Evaluation of the Atrazine-Fallow Technique for Weed Control and Seedling Establishment

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Highlight: *The atrazine-fallow technique was evaluated for 3 years on study areas of from 50 to 1,000 acres. Atrazine at 0.6 to 1.2 lb/acre was applied in the fall by ground rig, by fixed-wing aircraft, or by helicopter. Ground-rig application gave the most uniform control of cheatgrass and tumble mustard during the fallow year. Air application usually left weedy strips between swaths of excellent weed control. Wheatgrasses and other species of grasses and forbs were fall-seeded with the standard and deep-furrow rangeland drills 1 year after herbicide application. Fair to excellent seedling stands were obtained in all years. However, in 1 year a valid evaluation of treatment effects was not possible because of depradation and unusually high spring precipitation in the seedling year. In 2 years, environmental conditions were near normal, and depredation was reduced by use of large study areas and insect control. Under these conditions, good established stands of crested, intermediate, pubescent, and Siberian wheatgrasses were obtained by the chemical-fallow technique.*

Many workers have shown that seeding perennial wheatgrass into dense stands of cheatgrass (*Bromus tectorum*) results in stand failure in most years. Mechanical fallow for control of cheatgrass has been successful; however, the period available for disking in the spring, and therefore the acres that can be worked, is limited. Late germination of weed species in response to spring precipitation can reduce the effectiveness of the fallow. Inclement spring weather may also preclude the use of contract work for mechanical treatment.

The atrazine-fallow technique has shown promise for weed control and establishment of seeded species and overcomes problems associated with a mechanical fallow. Research on this technique was done on small plots from 1962 to 1969 (Eckert and Evans, 1967; Evans et al., 1969; and Eckert et al., 1972). Atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine) at 1 lb/acre applied in the fall has given good weed control throughout the fallow year; soil moisture is conserved; and NO_3-N is accumulated (Eckert et al., 1970). During the fallow year, atrazine is degraded and leached so that little toxic residue remains in the soil when perennial grasses germinate. Perennial grasses are fall-seeded 1 year after herbicide application and germinate 16 to 17 months after herbicide application. Good seedling stands have been obtained most years by the deep-furrow seeding technique (Evans et al., 1970; Asher and Eckert, 1973; and Eckert, 1974).

The practical application of the atrazine-fallow technique was evaluated on demonstration-size plots in 1966 and 1969 and on a field-scale seeding of cheatgrass-infested rangeland in 1970. This paper presents the results of these studies.

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The study is a contribution from the U.S. Dep. Agr., Agr. Res. Serv., and the Agricultural Experiment Station, Univ. of Nevada, Reno. (Journal Series Number 264.)

Manuscript received July 25, 1973.

Demonstration Studies

Procedures

Atrazine at 1 lb/acre active was applied by ground rig to one site in fall, 1966; and in fall, 1969, by fixed-wing aircraft to one site and by helicopter to two sites. Atrazine was applied in 5 gpa water by air and in 20 gpa by ground rig. Study areas were located in central and eastern Nevada and varied from 50 to 160 acres.

In the 1966 trial, Amur intermediate wheatgrass (*Agropyron intermedium*) was seeded at 6 lb/acre with a deep-furrow drill in fall, 1967. In fall, 1970, two sites of the 1969 trials were seeded to standard crested wheatgrass (*A. desertorum*) at 6 lb/acre. Five mixtures of species were seeded on the third site: 1) Siberian wheatgrass (*A. sibericum*) and sainfoin (*Onobrychis viciaefolia*); 2) western wheatgrass (*A. smithii*), red fescue (*Festuca rubra*), and alfalfa (*Medicago sativa*); 3) Luna pubescent wheatgrass (*A. trichophorum*), beardless wheatgrass (*A. inerme*), and small burnet (*Sanquisorba minor*); 4) Greenar intermediate wheatgrass, smooth brome (*Bromus inermis*), and alfalfa; 5) crested wheatgrass, Russian wildrye (*Elymus junceus*), and yellow sweetclover (*Melilotus officinalis*). Grasses were seeded at the rate of 4 lb/acre alone or at 2 lb/acre in combinations. Forbs were seeded at 1 lb/acre. All seedings were made with both the deep-furrow drill (20-inch rows) and the standard rangeland drill (12-inch rows). Broadleaf annual weeds were controlled during the seedling years of 1968 and 1971 with 1/2 or 1 lb/acre of 2,4-D [(2,4-dichlorophenoxy) acetic acid] applied in May, except on the site with grass-forb mixtures.

Weed control was evaluated by density (plants/ft^2), frequency (% occupancy/ft^2), and cover (%). Success of seeded species was evaluated by plant density (plants/ft of row—pfr), frequency (% occupancy/ft of row), and height during the seedling year and by frequency of established plants.

Results

Fallow Year

Ground application of atrazine gave uniform and excellent weed control in the fallow year (Fig. 1). Aerial application resulted in uncontrolled strips of cheatgrass, tumble mustard (*Sisymbrium altissimum*), Russian thistle (*Salsola iberica*), and yellowflowered pepperweed (*Lepidium perfoliatum*) (Fig. 2). Weed

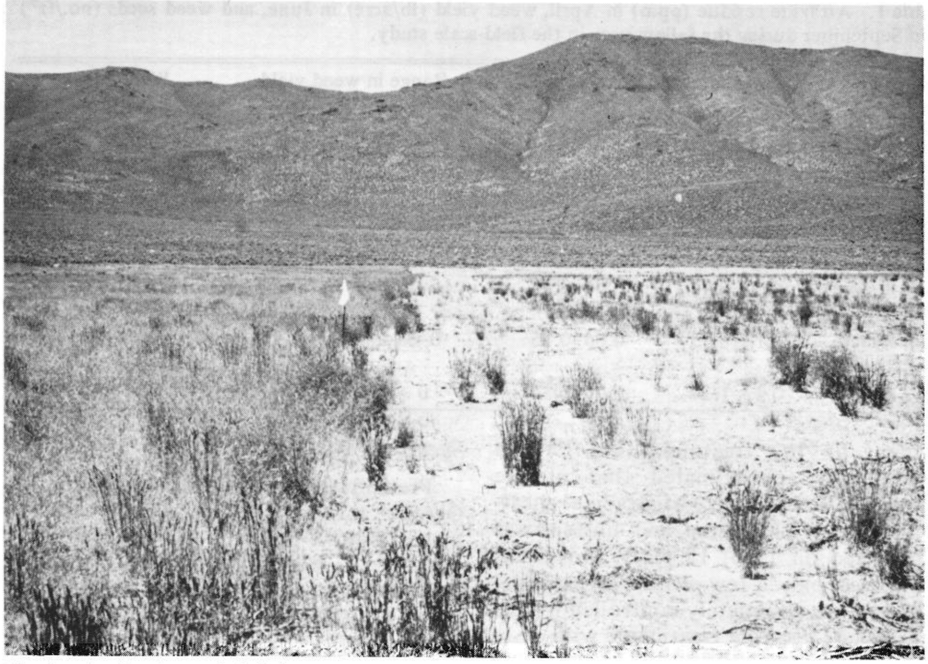

Fig. 1. *Application of 1 lb/acre atrazine by ground rig gave uniform and excellent control of annual weeds on right side of photo.*

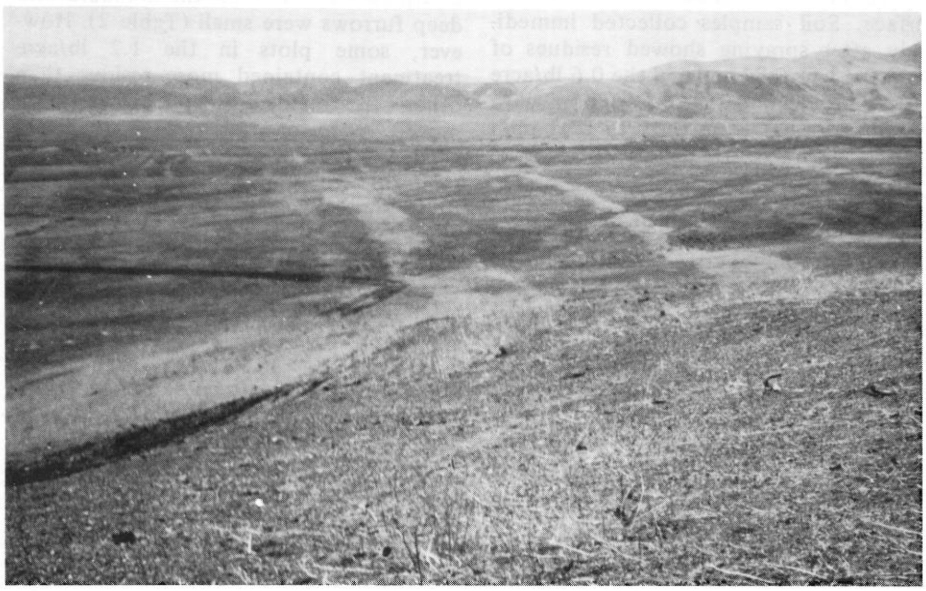

Fig. 2. *Application of 0.6 lb/acre atrazine by helicopter resulted in strips of uncontrolled annual weeds between and within swaths.*

control between weedy strips was very good (< 5% cover, compared to 23% on the check). On areas of good weed control, the soil surface was essentially bare of litter cover by spring of the seedling year.

Seedling Year

Normal or below-normal (5% probability) precipitation in the seedling year resulted in very sparse stands of cheatgrass because of unfavorable microclimate (Evans and Young, 1970) and dormant caryopses (Young et al., 1969). Stands of annuals were very dense in years of much-above-normal precipitation (8 to 12% probability), because of the large number of safe microsites provided by the rough surface of furrows (Evans and Young, 1972) and the moist environment. In addition, more cheatgrass caryopses break dormancy during a long, moist spring, and germination is enhanced (Young et al., 1969).

Fair to excellent stands (0.7 to 4.4 plants/foot of row [pfr]) of crested, intermediate, pubescent, and Siberian wheatgrasses were obtained by the atrazine-fallow technique. Stands of beardless and western wheatgrasses, red fescue, and Russian wildrye were poor; and establishment of forbs was very poor. Best stands were obtained in deep furrows and with good weed control during both the fallow and seedling years. Average production (2,390 lb/acre) of intermediate wheatgrass in 1969 and 1970 on the 1966 atrazine-fallow plot was double that on the mechanical fallow and at least ten times greater than that of stands established without weed control.

Dense stands of weeds or very high spring precipitation in the seedling year masked some treatment effects. In these instances, no weed control or furrow treatment increased seedling density and frequency of seeded species when compared with the check or standard drill treatments. However, seedling height, vigor, and survival indicated an advantage for seedlings in atrazine-fallow and furrowed areas.

The demonstration studies indicated that adequate seedling stands could be obtained by the atrazine-fallow technique. However, a valid evaluation of all treatment effects on the 1969 trials was not possible because of depredation by small mammals and grasshoppers and by unusually high spring precipitation during the seedling year.

Field-Scale Study

Procedures

A field-scale study was initiated in 1970 in an attempt to overcome the disadvantages of small areas. The site was near Elko in northeastern Nevada. Three major soils were described in the area. The Orovada series (Durixerollic Camborthid coarse loamy, mixed mesic) was found adjacent to drainage channels in the valleys. The Cherry Spring series (Haploxerollic Durargid fine loamy, mixed mesic) was found on the broad terraces. The Cortez series (Xerollic Nadurargid fine montmorillonitic, mesic) was found as inclusions in the Cherry Spring series. Atrazine at 0.6, 0.8, and 1.2 lb/acre active in 5 gpa water was applied by helicopter to 99, 879, and 91 acres, respectively. A 75-acre mechanical-fallow treatment and a 56-acre check were included. Twelve permanent plots were established on the 0.8 lb/acre atrazine treatment, with five plots on each of the other treatments. Immediately before and after spraying, a 0- to 1-inch soil sample was collected from these plots and analyzed for atrazine (Mattson et al., 1970) to assess the variability in herbicide application. Soil samples to 4 inches by 1-inch increments were collected in the spring of the fallow and seedling years and analyzed for atrazine residue to relate to weed control and seedling establishment. Runoff water samples were collected in early and late spring of the fallow year from the check and from the 0.8 lb/acre atrazine treatment and analyzed for atrazine and its two major metabolites.

Crested and Siberian wheatgrasses were seeded at 6 lb/acre in fall, 1971, with both the deep-furrow and standard rangeland drills. Alfalfa at 1 lb/acre was seeded with both grasses. Frequency, cover, and yield of weeds were determined in the fallow and seedling years. Reproductive potential (number of seeds/ft^2) (Young et al., 1969) of annual weeds was estimated at the end of the fallow year. Density and frequency of seeded species were evaluated in April and June of the seedling year. Data for both wheatgrass species were combined for results. In May of the seedling year, broadleaf annuals were controlled by 1/2 lb/acre 2,4-D applied aerially in 5 gpa on 100 acres across portions of all treatments. The entire seeding (except the 2,4-D treatment) was evaluated by frequency, height, and seedhead production in June of the seedling year. Seedling establishment and weed control were sampled again in July to determine the effect of 2,4-D. Grasshoppers were controlled with malathion (diethyl mercaptosuccinate *s*-ester with *0,0*-dimethyl phosphorodithioate) in July of the seedling year. Frequency of established plants of seeded species also was determined at the start of the second growing season.

Results

Fallow Year

Precipitation from the time of atrazine application in fall, 1970, through March, 1971, was 6.8 inches, 1.2 inches above normal. Precipitation from April through June was 6.6 inches, 4.3 inches above average. Records from a nearby Weather Bureau Station indicate a probability of between 1 and 16% for this large amount of spring moisture. Under these conditions, we would expect germination of most weed seeds with the potential for germination, good activation of herbicide, and, consequently, excellent weed control and a reduction in the reserve of weed seeds in the soil.

Characteristics of weedy vegetation and atrazine residue in the fallow year are given in Table 1. Frequency and cover of weeds on the check were 100% and 36%, respectively, compared to averages of 16% and 4.2% on atrazine treatments. Cheatgrass yield on the check averaged 790 lb/acre and ranged from 506 to 1,057 lb/acre. This amount of cheatgrass completely suppressed mustard growth. The mechanical fallow eliminated cheatgrass and mustard in that year, but seeds on the soil surface were planted by disking. Treatment with atrazine at 0.6 lb/acre reduced cheatgrass to an average of 51 lb/acre and mustard to 18 lb/acre. The highest yield of annuals and the lowest atrazine residue were found on plots sprayed at this rate of atrazine. Many strips of uncontrolled annuals were evident on this treatment (Fig. 2) and their yield approximated that of the check. With 0.8 lb/acre of atrazine, cheatgrass averaged 8 lb/acre, and mustard was eliminated on 11 of 12 plots. This treatment had only a few strips. Both annual species were completely controlled by the 1.2 lb/acre atrazine treatment, with only an occasional strip of annual weeds.

Table 1. Atrazine residue (ppm) in April, weed yield (lb/acre) in June, and weed seeds (no./ft^2) in September during the fallow year in the field-scale study.

Treatment	Range in atrazine residue		Range in weed yield		Weed seeds	
	0–1"	1–2"	Cheatgrass	Tumble mustard	Cheatgrass	Tumble mustard
Check	<0.04	<0.04	506–1,057	0	570	92
Mechanical fallow	<0.04	<0.04	0	0	84	41
Atrazine 0.6 lb/acre	0.06–0.46	0.04–0.18	15–143	7–50	98	91
Atrazine 0.8 lb/acre	0.12–0.95	0.06–0.35	0–31	0–11	68	62
Atrazine 1.2 lb/acre	0.22–1.24	0.05–0.54	0	0	75	26

Strips within and between spray swaths were left because less than the desired rate of atrazine reached the soil surface. Soil samples collected immediately after spraying showed residues of from 0.13 to 0.81 ppm in the 0.6 lb/acre treatment; from 0.25 to 3.18 ppm with 0.8 lb/acre; and from 0.05 to 2.91 ppm with 1.12 lb/acre. Data from spring sampling in the fallow year also show a wide residue range (Table 1). This variation could result from flagging error or from an uneven spray pattern. Since flagging techniques were rigidly controlled, we believe that the latter was responsible for the variation in atrazine reaching the soil.

The reproductive potential is the number of residual weed seeds in the soil that can germinate in the fall or spring and produce plants to compete with perennial grass seedlings. The number of cheatgrass caryopses was reduced from 570/ft^2 on the check to between 68 and 98/ft^2 with different rates of atrazine (Table 1). Atrazine at 0.6 lb/acre did not reduce the number of mustard seeds; however, the other rates, particularly 1.2 lb/acre, did reduce mustard, At the end of the fallow year, two seedbed conditions were present: 1) strips of uncontrolled annuals with a dry soil, a low concentration of NO_3-N, and many weed seeds on the soil surface, and 2) a clean fallow with an accumulation of soil moisture and NO_3-N, and a reduced number of weed seeds on the soil surface.

Observations of various soil and topographic features indicated no soil erosion in spite of bare soil and heavy precipitation. No atrazine or its metabolites were found in spring runoff water. Therefore we would expect no off-site environmental problems with use of the atrazine-fallow technique.

Seedling Year

Precipitation from time of seeding in October through May was 6.2 inches, 1.1 inches below normal. June was an abnormally wet month with 1.5 inches of precipitation, 0.8-inch above normal. In addition, 1.1 inches fell between June 7 and June 20.

Differences in atrazine residue in the soil between the 0.6 and 0.8 lb/acre treatments or between the standard and deep furrows were small (Table 2). However, some plots in the 1.2 lb/acre treatment contained more residue than other treatments. Deep-furrowing removed more of this residue than did shallow-furrowing because more soil was removed from the vicinity of the seeded row. Since the toxic level for wheatgrasses appears to be about 0.13 ppm (Eckert et al., 1972), deep-furrow planting will improve the chance of seedling establishment in areas of high atrazine residue.

All atrazine treatments and the check had good seedling stands of wheatgrass in April. Average seedling density and frequency ranged from 2.4 pfr and 68% on the 0.8 lb/acre atrazine treatment to 3.8 pfr and 78% on the check. A better stand on the check compared to that on the atrazine-treated areas may have been caused by improved microclimate on the check because of litter cover (Evans and Young, 1970) and to some seedling mortality from herbicide residue on treated areas. Stands were not as good on the mechanical fallow (1.0 pfr and 48% frequency). Many germinated seeds were noted at depths of 3 to 4 inches. Evidently wheatgrass seed was planted too deep in the loose seedbed created by disking. Seedling stands on the atrazine treatments were better in deep furrows (4.0 pfr and 84%), compared to standard furrows (1.9 pfr and 68%). This difference is a response to improved microclimate as well as to lower herbicide residue in the deep furrows.

Change in seedling density from April to June indicated 87% seedling mortality

Table 2. Atrazine residue (ppm) in April; and seedling density (plants/ft of row); frequency (% occupancy/ft of row); height (inch); % of crested and Siberian wheatgrass plants headed; weed yield (lb/acre) in June of the seedling year; and frequency (%) of established plants in the second growing season on the field-scale study. Residue, density, and yield data were collected on established plots. Data on frequency, height, and plants headed were taken over entire seeding.

Treatment	Range in atrazine residue in surface 4 inch of soil		Seedling characteristics								Weed yield		Established plants	
			Density		Frequency		Height		Headed				Frequency	
	DF[1]	SF[2]	DF	SF	DF	SF	DF	SF	DF	SF	Cheat-grass	Tumble mustard	DF	SF
Check	<0.04	<0.04	0.6	0.4	27	10	4.5	3.6	6	0	358	596	24	9
Mechanical fallow	<0.04	<0.04	0.5	0.4	14	18	5.5	9.2	16	36	236	1,484	23	22
Atrazine 0.6 lb/acre	<0.04–0.05	<0.04–0.05	0.9	1.3	63	51	10.4	8.4	58	44	200	1,114	65	59
Atrazine 0.8 lb/acre	<0.04–0.04	<0.04–0.06	1.3	1.0	56	54	9.4	8.6	50	42	108	1,642	62	56
Atrazine 1.2 lb/acre	<0.04–0.12	<0.04–0.17	0.8	1.0	65	56	9.0	8.1	62	46	144	1,316	60	49

[1] DF—Deep-furrow rangeland drill.
[2] SF—Standard-furrow rangeland drill.

on the check, 61% with atrazine at 0.6 lb/acre, 50% with atrazine at 0.8 lb/acre, 66% with atrazine at 1.2 lb/acre, and 50% on the mechanical fallow, with little difference between deep and standard furrows. Atrazine damage to seedlings was noted only with atrazine at 1.2 lb/acre. On the check, plant frequency was greater in deep furrows (Table 2). On the mechanical fallow, plant frequency and height were greater and more plants were headed in standard furrows. Differences in plant density among the three atrazine treatments or between standard- and deep-furrow seeding were small. However, frequency, height, and percent of plants headed indicated an advantage for deep-furrow seeding. These seedling stands were obtained with adequate precipitation for germination, emergence, and survival. The high precipitation in June was favorable for growth of the perennial-grass seedlings, but also for development of a very dense stand of vigorously growing tumble mustard. The alfalfa stand was poor on all treatments.

Observations made in April and May suggested good cheatgrass control and little potential problem with mustard. However, the accelerated growth of mustard in June resulted in a dense stand of tall plants. Total weed yield, mostly mustard, was much less on the check than on treated areas (Table 2).

Yield of cheatgrass was somewhat less on atrazine treatments than on the check. More important in terms of competition was cheatgrass density and size. The check had many small cheatgrass plants. A dense root mass in the top 3 to 4 inches of soil suggests that soil moisture was depleted rapidly from the areas where perennial-grass seedlings were rooted. On the treated areas, plant density was low, plants were large, and roots did not form a dense mat between plants. The very severe intra- and interspecific competition from dense cheatgrass was indicated by suppression of mustard and dry herbage on check areas in June compared to green herbage on the atrazine treatments. Seedling establishment was enhanced because some soil moisture from the previous year's fallow was available to both weedy and seeded species.

Mustard control with 0.5 lb/acre of 2,4-D was excellent (13.3% ground cover on check and 2.8% with 2,4-D). Cheatgrass ground cover was greater after mustard control, but total weedy cover was reduced from 24.8 to 15.0%. On a specific area of the seeding, density and frequency of crested wheatgrass in July were 1.9 pfr and 64%, respectively, without 2,4-D treatment and 5.3 pfr and 76% with treatment. Control of broadleaf weeds on research plots also increased seedling survival and subsequent years' yields of crested and intermediate wheatgrasses (Eckert and Evans, 1967). The decision by a land manager to use 2,4-D must be made on a project basis and will depend on cost, environmental considerations, degree of infestation of broadleaf weeds, stage of development of perennial grass seedlings, time of year, and residual soil moisture. Establishment of a desirable perennial forb in a seeding would preclude use of 2,4-D.

Discussion of the Technique

Good weed control was obtained in the fallow year with 0.6 to 1.2 lb/acre atrazine. However, weedy strips and high and low amounts of atrazine residue in the soil indicate that proper herbicide distribution was not obtained with the fixed-wing and helicopter equipment used. This was the only problem associated with the practical application of the technique. Recent work (Anon., 1971) has shown that relocation of spray nozzles on the boom of fixed-wing aircraft can improve the spray pattern. This development should greatly reduce the problem of uneven application.

The amount of competitive vegetation during the seedling year depends on the population dynamics of weed species (Young et al., 1969, 1970) and condition of the seedbed (Evans and Young, 1970). Poor weed control or weedy strips during the fallow year serve as a seed source to reinfest adjacent clean areas. A fallow year with environmental conditions favorable for germination of weed seeds and subsequent control results in less seed for potential germination in the seedling year. Conversely, poor germination in the fallow year results in more residual seed for the seedling year.

Germination of seeds of weedy species and of perennial grasses in the seedling year depends on macro- and microenvironmental conditions of the seedbed (Evans et al., 1970). The seedling year of 1968 was relatively dry, with minimal cheatgrass, and with 2,4-D application, few other weeds. Very high spring precipitation in 1970 resulted in high germination and vigorous growth of weeds, especially cheatgrass. Environmental conditions in early spring, 1972, were more favorable for mustard germination than for cheatgrass, possibly because of the influence of mustard's mucilaginous seedcoat (Young and Evans, 1973). Mustard seedlings did not develop until late spring, when favorable conditions resulted in a rapid growth of a dense, competitive stand.

Good seedling stands were obtained on atrazine treatments in the demonstration studies in 1970; however, differences in stand characteristics between treated and check areas and type of furrow were confounded by environmental conditions and depredation. The large size of the field-scale study in 1972 minimized rodent damage, and grasshoppers were controlled. Therefore, stands could be related more directly to treatments and climatic conditions. Good stands of crested and Siberian wheatgrasses were obtained on all atrazine treatments and on the check. Mortality on the check during the spring reduced stand density and frequency; plants were small, and few were headed. On atrazine-fallow areas, good stand density and frequency were maintained through June. Seedlings were large, and many were headed. At the start of the second growing season plants of crested and Siberian wheatgrasses were large and well established. Average frequency on the atrazine treatments was 58%, compared with 22% on the mechanical fallow and 16% on the check (Table 2).

In the demonstration studies, deep furrows appeared to increase seedling vigor and survival more than seedling density or frequency. However, on one site, deep furrows did increase density, frequency, and vigor of intermediate and pubescent wheatgrasses but did not affect stands of crested or Siberian wheatgrasses. In the field-scale study, deep furrows did not affect the density of crested and Siberian wheatgrasses but did increase plant frequency, height, and the number of plants headed.

Conclusions

The degree of success of the atrazine-fallow technique for seeding perennial grasses on cheatgrass-infested rangelands depends on uniform application of herbicide, amount and timing of precipitation during the fallow and seedling years, weed populations, site potential, and depredation. Fluctuations in these conditions have resulted in establishment of wheatgrass stands that varied from extremely good to poor. However, our results indicate that even under fairly adverse conditions, enough plants can be established to permit development of a full stand through proper livestock management.

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