Chemical Control of Eastern Redcedar in Mixed Prairie

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Abstract. Stands of eastern redcedar (*Juniperus virginiana* L.) have been increasing in prairies, often to the detriment of valuable prairie species. Initial control of dense stands of relatively tall eastern redcedar by herbicides may be necessary to alter population demographics before more environmentally sound mechanical methods and prescribed burning can be employed to maintain acceptable populations of this woody species. Previous control effectiveness with herbicides has been highly variable. This study was conducted to determine the effect of hexazinone [3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione] as Velpar L, picloram (4-amino-3,5,6-trichlora-2-pyridinecarboxylic acid) as Tordon 2K, and tebuthiuron N-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]N,N′-dimethylurea as Graslan brush bullets on eastern redcedar in the mixed prairie of central Nebraska. Each herbicide was soil applied at three rates, adjusted for tree height, spanning the manufacturers' range of recommended rates. Picloram and tebuthiuron were applied in October, and hexazinone was applied in May. Success of control was recorded after two growing seasons. Depending on application rate and tree height, hexazinone killed between 68 and 90%, picloram 70 to 94%, and tebuthiuron 71 to 90% of the trees. Although all herbicides preformed well in controlling eastern redcedar, picloram generally provided greater control than the two other chemicals. Picloram also achieved this control with a relatively low material cost.

Key Words. eastern redcedar, *Juniperus virginiana*, herbicides, mixed prairie, Nebraska

INTRODUCTION

Eastern redcedar (*Juniperus virginiana* L.) is a medium-sized conifer occurring in all states east of the Rocky Mountains. Historical records indicated that eastern redcedar was not common in Nebraska prior to European settlement (Miller 1902, Kellogg 1905, Harper 1912), growing only on a few protected ridges and along river channels. In more recent years, eastern redcedar has spread rapidly into previously unoccupied prairie. This increase is primarily due to the absence of naturally reoccurring fires and a widespread seed source from shelterbelt plantings (Beilmann and Brenner 1951, Bragg and Hulbert 1976, Van Haverbeke and Read 1976).

Several control techniques are available to limit the occurrence of eastern redcedar. These include mechanical, pyric, biological, and chemical methods. Mechanical methods, including digging and cutting, are effective since the trees will not resprout provided all green foliage is removed. However, these methods are time consuming and labor intensive, and access to individual tree trunks through the dense foliage is difficult. Thus, their usefulness is limited to scattered or extremely large trees (Owensby 1975). Prescribed burning can also be effective and economical for eastern redcedar control (Bragg and Hulbert 1976, Stritzke and Rollins 1984). The foliage burns readily, and the thin bark provides the cambium layer with little protection from damaging heat (Starker 1932, Kucera *et al.* 1963). Small trees (less than 2 m in height) were most susceptible to fire, since larger trees prevented understory growth and its associated fuel accumulation. Stevens *et al.* (1975) proposed biological methods, notably insects and fungi, as potential alternative controls for junipers. However, eastern redcedar has few natural enemies, reducing the potential for biological control (Williamson 1965).

Chemical control may be an alternative in those cases where the previous three methods are inappropriate due to location, economics, or management objectives. In general, herbicides may be applied to eastern redcedar by three methods: 1) foliar sprays, 2) injections, and 3) soil application. Eastern redcedar is quite resistant to foliar applied herbicides. They are thought to be inefficient due to foliar cuticle waxes preventing herbicide absorption, lack of translocation within the plant, and/or dense foliage arrangement preventing complete canopy wetting (Dalrymple 1969, Buehring *et al.* 1971, Owensby *et al.* 1973, Stritzke 1985). Control of eastern redcedar with herbicide injection into trunks is difficult, since access to the tree trunk thought the low, dense branches is difficult. Response to injection was highly variable, depending upon both the herbicide and the rate applied (Buehring *et al.* 1971)

Results from soil applied herbicides have also been variable (Scifres *et al.* 1981). Broadcast application onto soil is generally not desirable, since rates required to control eastern redcedar also damage non-target species (Hamilton and Scifres 1983). Direct application of the herbicide under individual trees was recommended to avoid this problem (Meyer 1982, Ueckert and Whisenant 1982), because few desirable prairie species grow under eastern redcedar trees. However, past research indicated considerable inconsistency in control success with this technique (Buehring *et al.* 1971, Owensby *et al.* 1973, Link *et al.* 1979, Crathorne *et al.* 1982). Therefore, more information is required to determine proper techniques for chemical control of this species. The objective of this study was to compare relative abilities of the herbicides hexazinone [3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione] as Velpar L, picloram (4-amino-3,5,6-trichlora-2-pyridinecarboxylic acid) as Tordon 2K, and tebuthiuron N-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]N,N′-dimethylurea to control eastern redcedar when applied a individual tree treatments.

METHODS AND MATERIALS

Experimental Site

The study site was located about 12 km west of Oconto, Custer County, Nebraska (Township 14 North, Range 23 West, Section 24). The location was on steeply dissected, upland hills with slopes ranging between 20 and 60%. Soils were a Uly-Coly [fine-silty, mixed mesic Typic Haplustoll and fine-silty, mixed (calcareous), mesic Typic Ustorthent, respectively] silt loam aggregate derived from loess parent material. Average precipitation at this location is about 530 mm. The native vegetation, following the descriptions of Weaver and Albertson (1956), was a mixed prairie consisting of western wheatgrass (*Agropyron smithii* Rydb.), big bluestem (*Andropogon gerardii* Vitman), sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.], and little bluestem [*Schizachyrium scoparium* (Michx.) Nash]. The oldest eastern redcedar trees on the site were about 80 years in age. Aerial photographs taken since 1938 indicated a steady spread of eastern redcedar, with a particularly dramatic increase during the last three decades. The area now supports a dense eastern redcedar stand.

Experimental Procedure

The experimental design was a randomized complete block. Ten treatments, replicated twice, were created; three herbicides, each at three application rates (low, medium, and high), plus a control. These rates were selected to span each of the manufacturers' recommended ranges for this species. Plots were located on the slopes of two adjacent canyons, with canyon location considered to be a blocking criteria. Each block contained a complete set of randomly applied treatment/replication combinations. The plots were 8 m wide and extended from the bottom of the canyon to the top of the slope, a distance varying from 50 to 75 m in length. These canyon sides were oriented to a northeast aspect.

Within each plot, the particular herbicide/rate/replication treatment combination was applied to all trees. Chemicals were distributed on the ground evenly within the canopy outline. The hexazinone was applied at full concentration in a liquid form (Velpar L) via a metered "spot gun." Picloram and tebuthiuron were applied in dry formulations as Tordon 2K and Graslan brush bullets, respectively. To compensate for differences in herbicide effectiveness with varying three size, five height classes (< 0.25, 0.25-1, 1-2, 2-4, and > 4 m) were established. Treatments were adjusted accordingly for each height class (Table 1).

Table 1. Herbicide application rates for each eastern redcedar tree height category.

Herbicide	*Tree Height*	*Rate*		
		Low	*Medium*	*High*
		ml of commercial product per tree		
Hexazinone[1]	0 to 0.25 m	1	2	3
	0.25 to 1 m	1	2	3
	1 to 2 m	1	2	3
	2 to 4 m	8	12	16
	> 4 m	16	24	32
		g of commercial product per tree		
Picloram[2]	0 to 0.25 m	11	22	33
	0.25 to 1 m	22	44	66
	1 to 2 m	44	66	88
	2 to 4 m	66	88	110
	> 4 m	88	110	176
		number of brush bullets per tree		
Tebuthiuron[3]	0 to 0.25 m	1	2	3
	0.25 to 1 m	2	4	6
	1 to 2 m	4	6	8
	2 to 4 m	6	9	12
	> 4 m	9	12	15

[1]25% active ingredient in a liquid as Velpar L (E. I. Du Pont De Nemours and Company)
[2]2.3% active ingredient in pellets as Tordon 2K (The Dow Chemical Company)
[3]1.0 g active ingredient in brush bullets as Graslan (Eli Lilly and Company)

Picloram and tebuthiuron rates were supplied by the manufacturer on a height basis. However, the hexazinone manufacturer's suggested application rate was based on rates of 0.79 to 1.57 ml/cm stem diameter at breast height (DBH). To convert this to a tree height basis for use in this study, diameter and height measurements were taken for eastern redcedar of various sizes on the site. From this, a regression equation [$Y = 0.225 (X) + 2.15$] was developed, where Y = tree height in meters, and X = DBH in centimeters. The coefficient of determination equalled 0.94. Dosages were applied on a height basis according to this equation. Since trees less than 1.5 m have no DBH, application rates of 1 to 3 ml were used for all height classes equal to or less than 2 m. Applications of less than 1 ml were not possible, since that was the minimum application the hexazinone "spot gun" would deliver. Following manufacturers' recommendations, picloram and tebuthiuron were applied in the fall (28 and 29 October), and hexazinone was applied the following spring (15 May).

Each tree was subsequently examined for mortality through the following two growing seasons. A tree was considered dead if less than 25% of its foliage was rated as green by a visual estimate. During the second growing season following application, many new eastern redcedar seedlings in the < 0.25 m height class were observed. This height class was not included in data analyses, because it was impossible to visually separate treated seedlings from untreated seedlings. Results presented in this paper are from the final evaluation at the end of the second growing season following treatment.

A total of 6,601 trees > 0.25 m in height were treated with herbicides. Hexazinone was applied to 1,780, picloram was applied to 2,666, and tebuthiuron was applied to 2,155. Each plot (control and treated) contained an average of 180 trees, equalling a stand density of 3,600 trees/ha.

Categorical data analysis procedures were utilized, with observations for each tree recorded as either "alive" or "dead." Following the weighted least squares procedures of Grizzle *et al.* (1969) and Koch *et al.* (1977), log-linear models of the categorical data were created, using Chi-square statistics to test for differences among response (dead or alive) probabilities. This analysis, distinguishing between dependent and independent variables in a multilevel contingency table format, was analogous to the analysis of variance approach used for testing continuous data. Orthogonal single degree of freedom contrasts were constructed to test for linear and quadratic relationships between response and the three application rates within each herbicide. Although analyses were conducted utilizing the observed and expected values of the number of alive and dead, results were standardized to percentages for ease of presentation.

Control rates were combined with herbicide costs in an economic analysis of herbicide effectiveness. This analysis was based on raw material costs of $15.85 per l for hexazinone, $3.37 per kg for picloram, and $0.12 per g for tebuthiuron. Average percentage kill for each herbicide was used as a weighting factor to adjust material costs required to kill one tree. The 2-4 m tree height class was selected for these comparisons.

RESULTS

All herbicide by rate interactions were significant. Given the precision due to the number of observations, analysis was therefore conducted on individual herbicides.

Combining percentage kill over tree height and rate generated an overall response to each herbicide (Table 2). Hexazinone and tebuthiuron each killed 83% of all trees, while picloram killed 88%. Although herbicide rate was adjusted for tree height, treatment by tree height interactions still occurred. Therefore, analysis was conducted separately by height class. A comparison averaged over application rate gave and indication of how well treatments were adjusted to fit individual height classes (Table 2). Hexazinone at the low, medium, and high rates killed 80, 82, and 88% of the trees, respectively (Table 2). While this showed a trend towards increased kill with increasing rate, no linear or quadratic relationships were significant at a probability of a greater Chi-square = 0.05 level (Table 3). Picloram killed 88, 87, and 87% of all trees at the low, medium, and high application rates, respectively (Table 2). No significant relationships were detected (Table 3). Low rates of hexazinone and picloram were, therefore, just as effective as the high rate. Tebuthiuron killed 80, 86, and 82%, respectively, at the low, medium, and high rates (Table 2). This increase at the medium level was depicted by a quadratic response (Table 3). The linear response over rate was not significant. All three herbicides provided good control when tree height classes were combined. However, picloram consistently provided control levels that were higher than the other two chemicals. It was the most effective herbicide against eastern redcedar when tree heights were combined.

Table 2. Percentage of eastern redcedar trees killed by tree height and application rate of hexazinone, picloram, and tebuthiuron.

Herbicide	Rate	Tree Height (m) 0.25-1	1-2	2-4	>4	Average
		%				
Hexazinone	low	90	68	78	76	80
	medium	79	78	87	84	82
	high	85	83	88	82	85
	Average	85	81	82	82	83
Picloram	low	88	90	88	88	88
	medium	86	94	90	70	87
	high	86	89	89	83	87
	Average	86	91	89	80	88
Tebuthiuron	low	73	90	81	71	80
	medium	88	82	81	89	86
	high	77	82	84	84	82
	Average	77	85	82	81	83

Table 3. Probabilities of > Chi-square for linear and quadratic contrasts of percentages of eastern redcedar trees killed following application of hexazinone, picloram, or tebuthiuron.

Comparison	Constrast	Probability > Chi-square Hexazinone	Picloram	Tebuthiuron
All tree heights combined:	Linear	0.09	0.39	0.41
	Quadratic	0.51	0.97	0.01
0.25 to 1 m tree height:	Linear	0.17	0.95	0.31
	Quadratic	0.01	0.42	0.01
1 to 2 m tree height:	Linear	0.90	0.45	0.02
	Quadratic	0.30	0.04	0.16
2 to 4 m tree height:	Linear	0.01	0.79	0.47
	Quadratic	0.39	0.88	0.65
Greater than 4 m tree height:	Linear	0.50	0.13	0.01
	Quadratic	0.35	0.01	0.01

Table 2 also provides percentage kill for individual tree height classes within each herbicide/rate combination. Control among all herbicide/rate/tree height combinations ranged from 68 to 94%, with a majority of responses in the 80 to 90% range. Hexazinone applied to 0.25-1 m trees generated a negative quadratic response (Tables 2 and 3) across rate, with the medium rate providing the least control at 79%. No linear relationship was evident, with low and high rates providing statistically equivalent control at 90 and 85%, respectively. Trees treated with picloram responded equally across rate, with no significant linear or quadratic relationships (Table 3). Control from the three rates varied only between 86 and 88% (Table 2). The response rates for tebuthiuron followed a positive quadratic relationship, with the medium rate generating greater control at 88% than either the low or high rates at 73 and 77%, respectively (Tables 2 and 3). The low and high rates were statistically equivalent, with no linear relationship apparent. For this height class, low rates of either hexazinone or picloram resulted in the greatest control.

No linear or quadratic relationships occurred for hexazinone treated trees in the 1-2 m height class (Table 3), with all rates providing equivalent control between 78 and 83% (Table 2). Picloram generated a positive quadratic response, with the medium rate resulting in the greatest control at 94% (Tables 2 and 3). No linear response occurred for picloram, with the low and high rates providing equivalent control at 90 and 89% respectively. The lowest tebuthiuron application rate generated greater control (90%) than did the medium (82%) or high (82%) rates, evidenced by a significant linear contrast (Table 3). Over the three application rates used with this tree height class, picloram consistently killed more trees, the highest control of 94% was at its medium rate (Table 2).

Increasing the hexazinone application rate corresponded with a linear increase in control of the 2-4 m height category from 68% at the low rate to 88% at the high rate (Tables 2 and 3). No linear or quadratic relationships were found for either picloram or tebuthiuron (Table 3). However, picloram generated greater control at all application rates than did tebuthiuron. Eighty-eight to 90% of the trees treated with picloram died, while 81 to 84% were killed with tebuthiuron (Table 2).

Hexazinone and tebuthiuron acted alike in their ability to control eastern redcedar in the > 4 m height class (Table 2). Both showed a curvilinear response to increasing rate, with maximum control at the medium rate. The curvilinear trend, however, was not significant for hexazinone, which provided 78 to 84% control (Tables 2 and 3). Tebuthiuron had both significant linear and quadratic relationships between response and application rate, with control varying between 71 and 89% (Tables 2 and 3). Picloram generated a significant quadratic response across rate. This arose from an unexplained low level of kill (70%) at the medium application rate. However, the low rate of picloram did provide 88% control (Table 2). The medium rate of tebuthiuron (89%) was the only other combination providing control near that level.

Herbicide material costs, adjusted for each herbicide's effectiveness, varied widely. Using the 2-4 m tree height class, hexazinone cost from $0.16 to $0.29/tree, picloram cost $0.17 to $0.32/tree, and tebuthiuron cost $0.75 to $1.47/tree. The range of costs reflects low and high application rates, respectively. The hexazinone costs did not include the initial $80 expense for the spot gun applicator.

DISCUSSION AND CONCLUSIONS

Although this study utilized a dense eastern redcedar stand for experimental purposes, these herbicides would also be suited to individual tree treatment of scattered individuals. Application of the dry formulations (picloram and tebuthiuron) was particularly easy, requiring little preparation or calibration for delivery. Directed application to the understory soil minimized the negative effect to non-target species that is often associated with herbicide use.

Hexazinone, picloram, and tebuthiuron all performed well in controlling eastern redcedar when applied to the soil under individual trees. Control levels were commonly greater than 80%. Whether viewed over all tree height classes or within individual height classes, picloram generally provided higher percentage kills than the two other chemicals. Overall, picloram killed 86% of the trees, while hexazinone and tebuthiuron each killed an average of 83%. In addition to providing a higher control level, picloram achieved this with a relatively low material cost of $0.17 to $0.32/tree for individuals in the 2 to 4 m height class. Hexazinone was slightly less expensive ($0.16 to $0.29), but did require an initial expense for the spot gun applicator. Comparative costs for tebuthiuron ranged from $0.75 to $1.47/ tree.

Increasing the application rate for picloram did not always result in greater control. Commonly, lower rates were just as effective as higher rates, indicating that the chemical was already producing its maximum effectiveness at the lower rate. This pattern was generally consistent throughout the four height classes. Further investigation of reduced rates of this chemical may result in eastern redcedar control at lower material costs.

Tebuthiuron showed a greater overall kill at the medium rate than either the low or high rates. This overall response was influenced by results occurring in the shortest (0.25-1 m) and the tallest (> 4 m) height classes. The reason for this pattern is unclear, although similar performance decreases with increasing herbicide rate on juniper species have been reported for picloram (Buehring *et al.* 1971) and tebuthiuron (Ueckert and Whisenant 1982).

Larger hexazinone application rates resulted in increases in overall percentage kill. However, this increase was not significant. Hexazinone appeared to be providing near maximum effectiveness at the lower application rate.

The inconsistent performances generated by some of the herbicide/rate combinations (e.g. increased herbicide rates did not always result in increased kill) over the tree height classes may have been due to unequal ranges of actual tree sizes within a particular height class. This would be particularly evident in the > 4 m class, where a particular treatment combination exhibiting reduced performance may have been applied to a greater number of trees much exceeding the 4 m minimum.

Yearly environmental variability will probably change the magnitude, but not the relative ranking, of these treatments. No environment by herbicide interaction would be expected within the scope of inference of this study, since all herbicides are soil applied during the preceding dormant season.

This research indicated that follow up treatments will be necessary if control levels greater than about 85% are desired. In addition, a large influx of seedlings was noticed within the treated areas during the second growing season following treatment. The seedling source was probably from a soil seed bank provided by the eastern redcedar over story. Visual observation showed no corresponding increase outside the treated areas, leading to the conclusion that removal of the over story may have been the causative factor. Therefore, use of herbicides will only be the first step in controlling eastern redcedar in prairies. Other control methods, such as periodic prescribed burning, will be necessary to maintain acceptable populations of eastern redcedar.

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