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OVERSTORY-UNDERSTORY GRASS SEEDINGS ON SAGEBRUSH-BUNCHGRASS RANGE

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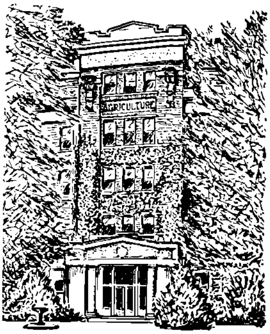

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Overstory-Understory Grass Seedings on Sagebrush-Bunchgrass Range

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INTRODUCTION

Mixed seedings of tall grasses (overstory species) and short grasses (understory species) are becoming popular for seeding sagebrush-bunchgrass range. Species with different rooting levels and different phenological patterns of growth can be combined to exert a more continuous condition of closed community than is exerted by single-species stands (Robertson and Pearse, 1945; Blaisdell, 1958). However, a single grass species that concentrates growth and competitiveness in a short season might control some weedy plants better and yield more forage than mixed stands. Competition is complex, and the advantages and disadvantages of pure and mixed seedings can not be generalized from existing knowledge. Specific evaluations among species and environmental conditions are required (Eckert, *et al.,* 1961).

Numerous observations of native plant communities have led to the generalization that overstory-understory grass mixtures will reduce the rate of big sagebrush (*Artemisia tridentata* Nutt.) invasion as compared with single-species plantings. Mixed seedings have been recommended for controlling sagebrush invasion. The degrees of brush control obtained by pure and mixed-species seedings were, therefore, the primary objectives of studies undertaken in eastern Oregon.

Since brush seedlings are most likely to become established in the first year after seeding (Blaisdell, 1949), the density of seeded grasses and the time required for their establishment to maximum competitiveness may affect the rate of brush invasion. The time and rate of seeding, seedbed firming (Hyder and Sneva, 1956a; Hyder, *et al.,* 1961), and the role of nitrogen fertilization in grass establishment and competition (Sneva, Hyder, and Cooper, 1958) are perti-

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nent to the main objective. In a broader sense, any condition or factor that hastens grass establishment might reduce brush invasion. On the other hand, it is unlikely that any grass seeding will affect appreciably the mortality rate of established brush (Blaisdell, 1949).

The timing and thoroughness of seedbed preparation is of primary importance in controlling the invasion of big sagebrush (Pechanec, *et al.,* 1954). Big sagebrush seed are dispersed near parent plants (Frischknecht and Bleak, 1957), and tillage prior to seed dissemination decreases the seed source and delays sagebrush reinvasion. However, a residual of seed in the soil, tillage after seed dissemination, incomplete removal of parent plants, or the introduction of more widely dispersed seeds of rabbitbrush (*Chrysothamnus* spp.) provide seed sources for brush invasion that affect most seedings on the sagebrush-bunchgrass range. Brush infestations can be controlled with herbicides (Hyder, Sneva, and Freed, 1962), but control obtained from grass competition can reduce maintenance costs for spraying. Therefore, the present investigations were deliberately limited to the establishment, competitiveness, and productivity of seeded grasses.

This bulletin describes pure and mixed grass seedings at four locations in eastern Oregon. Grass stands were evaluated for establishment success, brush invasion, herbage production, inter-species competition, and response to nitrogen fertilization.

LOCATION OF STUDY AREAS

Squaw Butte Experiment Station

Pure and mixed stands of overstory and understory grasses were seeded at Squaw Butte Experiment Station in 1956, 1957, and 1958. This Station is located 40 miles west of Burns, Oregon, at an elevation of 4,600 feet on the Oregon High Desert (Figure 1). The site selected for the seedings is classified as an example of the *Artemisia tridentata/Agropyron spicatum* habitat-type described by Eckert (1957). Big sagebrush, bluebunch wheatgrass (*Agropyron spicatum* (Pursh.) Scribn. and Smith), sandberg bluegrass (*Poa secunda* Presl), Idaho fescue, (*Festuca idahoensis* Elmer), thurber needlegrass (*Stipa thurberiana* Piper), bottlebrush squirreltail (*Sitanion hystrix* (Nutt.) J. G. Smith), Junegrass (*Koeleria cristata* (L.) Pers.), and green rabbitbrush (*Chrysothamnus viscidiflorus* (Hook) Nutt.) are common components of the vegetation. Big sagebrush greatly restricts the production of herbaceous plants (Hyder and Sneva, 1956), but less is known about the effects of rabbitbrush.

The soil is a well-drained, sandy loam Brown soil developed on a gently sloping fan derived from alluvial materials of basaltic and

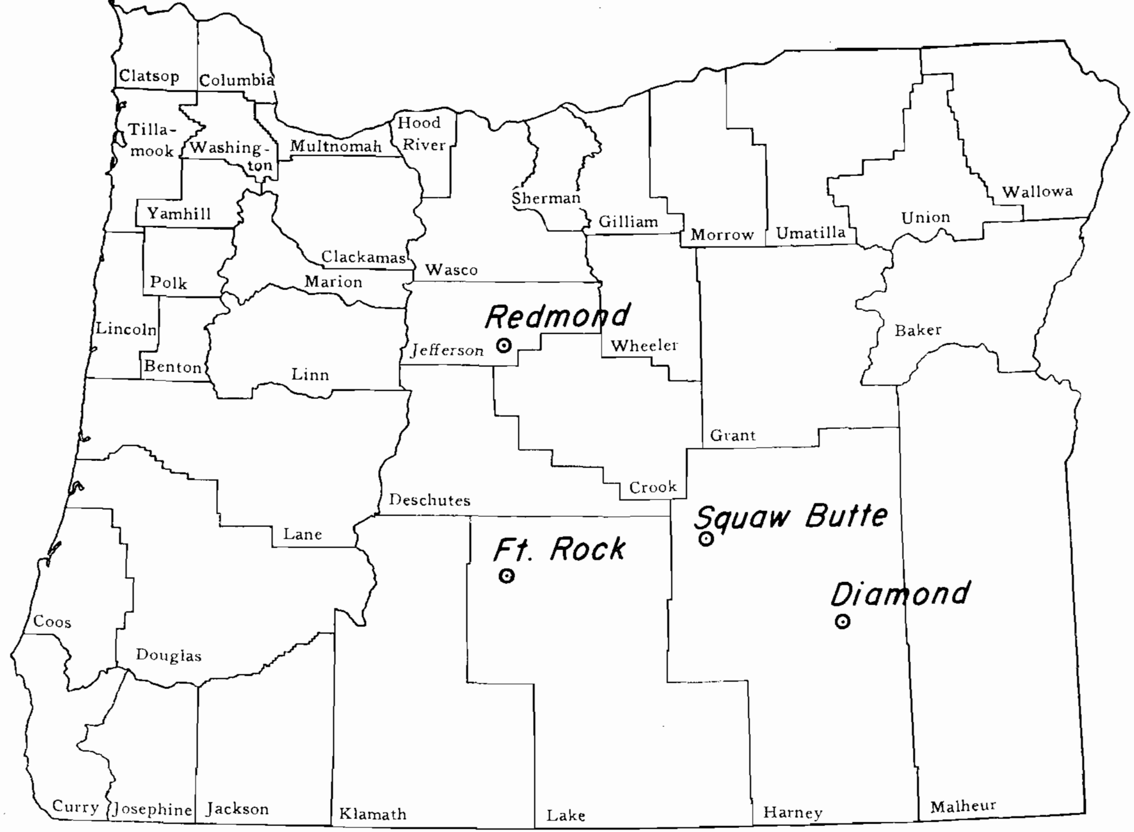

Figure 1. Study-area locations in eastern Oregon.

rhyolitic origin. Plowing leaves a very fluffy seedbed that must be packed to assure good grass establishment (Hyder and Sneva, 1956a). Soil moisture contents in the surface 6 inches averages about 16% at a tension of 1/3 atmosphere and about 8% at 15 atmospheres. Average annual precipitation is 11.8 inches.

Fort Rock

The Fort Rock Valley, located in south-central Oregon (Figure 1), differs significantly both climatically and in land-use history from the study area at Squaw Butte Experiment Station. Weather records are not available at the experimental area, but the average annual precipitation at Silver Lake is 9.8 inches. Nearly all of the valley bottom was homesteaded after World War I.

The arable soils were derived from pumice that originated from the eruption of ancient Mt. Mazama. Surface soils, varying in texture from sandy to sandy loam, are eroded by strong winds in February, March, and April. The B horizon is finer-textured than the A horizon and often appears as an indurated layer or pan when dry. Soil moisture is limiting in late spring when dry winds withdraw much of the surface moisture before soil temperatures are high enough to promote rapid plant growth.

Big sagebrush is the principal brush species on unplowed and unburned areas, but green rabbitbrush and gray rabbitbrush (*Chrysothamnus nauseosus* (Pallas) Britt.) are abundant on abandoned croplands and burned areas.

Diamond

The Diamond study area is located in the foothills of the Steens Mountains about three miles south of Diamond (Figure 1). Average annual precipitation is about the same as at the Squaw Butte Experiment Station, but more falls in the spring and summer. Diamond receives 5.4 inches, or about half of the annual total, of precipitation from April to September inclusive; whereas Squaw Butte receives 4.0 inches, or about one-third of the annual total. Otherwise, climate, vegetation, and soils are very similar for Diamond and Squaw Butte.

Grazing has been the principal land use in the vicinity of Diamond. Originally, much of this area was used by the cattle barons who eventually gave way to the homesteaders who, in turn, had their holdings acquired by early ranchers as water and hay bases that established grazing privileges on the surrounding Public Domain. Both sheep and cattle used these ranges prior to 1940, but more recently sheep have been replaced by cattle.

Redmond

Seeding trials near Redmond were located in the corner of a larger crested-wheatgrass seeding on the Madras Land Utilization Project (Figure 1). Sagebrush-bunchgrass communities occupied the area before homesteading. Severe drought and wind erosion in the 1930's forced homesteaders from the land, which was then purchased by the United States Department of Agriculture and classified as a Land Use Project under the administration of the Soil Conservation Service. The project was transferred from the Soil Conservation Service to the Forest Service in the mid-1950's. Restoration has been accomplished by grass seeding and judicious grazing since World War II. Although most of the abandoned croplands have been seeded to crested wheatgrass (*Agropyron desertorum* (Fisch.) Schult.) or Whitmar beardless wheatgrass (*Agropyron inerme* (Scribn. & Smith) Rydb.), the invasion of sagebrush and rabbitbrush has reduced herbage production and required herbicide treatments for brush control.

The study area is located about half way between two weather recording stations that report average annual precipitation of 8.6 inches, 40% of which has fallen during the spring and summer months. Surface soils are rather deep and coarse-textured at the study site. A seeding completed here in 1953 was unsuccessful.

PROCEDURES

Squaw Butte Experiment Station

A split-plot experiment in three replications with 12 seeding treatments on whole plots and 2 fertilization treatments of 0 and 30 pounds of nitrogen per acre on sub-plots was initiated in 1956 and repeated in 1957 and 1958. Plowing and seedbed preparation requirements caused the separation of year blocks, and this design obviously confounds year and location differences. The 12 seeding treatments included factorial combinations of the following overstory and understory grasses: none, standard crested wheatgrass, Whitmar beardless wheatgrass, and Sherman big bluegrass (*Poa ampla* Merr.) were overstory grasses; none, Sodar streambank wheatgrass (*Agropyron riparium* Scribn. & Smith), and canby bluegrass (*Poa canbyi* (Scribn.) Piper) were understory grasses. All of these grasses are adapted to sagebrush-bunchgrass range (Hanson, 1959; Schwendiman, 1958; Douglas and Ensign, 1954).

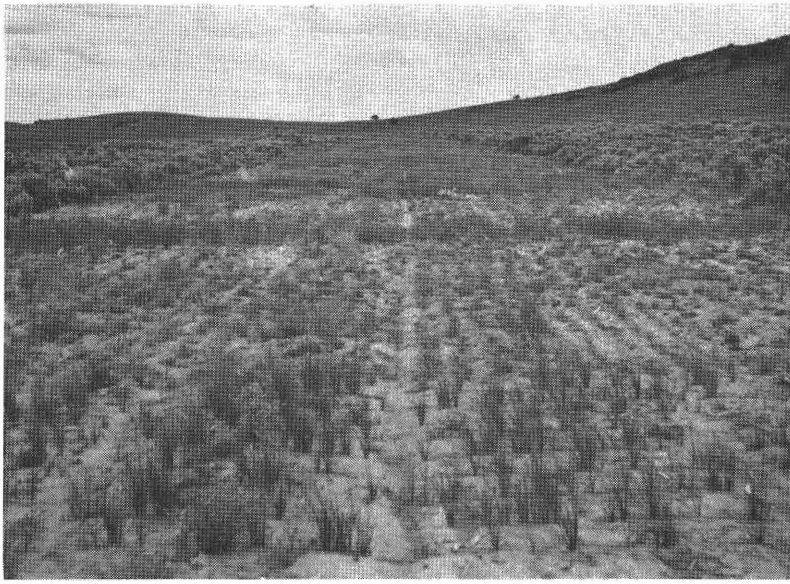

Figure 2. Seedings at Squaw Butte were made in a narrow strip through big sagebrush.

To provide a seed source for big sagebrush, a strip 40 feet wide was cleared through native vegetation (Figure 2). Clearing involved chopping with a rotary beater and plowing twice with a wheatland plow in May and June. The cleared area was then left in fallow without additional tillage until seeding time. Ammonium nitrate was surface broadcast in October. Shortly after snow melt the following March or April, the seedbed was packed with a double-section cultipacker and seeded to the various grasses. The sequence of clearing, summer fallowing, fertilizing, and seeding was followed each year with minor changes in dates.

Drilling was accomplished with a double-disc, cone-type, single-row plot drill. Pure stands of understory grasses were planted in rows 6 inches apart (10 lbs. of seed/A.), mixed stands were planted in rows 6 inches apart with overstory and understory species alternating (each at 5 lbs. of seed/A.), and pure stands of overstory grasses were planted in rows 12 inches apart (5 lbs. of seed/A.).

Seeded plots were 10 feet wide and 40 feet long running across the cleared strips, but plot evaluations were restricted to the center 20 feet. Each of these plots was divided into paired sub-plots measuring 10 by 10 feet. One of each pair, by random assignment, remained unfertilized and the other was fertilized annually.

All plots were evaluated for seeding success in late summer, the year of planting, by frequencies of occurrence in 80 quadrats measuring 6 by 6 inches per sub-plot. Seedlings of big sagebrush and green rabbitbrush were counted in the early fall after planting and each fall thereafter for four consecutive years.

Herbage yields of individual seeded species and of herbaceous weeds were harvested in July or August for three consecutive years beginning in the year after planting. The herbage was harvested by hand clipping at ground level within 4- by 4-foot quadrats centered in each plot, dried in a forced-air electric oven at 70° C., weighed, and expressed in pounds per acre oven dry.

Herbage yields were adjusted to a median amount of crop-year precipitation as described by Sneva and Hyder (1962 and 1962a) to reduce yield variations among years. Dividing a given herbage yield by the yield index (in decimal form) for that year gives an adjusted weight corresponding to a yield index of 100% (Table 1).

Table 1. CROP-YEAR PRECIPITATION AMOUNTS WITH PRECIPITATION- AND YIELD-INDEXES AT SQUAW BUTTE EXPERIMENT STATION

Crop year Sept. 1-June 30[a]	Precipitation	Precipitation index	Yield index
	inches	%	%
Median	11.3	100	100
1955	5.9	52	47
1956	14.3	127	130
1957	13.1	116	118
1958	16.2	143	148
1959	6.1	54	49
1960	9.7	86	85
1961	7.2	64	60

[a] Precipitation amounts are identified by the year in which the crop-year periods terminate.

Fort Rock

Two strip-plot experiments in four replications, with five treatments of companion species on whole plots measuring 20 by 150 feet and two fertilization rates on whole plots at a right angle across species plots, were established in 1957. Standard crested wheatgrass was planted uniformly across all plots by drilling 5 pounds of seed per acre in rows 12 inches apart. The treatments of companion species were: none, bulbous bluegrass (*Poa bulbosa* L.), canby bluegrass, streambank wheatgrass, and Ladak alfalfa (*Medicago sativa* L.). Companion species were planted by drilling at a right angle across crested wheatgrass rows. Ammonium nitrate was applied at 0 and 20 pounds of N per acre by surface broadcast just before drilling.

One of the 1957 experiments was established on a plowed seedbed, and the other was established on a burned seedbed. Unburned brush stems were cleared by rotobeating. Plowing and burning were completed in early April 1957. Planting was accomplished on April 19, 1957. The plots were opened to grazing in the fall of 1958 and annually thereafter.

Herbage yields were obtained by hand clipping 9.6 square feet per plot on June 24, 1958. Herbage samples were separated into the components, crested wheatgrass, companion species, and weeds. Established stands were evaluated by the percentage of 12- by 12-inch quadrat areas found stocked with seeded species in October 1962. Big sagebrush, green rabbitbrush, and gray rabbitbrush were counted in October 1962. Brush counts covered entire plot areas on the plowed area and mil-acre sub-samples on the burned area.

A third experiment was established at Fort Rock in 1958. The area was burned and rotobeat in early April 1958. Fertilizing and planting operations were completed on April 25. This strip-plot experiment in two replications included four companion-species treatments (none, streambank wheatgrass, Ladak alfalfa, and Ladak plus streambank wheatgrass) on whole plots in one direction and two fertilization rates (0 and 20 lbs. of N per acre) at a right angle across them. Companion-species plots were split into three subplots on which crested wheatgrass was planted in rows spaced 8, 12, or 24 inches apart. In the final operation, companion species were planted by drilling at a right angle to crested-wheatgrass rows. Established stands were evaluated by the percentage of 12- by 12-inch quadrat areas found stocked with seeded grasses in October 1962. Big sagebrush, green rabbitbrush, and gray rabbitbrush on mil-acre sub-samples were counted in October 1962. Experiment 3 at Fort Rock was fenced to exclude grazing.

Diamond

Two strip-plot experiments in four replications were established at Diamond in 1955. One experiment was seeded September 30, 1955, and the other was seeded the following spring (April 4, 1956). Five companion-species whole plots measuring 50 by 400 feet were oriented across replications in one direction and two fertilization rates (0 and 30 lbs. N/A) were oriented across replications at a right angle to species plots. The five companion-species treatments were: none, canby bluegrass, bulbous bluegrass, streambank wheatgrass, and crested wheatgrass. Crested wheatgrass was planted by drilling in rows 12 inches apart uniformly over all plots at 5 pounds of seed per acre. The companion-species treatment of crested wheatgrass involved drilling a second time at a right angle to the original seeding. Other companion species were planted by surface broadcast prior to the drilling of crested wheatgrass.

Ammonium nitrate was surface broadcast just before seeding. Also, established stands were fertilized in 1958, 1959, and 1960 by broadcasting in the fall preceding the years named.

These experiments were placed on the edge of a larger seeding near undisturbed vegetation that provided a brush-seed source. Companion-species plots were oriented at a right angle to the brush-seed source.

The entire area was prepared by double plowing with a heavy tandem disc in July 1955. This time of plowing provided an ineffective summer fallow because the soil was dry at plowing time and remained dry all summer. The seedings were opened to spring grazing by cattle annually beginning in 1957.

Established stands were evaluated by frequency and yield on September 26, 1956. Herbage yields under cages placed on selected plots were taken on July 19, 1961. Final stand evaluations by frequency and counts of big sagebrush and green rabbitbrush on entire plot areas were obtained on September 25, 1962.

Redmond

A strip-plot experiment in three replications with five companion-species treatments (none, streambank wheatgrass, bulbous bluegrass, canby bluegrass, and Ladak alfalfa) on whole plots (measuring 50 by 400 feet) in one direction and two fertilization treatments (0 and 20 pounds/A) on whole plots at a right angle across the species plots was established on the Redmond site in March 1957. Crested wheatgrass was seeded at 7½ pounds per acre in early March with a deep-furrow drill. Ammonium nitrate was surface broadcast in late March. The seed of companion species was diluted with rice hulls and planted with the same deep-furrow drill, but moving at a right angle to crested-wheatgrass rows, on April 2 and 3, 1957. This double use of the deep furrow drill covered some of the crested wheatgrass seeds too deeply.

This experiment was located near the edge of a larger seeding. A seeding failure here in 1953 left the area without perennial vegetation for four years prior to the 1957 seeding. The experimental plots were near a seed source of big sagebrush, green rabbitbrush, and gray rabbitbrush.

Big sagebrush, green rabbitbrush, and gray rabbitbrush on 200 square-foot sub-samples, located as near as possible to the brush-seed source on each plot, were counted on September 6, 1962, to evaluate the seeding treatments. Crested wheatgrass frequencies were taken at the same time to evaluate seeding success. A complete area inventory of brush was taken on two replications on August 5 and 6, 1963, to obtain distance profiles of brush invasion. Each plot was divided into 4-foot belts oriented parallel to the brush-seed source, and the established brush on each belt were counted.

RESULTS

Squaw Butte Experiment Station

Seeding success

Quadrat frequencies indicate excellent stands for most species and years (Table 2). Big bluegrass stands were poor (8%) in 1958 and canby bluegrass stands in 1957 were poor in association with crested wheatgrass (2%) and beardless wheatgrass (14%). These poor stands of canby bluegrass were the only indications of reduced seeding success attributable to a companion species. Fertilization failed to improve seedling establishment on these summer-fallowed plots, but it increased height of growth, grass yields, and weed yields.

Herbage yields

Yields of seeded grasses. All main effects and most first-order interactions introduced significant variation in adjusted grass yields. Most of the differences among means for years-of-seeding resulted from wide differences in the yields of big bluegrass, which, in turn, resulted from poor seeding success with this species in one year. Among the plots seeded in 1956, when seeding success was excellent for all species, those seeded to big bluegrass were most productive (Table 3). Over all years and harvests, crested wheatgrass was most productive.

Yields decreased with age, as indicated in the means by harvest years (Table 3), but interaction shows inconsistency among species. Crested wheatgrass and streambank wheatgrass became established quickly and were most productive in the first harvest year. Yields decreased with age in pure and mixed seedings that included either of these two wheatgrasses. The yields in the second and third harvest years are reasonably good estimates of yield capacities for these two species on this site (Hyder and Sneva, 1963). Beardless wheatgrass and big bluegrass became established rather slowly and their yields in pure stands increased with age (Schwendiman, 1958).

Table 2. SEEDING SUCCESS FOR INDIVIDUAL SPECIES AS EVALUATED BY FREQUENCIES IN 480, 6-BY 6-INCH QUADRATS

Year of seeding and companion species	Frequencies of indicated species[a]				
	Crested wheat-grass	Beardless wheat-grass	Big bluegrass	Stream-bank wheat-grass	Canby bluegrass
	%	%	%	%	%
1956					
Crested wheatgrass	54[b]	....	....	48	50
Beardless wheatgrass	....	32[b]	....	54	58
Big bluegrass	....	....	50[b]	62	58
Streambank wheatgrass	56	31	42	66[b]	....
Canby bluegrass	51	30	39	....	64[b]
1957					
Crested wheatgrass	58[b]	....	....	50	2
Beardless wheatgrass	....	56[b]	....	51	14
Big bluegrass	....	....	44[b]	55	27
Streambank wheatgrass	54	43	36	88[b]	....
Canby bluegrass	52	50	40	....	55[b]
1958					
Crested wheatgrass	53[b]	....	....	42	37
Beardless wheatgrass	....	38[b]	....	45	32
Big bluegrass	....	....	8[b]	46	28
Streambank wheatgrass	46	38	16	78[b]	....
Canby bluegrass	47	38	23	....	58[b]

[a] Frequencies of 30% or more indicate excellent stands. Confidence limits are about ±4%, but see Snedecor, 1956, Table 1.3.1.
[b] Frequencies in pure stands.

Over all conditions, yields of overstory grasses in pure stands exceeded (at a probability of 1%) those in mixed stands. Yields of mixed seedings usually were intermediate between those for the two companions in pure stands (Table 3). Relative yields will be considered in the next section.

Fertilization with 30 pounds per acre of nitrogen increased yields about 45%, but the effects were different among species (Tables 3 and 4). Crested and streambank wheatgrasses responded better and more consistently to fertilization than other species. This was due in part to consistently good stands, early establishment to maximum productivity, and the competitive elimination of weeds. Fertilization was effective on plots seeded in 1956 and 1957 but ineffective on those seeded in 1958. With poor stands, nitrogen fertilization promoted considerable weed production.

Table 3. Herbage Yields of Grasses Planted Alone and in Mixtures

Species planted	Means by years of seeding			Means by harvest years[a]			Means by N fertilization rates		Grand mean
	1956	1957	1958	H_1	H_2	H_3	N_0	N_{30}	
					Lbs./A. oven dry[b]				
Crested wheatgrass	1,819	1,436	1,837	2,161	1,506	1,425	1,383	2,012	1,697
Beardless wheatgrass	1,439	1,429	861	1,127	1,220	1,382	1,125	1,360	1,243
Big bluegrass	2,176	1,227	234	1,104	1,346	1,187	1,042	1,382	1,212
Streambank wheatgrass	1,069	1,091	796	1,298	949	709	690	1,281	986
Canby bluegrass	235	141	179	118	226	212	193	177	185
Crested w.-streambank w.	1,839	1,560	1,414	2,072	1,424	1,317	1,355	1,854	1,604
Beardless w.-streambank w.	1,448	918	1,038	1,317	1,076	1,011	943	1,326	1,135
Bib b.-streambank w.	1,323	836	987	1,360	944	842	860	1,237	1,049
Crested w.-Canby b.	1,352	1,552	1,778	2,002	1,472	1,209	1,285	1,836	1,561
Beardless w.-Canby b.	1,182	1,372	769	956	1,149	1,217	795	1,420	1,108
Big b.-Canby b.	1,622	732	514	765	1,031	1,072	832	1,079	956
Significant ranges[c]		(616)			(450)		(411)		(320)
Grand mean	1,409	1,118	946	1,298	1,122	1,053	955	1,360	1,158
Significant ranges[c]		(390)			(90)		(65)		

[a] The first harvest year was one year after planting.
[b] Yields are adjusted to a medium amount of precipitation (Sneva and Hyder, 1962).
[c] Significant ranges at 5% were computed by Tukey's method (Snedecor, 1956, p .251).

Table 4. PERCENTAGE INCREASES IN HERBAGE YIELDS OF SEEDED GRASSES WITH AMMONIUM NITRATE

Understory grasses	Overstory grasses			
	None	Crested wheatgrass	Beardless wheatgrass	Big bluegrass
	%	%	%	%
None	....	45	21	33
Streambank wheatgrass	86	37	41	44
Canby bluegrass	0	43	79	30

Table 5. RELATIVE YIELDS OF GRASSES SEEDED IN MIXTURES

Seeded species		Relative yields in mixed stands[a]		
Overstory species	Understory species	Overstory grass	Understory grass	Sum
		%	%	%
Crested wheatgrass	Canby bluegrass	90	10	100
Crested wheatgrass	Streambank wheatgrass	82	14	96
Beardless wheatgrass	Canby bluegrass	79	41	120
Beardless wheatgrass	Streambank wheatgrass	47	49	96
Big bluegrass	Canby bluegrass	74	34	108
Big bluegrass	Streambank wheatgrass	42	51	93
Mean		71	36	107

[a] Yields by species in mixed stands were expressed in percent of corresponding yields in pure stands. Three years of seeding, each with three replications, two nitrogen-fertilization rates, and three consecutive years of harvest are included.

Relative yields of grasses in mixtures. The yield of a grass seeded in a mixture expressed in percent of its yield in a pure stand is termed relative yield. If the environmental factors utilized by different species are common, the sum of relative yields in a mixture will be near 100. But sums less than 100 indicate some competitive antagonism, and sums greater than 100 indicate competitive compatibility.

Crested wheatgrass was highly competitive (Hyder and Sneva, 1963, 1963a), producing 90% with canby bluegrass and 82% with streambank wheatgrass (Table 5). Beardless wheatgrass and big bluegrass were about equally competitive, being suppressed considerably more by streambank wheatgrass than canby bluegrass. Streambank wheatgrass performed relatively better than canby bluegrass with each overstory species, and it was about equal in competitive status to beardless wheatgrass and big bluegrass. The sums of most relative yields are near 100, indicating direct competition without antagonism. But the sum of relative yields for the mixed seedings of beardless wheatgrass and canby bluegrass was 120, indicating a fair degree of compatibility. Unless species are reasonably compatible, a mixed stand can not be as productive as a pure stand of the most productive individual thereof.

Trends in relative yields by age of seeding provide further evaluations of competitive status in mixed seedings. Figure 3 gives relative yields of the overstory species in mixed seedings. Crested wheatgrass and beardless wheatgrass gained in relative yields as age increased; whereas, big bluegrass lost in relative yields, especially with streambank wheatgrass.

Figure 4 gives relative yield of the two understory grasses in various mixtures. Both were low in relative yield and decreased with age in association with crested wheatgrass. Canby bluegrass seemed to hold its own with beardless wheatgrass, even though this overstory species gained with age. Thus, the apparent compatibility of these two species improved with age. Streambank wheatgrass declined steadily in association with beardless wheatgrass. Both understory species gained in relative yield with age in association with big bluegrass, and this overstory grass decreased. Companion species apparently prevented big bluegrass from expressing a gain in productive capacity with age as found on plots with pure stands. Therefore, big bluegrass should be seeded alone in narrowly spaced rows (Hyder and Sneva, 1963).

Streambank wheatgrass produced relatively better in mixed seedings on unfertilized plots than on fertilized ones. Canby bluegrass produced relatively better on fertilized plots than on unfertilized ones in association with the wheatgrasses, but relatively poorer in association with big bluegrass (Figure 4).

Yields of weeds. All main effects except years of seeding and several interactions introduced significant variation in weed yields. The largest variation, and the one of primary importance, was among plots seeded to pure stands (Table 6). Crested wheatgrass practically eliminated all weeds in the first harvest year (second growing season). With good seeding success, all grasses except canby bluegrass provided effective weed control by the third harvest year.

All mixed seedings controlled herbaceous weeds (Table 6). Canby bluegrass included as an understory species improved weed control only where seeding success was poor with the overstory species. Streambank wheatgrass with beardless wheatgrass or big bluegrass improved weed control even where the stands of these two overstory species were good. This advantage of streambank wheatgrass was derived from its relatively fast establishment to strong competi-

Table 6. YIELDS OF WEEDS ASSOCIATED WITH SEEDED GRASSES

Species planted	Means by harvest years[a]			Means by N fertilization rates		Grand mean
	H_1	H_2	H_3	N_0	N_{30}	
	Lbs./A. oven dry[b]					
None	516	835	714	570	807	688
Canby bluegrass	454	425	243	253	495	374
Big bluegrass	258	445	143	214	350	282
Beardless wheatgrass	232	117	16	68	175	121
Streambank wheatgrass	75	58	19	23	78	51
Crested wheatgrass	2	10	0	4	4	4
Big bluegrass-Canby bluegrass	331	208	80	218	195	206
Beardless wheatgrass-Canby bluegrass	139	137	91	173	71	122
Crested wheatgrass-Canby bluegrass	2	6	8	3	7	5
Big bluegrass-Streambank wheatgrass	32	58	34	26	56	41
Beardless wheatgrass-Streambank wheatgrass	18	18	7	7	22	14
Crested wheatgrass-Streambank wheatgrass	8	24	4	7	18	12
Significant ranges[c]	(233)			(292)		(170)
Grand mean	172	195	113	131	190	160
Significant ranges[c]	(44)			(46)		

[a] The first harvest year was one year after seeding.
[b] Yields are adjusted to a median amount of precipitation (Sneva and Hyder, 1962).
[c] Significant ranges at 5% were computed by Tukey's method (Snedecor, 1956, p. 251).

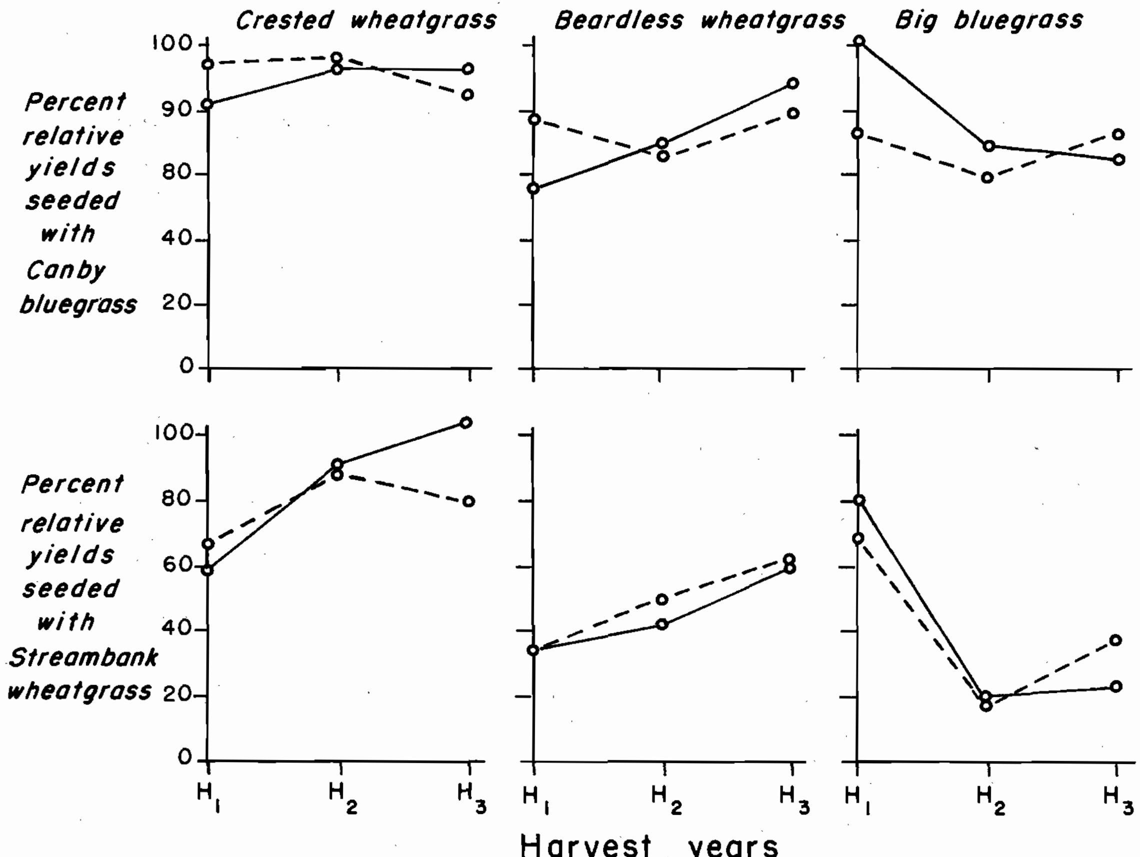

Figure 3. Yields of ~~under~~*over*story grasses in mixed stands expressed in percent of yields in pure stands (relative yields). Solid lines indicate unfertilized plots and broken lines indicate plots fertilized annually with 30 pounds of N per acre.

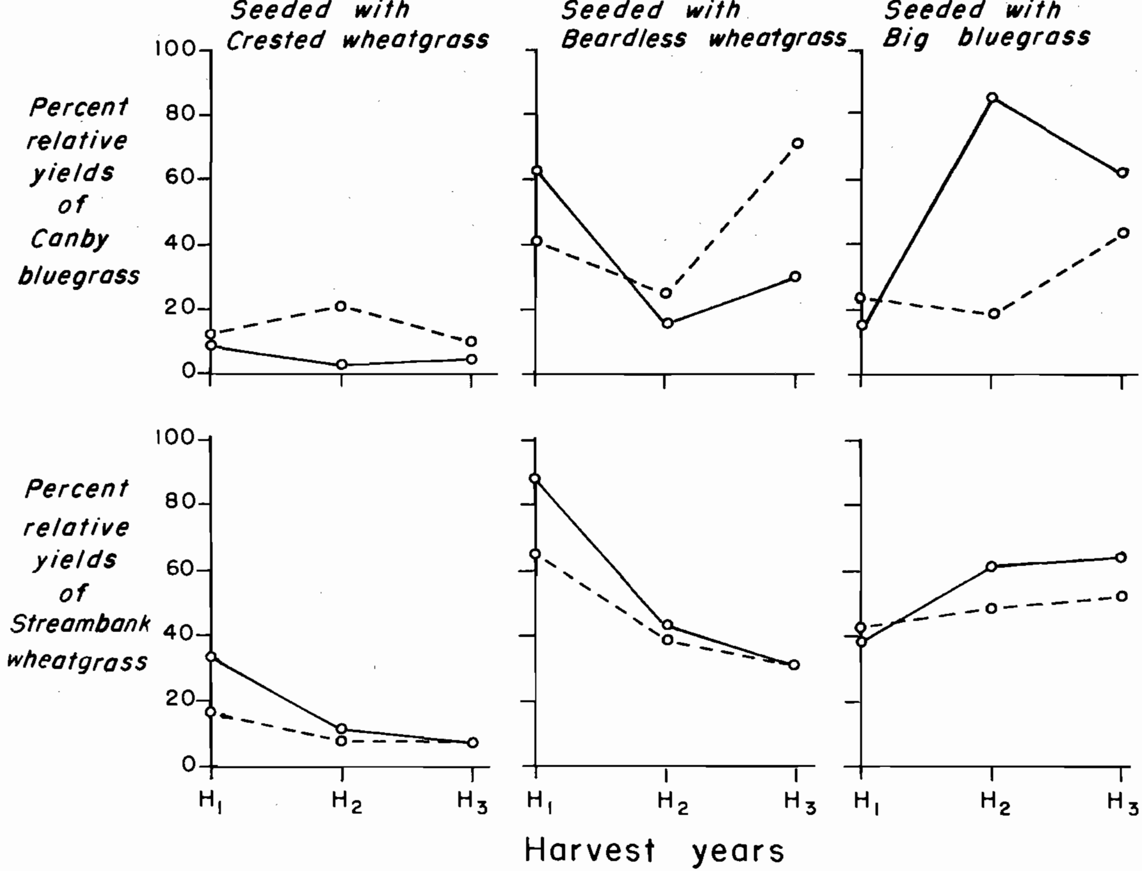

Figure 4. Yields of understory grasses in mixed stands expressed in percent of yields in pure stands (relative yields). Solid lines indicate unfertilized plots and broken lines indicate plots fertilized annually with 30 pounds of N per acre.

tive status, but is countered by the disadvantage of reduced herbage production and growth suppression of beardless wheatgrass and big bluegrass (Figure 3).

Nitrogen fertilization increased weed production 45% (Table 6). Weed response to nitrogen was quite uniform among treatments and decreased rapidly with age of the stands (Sneva, *et al.*, 1958).

Establishment of big sagebrush and green rabbitbrush

The species planted introduced highly significant differences in brush establishment on treated plots, and brush counts increased with time after seeding (Table 7). Crested and streambank wheatgrasses permitted the establishment of fewer brush than other grasses. Beardless wheatgrass was most ineffective in restricting brush establishment, and planting an understory grass with it helped considerably in reducing brush invasion. Mixed seedings generally were a little more resistant to brush establishment, and this effect of mixtures could have resulted from thicker stands of seeded grasses as well as from

Table 7. BRUSH ESTABLISHED IN THE FIRST FOUR YEARS AFTER SEEDING PLOTS TO VARIOUS GRASSES

Species planted	Counts in consecutive years C_1	C_2	C_3	C_4	Grand mean
	Number of plants per acre[a]				
None	992	1,162	1,355	2,372	1,470
Beardless wheatgrass	678	968	1,016	920	895
Big bluegrass	411	605	726	750	623
Canby bluegrass	169	363	387	774	424
Streambank wheatgrass	194	363	363	460	345
Crested wheatgrass	387	436	218	242	321
Beardless w.-Canby b.	218	460	484	508	417
Big b.-Canby b.	266	508	557	581	478
Crested w.-Canby b.	266	629	411	484	448
Beardless w.-Streambank w.	436	653	678	678	611
Big b.-Streambank w.	290	339	315	315	315
Crested w.-Streambank w.	73	194	145	145	139
Significant ranges[b]	(158)				(233)
Grand mean	366	558	556	687	540
Significant ranges[b]	(32)				

[a] Includes big sagebrush and green rabbitbrush.
[b] Significant ranges at 5% were computed by Tukey's method (Snedecor, 1956, p. 251).

complementary competition. Beardless wheatgrass and big bluegrass became established rather slowly, and the addition of an understory species provided some advantage in brush control. But crested wheatgrass became established quickly and restricted brush establishment as well as mixed seedings.

Brush became established in the first year after seeding in greater numbers than in any single year thereafter as was reported by Blaisdell (1949). But brush counts in the fourth year averaged about twice as much as in the first year (Table 7). Increases in brush were fairly consistent among seeded species except on plots seeded to crested wheatgrass where brush counts decreased after the second year. Otherwise, there was no appreciable mortality of established brush seedlings. The greatest contrast in brush establishment compares plots seeded to crested wheatgrass with those left unseeded (Figure 5).

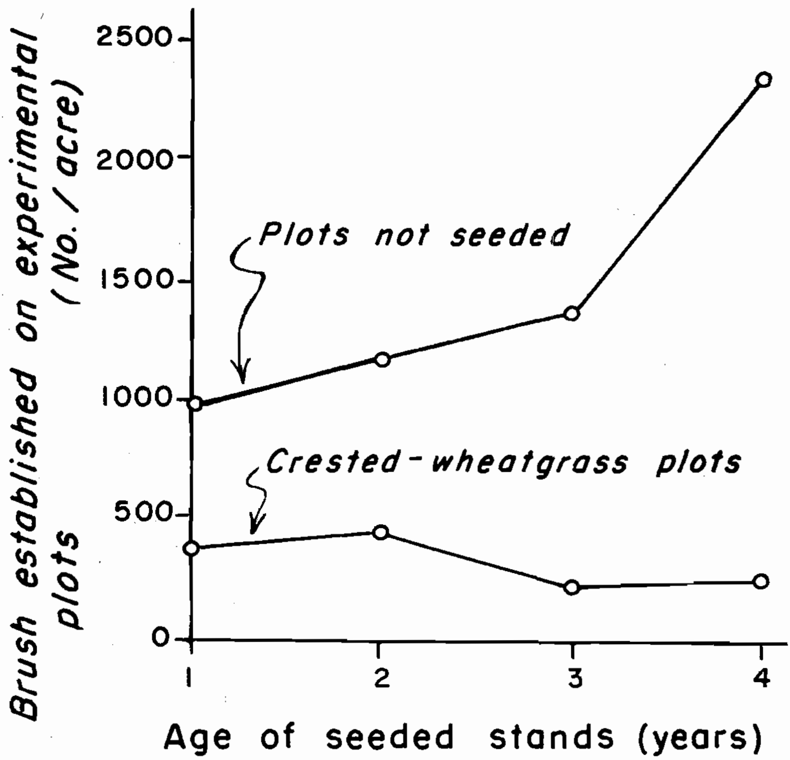

Figure 5. Brush invasion on plots not seeded and on plots seeded to crested wheatgrass (for the first four years after seeding).

Nitrogen fertilization did not produce a significant effect on brush establishment; but there were 23% fewer brush established on fertilized than on unfertilized plots. This small fertility effect is a reasonable trend derived from greater competition with increased herbage production.

Fort Rock

All stands of understory species at Fort Rock, Diamond, and Redmond were unsatisfactory. Accordingly, none of the understory species had a significant influence on brush establishment. Some significant differences did occur, however, in the establishment and yield of crested wheatgrass at Fort Rock. Stand differences indicating the value of nitrogen fertilization on a plowed seedbed are shown in Figures 6 and 7.

A small amount of nitrogen applied at the time of seeding on plowed, but not fallowed, seedbeds increased crested wheatgrass establishment and more than doubled its production a year later (Table 8). Fallowing through the summer prior to seeding might have given a response equal to fertilization. Fertilization did not increase establishment and yield on the burned seedbed, but burning is known to increase available N in the soil (Vlamis and Gowans, 1961). After five years only small differences in crested wheatgrass frequencies remained, as original stands were augmented by natural reseeding from the few vigorous plants established the first year.

A summary of brush establishment after five years on the 1957 seeding and four years on the 1958 seeding is presented in Table 9. These data show a relatively low brush population on the plowed

Table 8. Yield, Composition, and Frequency of Crested Wheatgrass Where Nitrogen Was Applied on Plowed and Burned Seedbeds at Fort Rock

Seedbed preparation[a]	Nitrogen fertilizer[a]	Herbage yield, 1958	Herbage composition by wt., 1958[b]	Frequencies in 12-inch quadrats, 1962
		Lbs./A.	%	%
Plowed	None	600 ± 140	47	72
	20 lbs./A.	1,500 ± 30	96	79
Burned and rotobeat	None	550 ± 50	94	78
	20 lbs./A.	625 ± 100	85	70

[a] Seedbed preparation, fertilization, and seeding were accomplished in April, 1957.
[b] The percentage of herbage produced by crested wheatgrass. The remaining herbage was produced by annual weeds and some native perennial grasses.

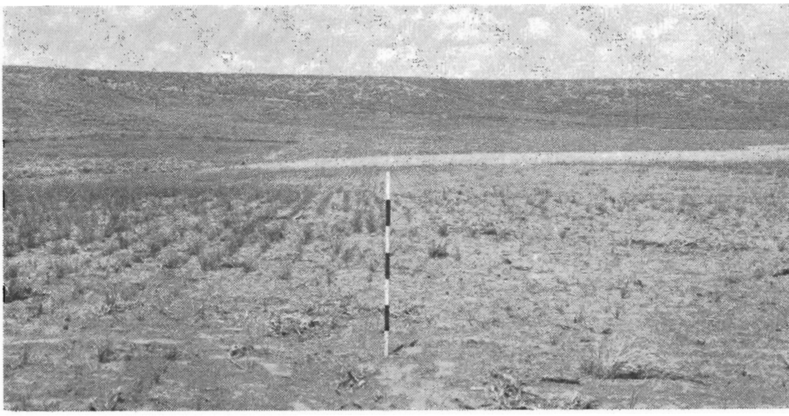

Figure 6. Photograph taken three months after drilling on a plowed seedbed at Fort Rock. Drilled rows of crested wheatgrass show clearly on the left where 20 pounds of nitrogen per acre was applied at the time of seeding.

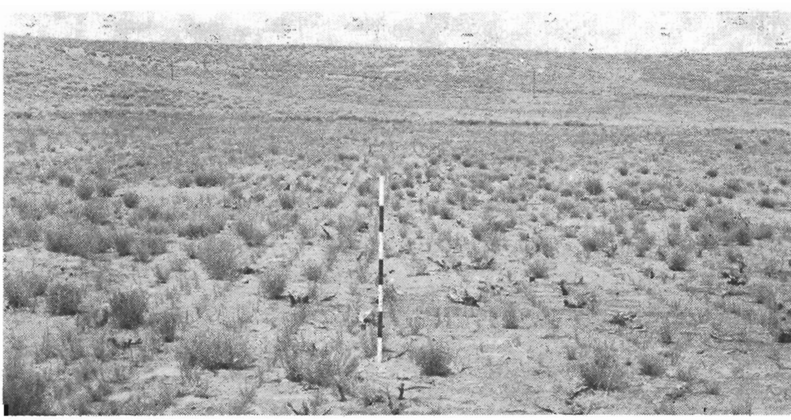

Figure 7. Photograph taken three months after drilling on a burned seedbed located near the plowed site shown in Figure 6. Nitrogen at 20 pounds per acre (to the left of the range pole) at the time of seeding crested wheatgrass had much less influence than on the plowed seedbed.

seedbed where all old brush was destroyed and a relatively high population on the burned seedbeds where many big sagebrush and green rabbitbrush survived.

A noticeable contradictory response is evident between green and gray rabbitbrush with row spacing (Table 9). The number of green rabbitbrush increased and that of gray rabbitbrush decreased with a

Table 9. SUMMARY OF BRUSH SEEDLINGS ON FORT ROCK SEEDINGS IN 1962 AS INFLUENCED BY SEEDBED PREPARATION AND NITROGEN FERTILIZERS

Year of seeding	Seedbed preparation	Row spacing	Nitrogen fertilizer	Brush species: Big sagebrush	Brush species: Gray rabbitbrush	Brush species: Green rabbitbrush	Total brush
		Inches	*Lbs. N/A.*	*Number of plants per acre*			
1957	Plowed	12	None	1	142	25	168
Counts made 5	Plowed	12	20	12	247	83	342
years after	Burned	12	None	1,075	150	2,425	3,650
seeding	Burned	12	20	2,525	75	2,125	4,725
1958	Burned	24	None	650	2,700	1,950	5,300
Counts made 4	Burned	16	None	200	1,000	3,750	4,950
years after	Burned	8	None	800	350	4,550	5,700
seeding	Burned	24	20	400	3,350	2,200	5,950
	Burned	16	20	100	1,150	2,450	3,700
	Burned	8	20	450	450	5,400	6,300

decrease in row spacing. Shallow cultivation by drill discs improved the chances for green rabbitbrush establishment as row spacing decreased; whereas, narrowly spaced rows reduced the chances for gray rabbitbrush establishment. This suggests that green rabbitbrush may become established more quickly than gray rabbitbrush.

Diamond

A summary of all brush plants enumerated at the Diamond location in 1962 is presented in Figure 8. These data show that more brush became established on fall-seeded plots than on spring-seeded ones. Since brush-seed pressure was greatest on the spring seeding, surrounded on three sides by unplowed sagebrush versus only two on the fall planting, time of seeding becomes more interesting. Spring-seeded plots were disced just before seeding; and this spring cultivation should have hindered brush establishment in the first year.

Herbage yields taken in 1961 after fertilizing in 1958, 1959, and 1960, are reported in Table 10. These data reflect a marked improvement in yield and percent composition of crested wheatgrass on ferti-

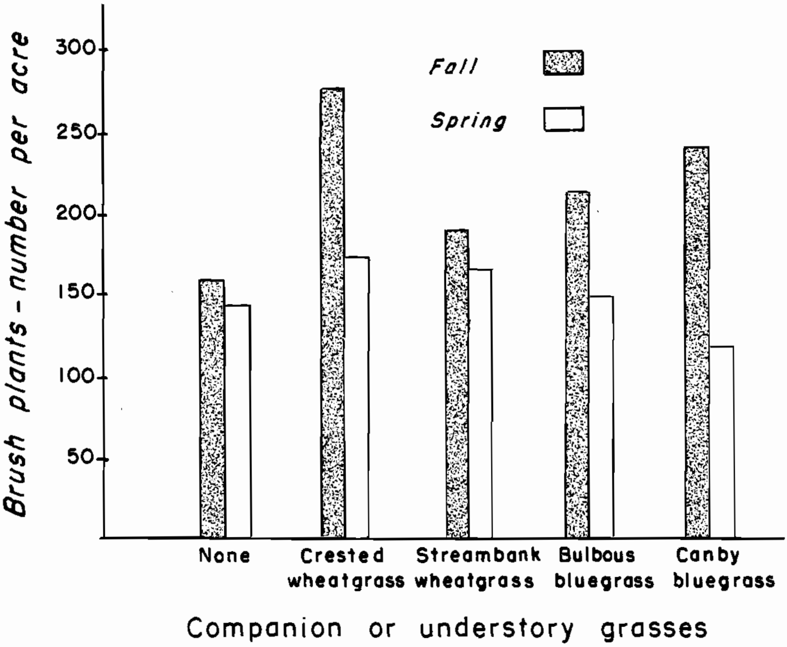

Figure 8. Influence of time of seeding crested wheatgrass with various companion species on the number of brush seedlings established in six years after seeding at Diamond.

lized spring seedings. Effects of fertilizing on the fall seeding are contradictory because the nitrogen response was large from the 5 pounds per acre seeding rate of crested wheatgrass and not significant on the plots seeded at the 10 pounds per acre rate. Over all the plots, the 30 pounds N per acre applied in 1958, 1959, and 1960 increased crested wheatgrass yields in 1961 by 2.4 fold. There may have been some residual fertilizer N remaining in 1961 (Sneva, Hyder, and Cooper, 1958), but the main effect of this fertilization was the thickening of stands that increased productivity about 500 pounds per acre.

Redmond

At the Redmond location, the brush-seed source was located in a narrow belt along the boundary fence and adjacent road right-of-way just south of the seedings. Since this physical layout provided an excellent opportunity to study brush establishment as a function of distance from seed source, the seeded plots were divided into 50, 4- by 50-foot belts and all brush plants therein were counted. Understory species did not significantly influence the establishment of brush (Table 11).

Counts of the three brush species from the contiguous belts are presented as a function of distance from seed source (Figure 9). Big sagebrush numbers drop off rapidly when the distance exceeds 25 feet. This same pattern is repeated in most crested wheatgrass seedings in the sagebrush-grass vegetation of central Oregon. Only occasional sagebrush plants were found farther than 50 feet from the seed source; whereas, significant numbers of rabbitbrush, particularly gray, were counted as far as 100 feet from the edge of the seeding.

Table 10. HERBAGE YIELDS AND COMPOSITION BY WEIGHT OF CRESTED WHEATGRASS IN 1961 AS INFLUENCED BY NITROGEN AND TIME AND RATE OF SEEDING AT DIAMOND

Time of seeding	Rate of seeding	Nitrogen fertilizer: None — Yield	Nitrogen fertilizer: None — Composition	Nitrogen fertilizer: 30 lbs. N/A. — Yield	Nitrogen fertilizer: 30 lbs. N/A. — Composition
	Lbs./A.	*Lbs./A.*	%	*Lbs./A.*	%
Spring, 1956	5	335	37	740	42
	10	275	32	1,270	86
	Mean	305	35	1,005	64
Fall, 1955	5	190	11	740	42
	10	715	68	875	57
	Mean	453	40	808	50

Table 11. NUMBERS OF BRUSH ESTABLISHED IN CRESTED WHEATGRASS SEEDED WITH VARIOUS COMPANION SPECIES AT REDMOND

Companion species	Brush densities five years after seeding: Big sagebrush	Rabbitbrush: Green	Rabbitbrush: Gray	Total
	Number of plants per acre			
None	161	653	314	1,128
Bulbous bluegrass	131	357	340	828
Canby bluegrass	113	348	410	871
Streambank wheatgrass	166	353	688	1,207
Alfalfa	100	409	536	1,045
Mean	134	424	458	1,016

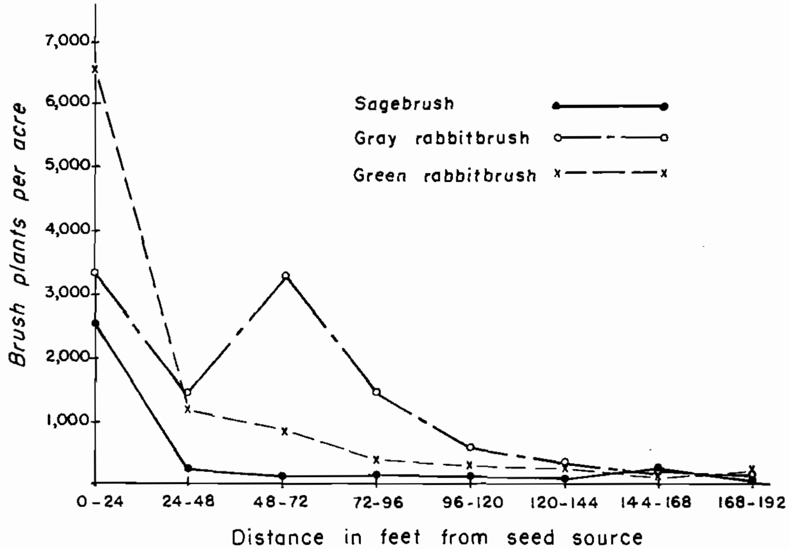

Figure 9. Number of big sagebrush, green rabbitbrush, and gray rabbitbrush as a function of distance from seed source.

CONCLUSIONS

• Herbage yields of mixed stands were intermediate between those of pure stands of the same species, depending on the relative performance and competitiveness of individual species in the mixed seedings. Planting an understory grass with an overstory one reduced total herbage production as compared with a pure stand of the overstory. This result should hold in other cases unless the mixture utilizes the environment considerably more thoroughly than either individual alone.

• Beardless wheatgrass and big bluegrass, after becoming established, are relatively slow in reaching maximum productivity, and were suppressed more than crested wheatgrass by companion understory species.

• Beardless wheatgrass recovered from competition with canby bluegrass, and these mixed stands expressed compatibility that improved with age. This species combination was the only mixed seeding studied that can be recommended as expressing sufficient advantage in weed and brush control to balance the disadvantage of a little less herbage production than resulted from pure stands of beardless wheatgrass.

• Big bluegrass was very sensitive to competition from understory species and failed to recover from it with age. Consequently, this species should be planted in pure stands with rows not wider than 12 inches. In thick, pure stands, big bluegrass was more productive than other species studied.

• Crested wheatgrass became established quickly in pure and mixed seedings, provided uniformly high yields, and was very effective in restricting the growth of understory grasses, weeds, and brush (Frischknecht and Bleak, 1957; Heinrichs and Bolton, 1950). Understory grasses planted with crested wheatgrass provided only small advantages in weed and brush control and a small disadvantage in reduced herbage production. Therefore, including an understory grass would introduce a small economic loss, unless soil stability advantages justified the added expense. The present study supports a recommendation for seeding crested wheatgrass in pure stands in the sagebrush-grass zone.

• Ammonium nitrate surface broadcast before seeding seldom improves seeding success, and especially not on summer-fallowed or burned seedbeds. Rather, seeding success depends on competition removal, seed quality, time of seeding, depth and uniformity of seed placement, seedbed firmness, and precipitation. Nitrogen fertilization increases height of growth and tillering during establishment, but contributes more to the growth of annual weeds than to the seeded perennial grasses. After grass establishment, nitrogen at 30 pounds per acre increases herbage production about 45%, and may increase crested wheatgrass density where stands are thin.

• Big sagebrush and green rabbitbrush became established in greater numbers in the first season after planting grasses than in subsequent years (Blaisdell, 1949). Drill-row spacing, seeding success, and the time required for grasses to reach maximum productivity introduced different rates of brush establishment on the plots. Established brush seedlings were not lost in subsequent years, except for a few that failed to withstand crested wheatgrass competition. All grass seedings restricted brush establishment, as determined by the comparison of seeded and unseeded plots. Crested wheatgrass was most effective and beardless wheatgrass least effective in restricting brush establishment. However, appropriate and effective seedbed preparation practices are of more concern in weed and brush control than the choice of seeded species or species mixtures. Good planting practices that obtain good stands of seeded grasses and the selection of a row spacing appropriate for the environment and species considered, provide additional assurance of weed and brush control in the first two or three years. Subsequently, season and intensity of grazing, precipitation amount and its seasonal distribution, and the availability of brush seed will determine the rate of brush invasion. Big sagebrush has become established in thick stands of grass in years with high May and June precipitation even where protected from grazing. Consequently, even the best of seeding and grazing practices leaves a need for chemical brush control on sagebrush-bunchgrass range.

• Distance from a seed source largely determines the rate of invasion of big sagebrush, green rabbitbrush, and gray rabbitbrush. Big sagebrush was most restricted and green rabbitbrush least restricted in seed distribution and plant establishment out into new grass seedings.

• General patterns of response were similar at all study-area locations, but gray rabbitbrush was limited to sites with coarser-textured soils. Where gray rabbitbrush is a problem, closer row spacings of crested wheatgrass may be needed to minimize brush establishment.

• Choice of species for seeding and the selection of pure or overstory-understory mixtures should be based more on forage production and soil conservation needs than on brush control.

SUMMARY

Crested wheatgrass, beardless wheatgrass, and big bluegrass were seeded as overstory grasses. Streambank wheatgrass, canby bluegrass, bulbous bluegrass, and Ladak alfalfa were seeded as companion species. Pure and mixed stands were seeded on sagebrush-bunchgrass range in eastern Oregon to compare yield and competitiveness. The grasses were planted in 1956, 1957, and 1958, and half of each plot was fertilized with ammonium nitrate at 20 or 30 pounds of N per acre. The plots were evaluated for seeding success, herbage production, weed production, and brush establishment in four consecutive years after planting.

Yields of overstory grasses in pure stands exceeded those in mixed stands. Nitrogen fertilization increased yields about 45% but did not increase seeding success on fallowed or burned seedbeds or alter greatly either competitive status or plant composition.

Relative yields of individuals in mixed stands (yields expressed in percent of that in a pure stand) were computed to indicate competitive status and compatibility. Crested wheatgrass was highly competitive, producing 90% with canby bluegrass and 82% with streambank wheatgrass. Beardless wheatgrass and big bluegrass were about equally, but weakly to moderately, competitive, and were suppressed considerably more by streambank wheatgrass than by canby bluegrass. The sums of relative yields in mixed stands were near 100, in-

dicating essentially direct competition, except for the mixture of beardless wheatgrass and canby bluegrass. In this case, the sum of relative yields averaged 120%, indicating reasonable compatibility that improved with age of the stands.

Crested wheatgrass in either pure or mixed stands practically eliminated all herbaceous weeds in the second growing season. All grasses except bulbous and canby bluegrass provided effective weed control by the fourth growing season. Crested and streambank wheatgrasses, and mixtures including them, permitted the establishment of fewer brush than other species. Beardless wheatgrass was least effective in restricting brush establishment. Brush became established in the seeding years in greater numbers than in any single year thereafter, but the counts in the fourth year were about twice that in the first year. Except on plots seeded to crested wheatgrass, there was no appreciable mortality of established brush seedlings. All seedings restricted brush establishment when compared to unseeded plots.

Big bluegrass was continually and severely suppressed by companion understory grasses and should be planted in pure stands. Understory grasses with crested wheatgrass offered little advantage or disadvantage, and would likely incur a small economic loss. Beardless wheatgrass and canby bluegrass were reasonably compatible and provided a mixed stand that could be recommended as preferable to beardless wheatgrass in a pure stand. In areas of coarse-textured soils where gray rabbitbrush is a problem, a closer row spacing of crested wheatgrass would likely provide maximum resistance to brush establishment.

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