

Leafy Spurge Control and Herbicide Residue From Annual Picloram and 2,4-D Application

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Abstract

Annual application of picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid) and picloram plus 2,4-D [(2,4-dichlorophenoxy)acetic acid] and biannual application of 2,4-D for 5 consecutive years was evaluated for leafy spurge (*Euphorbia esula* L.) control. The picloram treatments were evaluated for soil residue. The experiment was located at 2 sites in eastern North Dakota and 1 site in western North Dakota on various soil types. Picloram at 0.28, 0.42, and 0.56 kg/ha provided 48, 75, and 90% leafy spurge control after 4 annual treatments, respectively. Control increased to 85 and 91% when 2,4-D at 1.1 kg/ha was added to the annual treatment of picloram at 0.28 and 0.42 kg/ha, respectively. However, 2,4-D with picloram at 0.56 kg/ha did not increase leafy spurge control compared to picloram alone.

Picloram did not accumulate in the upper 15 cm of the soil profile and generally was not detected above the 2 ppbw level 12 months following each annual application. Greater picloram residue was found deeper in sandy than clay soil and in soil with high compared to low organic matter. Picloram at 500 and 250 ppbw was required to reduce leafy spurge seedling emergence and subsequent survival by 50%, respectively. However, picloram at 125 ppbw reduced leafy spurge regrowth from root segments of 4 lengths to near zero. Picloram at 8 to 32 ppbw stimulated leafy spurge seedling emergence compared to the control. Annual application of picloram at low rates gradually controlled leafy spurge, but picloram soil residues were not high enough to control subsequent seed germination and shoot regrowth from roots.

Key words: herbicide interaction, *Euphorbia esula* L., HPLC

Picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid) is the most effective herbicide for control of leafy spurge (*Euphorbia esula* L.) (Lym and Messersmith 1985a). Picloram at 2.2 kg/ha has given 80% leafy spurge control 27 months after application in North Dakota and for 36 to 39 months in Wyoming (Alley et al. 1983). The cost of picloram at 2.2 kg/ha is often 50% or more of the total land value and 8 to 10 times higher than the cash rent value of pasture and rangeland (Johnson 1984). Thus, it often is not economical to control leafy spurge with high rates of picloram on large infestations in pasture and rangeland.

2,4-D [(2,4-dichlorophenoxy)acetic acid] dimethylamine at 1.1 kg/ha enhanced leafy spurge control when applied with picloram at 0.6 kg/ha or less (Lym and Messersmith 1985a). Annual treatment of picloram at 0.3 to 0.6 kg/ha with 2,4-D at 0.3 to 1.1 kg/ha gradually improved leafy spurge control to 80% or better after 3 years. This combination treatment also increased forage production up to 71% and reduced leafy spurge yield by 96% after 3 annual applications in North Dakota (Lym and Messersmith 1985b).

Annual application of picloram could become an environmental hazard because of long persistence, relatively high water solubility and leaching potential, and high phytotoxicity. However, residue from picloram applied at 0.56 kg/ha or less generally does not persist in the environment. Herr et al. (1966) found that the highest picloram concentration in heavy to medium textured soil following annual application was near the surface but picloram residue was much deeper in light textured soil. Picloram dissipated faster at

low than high application rates on all 3 soil types. Picloram applied on rangeland generally has dissipated rapidly with the highest concentration remaining in the top 15 cm of the soil profile (Scifres et al. 1977). Picloram applied at 0.28 kg/ha or less often dissipated within 60 days (Bauer et al. 1972; Scifres et al. 1971a, 1971b). Picloram at 2.2 kg/ha applied 5 times in 2 years did not accumulate in the vegetation, soil profile, or well water on the prairie ecosystems of central Texas (Bovey et al. 1974, 1975).

The purpose of this study was to evaluate various annual picloram and 2,4-D treatments for leafy spurge control and determine picloram soil residue and effect on seedling emergence and growth in 3 areas of North Dakota following a 5-year annual treatment program.

Materials and Methods

An experiment to evaluate leafy spurge control from annual applications of picloram and picloram plus 2,4-D and biannual application of 2,4-D alone was established at 3 sites in North Dakota. The sites included a bluegrass (*Poa* spp.) pasture near Sheldon, a mixed grass prairie on a federal game management area near Valley City, both in eastern North Dakota, and a mixed grass pasture near Dickinson in western North Dakota. Soil properties and annual precipitation received during the study at each site are listed in Table 1. All sites had at least an 80% ground cover of leafy spurge with few other forbs present.

Herbicides were applied using a tractor mounted sprayer delivering 75 L/ha water at 240 kPa. The experiment was begun on 25 August 1981 at Dickinson, 1 September 1981 at Sheldon, and 11 June 1982 at Valley City. All treatments were applied annually except 2,4-D alone which was applied biannually (twice per year). Picloram treatments were applied in late August 1981 and in June 1982 through 1985. The 2,4-D biannual treatments were applied in June and August of each year. Thus, the Dickinson and Sheldon sites were sprayed with picloram and picloram plus 2,4-D treatments 5 times, and 2,4-D alone 8 times, while the Valley City site received 4 and 7 treatments, respectively. Herbicides were applied when leafy spurge was flowering in June or had resumed fall regrowth following a summer dormancy period in August. The plots were 3.1 by 9.1 m and each treatment was replicated 4 times in a randomized complete block at all sites. Evaluations were based on visual percent stand reduction as compared to the control.

Soil samples for picloram residue analysis were taken twice each year except 1985 at all locations. The first yearly sample was collected prior to herbicide application in June and the second in late August or early September from the untreated control and picloram-alone treated plots. Three subsamples 15-cm deep were collected per plot and combined for each sampling date from 1982 through 1984. Four subsamples 120-cm deep were collected per plot in September 1985 and divided into 5 segments consisting of 0 to 15, 15 to 30, 30 to 60, 60 to 90, and 90 to 120 cm depths and combined.

Picloram concentration was determined by bioassay using sunflower (*Helianthus annuus* L.) for samples collected from 1982 through 1984. Soil samples were forced-air-oven dried at 27° C, screened to pass through a 4-mm mesh screen and divided into 500-g subsamples. The standard curve was prepared by adding technical picloram at 2 to 250 ppbw to 4 replicate subsamples of untreated soil from each location and depth. Ten ml of water which

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Table 1. Physical and chemical characteristics of soils and annual precipitation at the various study sites in North Dakota.

Location	Soil type	Sand	Silt	Clay	Organic matter	pH	Cation ex- change capacity	Precipitation									
								1981		1982		1983		1984		1985	
								Trt. to ^{ab} samp- ling	Annual	Trt. to ^{ab} samp- ling	Annual	Trt. to ^{ab} samp- ling	Annual	Trt. to ^{ab} samp- ling	Annual	Trt. to ^{ab} samp- ling	Annual
(%)							(meq/ 100 g)	(cm)									
Sheldon	Hamar- Uleh fine sandy loam	78	13	9	2.1	7.7	12.8	27.1 (166)	58.3	15.7 (76)	51.6	19.0 (65)	46.3	10.4 (95)	53.5	15.3 (76)	38.2
Valley City	Barnes stony loam	43	41	16	9.4	6.7	37.7		45.0	7.4 (74)	45.4	22.5 (73)	36.0	11.0 (92)	38.8	15.3 (78)	42.0
Dickinson	Felor loam	17	56	27	3.6	6.6	20.0	47.0 (167)	40.0	13.3 (86)	60.1	14.5 (72)	39.5	20.8 (90)	45.2	13.0 (105)	43.4

*Number in () are the number of days from treatment to sampling each year.

^bTreatment applied fall 1981 and in June each year thereafter.

contained enough picloram to give the required concentration were added to each 500-g soil sample, air dried for 18 h, and thoroughly mixed. The samples for both the standard curve and field samples were placed in 11- by 11- by 5-cm plastic pots, watered to 80% field capacity, and allowed to equilibrate for 24 h. Eight sunflower seeds were placed on the soil surface and covered with 2 cm of styrofoam beads. The pots were arranged in a completely random design in a greenhouse at 24° C, and natural light was supplemented by metal halide lights with an intensity of 450 $\mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ for a 16-h photoperiod. The pots were rerandomized weekly. Sunflowers were harvested after 30 days. The topgrowth was oven dried at 60° C. A linear standard curve was calculated using regression analysis (Stat. Anal. Syst. 1982), and the mean sunflower dry weights for field samples were compared to those from known concentrations to estimate picloram concentration.

Picloram concentration from the samples collected in 1985 was determined by high pressure liquid chromatography (HPLC). Soil samples were dried and mixed as described earlier. Replicate 40-g soil samples were placed in 250-ml flasks, and then 80 ml of acetonitrile/water/ammonium hydroxide (70:18:12, v/v/v) were added and shaken for 0.5 h. The soil samples were held at room

temperature for 18 h and then shaken a second time for 0.5 h (Smith and Milward 1983). The sample was vacuum filtered through 6 μm filter paper and the aqueous extract was evaporated to approximately 14 ml with a rotary evaporator at 40° C. The sample was brought to 40 ml with 5% aqueous sodium carbonate (w/v) and centrifuged for 10 min at 10,000 rpm. The sample was filtered a second time through an 0.2 μm glass fiber syringe filter and then brought to 100 ml with the 5% sodium carbonate solution. The solution was transferred to a separatory funnel and extracted with 25 ml *N*-hexane. The inorganic fraction was discarded.

The aqueous phase containing picloram was acidified with 15 ml concentrated sulfuric acid. The sample was further clarified by adding 1.5 ml of saturated potassium permanganate and held at room temperature for 5 min, after which 5 M sodium bisulfite was added dropwise until the solution was colorless (Wells et al. 1984). The sample was extracted twice with 10 ml of methylene chloride and the eluate was evaporated to dryness on a rotary evaporator. The concentrated sample was redissolved in 3 ml of acetonitrile/-water (60:40, v/v) and a 10 μL injection of the eluate from this procedure was quantified by HPLC using a C-18 reverse-phase cartridge (0.45 i.d. by 25 cm). The solvent system consisted of:

Table 2. Leafy spurge control from five annual picloram or picloram plus 2,4-D treatments and eight biannual 2,4-D treatments at three locations in North Dakota.

Herbicide	Rate	Site and 1985 evaluation date						Mean			
		Sheldon		Dickinson		Valley City ^a		Months after treatment			
		June	Aug	June	Aug	June	Aug	12	24	36	48
		(kg/ ha)		(% control)							
Picloram	0.28	12	60	61	35	34	39	39	48	41	48
Picloram	0.42	55	88	66	62	78	48	65	62	50	75
Picloram	0.56	87	94	77	86	58	59	65	71	73	90
2,4-D biannual	1.1	31	61	44	43	23	31	22	30	35	52
2,4-D biannual	1.6	35	74	31	21	38	52	22	24	34	48
2,4-D biannual	2.2	51	87	29	21	41	46	19	30	35	54
Picloram+2,4-D	0.28+1.1	48	85	82	84	51	74	52	66	66	85
Picloram+2,4-D	0.28+1.6	72	97	71	75	48	60	58	66	67	86
Picloram+2,4-D	0.28+2.2	70	95	71	71	58	70	57	62	67	83
Picloram+2,4-D	0.42+1.1	77	97	82	84	65	72	69	72	71	91
Picloram+2,4-D	0.42+1.6	63	96	85	93	69	82	68	74	78	95
Picloram+2,4-D	0.42+2.2	90	99	75	86	64	66	68	59	73	93
Picloram+2,4-D	0.56+1.1	86	96	89	92	70	74	71	75	82	94
Picloram+2,4-D	0.56+1.6	78	96	85	97	81	62	64	73	73	97
Picloram+2,4-D	0.56+2.2	71	96	86	96	84	73	76	75	78	96
LSD (0.05)		33	12	23	21	24	30	18	14	18	16

*Experiment at Valley City received only 4 annual picloram or picloram plus 2,4-D treatments and 7 biannual 2,4-D treatments and data are not included in the 48 month mean.

eluent 'A', 1% acetic acid in water (v/v) and eluent 'B', 1% acetic acid in acetonitrile (v/v) using a linear gradient of 5 to 80% 'B' in 25 min. The detector was a variable wavelength spectrophotometer operated at 254 nm. Retention time was approximately 9 min. Data were quantified by comparing peak areas against standards of known concentrations. Analysis of fortified samples indicated the least detectable limit was 0.5 ppb.

Leafy spurge seedling susceptibility to picloram was determined in a petri dish bioassay. Ten g soil samples were prepared as described in the bioassay experiment. Technical picloram at 2 to 1,000 ppbw was added to 4 replicate subsamples of untreated soil from each location. Ten leafy spurge seeds were planted per dish just below the soil surface and the dishes were placed in a growth chamber. The temperature was 30/20° C (day/night) for the first week and 25/20° C (day/night) for the next 3 weeks with 80 to 90% relative humidity. A combination of fluorescent and incandescent bulbs provided $490 \mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ during the 12 h day. These are the optimum conditions for leafy spurge seed germination and seedling growth (Bakke 1936). Petri dishes were rotated weekly and plants were watered as needed. The percentage of emerged seed-

lings and seedling survival after 4 weeks was compared to the control.

Leafy spurge root segments 1, 5, 10, and 20 cm long of uniform diameter were obtained from 2-year-old greenhouse grown plants. One root segment was planted 1.5 cm deep per 4 cm diam by 20 cm long conical pot which contained 200 g of a soil-less medium of peat, perlite, and vermiculite. Technical picloram at 0 to 1,000 ppbw was added to the soil-less medium. The growth chamber temperature was 25/20° C (day/night) with 50% relative humidity in a 16-h day. The number of emerged shoots was recorded 28 days after planting. A similar experiment was conducted using 200-g soil samples from the 3 field locations and 10-cm leafy spurge root segments. All growth chamber experimental designs were completely random with 4 replications and repeated, except the field soil study which was repeated 3 times. Data for leafy spurge control, seed germination, and regrowth from root segments were analyzed using the general linear models procedure (Stat. Anal. Syst. 1982).

Table 3. Picloram concentration from various annual application rates for 4 years at three locations in North Dakota as determined by a sunflower bioassay in 1982 through 1984 and HPLC in 1985.

Location	Depth	Treatment rate	Sampling date							
			1982		1983		1984		1985	
			June	Aug	June	Aug	June	Aug	Sept	
	(cm)	(kg/ha)	(ppbw)							
Sheldon	0-15	0.28	<2	102	<2	12	<2	55	20	
		0.42	<2	121	<2	38	<2	46	45	
		0.56	<2	182	<2	45	<2	66	59	
	15-30	0.28	**	***	**	**	<2	**	25	
		0.42	**	***	**	**	<2	**	52	
		0.56	**	***	**	**	15	**	30	
	30-60	0.28	**	***	**	**	**	**	2	
		0.42	**	***	**	**	**	**	<1	
		0.56	**	***	**	**	**	**	4	
	60-90	0.28	**	***	**	**	**	**	3	
		0.42	**	***	**	**	**	**	6	
		0.56	**	***	**	**	**	**	18	
	90-120	0.28	**	***	**	**	**	**	<1	
		0.42	**	***	**	**	**	**	14	
		0.56	**	***	**	**	**	**	14	
	Dickinson	0-15	0.28	<2	<2	<2	10	<2	10	15
			0.42	<2	<2	<2	13	<2	13	19
			0.56	<2	11	10	83	<2	20	22
15-30		0.28	**	***	**	**	22	**	5	
		0.42	**	***	**	**	34	**	4	
		0.56	**	***	**	**	14	**	3	
30-60		0.28	**	***	**	**	**	**	2	
		0.42	**	***	**	**	**	**	3	
		0.56	**	***	**	**	**	**	ND	
60-90		0.28	**	***	**	**	**	**	ND	
		0.42	**	***	**	**	**	**	ND	
		0.56	**	***	**	**	**	**	ND	
Valley City	0-15	0.28	**	<2	<2	102	22	64	20	
		0.42	**	<2	<2	86	65	126	47	
		0.56	**	<2	31	95	55	105	30	
	15-30	0.28	**	***	**	**	**	**	20	
		0.42	**	***	**	**	**	**	16	
		0.56	**	***	**	**	**	**	8	
	30-60	0.28	**	***	**	**	**	**	7	
		0.42	**	***	**	**	**	**	<1	
		0.56	**	***	**	**	**	**	5	
	60-90	0.28	**	***	**	**	**	**	ND	
		0.42	**	***	**	**	**	**	<1	
		0.56	**	***	**	**	**	**	<1	
	90-120	0.28	**	***	**	**	**	**	ND	
		0.42	**	***	**	**	**	**	20	
		0.56	**	***	**	**	**	**	1	

Results and Discussion

Picloram at 0.28, 0.42, and 0.56 kg/ha provided 48, 75, and 90% leafy spurge control, respectively, after 5 annual applications when averaged across the Dickinson and Sheldon locations (Table 2). Control gradually improved over time with picloram at 0.42 and 0.56 kg/ha, but not at the 0.28 kg/ha application rate. Leafy spurge control from similar picloram applications averaged 39, 48, and 59%, respectively, following 4 annual treatments at Valley City.

Leafy spurge control was 51% following 8 biannual 2,4-D applications averaged over rate and location. Leafy spurge control gradually increased over time regardless of the 2,4-D application rate. 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 to 5 years. Biannual 2,4-D treatment would be useful in areas where environmental conditions would prohibit picloram use but likely would only prevent leafy spurge seed production and spread with little change in area of the original infestation.

Leafy spurge control increased when 2,4-D was applied with picloram at 0.28 or 0.42 kg/ha compared to picloram alone at similar application rates (Table 2). Control averaged 85 and 93% with picloram at 0.28 or 0.42 kg/ha plus 2,4-D at 1.1 to 2.2 kg/ha, respectively, compared to 48 and 75%, respectively, with similar picloram treatments applied alone. Picloram at 0.56 kg/ha plus 2,4-D provided 96% leafy spurge control and was similar to picloram at 0.56 kg/ha alone at 90% control. The benefit of applying 2,4-D with picloram for improved leafy spurge control decreased as the picloram rate increased. Leafy spurge control with picloram at 0.28 and 0.42 kg/ha increased 37 and 18%, respectively, when averaged over all 2,4-D rates compared to similar picloram treatments applied alone. Leafy spurge control did not improve as the 2,4-D rate was increased from 1.1 to 2.2 kg/ha in combination with picloram.

After 3 years of annual application of picloram at 0.56 kg/ha alone or at 0.28 and 0.42 kg/ha with 2,4-D at 1.1 to 2.2 kg/ha leafy spurge control was comparable to that from picloram applied once at 2.2 kg/ha (Lym and Messersmith 1985b). Leafy spurge control with picloram at 2.2 kg/ha averaged 76 compared to 71% with picloram applied annually either at 0.56 kg/ha alone or at 0.28 and 0.42 kg/ha with 2,4-D at 1.1 to 2.2 kg/ha. However, the combined 3-year annual treatment costs were 25, 55 and 36% lower, respectively, compared to picloram applied once at 2.2 kg/ha. Furthermore, a retreatment following the picloram at 2.2 kg/ha treatment would be necessary after the third year to maintain satisfactory leafy spurge control (Lym and Messersmith 1985a).

Picloram did not accumulate in the top 15 cm of the soil following annual application regardless of soil type or annual precipitation (Table 3). In general, picloram was not detected above 2 ppbw in the top 15 cm of the soil profile 12 months following application except at the Valley City site in 1984. The amount of picloram

detected in August of each year varied with the annual precipitation received from June to August; generally, more picloram remained in the upper 15 cm in drier than wet years (Tables 1 and 3). More picloram residue was retained in the upper 15 cm of soil at Valley City than at Dickinson and Sheldon probably because the Valley City soil contained more organic matter (Bauer et al. 1972; Herr et al. 1966; Phillips and Feltner 1972; and Scifres et al. 1971a). The greater retention of picloram at Valley City also could explain the reduced leafy spurge control compared to the other 2 sites. Less picloram may have been available for root absorption especially at lower soil levels, thus limiting long-term leafy spurge root control.

Picloram was detected throughout the entire 120-cm soil profile sampled in 1985 at Sheldon and Valley City, but not at Dickinson (Table 3). In general, the picloram concentration in lower soil depths increased directly with the sand content of the soil. The soil at Sheldon has 71% sand and there was 14 ppbw picloram at 120 cm, while the soil at Dickinson has only 17% sand and no picloram was detected below 60 cm (Table 1). Picloram residues were not uniformly distributed throughout the soil profile. Picloram moves through soil in concentration pulses following high precipitation and is relatively immobile during drought periods (Neary et al. 1985). Thus, higher picloram residue at the 90 to 120 cm level than at 30 to 60 or 60 to 90 cm at Valley City and Sheldon, respectively, is probably due to concentration pulses. Generally, concentration pulse patterns at lower depths are of lower magnitude and delayed compared to upper soil levels.

Since picloram did not accumulate in the soil profile after 4 annual applications of 0.56 kg/ha or less, this treatment program should not be considered an environmental hazard when herbicide label directions are followed. Previous studies have shown that residue in runoff water from picloram application of 0.56 kg/ha or less was of little consequence especially 10 to 20 days after application (Bauer et al. 1972; Scifres et al. 1969, 1971b; Trichell et al. 1968). The possibility of accidental contamination of open wells or surface water still exists if the applicator is careless. Since picloram should not be applied in areas where the water table is within 3 m or less of the soil surface, introduction into underground water by leaching does not seem likely.

A picloram concentration of 500 and 250 ppbw was required to reduce leafy spurge seedling emergence and survival by at least 50%, respectively (Table 4). A picloram concentration of 8 to 32 ppbw tended to increase leafy spurge emergence compared to the control and did not affect seedling survival. Bowes and Thomas (1978) found that picloram concentrations up to 1,000 ppbw did not affect leafy spurge seed germination in the lab. Apparently, leafy spurge seed germination is not inhibited by picloram, but subsequent growth required for emergence is decreased at picloram concentrations of 500 ppbw or more.

Picloram at 125 ppbw was required to decrease seedling survival and 5% of the leafy spurge seedlings that emerged at 1,000 ppbw

Table 4. Leafy spurge seedling emergence and survival after 4 weeks in three North Dakota soil types and at various picloram concentrations.

Picloram concentration (ppbw)	Soil location							
	Sheldon		Dickinson		Valley City		Mean	
	Emergence	Survival	Emergence	Survival	Emergence	Survival	Emergence	Survival
	(%)							
0	75	100	85	100	60	100	73	100
8	90	75	100	100	100	100	97	100
16	90	97	100	96	100	96	97	100
32	100	98	90	95	70	95	87	96
64	60	89	75	89	70	86	68	88
125	80	79	80	72	65	52	75	68
250	80	50	60	56	70	34	70	47
500	40	29	40	19	50	9	43	19
1000	40	6	40	4	50	4	43	5
LSD (0.05)	30	28	27	16	31	32	19	17

picloram grew for at least 4 weeks in a growth chamber (Table 4). A higher mortality rate may be expected under field conditions where environmental conditions are less favorable for survival than in the growth chamber. However, less than 100 ppbw of picloram generally remained in the upper 15 cm of soil 3 months after application, so the herbicide residue probably would not limit the growth of leafy spurge seedlings. Indeed, the low concentration of picloram remaining in the soil 3 to 12 months after application may stimulate leafy spurge seed germination.

Table 5. Leafy spurge shoot regrowth from root segments of four lengths exposed to various picloram concentrations for 28 days.

Picloram concentration ppbw	Original root length			
	1 cm	5 cm	10 cm	20 cm
	-----(% of roots with shoots)-----			
0	6	38	38	81
125	0	13	13	6
250	0	0	0	0
500	0	0	0	0

LSD (0.05) = 17

Lower picloram concentrations were required to control leafy spurge regrowth from roots than from seeds (Tables 4 and 5). More leafy spurge shoots were produced from 20 cm long root segments than shorter segments, but 5 and 10 cm long segments provided a similar number of new shoots when grown in a soil-less plant mixture. Regrowth was reduced when picloram at 125 ppbw was added to the soil-less medium, and no regrowth occurred at higher picloram concentrations.

Leafy spurge shoot regrowth increased as root segment length increased, but segment length had little effect on the regrowth response to picloram (Table 5). Leafy spurge shoots grew from 81% of the 20 cm root segments compared to 6% from 1 cm root segments, but regrowth fell to 6 and 0%, respectively, when treated with 125 ppbw picloram in the soil-less medium.

Regrowth from 10-cm leafy spurge segments declined as picloram concentration increased in soil from the 3 experimental sites, but not as rapidly as when grown in the soil-less medium (Table 6).

Table 6. Leafy spurge shoot regrowth from 10 cm root segments in three North Dakota soils exposed to various picloram concentrations for 28 days.

Picloram concentration ppbw	Soil location			Mean
	Sheldon	Dickinson	Valley City	
	-----(% of roots with shoots)-----			
0	75	63	63	67
64	50	25	38	38
125	25	38	50	38
250	13	13	38	21
500	0	25	13	13
1000	38	0	0	13
LSD	46	51	52	24

Leafy spurge regrowth averaged 67% (at all 3 locations) in untreated soil, but averaged 13 to 38% in soil treated with picloram concentrations of 64 to 1,000 ppbw. The picloram residue concentration detected in soil may be high enough through August to reduce leafy spurge regrowth from roots (Table 3), but generally were low enough that at least half of the newly emerged shoots would survive (Table 6).

The addition of 2,4-D to picloram at 0.28 to 0.42 kg/ha improved leafy spurge control, but did not affect control from picloram at 0.56 kg/ha. Picloram at 0.28 to 0.56 kg/ha did not accumulate in the upper soil profile after 5 annual applications regardless of location. Control was slightly less and picloram

residues were higher in soil with high organic matter contents, and organic matter apparently was the only soil characteristic that affected leafy spurge control. Picloram at 250 to 500 ppbw or greater was needed to decrease leafy spurge seedling emergence and growth by 50%, but leafy spurge shoot regrowth from root segments was reduced by picloram at 64 ppbw.

Picloram plus 2,4-D at 0.28 plus 1.1 kg/ha applied annually over time provided similar leafy spurge control to picloram at 0.56 kg/ha applied annually or picloram at 2.2 kg/ha applied once. The combination treatment over a few years can increase a landowner's net income by 50% or more through reduced herbicide cost and increased forage production as compared to less frequent treatment with higher herbicide rates. The potential for unacceptable environmental contamination by picloram should be much smaller from low rates applied annually compared to high rates applied less frequently.

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