Reseeding Trials on Columbia Basin Rangelands Dominated by Winter Annual Grasses

W. C. ROBOCKER AND R. D. SCHIRMAN

Highlight: From 1960 to 1975, a series of trials on the eastern side of the Columbia Basin north of the Snake River was conducted to determine the feasibility of establishing crested wheatgrass on rangelands now dominated by downy brome and medusahead. Excellent annual grass and annual broadleaf weed control was obtained with several herbicides, with atrazine at 1:1 kg/ha as a fallow treatment before seeding being the most satisfactory. Seeding in late autumn or early spring with a rangeland drill, modified to give some seedbed preparation in the row, combined with annual weed control, generally provided favorable conditions for germination and emergence of crested wheatgrass seedlings. However, seedlings failed to become established in most experiments. Trials with a soil fumigant, methyl bromide, resulted in excellent stands of established plants and presented strong evidence that with seedling plants under environmental stress, microbiological factors may be a primary cause of seedling failure.

The introduction of Eurasian species of plants into North America, beginning in colonial times, has wrought profound and permanent changes in many native vegetational communities of this continent. Among the successful invaders are downy brome (*Bromus tectorum*) and medusahead (*Taeniatherum asperum*), which individually as the dominant species or in mixed stands inhabit millions of hectares of western grazing lands. Downy brome was introduced into North America about the middle of the nineteenth century. Its spread throughout all but the southeastern states was extremely rapid, but it became a problem primarily in the arid and semiarid western states. The economic consequences of conversion of perennial, native grass rangelands to downy brome, its ecological significance, and the importance of its control in reseeding of perennial grasses is pointed out by Klemmedson and Smith (1964), who cite over 100 papers published on downy brome. With the advent of new herbicides and modifications of tillage, burning, and reseeding techniques, research on re-establishing perennial forage species, principally crested wheatgrass (*Agropyron cristatum*), on ranges now dominated by downy brome has been continued (Eckert et al., 1974; Eckert and Evans, 1967; Evans et al., 1966, 1969; Klomp and Hull, 1972; and Robocker et al., 1965).

The authors are research agronomist and research plant physiologist, Agricultural Research Service, U.S. Department of Agriculture, Washington State University, Pullman.

This report is a contribution of the Agr. Res. Serv., U.S. Dep. Agr., in cooperation with the College of Agriculture Research Center, Washington State Univ., Scientific Paper No. 4487 of the latter.

Manuscript received October 28, 1975.

Medusahead was probably introduced later than downy brome, but well before 1900. Its spread has been neither so rapid nor as extensive as that of downy brome, and it is now of primary concern in Idaho, Washington, Oregon, California, and Nevada. The earliest reference to the economic aspects of medusahead appeared to have been made by Peck (1948). Since then, the undesirable qualities, ecology, and control of medusahead have received increasing attention (Bovey et al., 1961; Furbush, 1953; Kay and McKell, 1963; Major et al., 1960; Peck, 1948; Torell et al., 1961; Turner et al., 1963; and Young et al., 1969).

Daubenmire (1970) states that in Washington, once it has invaded a disturbed area, downy brome is capable of assuming dominance as grazing pressure eliminates native perennial grasses, and there is no concrete evidence that it ever relinquishes an area to indigenes once it is established. On abandoned fields in the driest climates, Russian thistle (*Salsola kali* var. *tenuifolia*) or tumble mustard (*Sisymbrium altissimum*) commonly precede downy brome. In less arid areas, other annual bromes may be present, and medusahead can at least partially displace downy brome as the dominant. Daubenmire also states that it is too early to determine the ultimate role of medusahead in Washington. Our own observations over the past 15 years uphold these assessments of downy brome and medusahead. Although studies have been made on the ecology of medusahead, we have found populations to fluctuate widely for reasons which are not clear.

The objectives of these investigations were to study methods of reseeding annual grass ranges with perennial grass species in the Columbia Basin, most of which are unsuitable for cultivation or use of conventional seeding equipment. Herbicides were used to reduce the competition of the annuals with seeded species, followed or accompanied by mechanical seeding to prolong the contact of seed with moist soil and to reduce consumption of seeds by rodents and birds.

Materials and Methods

Trials at Hooper, Wash., and Coyote Grade, Ida., 1960 to 1967

Beginning in 1960, trials to evaluate herbicides for control of annual grass species, followed by reseeding with perennial grasses, were conducted in eastern Washington and northern Idaho over periods of 2 to 6 years at each location. Experiments were conducted on 3- by 6-m plots in two to four replications, as indicated in the individual trial

Table 1. Sites and time of herbicide application, herbicide evaluation, seeding, seedling counts, and seedling establishment of crested wheatgrass.

Site	Date of				
	Herbicide application	Herbicide evaluation	Seeding	Seedling count	Establishment rated
Hooper, Wash.	Oct. 1960	June 1961	Oct. 1961	June 1962	June 1963
	Oct. 1961	June 1962	Oct. 1962	June 1963	June 1964
	Oct. 1965	June 1966	—	—	—
Coyote Grade, Ida.	Mar. 1962	June 1962	—	—	—
	Nov. 1963,				
	Feb. 1964 ¹	May 1964	Feb. 1964	May 1964	June 1965
	Nov. 1964,				
	Apr. 1965 ¹	June 1966	Nov. 1964	June 1965	June 1966
	Dec. 1966,				
	Mar. 1967 ¹	June 1967	Mar. 1967	June 1967	June 1968

¹Paraquat application, 0.8 kg/ha.

descriptions. Sites and dates of herbicide application and evaluation, seeding, seedling counts, and establishments are summarized in Table 1. Herbicides used in trials reported herein and the range of rates used are in Table 2. Specific rates are indicated in Tables 3 to 5. Herbicides were applied in a volume of 187 liters/ha, and seeding was done mechanically with a single-furrow, disc-opener seeder. Each plot was seeded with four rows of crested wheatgrass on 4.6-dm spacing. Stand counts of emerged seedlings per 2 m of row were made the first spring following seeding; establishment was evaluated 1 year later.

Table 2. Herbicides and rates (kg/ha) used in experiments reported in these trials.

Common name	Chemical name	Rate(s)
Amitrole ¹	3-amino- <i>s</i> -triazole	1.1
Atrazine	2-chloro-4-(ethylamino)-6-(isopropyl-amino)- <i>s</i> -triazine	0.6 to 2.7
Chlorpropham	isopropyl <i>m</i> -carbanilate	3.4
Dalapon	2,2-dichloropropionic acid	1.1 to 4.5
Diuron	3-(3,4-dichlorophenyl)-1-dimethylures	0.8 to 3.4
Glyphosate	<i>N</i> -(phosphonomethyl)glycine	0.6
Paraquat	1,1'-dimethyl-4,4'-bipyridinium ion	0.8 to 1.7
Pronamide ¹	3,5-dichloro- <i>N</i> -(1,1-dimethyl-2-propynyl)benzamide	0.6 to 0.8
Propham	isopropyl carbanilate	2.2 to 6.7
Simazine	2-chloro-4,6-bis(ethylamino)- <i>s</i> -triazine	1.1 to 3.4
2,4-D	(2,4-dichlorophenoxy)acetic acid	1.1

¹Applied with 2,4-D at 1.1 kg/ha.

Atrazine, chlorpropham, dalapon, diuron, paraquat, propham, and simazine were applied in two or three replications at Hooper or Coyote Grade in 2 or more years and at two or more rates at the times indicated in Table 1. Twenty-six other related or experimental compounds were also tried and discarded because of low efficiency or necessity for incorporation into the soil following application.

The Hooper, Wash., series of trials was begun in the Palouse scabland in 1960 and continued until 1966. The soil was a shallow silt loam, 3 to 6 dm deep, overlying basalt. Existing vegetation was a mixture of medusahead, downy brome, and sixweeks fescue (*Festuca octoflora* var. *tenella*) and broadleaf winter annuals. Average precipitation is about 33 cm per year, of which less than 2 cm falls from mid-June to mid-September.

The Coyote Grade, Ida., trials were on the north side of the Clearwater River Canyon in Idaho, approximately 14 km east of Lewiston. Annual precipitation is approximately 41 cm, with the typical dry summer months of the Columbia Basin. Soil was a silt loam with a southwestern exposure. The native bluebunch wheatgrass (*Agropyron spicatum*) had disappeared, and the area was populated with a dense stand of medusahead and small amounts of downy brome, hairyvetch (*Vicia villosa*), redstem filaree (*Erodium cicutarium*), and moth mullein (*Verbascum blattaria*).

Trials at Alpowa Grade and Palouse Falls, Wash., 1968 to 1975

These sites were on soil that was more uniform in depth and slope than trial areas at Hooper and Coyote Grade. Trials consisted of various combinations of autumn or spring herbicide applications with autumn or early spring seeding. Herbicide evaluations and stand counts of emerged seedlings of planted species per 2-m of row were generally made the first spring following seeding. Perennial grass establishment was evaluated not less than 1 year later. Seeding in these trials was done with a modified rangeland drill on 3-dm spacings, with eight rows seeded per plot.

The rangeland drill, as designed for seeding into plowed sagebrush, was modified for use on stoney as well as brushy ground and undisturbed annual grass range to obtain more certain seed placement and coverage (Fig. 1). To accomplish tillage in each drill row, a commercially available fluted coulter was mounted on an arm which was pivoted at the opposite end in the center of and loaded by a heavy, synthetic rubber disk. The coulter assembly was attached to a separate, adjustable tool bar ahead of a double-disk opener, which in turn was attached to a separate hinged arm behind the coulter. The opener was both spring- and gravity-loaded by the weight of the forward end of a press wheel assembly. The press wheel, with adjustable weights, was required to aid in covering the seed and in firming the soil. The individual components in this arrangement had maximal independence in vertical action in riding over stones, brush, and surface irregularities

Fig. 1. Rangeland drill modified to loosen soil in the drill row and operate on stony soil and rough terrain. (Upper) Attachment of adjustable tool bar carrying fluted coulters. (Lower) Fluted coulter, double-disk opener, and press wheel with independent suspension of components.

with minimal interaction on the other components. The fluted coulter did not function well in wet soil or in sod but had its best action in friable soil with annual species and in areas previously cultivated or chemically fallowed.

The Alpowa Grade area was on a slight southerly slope of a narrow valley, tributary to the Snake River Valley, approximately 11 km west of Clarkston, Wash., in an area estimated to receive 33 to 36 cm of precipitation annually. Soil was a silt loam. Vegetation was primarily downy brome in a sparse stand of bluebunch wheatgrass, Sandberg bluegrass (*Poa secunda*), and sand dropseed (*Sporobolus cryptandrus*), which appeared to be slowly increasing.

Four replicates of 3- by 6-m plots were treated with paraquat or amitrole plus 2,4-D in mid-February, 1971, and seeded 4 days later. Weed control was evaluated, and crested wheatgrass seedlings were counted in April. One-half of each plot was treated with 2,4-D in early May, 1971, for broadleaf weed control.

A second series of plots was treated with amitrole plus 2,4-D, atrazine, and pronamide plus 2,4-D in February, 1971, and seeded in October, 1971. A third series of plots received amitrole plus 2,4-D in October, 1971; chlorpropham with a degradation inhibitor (*p*-chlorophenyl N-methyl carbamate), and pronamide plus 2,4-D in early December, 1971, followed by seeding in late February, 1972.

The Palouse Falls area was on a silt loam soil bordering the Palouse scabland. The site had a northerly slope, a soil depth of 6 or more dm, and received 28 to 30 cm of precipitation yearly. The vegetation was almost totally downy brome, medusahead, and sixweeks fescue with an admixture of broadleaf winter annuals.

A trial of four replicates of 6- by 9-m plots was treated with atrazine or simazine in late October, 1969. Plots were rated for percentage of weed control in late May, 1970, seeded with crested wheatgrass in mid-November, 1970, and wheatgrass seedlings per 6-m of row were counted in mid-April, 1971. Data on seedlings were converted to the scale of the square root of ($X + \frac{1}{2}$) for analysis. Actual means are reported.

In mid-March, 1970, four replicates of 3- by 8-m plots were treated with (1) dalapon plus 0.5% surfactant (alkylaryl polyoxyethylene glycols), (2) dalapon plus atrazine plus surfactant, (3) dalapon plus amitrol plus surfactant, (4) amitrol plus 2,4-D, and (5) paraquat with surfactant. A mechanical treatment (double disking) was also included. Plots were seeded in November, 1970. Percentage control of annual weeds was estimated, and seedlings of crested wheatgrass per 6-m of row were counted in April, 1971. Data were converted to the

scale of the square root of ($X + \frac{1}{2}$) for analysis. Actual means are reported.

Exploratory Fungicide and Fumigation Trial, 1972

One-half of the duplicate 3- by 6-m plots were fumigated with methyl bromide under a plastic tarp at 567g per 929 dm² in early November, 1972. Eight days later, crested wheatgrass and intermediate wheatgrass (*Agropyron intermedium*), both treated with captan (cis-N-[(trichloromethyl) thio]-4-cyclohexene-1,2-dicarboximide), were seeded at about 20 seeds per 3 dm with a double-disk opener hand seeder. Four rows of treated and four rows of untreated seed of each species were seeded on each plot. Plants per 2 m of row were counted in early October, 1973. Numbers were converted to the scale of the square root of ($X + \frac{1}{2}$) for analysis of variance. Actual means are reported.

Autumn Fungicide, Fumigation, and Seeding, 1973

Duplicate 3- by 20-m plots were seeded with crested wheatgrass, which had been treated with 1 g of the following fungicides per 100 g of seed: captan, benomyl (methyl-1-(butylcarbamoyl)-2-benzimidazole-carbamate), carboxin (5,6-dihydro-2-methyl-1,4-oxathin-3-carboxamide) plus thiram [bis(dimethylthiocarbamoyl)disulfide] (37.5%:37.5%), and benomyl plus thiram (30%:30%). Methyl bromide was applied at 454 g per 929 dm² in late October, and plots were kept covered for 15 days. All other plots were sprayed with amitrole-T (amitrole plus ammonium thiocyanate) plus 2,4-D, 1.1 plus 1.1 kg/ha, respectively, before seeding. Plots were seeded in December, 1973. Plants per 4 m of row were counted the following May, and means were compared with Duncan's multiple range test.

Autumn Soil Treatments, 1973, and Spring Seeding, 1974

Duplicate 3- by 20-m plots were treated as follows in late October, 1973: potassium azide, banded on row location at rates of 17, 34, or 67 kg/ha; calcium cyanamide banded at 448 or 896 kg/ha; calcium cyanamide broadcast at 168 or 336 kg/ha; ammonium sulfate banded on row location at 448 or 896 kg/ha; and methyl bromide at 487 kg/ha. The entire plot area was treated with glyphosate at 0.6 kg/ha before seeding. Plots were seeded in mid-March, 1974, and plants were counted in June, 1975. Means were compared by Duncan's multiple range test.

Table 3. Summary of average percentage herbicidal control of medusahead and downy brome treated in two or more trials in autumn or early spring from 1960 through 1966 and number of seedlings and established crested wheatgrass plants per 2 m of row after herbicide treatment.

Herbicide	Rate (kg/ha)	Number of herbicide trials ¹		Annual grass control (%)		Wheatgrass plants per 2 m of row			
						seedlings		established	
		H.	C.G.	H.	C.G.	H.	C.G.	H.	C.G.
Atrazine	0.6	2	2	75	90	4	0	0	0
"	1.1	3	3	100	75	1	3 ²	0	0
"	1.7	2	3	100	90	—	5	—	0
Chlorpropham	6.7	1	1	75	20	—	11	—	0
Dalapon	2.2	—	2	—	45	—	10	—	0
Diuron	0.8	1	1	70	70	—	—	—	—
"	1.7	2	1	70	60	1	—	0	—
"	2.2	1	2	40	95	—	3	—	0
"	3.4	1	1	90	85	1	—	0	—
Paraquat	0.8	—	3	—	50	—	14	—	0
"	0.6	—	2	—	65	—	9	—	0
Propham	2.2	1	1	80	65	1	—	0	—
"	4.5	2	3	85	60	1	20	0	0
"	6.7	2	3	90	70	0	9	0	0
Simazine	2.2	1	1	100	85	—	—	—	—
Untreated	0.0	3	4	0	0	0	0	0	0

¹H. = Hooper, Washington; C.G. = Coyote Grade, Idaho.

²Three seedlings.

Results and Discussion

Trials at Hooper, Wash., and Coyote Grade, Ida., 1960 to 1967

Seven herbicides which were tried two or more times (Table 3), showed some promise for control of both medusahead and downy brome. Only in plots treated with the lowest rate of atrazine at Coyote Grade and the highest rate of propanil at Hooper were no crested wheatgrass seedlings found following seeding. Atrazine at 1.1 kg/ha and propanil at 4.5 kg/ha appeared to give the most consistent results. Higher precipitation and higher organic matter on Coyote Grade apparently combined to result in somewhat less control of annual grasses and a higher rate of emergence of the planted crested wheatgrass seedlings. At both locations, the stands of annual grasses were variable—at Hooper because of the shallow soil and occurrence of pockets of deeper soil and at Coyote Grade because of slope and abundance of broadleaf weeds. Because of the lack of establishment and variability of the sites, these trials were viewed at their conclusion as a basis for a new series of trials.

Trials at Alpowa Grade and Palouse Falls, Wash., 1968–1975

Annual grass control in these trials was generally satisfactory, and emergence of some wheatgrass seedlings almost always occurred. However, the seedlings usually lacked the vigor to survive through the summer and autumn, and established plants were seldom found the following spring. For this reason, only two of the trials at Palouse Falls were reported.

Alpowa Grade

Good seedling emergence and establishment were obtained with late winter-early spring treatment with herbicides, followed by seeding a few days later (Table 4). Application of 2,4-D in May did not affect seedling vigor or establishment. Weed control was about the same for the paraquat and the combination of amitrole and 2,4-D. No significant difference was shown among the treated and untreated plots in number of wheatgrass seedlings emerged. Although statistical analysis showed no significant difference between the two herbicide treatments in established plant numbers, plants on treated plots significantly exceeded the number on the untreated plots. Possibly the stand on the amitrole plus 2,4-D plots was somewhat better than on the paraquat plots because of the residual action of amitrole in suppressing the later emerging sunflower (*Helianthus annuus*) and prickly lettuce (*Lactuca serriola*).

Spring application of herbicides followed by autumn seeding and autumn-early winter application of herbicides and early spring seeding did not lead to establishment of crested wheatgrass seedlings. The residual action of pronamide appeared to be too long to permit seeding within the allowable fallow period

Table 4. Average percentage weed control and number of seedlings and established plants per 4 m of row from herbicide application on February 18 and seeding on February 22, 1971, at Alpowa Grade, Wash.

Herbicide	Rate (kg/ha)	Weed control	Crested wheatgrass	
			Seedlings ¹	Established ²
Paraquat	0.8	60	84	29 a
Amitrole + 2,4-D	0.8 + 1.1	70	86	38 a
Untreated	—	0	56	4 b

¹Counted on April 19, 1971. Differences N.S.

²Counted on April 12, 1973. Means followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

of 3 to 6 months.

Palouse Falls, 1969 and 1970

Practically total weed control was obtained from the triazines applied in October, 1969 (Table 5). Plots treated with the 1.8-kg/ha rate of atrazine and simazine had the largest number of crested wheatgrass seedlings, although there were no significant differences among means. When herbicides were applied in March, followed by autumn seeding, differences in seedling emergence were significant, with the atrazine, atrazine plus dalapon, and dalapon being significantly superior to other treatments.

Table 5. Average percentage control of annual weeds following herbicide applications and number of seedlings of crested wheatgrass per 6 m of row after seeding at Palouse Falls, Wash.

Herbicide	Rate (kg/ha)	Weed control ¹		Wheatgrass seedlings ²
		Annual grass	Broadleaf	
Herbicides applied October 22, 1969 ³				
Atrazine	0.9	90	95	6
"	1.8	100	100	10
"	2.7	100	100	6
Simazine	1.8	100	100	13
Untreated	—	0	0	0
Herbicides applied March 10, 1970 ⁴				
Atrazine	1.1	100	95	22 a
Atrazine + dalapon	1.1 + 2.2	95	95	15 ab
Dalapon	4.5	100	70	10 bc
Dalapon + amitrole	2.2 + 1.1	95	90	7 b-e
Amitrole + 2,4-D	1.1 + 1.1	40	95	8 b-d
Paraquat	1.1	20	90	2 ef
Double disk	—	90	85	5 c-e
Untreated	—	0	0	1 f

¹Estimated on May 25, 1970.

²Seeded on November 18, 1970, and seedlings counted on April 21, 1971.

³Differences in means of seedlings from autumn herbicides N.S.

⁴Means of wheatgrass seedlings not followed by the same letter are significantly different at the 5% level according to Duncan's multiple range test.

Dalapon alone performed well in this trial, but in others its effect has been erratic, and its ineffectiveness on broadleaf weeds makes it unsuitable for this use. Atrazine in the 1.1-kg/ha range has been most reliable because of its broad spectrum of weed control and lack of residual activity if applied early enough to receive winter or spring moisture for activation and decomposition. Amitrole and 2,4-D, which performed well at Alpowa, did not control annual grasses sufficiently, and numbers of seedlings on paraquat-treated plots were not significantly greater than those on control plots. The number of crested wheatgrass seedlings on plots which had been double-disked was less than one-fourth of those on plots treated with atrazine, even though weed control appeared to be adequate.

A year after seedlings of crested wheatgrass had been observed and counted in these two trials, only scattered plants were found, and the treatments were all rated as failures in establishing a perennial grass. The preponderance of failures in these many trials indicated that while weed control was an important and necessary measure for establishment of perennial species, an unknown factor(s) was responsible for lowered vitality or death of emerging seedlings. Early spring or late autumn seeding showed no particular advantage for either season as long as residual herbicides were given favorable

conditions for action and decomposition to the point of being nontoxic to the crested wheatgrass seedlings.

Fungicide and Fumigation Trial, 1972

In this exploratory trial, treatment of the seeds of crested wheatgrass and intermediate wheatgrass with captan resulted in no increased number of emerged seedlings. Soil fumigation with methyl bromide led to increased numbers of crested wheatgrass seedlings, from 1 per 2 m of row on the untreated soil to 32 on the treated, and intermediate wheatgrass seedlings, from 4 to 8 per 2 m of row, untreated vs treated, respectively. Differences were significant at the 1% level for crested wheatgrass and at 5% for intermediate wheatgrass. Weed control was nearly 100%. Although the summer was drier than usual, very little mortality of seedlings occurred on the fumigated plots, and the vigor of many plants was such that they produced seed the first year.

Autumn Seed Treatment and Fumigation, 1973

Inasmuch as crested wheatgrass seemed to be better adapted to the climatic limitations of Palouse Falls, intermediate wheatgrass was not included in this or the following trial. Competition with seedlings of crested wheatgrass was reduced an estimated 50% on all plots treated with amitrole plus 2,4-D. These plots were situated on an area which had deeper and more uniform soil than some of the other sites, and they were within the drainage area from gentle slopes on two sides. Reduced competition and better moisture conditions apparently permitted unusually good germination, emergence, and establishment (Table 6); there was no significant difference in numbers of plants from any of the treatments. At the end of the growing season, plants on plots treated with methyl bromide were significantly taller than those on all other plots. A count of established plants 18 months after seeding showed a general decrease in numbers and a definite trend toward uniformity in numbers. Plots treated with methyl bromide, however, were still easily found because of the residual weed control and vigor of crested wheatgrass.

Autumn Soil Treatments, 1973, and Spring Seeding, 1974

Among the treatments applied in autumn of 1973, the plots treated with methyl bromide had significantly more established

plants than those from any other treatment (Table 7). Many plants on the methyl bromide plots had produced rhizomes, and stems from crowns of individual plants were so intermingled as to make separation of plants difficult. The area was not protected from grazing, and accurate production data were not obtainable. However, the unutilized portion of 4 m of each row was harvested, and when it was estimated that 80% of the forage produced had been removed, the possible production from the plots treated with methyl bromide was 970 kg/ha; from banded calcium cyanamide at 448 kg/ha, 140 kg/ha; from banded ammonium sulfate at 448 kg/ha, 60 kg/ha; and from the untreated plots, 10 kg/ha.

Table 7. Average number of established crested wheatgrass plants per 4 m of row from fungicide, fumigant, or fertilizer applied in autumn, 1973, and seeded early spring, 1974.

Treatment	Rate (kg/ha)	Established plants, 1975 ¹
Potassium azide, banded	17	16 cd
Potassium azide, banded	34	14 cd
Potassium azide, banded	67	20 bcd
Calcium cyanamide, banded	448	20 bcd
Calcium cyanamide, banded	896	14 cd
Calcium cyanamide, broadcast	168	18 cd
Calcium cyanamide, broadcast	336	26 b
Ammonium sulfate, banded	448	14 cd
Ammonium sulfate, banded	896	11 d
Methyl bromide	487	51 a
Untreated	—	22 bc

¹Means followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

Potassium azide appeared to have no effect in increasing the stand. Calcium cyanamide had a detectable visual effect on annual weed production at the higher rates, but in areas of limited precipitation, the use of compounds which ultimately released nitrogen in a nutrient form is questionable. Although nitrogen may benefit perennial grass seedlings, the necessity for a prolonged supply of soil moisture places them in a position of disadvantage with the winter annual grasses, particularly so in the drier years. The latter grow rapidly and mature before midsummer. Readily available nitrogen stimulates even more rapid and profuse growth and depletes the limited soil moisture to an unavailable level. The effect of such competition was demonstrated by the decreased numbers of established crested wheatgrass plants when nitrogen was obtained from the calcium cyanamide or ammonium sulfate in this trial. The effect of such competition was further demonstrated when downy brome eliminated seedlings of Dalmatian toadflax in a recent study (Robocker, 1974).

Conclusions

It is apparent from these trials that weed control in most cases is a necessary step to conserve soil moisture and control competition with seeded species. Evidence of these trials indicates that an additional factor(s), microbiological in nature and including a nematode endemic to the arid West (Thorne, 1961), is responsible for reduced vigor and loss of seedling stands, particularly when seedlings are under stress from competition of other species and adverse climatic factors. Because adequate herbicides and procedures for their application are known and suitable seeding equipment has been developed, investigations of these soil-related factors should

Table 6. Average number of crested wheatgrass seedlings (5 months) and established plants (18 months) from time of seeding with treated seed or in fumigated soil, and plant height (cm) 11 months after seeding at Palouse Falls, Wash.

Seed treatment ¹	Plants per 4 m of row		
	Seedlings	Established	Height ²
Captan	41	32	39 b
Benomyl	42	36	40 b
Carboxin + thiram	62	46	42 b
Benomyl + thiram	44	37	40 b
Untreated (soil fumigated with methyl bromide)	60	38	65 a
Untreated	33	34	38 b

¹All plots, except those fumigated with methyl bromide, treated with 1.1 kg/ha amitrole plus 1.1 kg/ha 2,4-D on Dec. 4, 1973, and seeded immediately.

²Means not followed by the same letter are significantly different at the 1% level. Means in columns without following letters are not significantly different according to Duncan's multiple range test.

receive priority in further studies of perennial grass establishment in this region. Until reseeding can be done with greater knowledge of causes of seedling failure and a higher chance of success is assured, the most efficient use of these ranges will probably continue to be for early spring grazing of the annual species.

Literature Cited

- Bovey, R. W., D. LeTourneau, and L. C. Erickson. 1961.** The chemical composition of medusahead and downy brome. *Weeds* 9:307-311.
- Daubenmire, R. 1970.** Steppe vegetation of Washington. *Wash. Agr. Exp. Sta. Tech. Bull.* 62. 131 p.
- Eckert, R. E., Jr., J. E. Asher, D. M. Christensen, and R. A. Evans. 1974.** Evaluation of the atrazine fallow technique for weed control and seedling establishment. *J. Range Manage.* 27:288-292.
- Eckert, R. E., Jr., and R. A. Evans. 1967.** A chemical-fallow technique for control of downy brome and establishment of perennial grasses in rangelands. *J. Range Manage.* 20:35-41.
- Evans, R. A., R. E. Eckert, Jr., and B. L. Kay. 1966.** Wheatgrass establishment with paraquat and tillage on downy brome ranges. *Weeds* 15:50-55.
- Evans, R. A., R. E. Eckert, Jr., B. L. Kay, and J. A. Young. 1969.** Downy brome control by soil-active herbicides for revegetation of rangelands. *Weed Sci.* 17:166-169.
- Furbush, P. 1953.** Control of medusahead on California ranges. *J. Forest.* 51:118-121.
- Kay, B. L., and C. M. McKell. 1963.** Pre-emergence herbicides as an aid in seeding annual rangelands. *Weeds* 11:260-264.
- Klemmedson, J. O., and J. G. Smith. 1964.** Cheatgrass (*Bromus tectorum* L.). *Bot. Rev.* 30:226-262.
- Klomp, G. J., and A. C. Hull, Jr. 1972.** Methods for seeding three perennial wheatgrasses on cheatgrass ranges in southern Idaho. *J. Range Manage.* 25:266-268.
- Major, J., C. M. McKell, and L. J. Berry. 1960.** Improvement of medusahead-infested rangeland. *Calif. Agr. Exp. Sta. Ext. Serv. Leaflet* 123. 2 p.
- Peck, M. E. 1948.** Invasion of exotic plants and their economic significance in Oregon. *Northwest Sci.* 22:126-131.
- Robocker, W. C. 1974.** Life history, ecology, and control of Dalmatian toadflax. *Wash. Agr. Exp. Sta. Tech. Bull.* 79. 20 p.
- Robocker, W. C., D. H. Gates, and H. D. Kerr. 1965.** Effects of herbicides, burning, and seeding date in reseeding in arid range. *J. Range Manage.* 18:114-118.
- Thorne, Gerald. 1961.** Principles of nematology. McGraw-Hill Book Co., Inc., New York, N.Y. 553 p.
- Torell, P. J., L. C. Erickson, and R. H. Haas. 1961.** The medusahead problem in Idaho. *Weeds* 9:124-131.
- Turner, R. B., C. E. Poulton, and W. L. Gould. 1963.** Medusahead—a threat to Oregon rangeland. *Oregon Agr. Exp. Sta. Spec. Rep.* 149. 22 p.
- Young, J. A., R. A. Evans, and R. E. Eckert, Jr. 1969.** Wheatgrass establishment with tillage and herbicides in a mesic medusahead community. *J. Range Manage.* 22:151-155.