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Juniper Control with Soil-Applied Herbicides

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SUMMARY

Various herbicides active through the soil and plant roots were applied on juniper woodlands in New Mexico to determine effects on the trees and associated shrubs. Tebuthiuron pellets applied by an airplane at a 0.8 lb active ingredient (a.i.)/ac rate killed about 76% of one-seed juniper (*Juniperus monosperma*) growing on sand or loamy sand, whereas 1.5 lb a.i./ac was needed to control the trees on loam or clay loam soils. Picloram pellets controlled one-seed juniper at a 2.0 lb a.i./ac rate on sandy and loam soils, but did not kill a high percentage of the trees on clay loam soils. Where pinyon (*Pinus edulis*) grew with juniper, more than 50% of the trees were killed with 1.0 lb a.i./ac of tebuthiuron, and 0.8 lb a.i./ac of picloram. Wavyleaf oak (*Quercus undulata*), sand sagebrush (*Artemesia filifolia*), skunkbush (*Rhus trilobata*), and algerita (*Berberis* spp.) were controlled by tebuthiuron at 0.8 lb a.i./ac, but were not controlled by picloram. Higher rates of tebuthiuron and picloram applied as a broadcast or individual plant treatment were needed to control trees and shrubs on deep, fine-textured soils than on shallow, coarse-textured soils. Trees less than 10 ft tall were usually more readily controlled than larger trees. Hexazione applied at 4 ml per 3 ft of height or canopy diameter was more effective than tebuthiuron or picloram for individual plant control, but because the herbicide damages grasses it should not be used as a broadcast treatment.

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Juniper Control with Soil-Applied Herbicides

Kirk C. McDaniel and Keith W. Duncan[1]

Brush management in juniper woodlands since 1950 can be divided into three distinct phases. From 1950 to 1965, over one million acres throughout the western U.S. were treated with the objective of converting woodlands to grasslands. Mechanical methods were the primary technology employed during this era. During the mid 1960s to early 1980s, emphasis on land conversion began to diminish because of public concerns and questions about the ecological value of such practices. Further, the resource value of the trees was recognized and the optimization of a single-return product, such as increasing forage for livestock, could not be justified by benefit-cost analysis. Thus, from 1965 to 1980 little new technology was developed for brush management in juniper woodlands.

Presently, management of juniper woodlands is characterized by a comprehensive approach yielding benefits from the total resource base. The value of the trees can equal or exceed that of forage and, therefore in some situations, is taking precedence in management decisions. The primary goals for manipulating woodlands prior to the 1980s were (a) to increase forage production for

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livestock, (b) to improve watershed characteristics, (c) to improve wildlife habitat, and (d) to facilitate livestock handling (Evans and others 1975). Manipulating woodlands for the benefit of tree growth was usually not a primary consideration.

In recent years, interest in the use of herbicides for woodland management has increased, both for the reasons listed above by Evans and others (1975), but also as a silvicultural tool for removing unwanted trees selectively. Numerous herbicides for juniper control have been examined in research trials, but until recently few have been used commercially on a wide scale. In general, herbicides have been used for juniper control on an individual plant basis, but were considered for aerial broadcast only when tebuthiuron and picloram were registered for this use in the early 1980s.

In New Mexico, aerial field trials using picloram and tebuthiuron have been applied since 1981 by various agencies, chemical companies, and ranchers in addition to those applied by New Mexico State University. Some of these results were reported previously (McDaniel and White-Trifaro 1987) and are repeated here with other final treatment evaluations. Additionally, fifteen individual plant trials were conducted between 1985 to 1990 to compare several commercially available products. We evaluated treatment results from these aerial and hand-applied herbicide trials 3 years after the chemicals were applied. Many of the herbicide trials reported herein were not established strictly for research purposes, but do provide a valuable comparison of different herbicide rates and formulations. Data describing site conditions, species treated, size of trees, associated vegetation, and soil type were included in order to develop treatment recommendations and to identify areas where further research may be required.

JUNIPER CONTROL WITH PICLORAM AND TEBUTHIURON

Picloram [4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid] is formulated as a liquid for either root or foliage activity or as a granule or pellet (10% active ingredient, a.i.) for soil activity. It has a low level of toxicity to mammals and is relatively selective for forbs and woody plants, thus grasses are not harmed. Pelleted picloram applied by hand or aircraft at 2 to 4 lb a.i./ac has effectively controlled mature redberry juniper (*Juniperus pinchotti*) in the Rolling Plains and Edward Plateau regions of Texas (Scifres 1972; Schuster 1976). Ueckert and Whisenant (1982) reported redberry juniper seedlings were more easily controlled by foliar sprays of picloram than equivalent rates of pelleted or granular formulations. Young and others (1982) reported a lower investment in time and cost when applying picloram by hand compared to mechanical clearing of western juniper (*Juniperus occidentalis*). Johnsen and Dalen (1984) applied pelleted picloram to juniper trees and found Utah juniper (*Juniperus osteosperma*) most sensitive to the herbicide, one-seed juniper least sensitive, and alligator juniper (*Juniperus deppeana*) intermediate. Applications of 3.6 g a.i. of picloram/m of tree height controlled all species, but only Utah and alligator juniper were consistently control with 1.8 g a.i. or less per meter of height.

Tebuthiuron [N(5[1,1-dimethylethyl]-1,3,4-thiadiazol-2-yl)-N,N^1-dimethylurea] was registered for commercial rangeland use in Texas and Oklahoma in 1980, and in New Mexico in 1981, for control of a variety of woody plants including pinyon and some juniper species. In eastern Oregon, Britton and Sneva (1980) reported only 1 and 22% of western juniper trees were killed when pelleted tebuthiuron was applied by aircraft at rates of 2 and 4 lb a.i./ac, respectively. However, results from individual plant applications indicated smaller western juniper trees could easily be killed by the herbicide (Britton and Sneva 1981). Tebuthiuron applied at rates of 2 and 4 lb a.i./ac to eastern red cedar (*Juniperus virginiana*) did not provide satisfactory control where trees occurred as a scattered components in areas dominated by post oak (*Quercus stellata*) and blackjack oak (*Quercus marilandica*) (Scifres and others 1981). Clary and Goodrich (1983) applied pelleted tebuthiuron aerially on several sites in the Fish Lake National Forest in Utah and reported crown kills of Utah juniper at 78, 97, and 98% at rates of 1.0, 2.0, and 2.5 lb a.i./ac, respectively. They found trees under 1.5 ft were less susceptible to the herbicide, and percent crown kill of trees was higher on ridges and side slopes compared to bottomlands. Van Pelt and West (1990) compared methods for hand application of this herbicide and felt placement of particles at the stem base and basing dosages on stem height preferable to dripline applications and crown-volume based dosage estimates.

Tebuthiuron and picloram are classified as nonselective, soil-applied sterilants, although selectivity is accomplished by dosage (Masters and Scifres 1984). When formulated as clay pellets, the herbicides require rainfall to dissolve and transport the chemical into the root zone where it is normally concentrated in the surface 6" of soil (Bovey and others 1978). As a general rule, the optimum application time is just prior to seasonal rainfall, which dissolves the pellet and often stimulates rapid vegetative growth (Elanco 1983). Once in the root zone, the chemicals are absorbed by the roots of woody species and translocated in the xylem to the plant and leaves.

Picloram is translocated by the xylem if the chemical is applied through the soil and absorbed by roots. However, it can also be foliar applied as a liquid and transported in the phloem. The most active mechanism for picloram uptake usually differs among particular species. Picloram affects many vital plant processes, so it is difficult to attribute its biological activity to disrupting any given process (Bovey and Scifres 1971). Low levels of picloram promote the growth of some plants and inhibit others depending on species, stage of growth, herbicide concentration, and the specific tissue to which it is applied (Scifres 1980). Nucleic acid metabolism and various enzymes in plants are disrupted by picloram. In general, broadleaf species are most susceptible to picloram; grasses are least susceptible; and shrubs and trees are intermediate. Pinyon and juniper species are probably most susceptible to soil-applied formulations of picloram, with the exception of seedlings, which have a small root system and are less likely to absorb the chemical in the soil (Ueckert and Whisenant 1982).

The primary control mechanism of tebuthiuron within a plant is photosynthesis inhibitions (Bauer and Bovey 1975). Specifically, electron transport at the reducing side of photosystem II is inhibited along with the ability to produce carbohydrates: thus non-structural carbohydrates are reduced (Hatzios and others 1980). The response of most woody plants to tebuthiuron is slow, with repeated defoliations, until carbohydrate reserves are depleted and death occurs. The defoliation-refoliation cycles caused by tebuthiuron are dictated by rainfall patterns (Sosebee and others 1978; Scifres and others 1979). The first defoliation after application typically occurs between 30 and 90 days after rainfall (Scifres and Welch 1982).

Tebuthiuron, then, acts more slowly than other soil-applied herbicides such as picloram (Meyer and Bovey 1979), and control of woody species may take as long as three years, especially in arid and semi-arid rangelands (Elanco 1983). The persistence of tebuthiuron or picloram in the soil is often considered a beneficial characteristic, as they can provide continuous woody plant control for five or more years (Sosebee and others 1979; Jacoby and Meadors 1982; Britton and Sneva 1983). Within the soil, tebuthiuron and picloram are adsorbed to organic matter and clay particles (Chang and Stritzke 1977). Organic matter could be more significant than clay in regulating herbicide availability. However, the organic matter in most New Mexico rangeland soils is so low that its net influence is less than clay is.

Duncan and Scifres (1982) have listed three principles for bioactivity of soil herbicides. First, the single most important variable in regulating response of susceptible species is application rate. Second, given a specific application rate, the most important variable in regulating response of susceptible species is soil clay content. This becomes especially important where the rate to be applied is marginal relative to susceptibility of the target species. This second principle is demonstrated in a study by Fischer and Stritzke (1978) in Oklahoma, where 2 lb/ac tebuthiuron killed 98% of the oak on soils with 12.5% clay, but no trees were killed on soils with 60% clay. Third, soil organic matter can affect availability and thus phytotoxicity of herbicides. But, again, due to the low organic matter content of most New Mexico rangeland soils, this is usually the least significant of the three.

INDIVIDUAL PLANT TRIALS

Prior to conducting our individual plant treatments, we examined the results from about 85 demonstration trials established for juniper control. The trials were conducted by the NMSU Cooperative Extension Service beginning in 1968. These trials were rarely replicated except by locations, and were not designed for statistical analysis. However, they provided useful information on the degree of control that might be anticipated using a particular herbicide (table 1). Many of the trials were repeated at the same location for 5 or more years.

Table 1. Recommended application rate for control of juniper species using soil-active herbicides on an individual plant basis.

Herbicide	A.I.	Minimum rate per 3 ft canopy diam. Soil texture[1] Coarse	Fine
	(%)	(tbs)	(tbs)
Lithium salt of bromacil	22P[2]	2	4
Karbutilate	10G	2-1/2	3-1/2
Prometone	5P	No effective rate determined	
Fenuron	25P	1	2
Dicamba	5G	No effective rate determined	
Picloram	10P	1	2
Tebuthiuron	25B	3B	Not recommended
Hexazione	25L	2 ml	4 ml

[1]Coarse = gravelly, sand, or sand loam textures; fine = silty or clay textures.
[2]L – liquid, G – granule, P – pellet, B – bullet.

Beginning in 1984, herbicide rates were applied based on the plant height or canopy diameter (table 2). Application rates were uniform across all sites, soil types, and plant species. This approach emphasized the practical application of herbicides and a uniform recommendation by product. Spike Bullets® (tebuthiuron) were manufactured until the mid-1980s, when Elanco Products Company (now DowElanco) changed the formulation to a 20% pellet and changed the name to Spike 20P®. Likewise, DowElanco Company ceased to make picloram pellets (Grazon 10K®) in the mid-1980s. Therefore, the liquid formulation of picloram (Grazon PC®) was compared later in the individual plant trials. Also, hexazinone (Velpar®), a liquid soil-applied herbicide by Dupont Agricultural Products, was compared in the individual plant trials since 1985.

In general, hexazinone has provided a greater level of juniper control than either tebuthiuron or picloram when applied to an individual plant (table 2). Hexazinone applied at 4 or 6 ml per 3 ft of tree height provided at least 70% juniper mortality in 12 of the 15 treatment locations. The 3 exceptions where results were poorer were from trials conducted in 1985 at Capitan and Bigham (loam

Table 2. One-seed juniper mortality following individual plant treatments with various herbicides in New Mexico.

Date	3/21/85	6/20/85	7/1/85	7/2/85	7/11/85	7/23/85	3/5/86	6/25/86	7/17/86	8/13/86	7/13/85	8/9/88	5/18/90	3/27/90	4/16/90
Location	Capitan	Corona	Bingham	Magdalena	Silver City	Gr. Quivira	Las Vegas	Piñon	Tucumcari	Magdalena	Quemado	Mosquero	Quemado	Socorro	Socorro
County	Lincoln	Lincoln	Socorro	Socorro	Grant	Torrance	San Miguel	Otero	Quay	Socorro	Catron	Harding	Catron	Socorro	Socorro
Soil type	loam	rocky sandy loam	loam	gravelly sandy loam	gravelly clay loam	sandy loam loam	sandy loam	rocky loam	sandy clay loam sandy loam	gravelly sandy loam	loam	gravelly sandy loam	sandy loam	clay loam	sandy loam
Spike[1]															
2 BB/3 ft	4	16	0	20	8	12 5	96	5	8 57	—	—	—	—	—	—
4	8	76	38	44	12	28 8	100	68	44 63	27	—	—	—	—	—
6	0	88	20	22	36	40 57	92	54	80 84	0	—	—	—	—	—
.25 gm/3 ft	—	—	—	—	—	— —	—	—	— —	—	0	60	5	68	8
.50 oz	—	—	—	—	—	— —	—	—	— —	—	36	100	90	100	44
Velpar[2]															
2 ml	0	48	38	27	32	12 82	61	69	68 100	69	12	92	75	—	—
4	24	93		53	80	76 96	90	88	88 100	67	80	96	90	92	60
6	32	92	52	72	88	52 100	94	100	92 99		72	96	90	48	96
Grazon PC[3]															
2 ml										—	—	20	50	—	—
3										14	8	—	—	—	—
4										30	76	76	76	60	20
5										36	64	—	—	—	—
6										—	—	68	68	92	68

[1]Spike® = tebuthiuron; formulated as a brush pellet (BB) or 20% active pellet.
[2]Valpar L® = hexazione; formulated as a liquid.
[3]Grazon PC® = picloram; formulated as a liquid.

soils), and at Magdalena in 1987 (sandy loam soil). These three locations had a large number of trees taller than 12 ft within study plots. These trees were only partially defoliated, and were usually not killed by the herbicide. These trials suggest that juniper trees greater than 12 ft tall are more difficult to control than smaller trees, regardless of soil type. Conversely, trees less than 3 ft tall are usually killed easily with hexazione applied at 2 ml per tree (data not shown).

Tebuthiuron applied at 0.5 gm per 3 ft of tree height provided greater than 90% mortality in three of five trials, but less than 45% mortality in two other trials (table 2). Picloram liquid applied at 4–6 ml per 3 ft of tree height provided >80% mortality in only two of six trials. These results suggest that tebuthiuron pellets and picloram liquid can be used for juniper control, but that hexazinone provides a more consistent level of tree control than either of the other two herbicides.

From NMSU trials and from similar trials reported from nearby states, we have developed guidelines for the control of juniper species on an individual plant basis in New Mexico (Duncan and McDaniel 1991). When a soil-active herbicide is applied on an individual tree basis, control is related to tree species, tree height or canopy diameter, soil texture, application method, herbicide, formulation, and rate. General guidelines developed for New Mexico include:

1. One-seed juniper and Rocky Mountain juniper (*Juniperus scopulorum*) are the most difficult species to control, Utah juniper is least difficult, and alligator juniper is intermediate.

2. Treating stands of young junipers is recommended because trees less than 12 ft in height are controlled more effectively than larger trees. Areas previously cabled, chained or cleared, or areas where juniper appears to be invading, are stands preferred for control.

3. Because of herbicide and application costs, tree densities of fewer than 150 plants per acre are recommended for control.

4. An exact relationship between herbicide rate and clay content has not yet been developed, but with the chemicals available today, rate must be increased as soil clay content increases. Our studies suggest that soil-active herbicides are more effective when clay content is less than 15%, organic matter is less than 1%, and the cation exchange capacity is less than 25 meq/100 g.

5. Liquid or pelleted soil-applied herbicides should be distributed uniformly around the tree and below the canopy drip zone. High organic matter content and reduced rainfall penetration under the canopy reduces herbicide activity.

6. Forage response usually occurs after control and is highly dependent upon species present before treatment. However, a primary goal for controlling trees on an individual plant basis is usually to maintain existing forage yields in a treated area.

7. Soil-applied herbicides can be used to control unwanted trees selectively, which can enhance the growth of desirable trees. However, from a practical standpoint, it is usually not possible to control dense stands of associated unwanted shrubs. Composition of understory species must be considered in the control program.

8. Pinyon is rarely a target species for control. Mature pinyon are prized by humans and wildlife because of their nut production. In New Mexico, pinyon is the state tree.

BROADCAST TRIALS

While considerable research has been conducted on the control of juniper on an individual tree basis, relatively little work has been done examining control with broadcast applications of soil-active herbicides. Tebuthiuron and picloram were first broadcast on juniper woodlands in New Mexico in 1981. About 600 acres across 10 different locations were treated in various research-demonstration trials. We evaluated all of these trials from 3 to 5 years after herbicides were applied by hand scatter or aircraft.

When these broadcast trials were established we did not intend to be able to compare results in a comprehensive manner. Several of the sites were established with chemical companies (i.e., Dow Elanco Co.) in cooperation with NMSU, a rancher, or an agency. The primary purpose of the trials was to establish an optimum rate for either tebuthiuron or picloram at a particular location. Results from these trials have been used as a guide for later commercial applications. Approximately 27,000 acres of woodlands were commercially treated by aerial broadcast with these two chemicals from 1981 to 1990 in New Mexico.

Our primary purpose for evaluating the sites was to determine efficacy of herbicides by species of juniper, pinyon, and associated woody plants, and to determine effects on different size classes of trees. To evaluate sites, four belt transects were taken in each treated plot, the length of the transect varying depending on the size of area. Trees were divided into one of four size classes (less than 3, 4–6, 7–9, and 10+ ft) and herbicide damage was noted. Damage rating categories were no effect (alive), no green growth (dead), and partial defoliation. This last category was further detailed by percent of plant defoliated: 1–25%, 26–50%, 51–75%, or 76–99%. If fewer than 25 plants were observed in a plot for a particular height class, data were not included in summary tables. Untreated woodlands adjacent to herbicide plots were used as a control unless these areas were included in the original study design. Soil cores to a 6" depth were obtained from areas between trees and were analyzed for soil pH, cation exchange capacity, percent organic matter, and particle size.

Picloram (10% a.i.) was applied aerially at four sites in 1983 with a Piper Pawnee "C" equipped with a Transland® spreader. The equipment was calibrated and rates determined for each plot by taking beginning and ending weights of the herbicide. Plot size was about 20 acres (336 x 5280 ft) with 200-ft buffers between plots. Table 3 shows the soil texture, annual rainfall, and kill of pinyon at each of these sites. Picloram killed 88% or more of the pinyon at all locations. Observations on pinyon not killed showed trees to be highly defoliated (usually greater than 75%). By comparison, the kill range on one-seed juniper varied greatly by soil texture and tree size (table 4). In general, as soil texture became finer or tree size increased, control of one-seed juniper by picloram decreased. One-seed juniper not killed in plots with low picloram rates were usually

Table 3. Pinyon control following aerial broadcast of picloram at four locations in New Mexico.[1]

Site	Soil type	Annual rainfall	Rate	Mortality of pinyon
		(")	(lb ai/ac)	(% dead)
Gran Quivira	Sand	15	0.8	100
			1.2	98
			1.5	100
			2.0	100
Montoya	Loam	14	0.8	88
			1.2	89
			1.5	99
			2.0	100
Wagon Mound	Cobbly Clay loam	17	0.8	94
			1.1	99
			1.5	89
Guadalupe Mts.	Shallow Clay loam	16	0.8	99
			1.2	98
			1.5	99
			2.0	99

[1]Applied in February 1983 at Gran Quivira, Montoya, and Wagon Mound; and August 1983 in the Guadalupe Mountains, NM.

only slightly defoliated (less than 25%), whereas higher rates did increase the amount of defoliation. It was our impression that one-seed juniper trees that were highly defoliated but alive after three years would continue to survive. Observations on shrubs showed skunkbush, wavyleaf oak, and mountain mahogany (*Cercocarpus mountanus*) were partially defoliated but rarely killed by picloram. Shrubs that were not affected by picloram included algerita (*Berberis trifoliotata*) and sand sagebrush.

Tebuthiuron (40% a.i.) was applied by hand broadcasting pellets in one-quarter acre plots near Gran Quivira and Corona, New Mexico in September 1981. Aerial trials were established in 1983 near the hand broadcast treatments at Gran Quivira and at Ft. Stanton and in the Guadalupe Mountains, New Mexico. Aerial treatments were applied with a Cessna Ag. Husky aircraft equipped

Table 4. One-seed juniper control following aerial broadcast of picloram at four locations in New Mexico[1].

Site		Mortality of one-seed juniper following application of picloram by tree height				
(Soil texture)	Rate	< 3 ft	4–6 ft	7–9 ft	10+ ft	x
	(lb ai/ac)	(% dead)				
Gran Quivira	0.8	41	59	42	29	37
(sand)	1.2	55	69	70	51	58
	1.5	57	80	67	69	70
	2.0	94	85	75	76	77
Montoya	0.8	38	19	9	6	9
(loam)	1.2	18	10	3	3	8
	1.5	77	60	65	46	58
	2.0	86	75	75	63	70
Wagon Mound	0.8	10	17	7	12	11
(clay cobbly loam)	1.2	30	16	22	20	21
	1.5	29	21	18	22	21
Guadalupe Mts.	0.8	4	5	0	0	2
(shallow clay loam)	1.1	17	2	3	4	7
	1.5	9	4	4	7	17
	2.0	58	22	24	13	56

[1]Applied in February 1983 at Gran Quivira, Montoya, and Wagon Mound; and August 1983 in the Guadalupe Mountains, NM.

with an Elanco meterate and a Transland spreader. The plane flew at a height of 100 ft, and swath width was about 40 ft. Plots were from one-half to one mile in length and 336 ft wide with 150–200 ft buffer strips between treatments. Table 5 shows the kill of one-seed juniper by height classes at each of these sites. Tebuthiuron proved to be highly effective for control of one-seed juniper on sandy textured soils, but higher rates were necessary to control the trees on deep, finer textured soils than in shallow, coarse textured soils.

Pinyon kill at the Corona site was 79, 73, and 100% for the 1.0, 1.5, and 2.0 a.i./ac rates of tebuthiuron, respectively (table 6). Pinyon kill at Ft. Stanton was 60, 56, and 78% for rates of 0.8, 1.2 and, 1.5 lb a.i./ac, respectively. Few pinyon were present on the Gran Quivira sites but all trees were killed. Sand sagebrush and

Table 5. One-seed juniper control following broadcast of tebuthiuron at four locations in New Mexico.[1]

Site		Mortality of one-seed juniper following application of picloram by tree height				
(Soil texture)	Rate	< 3 ft	4–6 ft	7–9 ft	10+ ft	x
	(lb ai/ac)	(% dead)				
Gran Quivira[1]	1.0	100	100	100	100	100
(sand and shallow	1.5	100	100	100	100	100
sand[2])	2.0	100	100	100	100	100
Corona[1]	1.0	50	67	58	27	49
(shallow clay loam)	1.5	50	86	76	76	75
	2.0	100	80	100	67	89
Gran Quivira[2]	0.8	100	77	84	67	76
(deep sand)	1.0	90	78	75	75	77
	1.25	98	97	93	89	92
	1.6	92	99	97	88	94
Guadalupe Mts.	1.0	2	1	0	0	2
(shallow clay loam)	1.2	10	8	0	2	12
	1.5	6	6	0	0	8
	1.7	8	4	2	12	15
Ft. Stanton[2]	0.8	14	13	0	2	7
(silty to sand loam)	1.25	47	50	57	36	38
	1.5	75	100	94	66	73

[1]Applied by hand scatter in September 1981 at Gran Quivira and Corona.

[2]Applied by aircraft at Gran Quivira in March 1983, at Ft. Stanton in August 1983, and in Guadalupe Mountains in February 1984.

skunkbush growing at Gran Quivira (sandy textured soil) were usually controlled (at least 70% mortality) by all rates of tebuthiuron. On loam or clay loam soils, tebuthiuron at 2.5 lb a.i./ac proved most effective for control of algerita and wavyleaf oak (approximately 50% or higher mortality) but was less effective for control of skunkbush (usually less than 70% mortality). Tebuthiuron had little effect on cholla cactus.

Tebuthiuron (40% a.i.) and picloram (10% a.i.) were applied side by side for control of Rocky Mountain juniper and pinyon at one location near Maxwell, New Mexico in October 1981. The

Table 6. Woody plant control (beside one-seed juniper) following broadcast of tebuthiuron at four locations in New Mexico.

Site (Soil texture)	Plant species	0.8	1.0	1.2	1.5	1.7	2.0
		Tebuthiuron application rate (lb/ac) (% dead)					
Gran Quivira (sand and shallow sand)	Pinyon	—	100	—	100	—	100
	Skunkbrush	—	90	—	82	—	100
	Sand sagebrush	—	79	—	92	—	98
Corona (shallow clay loam)	Pinyon	—	79	—	73	—	100
Guadalupe Mts. (shallow clay loam)	Pinyon	—	25	40	45	63	—
	Skunkbrush	—	40	73	70	80	—
	Wavyleaf oak	—	55	95	90	95	—
	Algerita	—	25	70	75	95	—
	Mountain mahogony	—	25	90	65	95	—
	Cholla	—	0	0	0	95	—
						0	—
Ft. Stanton (silty to sand loam)	Pinyon	60	—	56	78	—	—
	Skunkbrush	8	—	36	72	—	—
	Wavyleaf oak	60	—	69	96	—	—
	Algerita	45	—	90	80	—	—

herbicides were aerially applied with a Piper Pawnee “C” aircraft on plots 336 x 1640 ft. Soil on the site is a sandy loam and annual rainfall is 17". Neither tebuthiuron or picloram killed Rocky Mountain juniper at the 0.8 lb a.i./ac rate (table 7). About 34% of the Rocky Mountain juniper trees were killed with a 1.25 lb/ac rate of tebuthiuron, but few trees were killed at the same rate by picloram. Control of Rocky Mountain juniper and pinyon with tebuthiuron generally decreased as the trees became larger. Picloram was more effective than tebuthiuron in killing pinyon and a few ponderosa pine (*Pinus ponderosa*) that occurred mainly in drainage bottoms at this site. Most of the pinyon trees were mature, reaching heights of 30 ft or higher. These trees are prized for their nut production and killing the trees was not considered beneficial.

Table 7. Mortality of trees with broadcast aerial applications of pelleted tebuthiuron and picloram near Maxwell, NM.[1]

Plant species	Plant size	Tebuthiuron rate (lb/ac) 0.8	1.25	1.7	Picloram rate (lb/ac) 0.8	1.25
	(ft)	(% dead)				
Rocky Mountain juniper	1–3	0	100	40	0	0
	4–6	0	50	39	0	0
	7–9	0	63	30	1	0
	10+	0	16	26	0	4
	mean	0	34	30	0	3
Pinyon	1–3	17	50	—	52	86
	4–6	24	77	73	57	98
	7–9	35	62	51	63	97
	10+	18	54	16	77	73
	mean	22	59	56	66	81

[1]Applied October 21, 1981, evaluated June 14, 1986.

DISCUSSION

From these data in New Mexico, several important factors were determined that we believe can provide direction for future research needs in the aerial application of herbicides in juniper woodlands.

1. At comparable rates, tebuthiuron is more effective than picloram for control of a wider range of tree and shrub species. Tebuthiuron killed or suppressed one-seed juniper, Rocky Mountain juniper, pinyon, sand sagebrush, skunkbush, wavyleaf oak, and algerita. Picloram killed pinyon and ponderosa pine, but provided less control than tebuthiuron on the other tree and shrub species.

2. A better understanding of the relationship between soil texture and herbicide activity is needed. Unquestionably, soil type is an important factor affecting herbicide activity.

3. A minimum herbicide rate needs to be determined for unwanted understory shrubs when the goal is to maintain an existing tree stand. For example, it may be desirable to control sand sagebrush and skunkbush in the understory while maintaining a widely scattered tree layer. Low rates (<0.5 lb/ac) of tebuthiuron could be applied with the goal of controlling shrubs but killing a minimum number of trees.

4. An objective for juniper management some agency conservationists working in these woodland expressed to us is to be able to kill smaller trees by broadcast applications while maintaining larger trees. While larger trees were usually not killed as often as smaller trees in the trials we examined, the difference was usually not very great at a particular herbicide rate. Further work is needed in this area.

INTEGRATED BRUSH MANAGEMENT IN JUNIPER WOODLANDS

Development of Integrated Brush Management Systems (IBMS) has become a popular approach to applying control programs in rangeland ecosystems (Scifres 1980; Scifres and others 1983; Young and others 1983). This approach, which recognizes the potential value of woody plants, may be particularly appropriate in juniper woodlands. The IBMS approach uses a favorable economic result from brush control or any other alternative management practice as a primary consideration for management.

The first step in IBMS according to Scifres and others (1983) is to develop clearly stated objectives for the long-term use of land. Management goals are then set and a sequence of treatments and practices is devised at the outset to reach these objectives (Scifres 1981). However as we have observed from juniper woodlands, management goals change over time. This change may result from new technologies, new uses demanded by the public, or a changing political or economic environment.

Herbicides can be utilized as a method of initial control or as a low-cost secondary treatment to maintain and extend the effective life of a previous brush control project. However, applying a herbicide as a single brush management method in juniper woodlands may not provide a return on the investment. In the IBMS context the initial treatment and follow-up treatments should be subjected to an economic analysis as if they were a single entity. Alternative brush management methods should be compared for their applicability, availability, and projected potential return to benefit all other major resource products (trees, wildlife, forage, etc.).

While economic viability is a primary consideration in the IBMS approach, it is not the only criterion. The relative degree of emphasis on each resource product when planning an IBMS varies with the current or projected land-use goals; thus, no two programs developed for potential application would likely be identical.

LITERATURE CITED

Bauer, J. R.; R. W. Bovey. 1975. Herbicidal effects of tebuthiuron and glyphosate. Agron J. 67:547–553.

Bovey, R. W.; C. J. Scifres. 1971. Residual characteristics of picloram in grassland ecosystems. Texas Agr. Exp. Sta. Bull. 1111.

Bovey, R. W.; E. Burnett; R. E. Meyer; C. Richardson; L. Loh. 1978. Persistence of tebuthiuron in surface runoff water, soil and vegetation in the Texas Blacklands Prairie. J. Environ. Qual. 7:233–236.

Britton, C. W.; F. A. Sneva. 1981. Effects of tebuthiuron on western juniper. J. Range Manage. 34:30–32.

Clary, W. P.; S. Goodrich. 1983. Response of woody species to tebuthiuron in central Utah pinyon-juniper. Soc. for Range Manage. Ann. Mtg. 36:41 (Abstr.).

Chang, S. S.; J. F. Stritzke. 1977. Sorption, movement and dissipation of tebuthiuron in soils. Weed Sci. 25:184–186.

Duncan, K. W.; K. C. McDaniel. 1991. Chemical weed and brush control guide for New Mexico rangelands. New Mexico Coop. Exten. Service. 400 B-17.

Duncan, K. W.; C. J. Scifres. 1982. Influence of soil clay and organic matter contents on the bioactivity of tebuthiuron. *In*: Brush Manage. and Range Improvements Res. 1980–81:16–18. Texas A&M University, College Station, Texas.

Elanco Products Co., Division of Eli Lilly and Co. 1983. Grassland Technical Manual. Indianapolis.

Emmerich, W. E. 1985. Tebuthiuron—environmental concerns. Rangelands. 7:14–16.

Evans, R. A.; R. E. Eckert Jr.; J. A. Young. 1975. The role of herbicides in management of pinyon-juniper woodlands. *In*: The Pinyon-Juniper Ecosystem: A Symposium. May 1978. Utah State University, Logan, Utah.

Fischer, M. L.; J. C. Stritzke. 1978. Effects of various soil physical properties on phytotoxicity of tebuthiuron. Proc. South. Weed. Sci. 31:204.

Hatzios, K. K.; D. Penner; D. Bell. 1980. Inhibition of photosynthetic electron transport in isolated spinach chloroplasts by two 1,3,4-thiadiazolyl derivatives. Plant Physiol. 65:319–321.

Jacoby, P. W.; D. N. Ueckert; F. S. Hartmann. 1982. Control of creosotebush (*Larrea tridenta*) with pelleted tebuthiuron. Weed Sci. 30:307–310.

Johnsen, Jr., T. N; R. S. Dalen. 1984. Controlling individual junipers and oaks with pelleted picloram. J. Range Manage. 37:380–384.

Masters, R. A.; C. J. Scifres. 1984. Forage quality responses of selected grasses to tebuthiuron. J. Range Manage. 37:83–87.

McDaniel, K. C.; L. White-Trifaro. 1987. Selective control of pinyon-juniper with herbicides. *In*: Proceedings: Pinyon-juniper conference. Reno, NV. p. 448–455.

Meyer, R. E.; R. W. Bovey. 1979. Control of honey mesquite (*Prosopis juliflora* var. *glandulosa*) and Macartney rose (*Rosa bracteata*) with soil-applied herbicides. Weed Sci. 27:280–284.

Schuster, J. L. 1976. Redberry juniper control with picloram. J. Range Manage. 29:490–491.

Scifres, C. J. 1972. Redberry juniper control with soil-applied herbicide. J. Range Manage. 25:208–310

Scifres, C. J. 1980. Brush Management: Principles and Practices for Texas and the Southwest. Texas A&M Press, College Station.

Scifres, C. J.; J. L. Mutz; W. T. Hamilton. 1979. Control of mixed brush with tebuthiuron. J. Range Manage. 32:155–158.

Scifres, C. J.; J. W. Stuth; R. W. Bovey. 1981. Control of oaks (*Quercus* spp.) and associated woody species on rangelands. Weed Sci. 29:270–275.

Scifres, C. J.; T. G. Welch. 1982. Tebuthiuron for brush management: Research synthesis. *In*: Brush Manage. and Rangeland Improvement Res. 1980–81:7–11. Texas A&M University, College Station, Texas.

Scifres, C. J.; W. T. Hamilton; J. M. Inglis, J. R. Connor. 1983. Development of integrated brush management systems (IBMS): Decision making processes. *In*: Proceedings Brush management Symposium. Soc. for Range Manage. Albuquerque, NM p. 97–104.

Sosebee, R. E.; C. S. Brumley; W. E. Boyd. 1978. Mesquite control with tebuthiuron. *In*: Noxious Brush and Weed Control Res. Highlights 9:34–35. Texas Tech University. Lubbock, Texas.

Ueckert, D. N.; S. G. Whisenant. 1982. Individual plant treatments for controlling redberry juniper seedlings. J. Range Manage. 35:419–423.

Van Pelt, N. S.; N. E. West. 1993. Interactions of pinyon and juniper trees with tebuthiuron applications at 2 matched reinvaded sites in Utah. J. Range Manage. 46:76–80.

Young, J. A.; R. A. Evans; J. D. Budy; A. Torell. 1982. Cost of controlling maturing western juniper trees. J. Range Manage. 35:437–442.

Young, J. A.; R. A. Evans; D. M. McKenzie. 1983. History of brush control on western U.S. rangelands. *In*: Proceedings Brush Management Symposium. Soc. for Range Manage. Albuquerque, NM p. 17–25. Texas Tech University Press.