Weed Control-Revegetation Systems for Big Sagebrush-Downy Brome Rangelands

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Highlight: Chemical weed control systems integrating 2,4-D or picloram spraying for brush control and atrazine fallow for downy brome control were investigated in a series of rangeland communities. Application of both weed control techniques greatly enhanced seedling growth and increased yield of perennial grasses seeded the year after the fallow. Added nitrogen either had negligible effects or tended to negate the benefits of the weed control systems on establishment of perennial grasses. The 2,4-D/atrazine-fallow system also allowed establishment of the browse species, cliffrose, in a big sagebrush/downy brome community. Increased soil moisture available during the growing period of the fallow and seedling years, because of decreased weed competition, was the major factor for the better stands of grass and browse that resulted from chemical weed control systems.

Downy brome (*Bromus tectorum*) has invaded millions of hectares of formerly big sagebrush (*Artemisia tridentata*)/ bunchgrass vegetation in the Intermountain portion of western North America (Klemmedson and Smith 1964). Where recurrent fires have eliminated native shrubs, downy brome has become completely dominant. This alien annual grass is a source of forage but does have definite limitations, such as: slow growth in the spring, short green feed period, high flammability in the summer, and highly erratic yield among years. Weed control-revegetation techniques have been developed to permit the establishment of desirable perennial grasses in these downy brome areas (Eckert and Evans 1967; Eckert et al. 1974; Evans et al. 1967). On rangelands, the application of the soil-active herbicide atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine] to fallow downy brome communities for establishment of perennial wheatgrass (*Agropyron* spp.) is registered by the Environmental Protection Agency.

Degraded big sagebrush communities, where downy brome has not invaded, have been successfully converted to productive areas by reducing the brush stand with applications of 2,4,-D [(2,4-dichlorophenoxy)acetic acid] followed by seeding through the standing dead brush with a rangeland drill (Kay and Street 1961; Asher and Eckert 1973). Rangeland use of 2,4-D is registered by the Environmental Protection Agency. There are extensive areas in the Great Basin that have dense big sagebrush or rabbitbrush overstories with downy brome dominance under the shrubs. The only revegetation technique applicable to these areas has been expensive, environmentally disruptive rangeland plowing.

In this investigation, we have evaluated alternative approaches that integrate existing and registered chemical weed control techniques for the manipulation of both shrub (with 2,4-D) and herbaceous vegetation (with atrazine) for the establishment of desirable species in degraded big sagebrush plant communities. In addition, picloram, an experimental herbicide on rangelands was tested for brush control in the weed-control systems.

Methods

The study areas were located at Medell Flat and surrounding vicinity, 35 km north of Reno, Nevada, in a 20–30 cm precipitation zone at 1,520–1,800-m elevation. In 1969–70, total precipitation was 30.3 cm, with 9.2 cm occurring in the spring and summer growing season; in 1970–71, precipitation totalled 35.5 cm, with 10.6 cm during the growing season; and in 1971–72, 20.2 cm occurred, with 4.9 cm in the growing season. Soils of these areas belong to the order Aridisols and the group Haplargid or Duragid, depending on the presence of indurate pan development.

Trials were conducted over a 3-year-period in four plant communities: (a) green rabbitbrush (*Chrysothamnus viscidiflorus*)/downy brome in 1969–70 and 1971–72, (b) big sagebrush/downy brome in 1970–71, (c) big sagebrush-rabbitbrush/Sandberg bluegrass (*Poa sandbergii*)-downy brome in 1970–71 and 1971–72, and (d) horsebrush (*Tetradymia canescens*)-rabbitbrush/downy brome in 1971–72. The dates denote years of atrazine application and chemical fallow. Seeding was 1 year later. All of these communities are seral to a big sagebrush/Thurber needlegrass (*Stipa Thurberiana*) potential community (Young and Evans 1974). Studies in the four communities were conducted in three adjacent exclosures at Granite Peak, Medell Flat (two communities), and Horsebrush.

Experimental design used in each study area consisted of four replications of 6.2 by 6.2-m plots arranged in a randomized block design.

The basic procedure involved seven herbicide-fertilizer combinations and a control (Table 1). We also tested variations of the basic 2,4-D plus atrazine system on separate plots by: applying 2,4-D in May 1971 and atrazine in October 1971; applying atrazine with 2,4-D in May 1971; and applying atrazine in October 1971 and 2,4-D in May 1972. The latter timing of application of atrazine (fall) and 2,4-D (the next spring) was tested at all locations and in all years. Some of the combinations, or single herbicide treatments, were not meant to be practical systems. For example, 2,4-D alone was included to compare the influence of shrub removal with that of total vegetation control with 2,4-D plus atrazine in terms of competition with perennial grass

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Table 1. Herbicide-fertilizer combination evaluated for shrub and annual weed control before seeding of perennial grasses.

Treatment	Rate (kg/ha)	Time of application
Control	—	—
Atrazine	1.12	Fall
Atrazine + 2,4-D	1.12 + 3.36	Fall-spring
Atrazine + picloram	1.12 + 0.56	Fall-spring
Atrazine + 2,4-D + nitrogen[1]	1.12 + 3.36 + 56	Fall-spring-fall
2,4-D + nitrogen	3.36 + 56	Spring-fall
2,4-D	3.36	Spring
Picloram	0.56	Spring

[1] Nitrogen source was ammonium sulfate 20-0-0.

seedlings. Nitrogen was applied in some comparisons to assess its effect on shrub control and seedling establishment. With the two-application systems, atrazine (wetable powder) was applied in September or October and low-volatile esters of 2,4-D or picloram (4-amino-3,5,6-trichloropicolinic acid) as potassium salt in May in 94 liters/ha of water. Herbicides were applied with a backpack sprayer and hand-held boom. Picloram and 2,4-D were applied with 80° flat spray tip nozzles with 1.4 kg/cm^2 pressure. Atrazine and the single simultaneous atrazine plus 2,4-D mixture were applied with whirl-chamber 49 by 49 nozzles (Klingman 1964) with 0.7 kg/cm^2 pressure.

Plots were seeded in October of the year following application of the atrazine. In one case in 1972, we reseeded part of the plots because of a failure to establish seedlings. In 1970 and 1971, we used a modified rangeland drill to furrow and seed all plots. In 1972, the plots were furrowed with fixed shovels mounted on a tool bar and seeded by hand. Plots were seeded with intermediate wheatgrass (*Agropyron intermedium*) cultivar "Greener" in 1970 and 1971. In 1972, the plots were split, with one-half seeded to "Amur" intermediate wheatgrass, and the other to "Nordan" crested wheatgrass (*A. desertorum*).

In the 1970–71 trial at Granite Peak, year-old cliffrose (*Cowania mexicana* var. *Stansburiana*) plants were transplanted in April, 1971, into the check and 2,4-D/atrazine-fallow plots. Six plants were transplanted per plot with 1-m spacing. These same plots were also seeded with intermediate wheatgrass in October 1970.

Infestations of broadleaf weeds at varying intensities occur the seedling year on atrazine fallows, with resultant competition to seedling perennial grasses (Eckert and Evans 1967). In the spring of 1972, we applied 0.56 kg/ha of 2,4-D to one-half of each plot, over the seedling wheatgrass stands, for control of broadleaf weeds.

Shrub control was determined by counting dead plants the season after the herbicides were applied. Herbaceous weed control was determined by estimating cover of weedy species, on a plot basis, both in fallow and seedling years. Herbaceous weed competition in the seedling year of the perennial grasses was ascertained by clipping four square 0.1-m^2 plots located over the drill rows in each treatment. Seedling stand establishment was evaluated at the end of the seedling year by counting and measuring the height of seedlings per meter of row. Second-year herbage production of the wheatgrass was determined by clipping four randomly located 1-m sections of row in each plot at the maximum stage of herbage production.

Available soil moisture was measured in the profile with gypsum blocks at five depths (7.5, 15, 30, 60, and 112 cm-effective depth of profile) for three treatments (control, 2,4-D, and 2,4-D plus atrazine) periodically during the growing season in 3 years of the study.

Results

Weed Control

Shrub Control

Control of green rabbitbrush and sagebrush was excellent with all 2,4-D and picloram treatments (Table 2). Control of horsebrush by these herbicides was variable in one year and at one location; otherwise, it was also consistently good.

The atrazine-alone treatment was not expected to control shrubs. Its inclusion in the systems was designed to obtain a comparison of shrub versus herbaceous weed competition. However, 1.12 kg/ha of atrazine consistently controlled small rabbitbrush plants throughout the study. Even in 1972, at the Horsebrush exclosure where shrub control tended to be lower, atrazine alone killed 65% of the rabbitbrush plants present (Table 2). Atrazine was ineffective in controlling horsebrush or big sagebrush plants.

Among the integrated shrub-herbaceous weed control systems and the shrub control treatments, there were no clear advantages to any one treatment. All treatments produced excellent and almost consistent shrub control (Table 2). It was surprising that picloram alone adequately controlled big sagebrush, a species considered fairly resistant to this herbicide (Tueller and Evans 1969).

Shrub control with 2,4-D was not different when atrazine was applied before, after, simultaneously, or not at all (Table 3). The whirl-chamber nozzles are designed to apply wettable powders with low volumes of carriers, but satisfactory brush control resulted when they were used to apply 2,4-D and atrazine simultaneously (Table 3).

In 1972, in the Horsebrush exclosure, all shrub control treatments gave adequate control of green rabbitbrush, although some produced results lower than the average for the entire experiment. Horsebrush control was unacceptable, except for marginal control with 2,4-D (Table 2). The combination of 2,4-D plus atrazine resulted in significantly ($p=0.01$) less control than 2,4-D alone. The combination of nitrogen with 2,4-D did not significantly affect control. Control of horsebrush with picloram was satisfactory during the course of the experiment, except in 1972.

Table 2. Shrub control (%) with herbicides and nitrogen (N) alone and in combination. All dates and locations averaged together with the exception of 1972 at the Horsebrush Exclosure, where shrub control was variable.[1]

	Mean of 3 years and 5 locations[2]			1972 Horsebrush exclosure[3]	
Treatment	Rabbitbrush	Horsebrush	Big Sagebrush	Rabbitbrush	Horsebrush
Control	0	0	0	0 c	0 d
Atrazine	59	6	18	64 b	4 d
Atrazine + 2,4-D	96	98	100	92 a	41 c
Atrazine + picloram				93 a	49 bc
Atrazine + 2,4-D + N	98	94	100	100 a	59 b
2,4-D + N	94	90	98	80 a	75 a
2,4-D	96	94	100	100 a	84 a
Picloram	98	95	96	86 a	40 c

[1] Means for Horsebrush Exclosure followed by same letter are not significantly different at the 0.05 level of probability as determined by Duncan's multiple range test. Species compared individually.
[2] Not all locations compared each year and not all species present at each location.
[3] No big sagebrush plants were present in the Horsebrush Exclosure.

Table 3. Control (%) of rabbitbrush and big sagebrush with 3.36 kg/ha of 2,4-D applied alone and with 1.12 kg/ha of atrazine in different timing of application combinations.

Treatment	Date of application	Rabbitbrush	Big sagebrush
2,4-D and Atrazine	May 1971 October 1971	100	100
2,4-D and Atrazine	Simultaneous (May 1971)	87	86
Atrazine and 2,4-D	October 1971 May 1972	96	100
2,4-D	May 1972	98	100

Herbaceous Control

In the fallow year of all the atrazine treatments, the plots were virtually free of downy brome or Sandberg bluegrass. Only under the dense shrub canopies did occasional downy brome plants escape the herbicide.

Even the treatment where 2,4-D and atrazine were applied together gave satisfactory herbaceous weed control. The atrazine had to lie on the shrub canopies and on the soil surface from June until October without precipitation to move it into the soil.

The pertinent measure of herbaceous weed control is how much competition results from the treatment in the seedling year of the wheatgrass or in the season after the fallow. This competition can be from downy brome or from an alternate flora of broadleaf species, with tumble mustard (*Sisymbrium altissimum*) being the most common species.

In the seedling year, downy brome was eliminated or nearly so between shrub canopies by all atrazine treatments, alone or in combination with 2,4-D or picloram (Table 4). Downy brome was only partially controlled under the canopies of the shrubs by the atrazine treatments and enough plants remained, as we shall present later, to reduce establishment of wheatgrass seedlings. Atrazine treatments controlled downy brome under shrub canopies even less when nitrogen was included in the system. Between shrubs, added nitrogen had no adverse effect on control of downy brome.

The major reason that the atrazine-fallow technique works in a pure downy brome stand is that all herbaceous litter disappears during the fallow season. This decreases the number of caryopses (seeds) of downy brome and also puts the seedbed (bare soil surface) outside the germination potential of downy brome in terms of temperature and moisture and, therefore, effective weed control is attained the seedling year of the perennial grasses (Evans and Young 1970, 1972). There are large accumulations of litter under shrubs that contain many viable downy brome seeds (Young and Evans 1975). This litter was not entirely lost during the fallow period in this study and, consequently, downy brome was able to establish and compete with wheatgrass in its seedling year. Subcanopy litter with its favorable microenvironment and its reservoir of downy brome seeds is the major stumbling block in integrating brush and herbaceous weed control methods in these communities.

Table 4. Herbage yield (kg/ha) of downy brome and broadleaf weed species in relation to weed control treatments under and beneath shrubs in the wheatgrass seedling year in a rabbitbrush/downy brome community.[1]

	Location of treatment			
	Undershrubs		Between shrubs	
Treatment	Downy brome	Broad-leaf	Downy brome	Broad-leaf
Control	340 a	40	90	20 b
Atrazine	90 b	110	0	310 a
Atrazine + 2,4-D	80 b	80	0	240 a
Atrazine + picloram	110 b	0	10	10 b
Atrazine + 2,4-D + N	420 a	80	20	370 a
2,4-D + N	410 a	90	140	60 b
2,4-D	470 a	60	110	40 b
Picloram	390 a	0	60	0 b

[1] Means followed by the same letter are not significantly different at the 0.01 level of probability as determined by Duncan's multiple range test. Columns are compared independently. Columns without letters have no significantly different means.

When the downy brome population was reduced by atrazine treatment, a broadleaf weed infestation usually filled the ecologic void (Table 4). This was especially evident in the area between shrub canopies because of the more complete control of downy brome. The amount and species composition of this replacement vegetation were variable among years and plant communities. Tumble mustard was very abundant on atrazine-fallow plots in the rabbitbrush/downy brome community in the 1972 seedling year (Table 4), but was almost absent from the same treatments repeated in the community in 1973 (data not shown).

Sufficient picloram herbicidal activity carried over in the litter and soil to reduce or eliminate tumble mustard in the seedling year on plots where this herbicide was used for brush control (Table 4).

Seedling Establishment

Stand Density

No herbicide treatment markedly enhanced the establishment of stands of either intermediate or crested wheatgrass (Table 5). If we consider three seedlings per meter of row to be an acceptable density for this environment, the control plots contained adequate wheatgrass plants in five out of seven trials.

Table 5. Seedlings per m of row of intermediate and crested wheatgrasses in relation to weed control treatments.[1]

Treatment	Intermediate wheatgrass	Crested wheatgrass
Control	4.8	5.0
Atrazine	6.6	5.0
Atrazine + 2,4-D	8.8	6.5
Atrazine + picloram	8.1	5.0
Atrazine + 2,4-D + N	8.0	6.5
2,4-D + N	4.6	4.8
2,4-D	7.0	7.5
Picloram	5.8	5.8

[1] Seedling numbers expressed as means among various trials in years of study. No statistically significant differences were found among means of different treatments.

Virtually all wheatgrass seedlings were established in the interspaces between shrubs and none under the shrub canopies. This probably was jointly caused by competition from downy brome and failure of the furrow-opener on the rangeland drill to penetrate the woody canopy and litter and, therefore, to provide an adequate furrow in seeding of perennial grasses. The favorable microenvironment created by furrowing is an important part of seedling establishment in this environment (Evans et al. 1970).

Seedling Vigor

Although stand density was not enhanced by herbicide treatment, seedling vigor, as indicated by height of plants at the end of the first growing season, was greatly affected (Table 6).

Table 6. Height (cm) of intermediate wheatgrass seedlings at end of first growing season in relation to weed conrol treatments.[1]

Treatment	Plant communities and seedling year				
	Rabbitbrush/ downy brome 1971	Sagebrush/ downy brome 1971	Sagebrush/ downy brome 1973	Sagebrush/ downy brome 1972	Average
Control	14 c	8 b	12 b	13 bc	12 b
Atrazine	32 b	32 a	36 a	29 ab	32 a
Atrazine + 2,4-D	45 a	48 a	36 a	38 a	42 a
Atrazine + picloram	35 ab	34 a	34 a	35 a	35 a
Atrazine + 2,4-D + N	26 bc	46 a	44 a	36 a	38 a
2,4-D + N	16 c	8 b	6 b	16 bc	12 b
2,4-D	16 c	10 b	12 b	18 b	14 b
Picloram	16 c	6 b	14 b	12 c	12 b

[1] Means followed by the same letter are not significantly different at the 0.01 level of probability as determined by Duncan's multiple range test. Communities and seeding years compared separately.

Heights of perennial grass seedlings were three and one-half times as great on 2,4-D/atrazine-fallow plots where both brush and downy brome had been controlled as they were on check plots.

In general, taller and more vigorous seedlings were found on plots with brush and downy brome control (2,4-D/atrazine-fallow), the next on atrazine-fallow plots with usually only numeric difference between these two treatments, and the third on plots with brush control but no downy brome control. The latter group were no different than seedlings on check plots. Overall, the influence of added nitrogen was negligible on height and vigor of seedlings.

Second Year Yield

The influence of herbicide treatments on seedling vigor was also measured on plots where we obtained second-year yields of the perennial grasses (Table 7). The atrazine-fallow plots always had significantly higher yields than the control. As was true for seedling vigor, a trend existed for greater yields on plots where brush and downy brome were both controlled (2,4-D/atrazine-fallow). Differences were only numerical and not statistical between yields on these plots and on the atrazine-fallow plots. Added nitrogen reduced second-year yields of perennial grasses on atrazine-fallow plots in the rabbitbrush/downy brome community. In other trials, yields were not affected by nitrogen.

Alternate Flora Interactions

We controlled tumble mustard competition the seedling year

Table 7. Herbage yield (kg/ha) of perennial grasses the second year after planting in relation to weed control treatments.[1]

Treatment	Rabbitbrush/ downy brome	Sagebrush/ downy brome	Sagebrush-rabbitbrush/ downy brome
Control	50 c	30 c	70 c
Atrazine	390 a	470 a	810[2] a
Atrazine + 2,4-D	480 a	560 a	840[2] a
Atrazine + picloram	390 a	460 a	850[2] a
Atrazine + 2,4-D + N	140 bc	490 a	790[2] a
2,4-D + N	190 b	210 b	170 bc
2,4-D	120 bc	290 b	220 b
Picloram	190 b	270 b	240 b

[1] Means followed by the same letter are not significantly different at the 0.05 level of probability as determined by Duncan's multiple range test. Columns are compared separately.

[2] These plots were seeded in 1972 but stands were unsatisfactory and the plots were reseeded. Yields were taken one year later.

Fig. 1. *Weed control systems trial:* (top) *check plot with rabbitbrush, balsamorhiza, and downy brome;* (middle) *weed control (2,4-D/atrazine-fallow) and seeding plot with established intermediate wheatgrass;* (bottom) *weed control (2,4-D/atrazine-fallow) and seeding plot with established intermediate wheatgrass and cliffrose.*

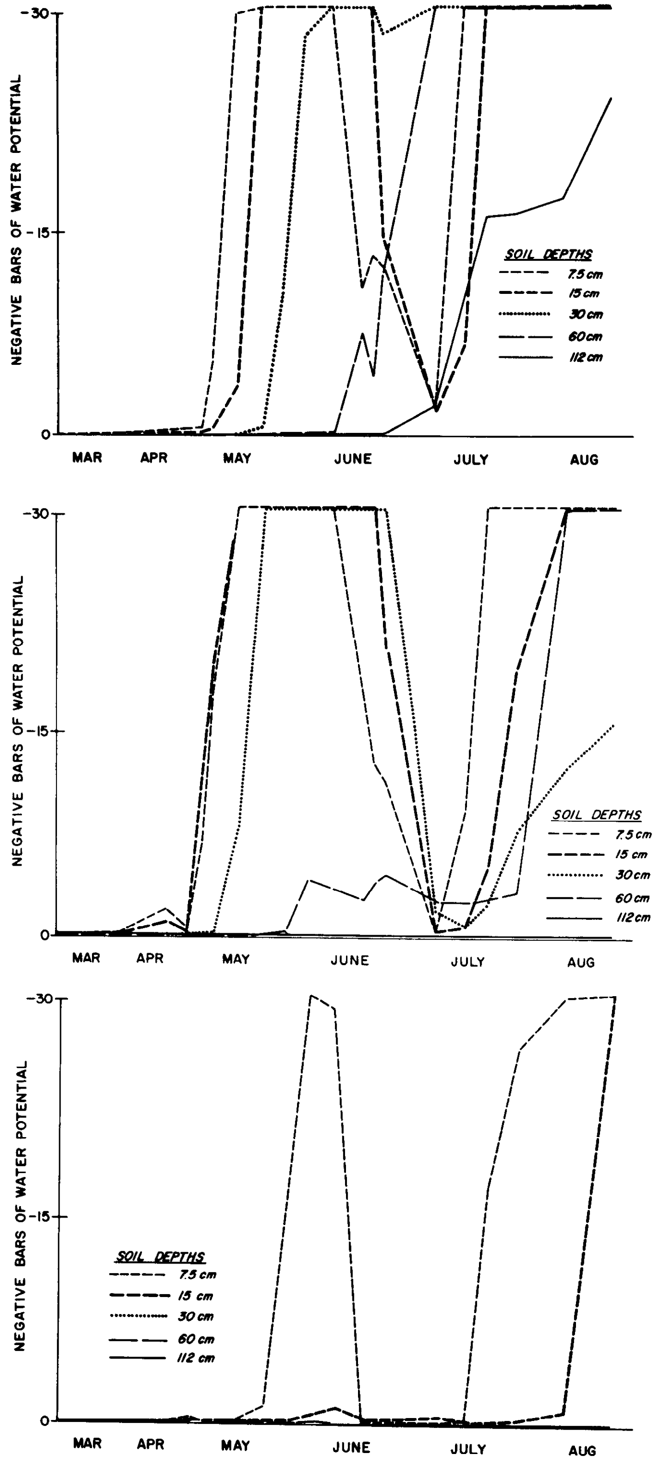

Fig. 2. *Soil-moisture depletion at various depths in the profile during the growing period and in relation to treatment in the fallow year:* (top) *depletion without weed control (check);* (middle) *with brush control by spraying 2,4-D; and* (bottom) *with brush control plus atrazine fallow for downy brome control.*

on one-half of each plot in the rabbitbrush/downy brome community with an application of 0.56 kg/ha of 2,4-D in 1972. Control of tumble mustard in this manner did not markedly influence seedling establishment even though there were high weed infestations, especially on the atrazine-fallow plots. However, herbage yield of perennial grasses that had been established with atrazine fallow alone and combined with 2,4-D brush spraying, was increased three times by the end of the second year (1973) when mustard was controlled the seedling year (1972) with 2,4-D (Table 8). Picloram used for brush control the previous year controlled tumble mustard in the seedling year on the picloram/atrazine-fallow plots, so no decrease resulted in yield of perennial grasses in the unsprayed portion of the plots. Added nitrogen resulted in decreased yield on 2,4-D/atrazine-fallow plots when mustard was controlled in the seedling year. Without mustard control, yields on these plots were low regardless of nitrogen application.

Table 8. Cover of tumble mustard during the seedling year and subsequent yield (kg/ha) of intermediate wheatgrass in relation to original treatment and with and without mustard control in the seedling year with 0.56 kg/ha of 2,4-D.[1]

Treatment	Tumble mustard cover 1972 (%)	Intermediate wheatgrass yield 1973 (kg/ha/m of row): Tumble mustard control	No control
Control	9 b	50 d	50 c
Atrazine	53 a	390 a	120 bc
Atrazine + 2,4-D	43 a	480 a	170 b
Atrazine + picloram	4 c	390 a	410 a
Atrazine + 2,4-D + N	32 ab	140 cd	100 bc
2,4-D + N	13 b	190 c	140 bc
2,4-D	14 b	120 cd	150 bc
Picloram	1 c	290 b	310 a

[1] Means followed by same letter are not significantly different at 0.05 level of probability as determined by Duncan's multiple range test. Each column compared separately.

Shrub Transplants

Cliffrose transplants that were planted in the 2,4-D/atrazine-fallow plots at Granite Peak all survived and were 1-m high and flowering by 1975 (Fig. 1). The transplants in the check plots all died.

Available Soil Moisture

Fallow Year

With complete vegetation control in the fallow year from the 2,4-D/atrazine-fallow treatment, soil moisture was depleted from only the surface layer (0–7.5 cm), or not at all, during the growing season. In one instance, soil-moisture depletion occurred to 15 cm in late summer (Fig. 2). In contrast, with no weed control available, water was depleted from the soil to 30 cm in May, 60 cm in June, and to 112 cm (complete profile) by August. With brush control by 2,4-D, depletion was slowed at 60 cm, and water remained available through the growing season at 112 cm. At shallower depths, recharge of the profile by rain was more apparent with brush control than without.

Similar trends were apparent in all plots and in all years of the study.

Seedling Year

The year after chemical control, when seedlings of perennial grasses were growing, soil moisture depletion was delayed until the end of the growing season on 2,4-D/atrazine-fallow plots at 30 cm and deeper (Fig. 3). No depletion occurred at the 112 cm depth. Recharge from rains during the growing season was more effective (in terms of available water) at the shallow depths on these plots compared to that on check plots. With brush control from 2,4-D, water depletion beyond the available range (−15 bars) did not occur at 60 cm or deeper. At shallower depths, depletion was similar to that on check plots.

With no weed control, available water was depleted to 30 cm in June, 60 cm in July, and from the entire profile by August. There was some temporary recharge of shallow depths by rains in July.

Control of downy brome was strikingly reflected by soil-moisture retention at all but the shallowest depths in both the

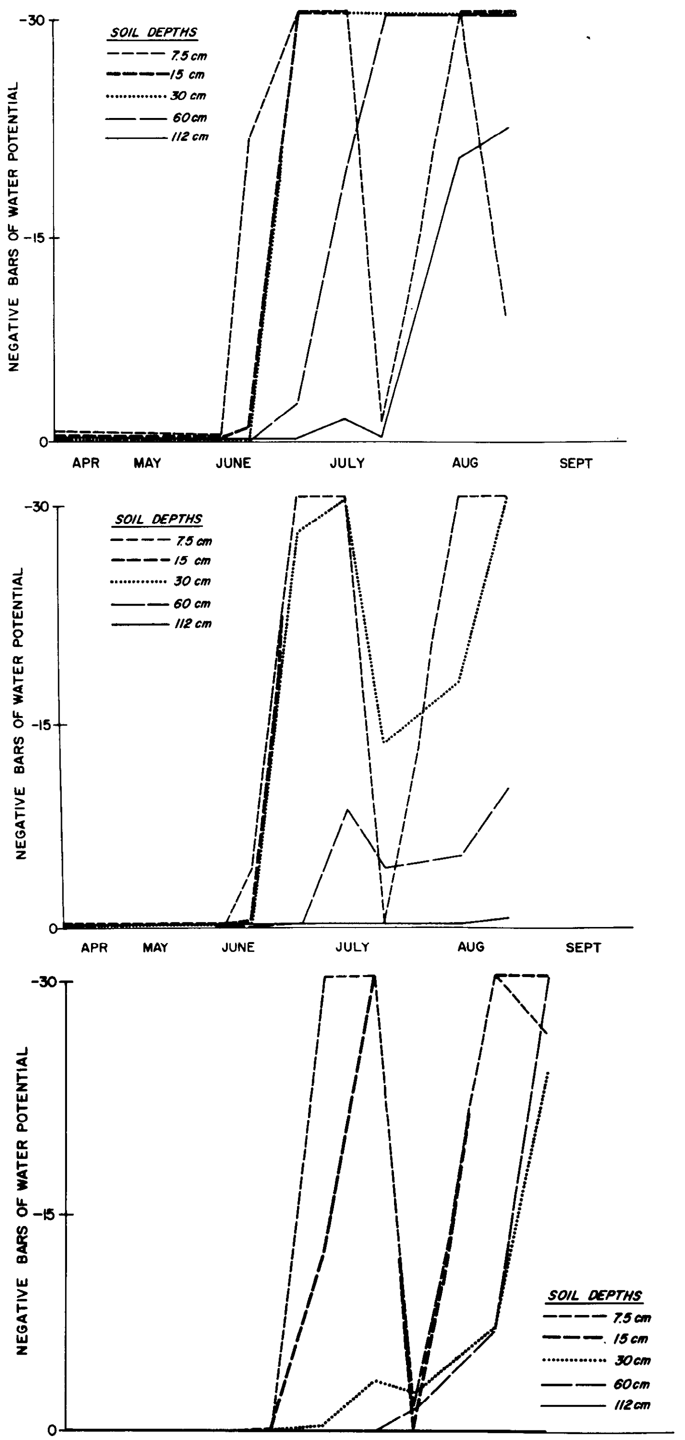

Fig. 3. *Soil-moisture depletion at various depths in the profile during the growing period and in relation to treatment in the seedling year of perennial grasses:* (top) *depletion without weed control (check);* (middle) *with brush control by spraying 2,4-D; and* (bottom) *with brush control plus atrazine fallow for downy brome control.*

fallow and seedling years. Soil moisture depletion was curtailed by brush control only at the deeper depths (60 cm and deeper) in both of these years.

Discussion

Based on the results of this investigation, chemical weed control systems are a viable alternative to rangeland plowing for conversion of degraded downy brome-infested big sagebrush areas to stable perennial grass-dominated communities. Also, when a converted area is to be used as wildlife habitat as well as for cattle production, the possibility exists of transplanting browse shrubs by use of this technique.

The basic problem of the integrated shrub-herbaceous weed control technique is the accumulation of litter and seed reserves under the shrub canopies. Plant litter on the soil surface moderates the microenvironment to the extent that downy brome seeds can germinate and plants can become established. Seed reserves under shrubs provide ample opportunity for continued dominance of downy brome in these restricted areas. Enhancement of germination of downy brome seeds during the fallow period is one possibility of solving this problem (Evans and Young 1975). By use of the enhancement technique, all or most all of the seeds would be induced to germinate at the time of atrazine activity in the soil and would thus be killed.

Despite the difficulties from downy brome competition beneath shrub canopies, enough seedlings were established in the interspaces to provide full stands of perennial grasses with 2,4-D/atrazine-fallow technique. Differences in stand establishment between control and treated plots in these studies were not great, but in less favorable years, virtually no perennial grasses would be established in these communities without weed control (Evans et al. 1970). Increased plant vigor and yield of perennial grasses with weed control are indicative of the severe competition of downy brome and other annual weeds. Added nitrogen tended to increase this competition and negated the effects of weed control treatment in one trial. In the other trials, the effect of added nitrogen was negligible. Making soil moisture available over a longer period during the growing season was the primary factor enabling perennial grass seedlings to become established when downy brome and big sagebrush were controlled. Transplants of the browse shrub species, cliffrose, were also exceedingly sensitive to competition for moisture by downy brome and big sagebrush and became established only when the latter were controlled.

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