	...	...
0.3	1.7	74(8)	41(8)	47(4)	...	...	...	...
0.3	2.2	73(8)	52(8)	36(4)	...	...	...	...
0.6	0	58(62)	53(24)	50(62)	23(30)	...	3(4)	1(4)
0.6	1.1	85(29)	71(8)	87(33)	7(4)	...	...	...
0.6	1.7	91(8)	73(8)	79(4)	...	...	...	...
0.6	2.2	93(8)	66(8)	93(4)	...	...	...	...
LSD (0.05)		18	Non-est	10	Non-est	Non-est	Non-est	Non-est
Retreatments								
Dicamba + 2,4-D applied biannually								
0.6	0	47(34)	...	49(19)	38(14)	...	45(8)	33(12)
0.6	2.2	68(18)	...	69(10)	84(14)	...	65(8)	70(12)
1.1	0	50(34)	...	57(10)	70(14)	...	58(8)	73(12)
1.1	2.2	53(14)	...	58(10)	65(10)	...	68(8)	71(8)
LSD (0.05)		15		Non-est	23		Non-est	Non-est
Picloram + 2,4-D applied annually								
0.3	0	56(41)	20(20)	56(16)	...	...	...	...
0.3	0.3	79(14)	...	84(14)	80(14)	...	83(12)	83(12)
0.3	1.1	62(20)	39(8)	45(16)	...	...	...	...
0.3	1.7	74(8)	41(8)	57(20)	...	...	...	...
0.3	2.2	73(8)	52(8)	53(12)	...	...	...	...
0.45	0	78(4)	49(20)	66(8)	...	...	...	...
0.45	1.1	67(4)	59(8)	70(8)	...	...	...	...
0.45	1.7	61(4)	66(8)	70(8)	...	...	...	...
0.45	2.2	64(4)	54(8)	74(8)	...	...	...	...
0.6	0	58(62)	56(24)	72(18)	87(10)	...	81(8)	86(8)
0.6	1.1	88(31)	71(8)	84(39)	84(26)	...	86(12)	89(12)
0.6	1.7	91(8)	73(8)	68(12)	...	...	...	...
0.6	2.2	93(8)	66(8)	83(12)	...	...	...	...
LSD (0.05)		8	Non-est	16	17		Non-est	Non-est

[1]Treatment applied once in spring or fall.
[2]Numbers in ( ) are the number of observations in the mean.
[3]Non-estimable due to insufficient number of similar experiments across all means.

increased to 70% when dicamba plus 2,4-D at 0.6 plus 2.2 kg/ha was applied as a combination treatment. The combination of dicamba plus 2,4-D at 1.1 plus 2.2 kg/ha did not have a synergistic effect over biannual treatments of dicamba at 1.1 kg/ha alone throughout the 27 month period.

Dicamba and 2,4-D at rates of 0.6 to 2.2 kg/ha generally provided less than 40% leafy spurge control after 1 year, so single treatments of these herbicides only are a short-term management tool (Table 1, 3, 4). The treatment of choice under these conditions would be 2,4-D because it is less expensive than dicamba. However, dicamba has an advantage over 2,4-D at high application rates, because leafy spurge control increased as the dicamba rate was increased whereas increasing the 2,4-D rate above 1.7 kg/ha did not increase weed control. A biannual application of dicamba plus 2,4-D at 0.6 plus 2.2 kg/ha maintained approximately 70% leafy spurge control, which was comparable to a single application of dicamba at 4.5 to 9.0 kg/ha (Table 3, 4, 5). Similar to 2,4-D, forage yield increased by 42% when leafy spurge was controlled with dicamba (Lym and Messersmith 1983).

Picloram

Picloram has been evaluated for leafy spurge control in North Dakota since 1964. Picloram at 2.2 kg/ha has given 77% leafy spurge control at 27 months when spring applied as the liquid formulation (Table 6). Picloram granules at 2.2 kg/ha averaged only 62% control at 3 months, which probably was due to inadequate moisture for herbicide activation during the summer months, but thereafter the liquid and granular formulations gave similar leafy spurge control up to 24 months. Picloram at 1.1 and 1.7 kg/ha gave good leafy spurge control for 12 months, but control decreased rapidly thereafter. Picloram applied at rates less than 1.1 kg/ha did not give satisfactory long-term leafy spurge control. Picloram generally provided similar leafy spurge control regardless of formulation at comparable rates. Leafy spurge control averaged across picloram at 0.6 through 2.2 kg/ha was 78 and 85% at 12 months and 35 and 43% at 24 months for the liquid and granular formulations, respectively.

Picloram gave similar leafy spurge control when fall applied compared to spring applications after 24 months, but initial control generally was lower with the fall applications (Table 6, 7). Picloram spring applied at 1.1 to 2.2 kg/ha gave 89 and 55% leafy spurge control at 12 and 24 months, respectively, and comparable fall applied treatments had 70 and 60% control, respectively. Picloram at 4.5 kg/ha gave excellent leafy spurge control but caused considerable grass injury. Generally, leafy spurge control remained above 80% for 12 to 15 months when picloram was applied at 1.1 kg/ha and for 24 to 27 months when applied at 2.2 kg/ha. Once leafy spurge control declined to 70% or less, the stand density increased rapidly thereafter regardless of original picloram treatment.

Table 6. Leafy spurge control with picloram spring applied as liquid and granular formulations in North Dakota.

Rate	Formulation	Months after treatment 3	12	15	24	27
(kg/ha)		(%)				
0.3	Liquid	56(49)[1]	30(27)	5(19)	...	...
0.6	Liquid	58(34)	63(46)	23(30)	3(4)	1(4)
0.6	2% Granule	73(4)	62(8)	5(4)	0(8)	0(4)
1.1	Liquid	76(45)	74(73)	68(62)	21(14)	25(4)
1.1	2% Granule	58(13)	86(42)	59(38)	39(8)	20(18)
1.7	2% Granule	92(16)	92(12)	85(32)	62(12)	53(6)
2.2	Liquid	93(73)	96(110)	91(97)	82(26)	77(10)
2.2	2% Granule	62(13)	98(41)	89(41)	69(22)	71(18)
4.0	2% Granule	96(17)	98(17)	92(17)	...	...
LSD (0.05)		13	11	12	26	38

[1]Number in ( ) are the number of observations in the mean.

Table 7. Leafy spurge control with picloram fall applied as liquid and granular formulations in North Dakota.

Rate	Formulation	Months after treatment 9	12	21	24	33
(kg/ha)		(%)				
0.3	Liquid	14(16)[1]	0(10)	...	...	...
0.6	Liquid	53(24)	13(16)	...	...	...
1.1	Liquid	83(60)	67(51)	61(15)	44(13)	19(9)
1.1	2% Granule	67(16)	43(20)	54(10)	44(10)	...
2.2	Liquid	99(46)	80(38)	95(21)	82(13)	74(9)
2.2	2% Granule	96(24)	89(24)	73(10)	71(10)	...
4.5	Liquid	100(8)	100(8)	100(4)	100(4)	...
4.5	2% Granule	100(8)	100(8)	100(4)	100(4)	...
LSD (0.05)		19	17	42	37	Non-est[2]

[1]Number in ( ) are the number of observations in the mean.
[2]Non-estimable due to insufficient number of similar experiments across all means.

Biannual treatments of picloram at low rates gradually decreased leafy spurge infestations over time (Table 2). Picloram at 0.3 kg/ha applied biannually or at 0.6 kg/ha applied annually for 2 consecutive seasons provided 82 and 86% control, respectively, after 27 months (Table 2), which is similar to picloram at 2.2 kg/ha applied once (Table 6). When picloram was applied at 0.3 kg/ha biannually, a total of 1.1 kg/ha of picloram had been applied after 2 years and provided 72% control at 24 months (Table 2); however, a single application of picloram at 1.1 kg/ha spring applied only provided 21% control at 24 months (Table 6) or fall applied only provided 44% control at 24 months (Table 7).

Leafy spurge control was better with a single treatment of picloram plus 2,4-D than picloram alone when the picloram rate did not exceed 0.6 kg/ha (Table 5). The mean for picloram applied at 0.3 and 0.6 kg/ha was 57 and 36% leafy spurge control at 3 and 12 months, respectively, compared to 77 and 76% control, respectively, when 2,4-D at 1.1 kg/ha was applied with the picloram. No benefit was detected for applying 2,4-D at greater than 1.1 kg/ha with picloram. Leafy spurge control with picloram at 1.1 kg/ha or more was not improved by adding 2,4-D (data not presented).

Annual treatment with picloram plus 2,4-D generally gave better leafy spurge control than picloram alone (Table 5). The largest increase in leafy spurge control occurred when picloram at 0.3 kg/ha was applied with 2,4-D at 0.3 kg/ha. Leafy spurge control with picloram at 0.3 kg/ha was 56% after 12 months compared to 84% control when 2,4-D at 0.3 kg/ha was added to the treatment. A 2,4-D rate greater than 0.3 kg/ha did not increase leafy spurge control when applied annually with picloram. Annual application of picloram at 0.6 kg/ha gradually decreased leafy spurge stands but control was not improved by adding 2,4-D after the initial treatment. The greatest potential for synergism between picloram and 2,4-D for leafy spurge control occurred in a range of picloram at 0.3 to 0.6 kg/ha and 2,4-D at 0.3 to 1.1 kg/ha.

Picloram at 0.3 to 0.6 kg/ha, dicamba at 0.6 to 2.2 kg/ha, and 2,4-D at 1.1 to 2.2 kg/ha generally provided similar control for 12 months (Table 1, 3, 6), but follow-up treatments would be required to maintain weed control. Repeat annual treatments with picloram have continued to reduce the leafy spurge density, whereas the repeat of 2,4-D and dicamba treatments have only maintained the leafy spurge control obtained by the initial treatment (Table 2, 5). Leafy spurge control with annual picloram treatments generally has resulted in a 60% increase in forage production (Lym and Messersmith 1983).

The two synergistic combinations of picloram combinations of picloram plus 2,4-D at 0.3 plus 1.1 kg/ha applied annually and dicamba plus 2,4-D at 0.6 plus 2.2 kg/ha applied biannually have provided similar control for 12 months (Table 5), but the picloram plus 2,4-D annual treatment generally provides better control after repeat applications than the dicamba plus 2,4-D biannual treat-

ment. Both synergistic combinations would be more economical for the leafy spurge control obtained than a single application of picloram at 2.2 kg/ha or dicamba at 9 kg/ha; the latter treatments are the maximum labeled rate for the liquid formulation of each herbicide.

Some areas infested with leafy spurge are not easily accessible, so an annual or biannual herbicide treatment program is impractical. Also, leafy spurge eradication is a logical objective when a new infestation is spotted before the weed has developed an extensive root system. In these situations, picloram at 2.2 kg/ha should provide at least 80 to 90% leafy spurge control for 15 to 24 months in North Dakota, whereas dicamba at 9 kg/ha has provided similar control for only 12 to 15 months. Leafy spurge control by picloram and dicamba generally have been maintained at 80% or more for 12 to 15 months longer in Wyoming than North Dakota, based on reports by Alley et al. (1983). Leafy spurge control declines rapidly with both herbicide treatments when the control falls below about 80% so retreatment would be necessary. Generally, dicamba provides shorter residual leafy spurge control and is more expensive than picloram, but dicamba has a shorter residual in soil and water than picloram. The environmental advantages of dicamba may be the most important consideration at some leafy spurge infested sites.

Glyphosate

Spring applications of glyphosate generally gave leafy spurge control of 30 to 40% (data not presented); however, fall applications of glyphosate at 0.8 to 2.2 kg/ha averaged 76% control after 12 months (Table 8). Glyphosate applied at rates greater than 0.8 kg/ha provided only small increases in control. Further, the cost of herbicide would negate the benefit from more than 0.8 kg/ha of glyphosate. Control decreased rapidly after 12 months regardless of the original application rate, primarily due to leafy spurge seedling establishment since glyphosate is non-selective and does not have a soil residual. An application of 2,4-D at 0.3 to 0.6 kg/ha is necessary the following spring to control seedlings. Glyphosate is nonselective, so it is useful as a spot treatment or in shelterbelts but cannot be used in pasture or rangeland.

Table 8. Leafy spurge control with glyphosate fall applied in North Dakota.

Rate	Months after treatment		
	9	12	21
(kg/ha)	(%)		
0.3	18(9)[1]	...	...
0.6	66(21)	...	...
0.8	87(21)	78(3)	12(3)
1.1	87(37)	66(7)	10(3)
1.7	83(13)	89(4)	...
2.2	92(20)	91(7)	8(3)
LSD (0.05)	6	47	Non-est[2]

[1]Numbers in ( ) are the number of observations in the mean.
[2]Non-estimable due to insufficient number of similar experiments across all means.

An overview of these experiments suggests that leafy spurge can be controlled for varying lengths of time depending on the herbicide treatment used. Eradication was not obtained with any treatment on established leafy spurge stands, although we have observed eradication of new leafy spurge patches that have not developed an extensive root system. Leafy spurge has deep roots with buds that can produce new shoots from 60 cm or more (Selleck et al. 1962), so a herbicide treatment can give visible eradication for 24 months or more before the new shoots emerge. Also, leafy spurge produces seed that can remain viable for at least 8 years, and seedlings can develop perennial characteristics by the time the plant has 6 to 10 leaves (Selleck et al. 1962). Thus, eradication of both roots and seed requires a thorough control program for several years.

Summary

2,4-D provided less than 40% leafy spurge control after 1 year when applied at rates up to 4.5 kg/ha in the spring or fall. 2,4-D as a biannual treatment did not decrease leafy spurge density more than the original treatment. The amine and ester formulations of 2,4-D gave similar leafy spurge control and cannot be expected to reduce the original stand for more than 1 year.

Dicamba at 9.0 kg/ha or more gave satisfactory control of leafy spurge for 1 year, but control decreased rapidly the second year regardless of formulation used or time of application. Dicamba liquid gave slightly better leafy spurge control than granules when applied in the spring at similar rates, but granules were better than the liquid formulation as a fall application. Biannual applications of low rates of dicamba decreased leafy spurge stands over time, but control was similar to that from a high rate applied once. Leafy spurge control improved with annual treatments of 2,4-D plus dicamba alone when the dicamba rate did not exceed 0.6 kg/ha.

Picloram at 2.2 kg/ha gave over 80% control of leafy spurge for 2 growing seasons regardless of formulation or time of application. Leafy spurge control with picloram was similar when spring and fall applied for both liquid and granular formulations. Biannual treatments of picloram at 0.3 kg/ha and annual treatments at 0.6 kg/ha decreased leafy spurge stands similar to 2.2 kg/ha applied once. The combination treatment of picloram at 0.3 to 0.6 kg/ha plus 2,4-D at 0.3 to 1.1 kg/ha provided greater leafy spurge control than picloram applied alone at the same rates. An annual application of the picloram plus 2,4-D combination would be a practical and economical treatment for leafy spurge control on many pasture and rangeland sites.

Fall applied glyphosate at 0.8 kg/ha or more has given good control of established leafy spurge for 1 year in shelterbelts and as a spot treatment. However, an application of 2,4-D at 0.3 to 0.6 kg/ha is needed the following spring to control leafy spurge seedlings.

A consistent theme throughout this summary is that leafy spurge cannot be eradicated with a single herbicide treatment. However, there are herbicide combinations that will substantially reduce the leafy spurge stand using comparatively economical treatments. Eradication of leafy spurge should be possible if the landowner is committed to being more persistent than the weed. Unfortunately, none of the experiments in North Dakota have been continued for the 5 to 10 consecutive years that probably are required to eradicate an established leafy spurge stand.

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