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Efficacy and costs of controlling eastern redcedar

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Abstract

Eastern redcedar (*Juniperus virginiana* L.) is reducing grassland productivity across much of the Great Plains. Control methods include broadcast prescribed fire, herbicides, cutting, and individual tree ignition. All methods have disadvantages when used alone. Fire can be ineffective against larger trees. Intensive methods can be too expensive for low-productivity grasslands. The objectives of this research were to determine the effects of broadcast prescribed fire alone as measured at 3 weeks after fire; to compare the effects of picloram herbicide application with or without fire, sawing with or without fire, and individual tree ignition with fire; and to compare all treatment costs. Treatments were applied at a central Nebraska rangeland site in 1993 and 1994. Fire mortality was 77% in 1993 and 67% in 1994. Either picloram or cutting after fire provided nearly 100% control of trees < 3 m tall, but cutting was more effective for trees > 3 m tall. Total mortality due to treatment combinations generally was higher in 1993, when burning conditions were more favorable. Burning, at an estimated cost of \$4.96 ha^{-1}, before picloram application or cutting reduced total costs by nearly half. Picloram application costs were reduced from \$90.10 ha^{-1} to \$47.95 ha^{-1}, and cutting costs from \$62.92 ha^{-1} to 39.26 ha^{-1}. Burning first also reduced cutting time from 362 min ha^{-1} to 184 min ha^{-1}, but did not significantly decrease picloram application time. Prescribed fire should precede intensive treatment applications if possible, both to reduce costs and improve total effectiveness. Because the costs and effectiveness of burning followed by either picloram or cutting are similar, managers should choose the method most suitable to individual circumstances.

Key Words: *Juniperus virginiana* L., prescribed fire, brush control, range improvement

Resumen

El Cedro Rojo (*Juniperus virginiana* L.) está reduciendo la productividad de las praderas en gran parte de las Grandes Planicies. Los métodos de control incluyen quemas controladas, herbicidas, corte y quema individual por árbol. Todos los métodos tienen desventajas al ser usados en forma individual. El fuego usado en árboles grandes puede ser ineficaz. Métodos intensivos pueden ser demasiado costosos en praderas de baja productividad. Los objetivos de esta investigación fueron determinar los efectos de la quema controlada solamente, medida 3 semanas después de la aplicación del fuego; comparar el efecto conjunto del herbicida picloram con y sin fuego; cortar con y sin fuego, y la quema individual de árboles con fuego; y comparar los costos de todos los tratamientos. Los tratamientos se aplicaron en pastizales del centro de Nebraska en 1993 y 1994. La mortalidad por fuego fue de un 77% en 1993 y de un 67% en 1994. El uso de picloram o el corte después del fuego controló cerca de un 100% los árboles de menos de 3 m de altura, pero el corte fue mas eficiente en árboles de más de 3 m. La mortalidad total producto de una combinación de tratamientos fue mayor en 1993, cuando las condiciones de la quema fueron más favorables. La quema, a un costo estimado de US\$ 4.96 ha^{-1} aplicada antes del picloram o del corte redujo los costos totales en cerca de la mitad. Los costos de la aplicación de picloram se redujeron de US\$ 90.10 ha^{-1} a US\$ 47.95 ha^{-1}, y los costos del corte de US\$ 62.92 ha^{-1} a US\$ 39.26 ha^{-1}. El quemar primero también redujo el tiempo de corte de 362 min ha^{-1} a 184 min ha^{-1}, pero no redujo significativamente el tiempo de aplicación del picloram. De ser posible, una quema controlada debe anteceder a la aplicación de un tratamiento intensivo, para reducir costos y mejorar la eficiencia total. Debido a que los costos y eficacia de quemar seguido por el uso de picloram o el corte son similares, el propietario debe escojer el método más apropiado a su realidad individual.

Eastern redcedar (*Juniperus virginiana* L.) has increased in numbers and extent on Great Plains grasslands in recent decades (Bidwell et al. 1990, Schmidt and Kuhns 1990). This has had an adverse effect on livestock production because eastern redcedar reduces total forage production (Engle 1985, Engle et al. 1987, Smith and Stubbendieck 1990), leads to undesirable changes in plant species composition (Gehring and Bragg 1992), and increases livestock handling costs (Stritzke and Rollins 1984). The primary reason for eastern redcedar's increase is thought to be the suppression of wildfire (Bragg and Hulbert 1976, Briggs and Gibson 1992).

Broadcast prescribed fire has been widely used to control eastern redcedar (Bragg and Hulbert 1976). Fire is effective because eastern redcedar does not resprout. However, the effectiveness of fire declines with increasing tree height (Owensby et al. 1973).

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Other eastern redcedar control methods include herbicides (Buehring et al. 1971, Crathorne et al. 1982, Smith 1986), notably picloram (4-amino-3,5,6-trichloropicolinic acid), cutting (Buehring et al. 1971, Wilson and Schmidt 1990), and individual tree ignition (Engle and Stritzke 1992). Managers may view these more intensive methods as too expensive and economically risky for use on low-productivity grasslands (Bernardo and Engle 1990).

The objectives of this research were to: 1) determine eastern redcedar mortality from fire alone as measured 3 weeks after fire; 2) compare the effects of either picloram application or sawing, each with and without fire, and individual tree ignition with fire 1 year after treatment; and 3) compare costs of treatment combinations.

Materials and Methods

Site Description

The research was conducted on the Rowse Ranch on native rangeland in northeastern Custer County, Neb. (41°43'49.1"N 99°15'16.9"W) in the Loess Hills physiographic region. The elevation was between 710 and 770 m. The predominant soil type was a Coly silt loam [fine-silty, mixed (calcareous), mesic Typic Ustorthent] formed in Peorian Loess (Soil Conservation Service 1982). Slopes ranged from nearly level to > 60%. Average annual precipitation in Custer County is 572 mm, of which about 80% usually falls from April through September. The average winter temperature is -3°C and the average winter daily low is –11°C. The average summer temperature is 22°C and the average summer daily high is 30°C. The average relative humidity is 50%. The prevailing winds are northwesterly. Average windspeed is highest, 21 km hour^{-1}, in April (Soil Conservation Service 1982). The range site classification was thin loess (Soil Conservation Service 1982).

Grazing on the site had traditionally been season-long continuous with cow-calf pairs. Grazing management was not altered for the experiments. Range condition was generally good. Herbaceous vegetation was representative of the Nebraska Loess Hills Mixed Prairie, as described by Weaver (1965), and was dominated by little bluestem [*Schizachyrium scoparium* (Michx.) Nash], sideoats grama [*Bouteloua curtipendula* (Michx.) Torr], and western wheatgrass (*Agropyron smithii* Rydb.).

Eastern redcedar populations on the site were of 2 types: dense thickets of trees more than 30 years old and 5 m tall mostly confined to north aspects; and open stands of smaller trees generally less than 30 years old on the other aspects. This research specifically dealt with the second population because it is a greater threat to future forage production, is more susceptible to fire, is more economical to treat, and can be removed with less danger of soil erosion.

Field Methodology

There were 4 replications of all treatments applied in each 1993 and 1994. For the broadcast prescribed fire experiment, each replication initially was divided into randomly assigned burned and unburned square plots of about 1 ha to measure fire effects and provide a control. After the fires, these original plots were subdivided into smaller rectangular plots averaging about 0.25 ha that were randomly assigned to treatments for the intensive treatment experiment. There were 4 intensive treatments in the burned areas and 3 in the unburned areas (Table 1). All live eastern redcedar trees were counted before the fires, 1 month after the fires, and 1 year after application of intensive treatments. The trees were classified into 4 height classes (< 1, 1—2, 2—3, > 3 m). Initial eastern redcedar density averaged 630 ha^{-1}. Mortality ratios were constructed for each height class within each replication by dividing the number of dead eastern redcedars at the sampling dates by the initial number of trees.

Table 1. Intensive treatment combinations applied to eastern redcedars in central Nebraska in 1993 and 1994.

Treatment	Description
Burned/Control	Fire alone
Burned/Picloram	Fire with picloram
Burned/Cutting	Fire with cutting
Burned/Individual Ignition	Fire with individual ignition
Unburned/Control	Untreated control
Unburned/Picloram	Picloram alone
Unburned/Cutting	Cutting alone

Broadcast Prescribed Fire

Broadcast prescribed fires were conducted on 4 May 1993 and 22 April 1994. Plots were burned individually between noon and dusk. At the outset of burning in 1993, the temperature was 25°C, relative humidity was 34%, and winds were 32 km hour^{-1} from the SSE. In 1994 initial conditions were: temperature, 15°C; relative humidity, 73%, winds 16–24 km hour^{-1} from the ESE. Fine-fuel loads were determined by clipping before each year's fire. Ten randomly placed 0.25 m^2 quadrats were clipped to about 2.5 cm stubble height on each large fire plot and fuel weights determined after oven drying (Table 2).

Table 2. Means and standard errors of fine-fuel loads in central Nebraska by replication in 1993 and 1994.

	Replication							
	1		2		3		4	
Year	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	(kg ha^{-1})							
1993	3,040	330	3,620	650	2,070	380	1,960	420
1994	1,860	390	1,080	200	1,700	320	1,630	340

Intensive Treatment Combinations

There were 7 unique treatment combinations (Table 1), the intensive portion of which was applied to individual trees. Length of time to apply treatments and amounts of materials used were recorded by replication.

Undiluted 21.1% ai picloram was applied with an adjustable spot applicator to all live trees on 27 May 1993 and 24 May 1994 at a rate of 4 ml m^{-1} of total estimated tree height (Chemical and Pharmaceutical Press 1995). Application was on the soil within the tree dripline. Cutting was done on 16 and 20 June in 1993, and on 24 and 25 May in 1994. Smaller trees, generally 1 m tall, were cut off with a hand lopper and larger trees were cut down with a chain saw at a point on the trunk between the soil surface and the lowest foliage. Individual tree ignition was used on burned areas only; there was no corresponding treatment for unburned areas. This treatment was applied on 19 July 1993 and 31 May 1994 following the method described by Engle and Stritzke (1992). Average weather conditions in 1993 for individual tree ignition were: temperature, 27°C; relative humidity, 54%; wind, 0–8 km $hour^{-1}$. In 1994 conditions averaged: temperature, 26°C; relative humidity, 33%, winds, 0–5 km $hour^{-1}$. A Panama Pump Company Flame Gun[1] burning a mixture of 95% diesel fuel and 5% gasoline was used. In 1993 replication 2 was not treated because no trees survived the broadcast fire.

Economic Methodology

Costs for conducting broadcast fires were estimated, and included labor, fuel, and all equipment costs. Total costs for applying intensive treatments comprise estimated equipment costs, and actual costs for labor, fuel, and herbicide. Equipment costs were calculated by adding maintenance costs, purchase-cost life, and interest. Equipment prices were taken from the 1993 Ben Meadows Co. and Forestry Suppliers, Inc. catalogs[2]. The annual percentage rate of interest used, 7.5%, was arrived at after consultation with agricultural bankers in 1993. Interest was charged on average investment in fixed assets. No salvage value of equipment was claimed for interest or depreciation calculations. Depreciation terms were 4 or 7 years, depending on anticipated useful life of equipment. Costs were converted to a per-hectare basis to allow summation. A 129-ha pasture was used as the conversion unit as being about average for the Loess Hills region. This figure was determined by consulting a number of University of Nebraska Extension Division and USDA personnel in the study area. Labor for all treatments was valued at \$10 $hour^{-1}$, except for rank-and-file members of the fire crew, who received \$6 $hour^{-1}$. This pay scale was arrived at by consultation with area residents and Nebraska Department of Agriculture officials. Fuel was valued at \$0.31 $liter^{-1}$ (\$1.16 gal^{-1}). Picloram cost was \$21.14 $liter^{-1}$ (\$80 gal^{-1}), the 1995 Nebraska suggested retail price. Total costs reported for burned treatments are the sum of fire costs plus the calculated and measured costs of the follow-up treatments. Costs of unburned treatments exclude fire costs.

Experimental Design and Analysis

Broadcast Prescribed Fire

Eastern redcedar percent mortality as sampled 3 weeks after fire was analyzed as a randomized complete block design (RCBD) (Steel and Torrie 1980) with year and tree-height class as factors with 2 and 4 levels, respectively. The experimental unit was a height class of trees within 1 replication. Initially, burned and unburned treatments were included as a factor. However, no mortality was detected in the unburned plots so these data were not analyzed.

Intensive Treatment Combinations

This experiment was analyzed as a RCBD. The treatment design was a split-plot with treatment method as the whole-plot factor with 6 levels and tree-height class as the sub-plot factor with 4 levels. The experimental units for treatments were the small plots described at the beginning of the Field Methodology section; for height classes the experimental units were height classes of trees within a treatment replication. Trees were counted before treatment and 1 year after. There was no mortality from the unburned/control treatment, so these data were not analyzed.

[1]The use of tradenames is not an endorsement by the authors or the University of Nebraska.

[2]Addresses are 3589 Broad St., Chamblee, Ga. 30334, and Box 8397, Jackson Miss. 39284-8397, respectively.

Mortality data were analyzed with maximum-likelihood analysis-of-variance using the SAS Categorical Modeling Procedure (SAS 1990), which is designed to fit non-normally distributed categorical data (Agresti 1990). When necessary, means within rows and columns were tested for significance at the $P = 0.05$ level with step-wise paired contrasts.

Economic Analysis

Three economic measures were compared. These were: 1) length of time ha^{-1} to apply herbicide, cutting, and individual tree ignition treatments; 2) total cost ha^{-1}; and 3) total cost $tree^{-1}$ treated. All economic measures were analyzed as randomized complete block designs. Factors were year with 2 levels, and treatment with 5 levels for time and total cost ha^{-1}, and 6 levels for total cost $tree^{-1}$. The small plots from the intensive treatment combinations experiment were the experimental units. Means for all economic measures also were adjusted using initial tree density as a covariate. Separation of adjusted means for significant terms at $P = 0.10$ was by paired comparisons.

Results and Discussion

Broadcast Prescribed Fire

There were significant ($P < 0.01$) main effects for year and tree height class. Total mortality was 77% in 1993 and 67% in 1994. Both fine-fuel loads and weather conditions were more favorable for eastern redcedar control by fire in 1993 than in 1994. These are important factors in eastern redcedar broadcast fire mortality (Rollins 1985). Average fuel loads were significantly ($P < 0.01$) higher in 1993 than 1994, 2,700 vs. 1,600 kg ha^{-1}, respectively. Weather conditions in 1993 were within Nebraska recommended burning prescriptions, with the exception of wind speed, which was above prescription (Masters and Stubbendieck 1988). Relative humidity was above prescription in 1994. In addition, in 1994 the last replication was burned beginning at about sundown and concluded after 2100 hours CDT. By this time conditions had deteriorated to: temperature, 13°C; relative humidity, 75%; wind speed, nearly calm.

Mortality by height class was inversely proportional to height. Height-class mortality means were: < 1 m, 88%; 1–2 m, 60%; 2–3 m, 35%, and > 3 m, 10%. These means were all significantly different ($P < 0.01$). This is consistent with previous results (Martin and Crosby 1955, Buehring et al. 1971, Owensby et al. 1973). Reasons for reduced control of larger trees include relatively thicker bark (Starker 1932), sparse fine fuels below the canopy (Engle et al. 1987), and greater vertical distance of upper foliage from lethal temperatures at the flame front (Methven 1971).

Intensive Treatment Combinations

There was a significant ($P < 0.01$) year-by-treatment-by-height class interaction. Therefore years were analyzed separately. This produced a significant ($P < 0.01$) treatment-by-height class interaction for each year (Table 3). For both years, the primary source of the treatment-by-height class interaction is the difference in the behavior of the cutting treatments as opposed to the other treatments. Whereas for cutting, mortality tends to remain constant or even increase with greater height, mortality tends to decrease with increasing tree height in the other treatments. This is consistent with past results for herbicide application (Buehring et al.

Table 3. Mean eastern redcedar mortality percentages for the treatment-by-height class interaction for 1993 and 1994 as measured 1 year after treatment in central Nebraska.

Treatment	Height Class (m) < 1	1–2	2–3	>3
1993	(%)			
Burned/Control	99 C[1]d[2]	86 B b	80 B b	44 A ab
Burned/Picloram	99 B d	92 B b	97 B d	47 A b
Burned/Cutting	97 A c	99 A b	100 A de	97 A c
Burned/Individual Ignition	99 C d	94 B c	90 B c	36 A a
Unburned/Picloram	78 C a	63 B a	52 A a	53 A b
Unburned/Cutting	83 A b	98 B b	100 B e	97 B c
1994				
Burned/Control	86 D a	54 C a	40 B a	20 A a
Burned/Picloram	97 B c	99 B c	88 AB c	77 A c
Burned/Cutting	92 A b	99 B c	100 B d	90 AB cd
Burned/Individual Ignition	94 C bc	90 C b	68 B b	30 A b
Unburned/Picloram	85 B a	92 B b	70 A b	74 A c
Unburned/Cutting	86 A a	96 B c	93 B cd	92 B d

[1]Means within rows were tested with step-wise paired contrasts. Means with the same upper-case letter are not significant at $P < 0.05$.
[2]Means within columns and within years were tested with step-wise paired contrasts. Means with the same lower-case letter are not significant at $P < 0.05$.

1971, Crathorne et al. 1982, Smith 1986, Stritzke 1985), and individual tree ignition (Engle and Stritzke 1992). Cutting is potentially 100% effective regardless of height because eastern redcedar does not resprout. Mortality was less than 100% for the height class < 1 m tall because some trees were missed. Lower mortality percentages are particularly evident for the unburned cutting treatment because the smallest trees were difficult to locate in the intact grass. This is a result of the methodology used, which dictated that limited amounts of time be expended on treatment applications to generate realistic labor-cost data. A study of pure efficacy would have allowed sufficient time to locate and treat all trees, regardless of cost. The level of performance reported here is probably closer to what could be expected from landowner or commercial applications. Mortality is < 100% for the largest trees because in a few cases it was discovered on resampling that buried basal branches had escaped cutting and were still alive.

Missed trees also accounted in part for the less than complete control from picloram treatments, especially of small trees. This suggests some form of marking should be used when making spot herbicide applications. Picloram performance declined substantially for trees > 3 m tall in the burned treatment and for trees > 2 m tall in the unburned treatment. Other research (Ortmann 1995) indicated that the recommended picloram rate based on tree height may be inappropriate. Under this calibration scheme the amount of picloram used per tree increases additively as tree height increases, while crown volumes of the trees increase geometrically. The practical effect of this is that as tree height increases the picloram dose on a ml per tree-crown-volume basis decreases. This suggests that smaller trees may be overtreated and larger trees may be undertreated. If so, this may partially explain the variable performance of picloram spot applied to larger eastern redcedar trees (Stritzke 1985), which may vary widely in proportion by local phenotype (Minckler and Ryker 1959, Engle and Kulbeth 1992).

The burned/individual ignition treatment provided less control than either fire with picloram or cutting on the 2 largest classes (Table 3). In an Oklahoma study (Engle and Stritzke 1992), eastern redcedar trees that had survived broadcast fire were treated with this method. The current results are not directly comparable with the Oklahoma results because total mortality resulting from both broadcast fire and individual ignition is reported here. The Oklahoma authors found that mortality due to individual ignition was 67, 67, and 62% for trees < 1.5, 1.5 to 2.5, and 2.5 to 5.0 m tall, respectively. This appears to be superior to the additive effect from individual tree ignition only in the current study. Average fine-fuel loads for the initial broadcast fire were somewhat lower in Nebraska than in Oklahoma, and fuel was particularly sparse on many of the individual ignition plots. This may have produced a less than adequate amount of scorching of basal foliage and contributed to poor performance when the trees were reignited (Engle and Stritzke 1992). Careful fine-fuel management would be required to make this method feasible on grazed mixed-grass prairie.

Economic Analysis

Length of time ha^{-1} to apply intensive treatments

There were significant ($P < 0.1$) treatment main effects for all economic measures (Table 4). The burned/control treatment was excluded from this analysis because no follow-up treatment was applied. The 2 picloram treatments and the burned/individual ignition treatment were least time intensive and not significantly different at the $P = 0.10$ level. The unburned/cutting and burned/cutting treatments were the most time consuming. The 3 least time-intensive treatments all involved little more than walking through the plots and required only seconds per tree, regardless of height. Cutting time per tree was highly variable, depending on height. Cutting large trees took many minutes each because lower branches had to be removed before the stems could be cut safely. Nevertheless, the time-saving effect of burning first is clearly displayed in the reduced time for the burned/cutting treatment, which is little more than half that for the corresponding unburned treatment.

Table 4. Means of 3 economic measures for intensive treatment combinations used to control eastern redcedar in 1993 and 1994 in central Nebraska.

Treatment	Time	Cost	Cost $tree^{-1}$
	(min ha^{-1})	(\$ ha^{-1})	(\$ $tree^{-1}$)
Burned/Control	N/A	4.96[1]	0.01 a
Burned/Picloram	34 a[2]	47.95 bc	0.08 c
Burned/Cutting	184 b	39.26 b	0.07 c
Burned/Individual Ignition	37 a	14.51 a	0.04 b
Unburned/Picloram	57 a	90.01 d	0.15 e
Unburned/Cutting	362 c	62.92 c	0.11 d

[1]Estimated cost ha^{-1} with all replications = \$4.96 ha^{-1} and variance = 0. Not included in the analysis. All other cost ha^{1} means include this value.
[2]Means within columns with the same lower case letter are not significant at $P < 0.10$.

Total cost ha^{-1}

The burned/control treatment was excluded from this analysis because the \$4.96 ha^{-1} was estimated, not measured. Thus, the burned/control mean was \$4.96 ha^{-1} and the variance was 0. Regarding the other 5 treatments, the tests were non-significant ($P > 0.1$) when burning plus picloram was compared with either burning plus cutting or cutting alone, despite apparently large differences. This is because the effect of large trees is inconsistent among treatments, which induces considerable variation. Use of tree density as a covariate accounted for 6% of the total variation. Blocking the design to help account for differences among replications in size distribution also was helpful. However, some variation remained because the effect of large trees differed among treatments. For example, the picloram cost to treat a tree > 3 m tall is always exactly twice that for treating a 1–2 m tree. For cutting, the labor cost to cut a tree > 3 m tall is highly variable, but nearly always more than double that for treating a 1–2 m tree. Despite this, burning first significantly reduced cost when burning plus picloram or cutting are compared with their unburned counterparts. The unburned/picloram treatment is clearly the most expensive. The burned/individual ignition treatment is the least expensive, but this must be evaluated in light of the treatment's relatively poor performance. At \$14.57 ha^{-1} (including the \$4.96 ha^{-1} broadcast fire costs) this is substantially more than the \$2.21 ha^{-1} reported from Oklahoma (Engle and Stritzke 1992). This may be partially explained by higher densities of surviving trees in the present study.

Total cost tree^{-1} treated

The burned/picloram and burned/cutting treatments were not significantly different at the $P = 0.01$ level. These treatments were about half as expensive as their unburned counterparts. Picloram alone is clearly the most expensive. Individual tree ignition is least expensive of the combinations, but as with cost ha^{-1} this must be viewed in light of its performance. At \$0.04 $tree^{-1}$, this is comparable to previous results on a per-tree basis (Engle and Stritzke 1992).

All economic measures clearly show the cost-reducing effect of broadcast fire before cutting or picloram application. Savings of time and money were substantial, simply because many trees were killed inexpensively with fire before intensive treatments began. Little cost difference is apparent between the burned/picloram and burned/cutting treatments. However, the primary sources of these costs differ. For cutting, labor is the major contributor to total costs, while for picloram application the cost of the herbicide is the major contributor. Because control levels as well as costs are similar for trees < 3 m tall, the availability and cost of labor vs. capital should be an important consideration for individual managers.

Conclusions and Management Implications

The use of broadcast fire as an initial treatment generally increases total eastern redcedar mortality and decreases total costs when intensive methods are applied to survivors. Herbicide and cutting treatments provide similar control levels, except on the largest trees, on which cutting was more effective. Individual tree ignition is economically risky unless fine-fuel loadings are sufficient to produce adequate basal foliage scorching. More intense fires, as in 1993, not only produce greater initial eastern redcedar mortality, but also greater total mortality when intensive follow-up methods are applied to fire survivors. This underscores the need for fine-fuel management, and for burning under the best possible conditions, both of which can provide considerable monetary savings. Because the cost efficiencies of fire followed by either picloram or cutting are similar, managers can rationally choose either, deciding on the basis of whether capital or labor are more available. In view of relatively poor picloram performance on larger trees, cutting may be the preferred method if their removal is required. In addition, managers should consider selective treatment based on height, in light of the expense and economic risk of treating large trees.

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