SOME CHARACTERISTICS CONTRIBUTING

TO THE

ESTABLISHMENT OF RABBITBRUSH,

CHRYSOTHAMNUS spp.

by

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SOME CHARACTERISTICS CONTRIBUTING TO THE ESTABLISHMENT OF RABBITBRUSH (CHRYSOTHAMNUS spp.)

INTRODUCTION

In the past century shrub density in many areas of the Western Range has increased as a result of grazing pressure and other disturbances. The problem of an increase in gray rabbitbrush (*Chrysothamnus nauseosus* (Pall.) Brit.) and green rabbitbrush (*Chrysothamnus viscidiflorus* (Hook.) Nutt.) is of particular interest to rangeland managers, ranch owners, and individuals trained in range management. This increase in rabbitbrush is of extreme significance in light of the valuable space occupied which could be producing a stand of nutritious forage grasses. In addition, livestock in the eastern Oregon area have a very low preference for rabbitbrush.

Many problems need to be solved to answer the question of why rabbitbrush has increased. Propitious climatic patterns might explain the establishment of more seedlings in favorable years, but these same favorable conditions might also produce more competing vegetation if other conditions were optimum. As a rule, widespread increase in shrubby vegetation does not occur on ranges in good condition. Ranges in healthy condition might be described as closed communities (41). Through the activities of man the community is opened as the vegetation composition changes. Overstocking the more productive grazing areas has provided the main cause of rabbitbrush increase and spread.

Another means by which the range plant community has been opened occurred in the early settlement of marginal agricultural lands of Oregon east of the Cascade Mountains. Early settlers cleared grazing lands for agricultural use and later abandoned these homesteads when crops failed to materialize. W. A. Rockie (42) described how many of the lands in Lake County and Central Oregon were mis-represented by land advertisements as being the "Palouse region of Oregon" and were "wonderful farm lands". Homesteads failed to produce crops and the land became revegetated with aggressive plant species, particularly _C. nauseosus_ and _C. viscidiflorus_.

In some areas marginal agricultural lands have been seeded with Crested Wheatgrass (_Agropyron desertorum_ (Fish.) Schult.). The Land Utilization Project near Madras, Oregon[1] is a good example. Invasion of rabbitbrush into these stands of grass poses another problem concerning grass and shrub relationships. These areas are valuable pastures, but their value decreases with the establishment of rabbitbrush seedlings in them. How to manage these pastures to avoid rabbitbrush is an important problem to be solved.

More information concerning rabbitbrush is also necessary for an understanding of some of the relationships among range plants when these relationships become modified by brush control

1. Unless otherwise noted, all references to location are limited to the State of Oregon.

and reseeding. As an example, Oregon Agricultural Progress (38) reports that clearing sagebrush in areas that lack sufficient understory vegetation to compete successfully with rabbitbrush risks a marked increase in the latter species. How much understory vegetation is required on various soil types needs to be known before recommendations can be made concerning which areas will give the most satisfactory results following brush control.

Background information relating to the management of sagebrush-grass and bunchgrass ranges in climax or near climax condition to prevent an increase in rabbitbrush plants is needed.

Since rabbitbrush and sagebrush (*Artemisia tridentata* Nutt.) are in close competition on many Oregon rangelands, comparative information for various characteristics of sagebrush and rabbitbrush is needed. Such information would contribute to a better understanding of some of the rangeland management problems.

The avenues of approach are possible in solving some of the problems in managing rabbitbrush infested rangelands. The first approach is a study of the rabbitbrush community to work out the dynamic relationships between the plants in the community, particularly between shrubs and grasses. This approach is referred to as a synecological study and is used to solve many of the problems in vegetation management. However, Dr. Ernst Mayr (4) suggests that ecologists would be better able to understand the plant community if they better understood the individual species that make up the community. Therefore, the second approach is an autecological study which considers characteristics of the individual species, including such studies as phenology, seed germination, seed production, seedling growth, and seedling response to environmental conditions. These studies can be carried out in the laboratory and greenhouse as well as in the field. In the final analysis, both synecological and autecological studies need to be integrated for maximum understanding of the ecology of rabbitbrush.

As a partial solution to the problem of rabbitbrush management and control, this thesis presents an autecological study of some important characteristics of both _C. nauseosus_ and _C. viscidiflorus_ which are contributing factors in establishment. Autecological relationships between _A. tridentata_ and rabbitbrush are clarified by the inclusion of _A. tridentata_ in various experiments.

TAXONOMY AND DISTRIBUTION

The name Chrysothamnus comes from the Greek words crysos, meaning gold, and thamnos, meaning shrub, and refers to the golden yellow flowers produced by the plants in the late summer and early fall. The common name rabbitbrush is given to the shrub because of the shelter and browse that it furnishes to rabbits.

Chrysothamnus belongs to the Astereae tribe of the Composite family and is closely related to the genus Haplopappus. Chrysothamnus is differentiated from Haplopappus by its more cylindric involucre and by the tendency of the involucral bracts to be keeled and to be arranged in five vertical ranks. According to Jesperson (31) the genus Chrysothamnus Nuttall may be described as follows: Shrubs or subshrubs with erect or ascending stems, herbage with or without hairs, often resinous and aromatic. Leaves simple, alternate, entire. Flower heads in flattened dense or loose pyramidal clusters, spikes, panicles, or racemes, rarely solitary. Involucres cylindrical, bracts mostly keeled, overlapping and in more or less vertical rows, papery or leathery with tips sometimes greenish. Ray flowers none. Disk flowers 4-20 in a head. Flowers tubular-funnelform, 5-toothed. Achenes slender, rounded or slightly angled with or without hairs. Pappus of copious soft dull white to reddish bristles.

C. viscidiflorus grows as a low shrub and seldom exceeds 24 inches in height and averages about 12 to 18 inches. Most plants are much branched at the base which results in a round-topped, bushy plant. Lower stems are covered with brown, fibrous bark and upper stems may be minutely puberulent or glabrous. Leaves are linear, 1 to 2 mm. wide, average one to six cm. in length, and may be straight or twisted. Herbage on all varieties is viscidulous in varying degrees.

C. nauseosus also grows as a low shrub, but is, as a rule, somewhat larger than green rabbitbrush. Average height is from 12 to 30 inches depending upon age and environmental conditions. Plants are branched freely at the base and above to produce a very rounded shrub. Lower branches have a brown, fibrous bark, while the upper branches have a light green bark covered with varying amounts of felt-like tomentum. Leaves may also have a covering of tomentum and vary from linear to broadly linear. Twisting of leaves is usually not evident. Outer branches appear to have fewer leaves than do the branches of C. viscidiflorus.

Thomas Nuttal, an English botanist who collected in the Northwest in 1834-35, first established Chrysothamnus as a separate genus in 1840 (37). Considerable interest developed in the genus as a source of natural rubber prior to 1920 and during World War II which stimulated much of the investigation of the group from a taxonomic, anatomical and physiological point of view (23, 24, 25, 17).

Taxonomists have recognized the variability of the natural populations of rabbitbrush and have named many species and varieties. Hall (24) mentioned that no less than 113 species or varieties had been named at the time of his revision of the group in 1919. Hall and Clements (23) attempted to arrange the species, sub-species, and varieties of *Chrysothamnus* in a phylogenetic order on the basis of morphological characters in their revision of the complex in 1923. At that time they recognized twelve species with 22 sub-species of *C. nauseosus* and nine sub-species of *C. viscidiflorus*. This extensive work forms the basis of most of the subsequent keys to local species. Of particular interest in the southern part of the state of Oregon is the recent illustrated key by B. S. Jesperson, "The Genus Chrysothamnus in California and Western Nevada". This key uses various combinations of illustrated characters to identify the seven species in the area considered.

In Oregon east of the Cascade Mountains, Peck (39) based his treatment of *Chrysothamnus* on the work of Hall and Clements. He recognizes only two species for central and eastern Oregon, *C. nauseosus* and *C. viscidiflorus* with four varieties for each species. These varieties are differentiated primarily on the basis of size, shape of infloresccense, degree of pubescence, length of corollas, width and length of leaves, and bract characteristics.

A survey of plants in the field reveals a large amount of morphological variation in the populations of rabbitbrush. Even with the publication of the recent key to the Compositae by Cronquist (27) further work of an experimental nature is needed involving cytological and ecological studies to augment existing morphological information.

C. viscidiflorus and *C. nauseosus* occur in most of the semi-arid sections of Oregon east of the Cascade Mountains, predominantly on sandy pumice and coarse-textured soils at medium elevations. Gray rabbitbrush also occurs in the southwestern part of the state in the drier areas of the Siskiyou foothills and the Rogue-Umpqua valleys. Typically, rabbitbrush colonies may be seen in sagebrush (*Artemisia*) communities on slight mounds or accumulations of wind blown pumice materials and on the more sterile soils. In many areas where the rangeland has deteriorated or where repeated burning has occurred, rabbitbrush may dominate the entire area.

Figure 1 indicates the locations where specimens, now on deposit in the herbarium at Oregon State College, were collected. Even though collections are not by any means complete, this map suggests that both species have a similar range. However, field observations indicate that there is a separation of each species into particular habitats within this range.

In the Columbia Basin on upland slopes of the *Agropyron-Poa* Zone in the vicinity of Shaniko, Grass Valley, Pine City, and Pilot Rock *C. nauseosus* plants grow among the clumps of bunchgrass. On the north facing slopes and in the moist draws and

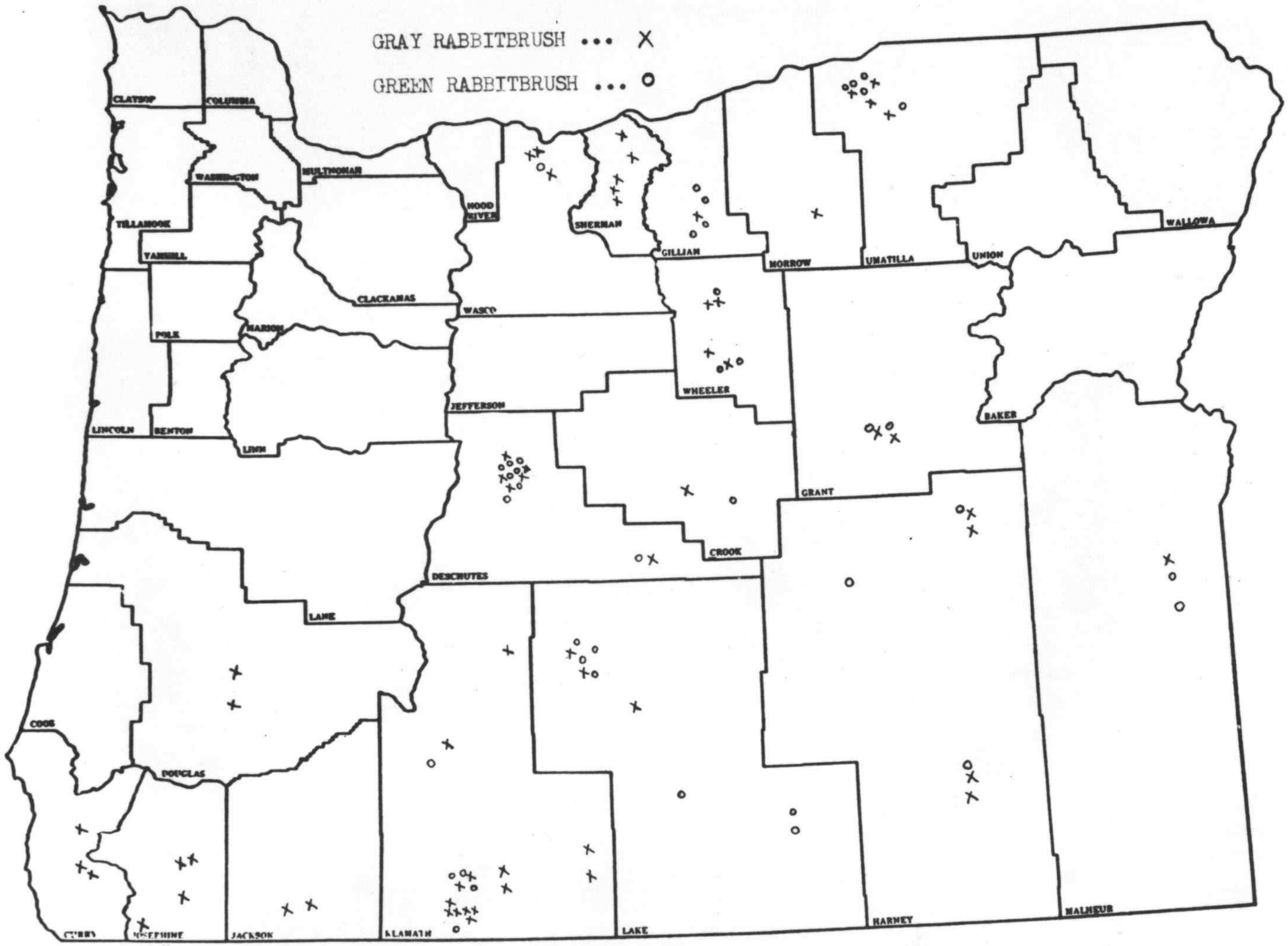

Figure 1. Collection locations of herbarium specimens of C. nauseosus and C. viscidiflorus.

valley bottoms, C. viscidiflorus predominates. At higher elevations in the foothills of the Blue Mountains C. viscidiflorus again appears in greater abundance. A semi-arid area along the Columbia river in the vicinity of Hermiston is dominated by shrubby vegetation including C. nauseosus and C. viscidiflorus. This area has experienced extreme disturbance in past years which may have caused the development of the present vegetation type.

South of the Blue and Ochoco Mountains, in what Peck (39) refers to as the Sagebrush and Lake sections, C. viscidiflorus appears to predominate in many of the dry valley bottoms in the high desert. Even so, C. nauseosus is abundant here, especially in the fringe of the Ponderosa Pine belt that extends north and south along the eastern slopes of the Cascade Mountains and out into the dry desert areas.

A typical distribution pattern may be seen in the area around Millican where the valley floor supports an extensive stand of A. tridentata and C. viscidiflorus. C. viscidiflorus appears to be associated more into colonies on sandy rises and areas of wind blown pumice particles. Around the margin of the valley floor the vegetation is dominated by C. nauseosus. Farther up the slopes of the foothills appear isolated juniper (Juniperus occidentalis Nutt.) trees which outline the margin of a Juniperus occidentalis community in which C. nauseosus and A. tridentata appear as co-dominants in the understory.

FIELD OBSERVATIONS

Both _C. viscidiflorus_ and _C. nauseosus_ are relatively short-lived shrubs. Ellison (18) reported _C. viscidiflorus_ var. _stenophyllus_ on the Wasatch Plateau in Utah reaches an age of 60 years. This age was verified by ring counts and by historical records. Chilcote (10) reported the oldest _C. nauseosus_ shrubs investigated in Oregon to be approximately 40 years. The oldest _C. viscidiflorus_ plants reported were 23 years. Older _C. viscidiflorus_ plants may be present, but ring counts were unreliable due to destruction of the xylum by a stem borer, _Crossidius hertipes_ Lec. which occurred in 95% of _C. viscidiflorus_ stems observed as compared to only 5% of the _C. nauseosus_ stems.

C. nauseosus along roadsides, fence rows and in abandoned agricultural fields exhibits a marked increase in growth due to lack of competition. Under these conditions the average size is 30 to 38 inches in height and 36 to 48 inches in diameter. _C. nauseosus_ plants with a crown spread of six feet and a height of four feet have been observed on abandoned farmlands at Fort Rock, Oregon.

C. viscidiflorus plants also appear larger in height, in crown spread, and in a more vigorous condition in situations where competing vegetation is lacking or low in number. In such locations plants often exceed 36 inches in height and 40 inches in crown diameter.

Resprouting at the crown and from roots (49) appears to be an important characteristic which enables rabbitbrush to persist on good range sites. For this reason many of the currently available brush control measures are ineffective when used on rabbitbrush. As compared with sagebrush, rabbitbrush may resprout after burning, roto-beating, or railing. Figure 2 illustrates C. viscidiflorus plants that have resprouted following a brush control operation by roto-beating. Profuse resprouting after burning has enabled rabbitbrush to assume dominance in many areas. A recent example is at Dry Canyon between Redmond and Sisters where sagebrush in the plant community was destroyed by a fire in 1947. This open habitat was then almost completely revegetated by C. nauseosus and C. viscidiflorus plants that survived and reseeded the area.

Phenology

Phenological data from a study of rabbitbrush during the summer of 1954 and 1955 indicate about a week or more difference in development between C. viscidiflorus and C. nauseosus. However, considerable variation in time of flower maturation has been observed between three separate areas of Oregon. Plants were in full flower and disseminated mature seeds almost a month earlier at Fort Rock than plants observed in the area between Shaniko and Grass Valley. Plants observed in the third area between Millican and Brothers were approximately intermediate with respect to the two previous areas mentioned.

Developmental stages are shown in Figure 3 for the Millican area during 1954 and 1955. Variations may be seen in initiation

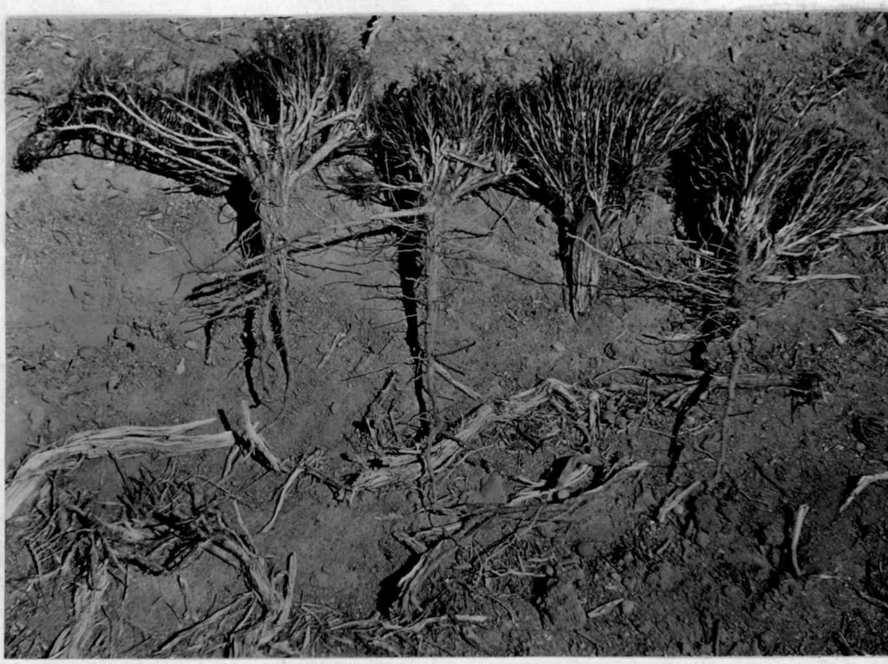

Figure 2. C. viscidiflorus plants one year following brush removal by roto-beating.

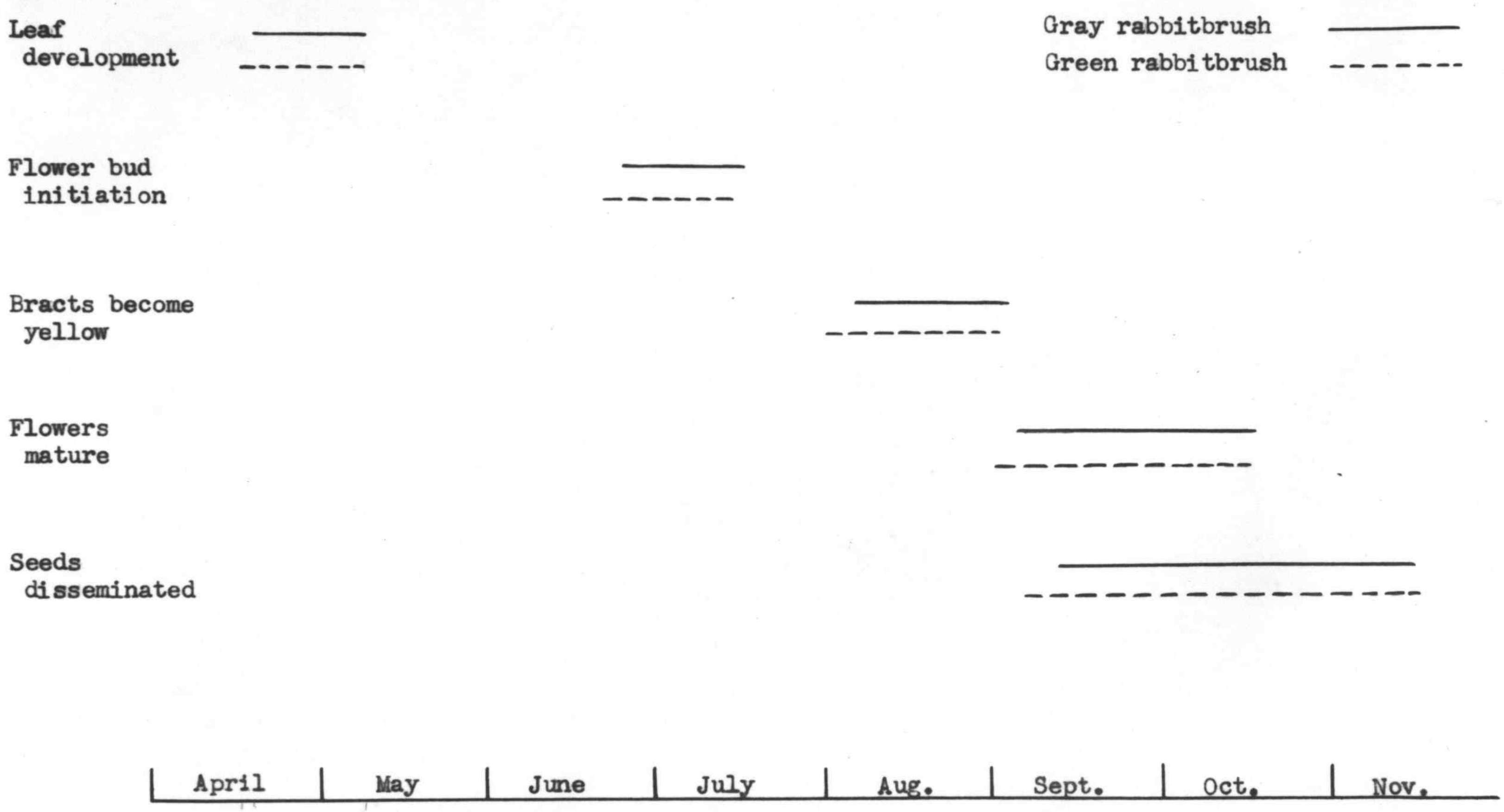

Figure 3. Phenology of *C. nauseosus* and *C. viscidiflorus*. Millican, Oregon 1954-55.

of leaf growth with different ecological conditions. As an example, on April 23, 1955, both species of rabbitbrush in the Millican area were just starting leaf growth with leaves about 2 to 3 mm. long as compared with plants in full leaf in the Dry Canyon area between Redmond and Sisters.

Flower bud initiation occurs approximately at the same time that Squirrel Tail grass (Sitanion hystrix (Nutt.) J. G. Smith) has matured seed. Flower development is extremely variable and depends upon environmental conditions, particularly on the amount of competition present. Plants along roadsides or cow trails generally initiate flower buds and produce mature flowers earlier than plants under close competition. Flower maturation is preceded by the appearance of yellow involucral bracts which can easily be mistaken at a distance for yellow flowers.

All flowers do not mature at the same time on any given plant. Typically, flowers in the center of the head mature first. In addition, flowers on the top of the plant mature before lower branches.

Seed dissemination starts before all of the flowers on a plant are fully mature. Duration of the period of seed dissemination may be quite extended due to retention of seeds in the heads and lack of favorable weather conditions such as winds and dry periods during late September, October and November.

A comparison of the flowering period of rabbitbrush with other shrubs reveals a very interesting sequence of flowering.

Gray horsebrush (Tetradymia canescens DC.) flowers about 4 weeks earlier than does C. viscidiflorus. C. viscidiflorus is a week or more earlier than C. nauseosus which is approximately two weeks earlier than A. tridentata.

FLOWER AND SEED PRODUCTION

Introduction

The production of a large number of seeds is important in the establishment of rabbitbrush in many areas of rangeland. Salisbury (43) mentions that "High reproductive capacity is not merely a life insurance, a purely defensive measure, but a positive asset that surpasses the needs imposed by mortality and provides for the occupancy of fresh territory". Certainly this would be true of rabbitbrush.

Field observations indicate that the amount of seeds produced is not the same for all rabbitbrush plants of equal size in all areas. Some of the factors important in controlling seed production appear to be the degree of competition furnished by grasses, sagebrush, other rabbitbrush plants, weather conditions previous to flowering and age of rabbitbrush plants.

Estimating seed production is a difficult problem because rabbitbrush plants do not mature all the seeds on the plant at the same time. As a result, seeds are being disseminated from the top of the plant by the time they are mature on the side branches. For this reason flower production was determined and used as a measure of seed production.

Flower Production Under Varying Degrees of Competition

Flower counting studies were carried on during the late summer of 1954 and 1955. Optimum time for flower counting in 1954 was August 25 to September 4 as compared to the period of August 29 to September 7 in 1955.

The flower production survey was conducted in two general areas. One area was located in the Great Basin Province between Horse Ridge and Hampton along U. S. Highway 20 in valley bottomlands. This area is dominated by C. viscidiflorus and A. tridentata. The other area was on undulating uplands in the Columbia Basin Province and individual plots were located near Shaniko, Grass Valley, six miles south of Pine City and Pilot Rock on gentle north-east slopes having a soil depth of at least one and one-half feet. Poulton (40) considers part of this second area to be in the Agropyron-Poa Zone which is characterized by the climax dominance of blue bunch wheatgrass (Agropyron spicatum (Pursh) Scribn. & Smith) and Sandberg's bluegrass (Poa secunda Presl.). The areas described were located by Dr. William W. Chilcote, Associate Professor of Botany, Oregon State College, as study areas in his analysis of the relationship of range condition and the abundance of rabbitbrush.

Methods. Plots 100' x 100' were established in each area on locations of varying degrees of range deterioration. Therefore, differences in flower production between various plots may be attributed partly to conditions of competition on specific plots. On each 100' x 100' plot five transects were located by means of a table of random numbers. At five-foot intervals along each transect a three-foot square frame subdivided into one-foot squares was placed on the ground. Presence or absence of vegetation in any square was recorded. Frequency refers to the number of times a species is recorded in a possible 450 squares. The frequency of occurrence of perennial bunchgrass (Agropyron spicatum and Festuca idahoensis Elmer) and C. nauseosus on Columbia Basin plots may be seen in Table 1.

Stem and crown frequencies and the crown/stem ratios of sagebrush and C. viscidiflorus in the Millican area appear in Table 2.

To study flower production, ten plants on each 100' x 100' plot were selected on a restricted random basis. Because of the observed differences in flowering the objective of the flower counting study was to assess the reproductive ability of average plants in different degrees of competition. Age determinations by means of growth ring counts indicated that most of the plants selected for flower production studies were in a 7 to 14 year age group.

Counting flowers was facilitated by using "counting units" instead of counting all individual flowers. Counting units consisted of number of flowers per head, number of heads per stem and number of stems per plant. To determine flower production on a particular plant, twenty-five flower heads were examined to determine the average number of flowers per head, twenty-five stems were observed at random to determine average number of heads per stem, and all stems on the plant bearing heads were then counted.

Results and Discussion. On the series of plots in each location in the Columbia Basin C. nauseosus flower production appears to increase as bunchgrass frequency decreases. (Table 1). An exception to this statement may be where slightly older plants were encountered. However, the general trend is quite clear for plants in a 7 to 14 year age class when plots with high and low bunchgrass frequency are compared for each area. Notable is the general decrease in flower production from Shaniko to Pilot Rock which suggests that rabbitbrush is not an aggressive competitor in good condition bunchgrass ranges in the eastern area.

A very interesting comparison of flower production can be made between plot 7 and 8 when past history and other characteristics of these plots are considered. Plot 7 is more xeric than plot 8 and has been severely overgrazed in past years. At the present time plot 7 is vegetated primarily by Festuca idahoensis and C. nauseosus in the younger age classes. Plot 8 was cultivated and planted to wheat at one time, but has since been abandoned. Flower production on plot 7 appears to be limited by the presence of bunchgrass even in years with more moisture. However, on plot 8, which supports very little Agropyron spicatum or Festuca idahoensis, the only control on flower production is from competition between young rabbitbrush plants and in moist years this type of competition does not appear to be very limiting.

Fewer plots were sampled in 1955 and as a result the data for this year are inconclusive except for plots 13, 11, and 9 at Grass Valley.

TABLE 1

Flower Production of *C. nauseosus* Plants on Selected Plots in the *Agropyron-Poa* Zone *

Plot No.	Location	Bunchgrass and Rabbitbrush Frequency			Av. No. of Flowers Per Plant	
		A. spicatum	*F. idahoensis*	*C. nauseosus*	1954	1955
1	3 mi. N. Shaniko	184	110	3	5,093	837
2	" " "	146	18	20	10,494**	---
3	" " "	1	0	69	6,899	621
4	2 mi. N. Shaniko	275	56	13	2,989	181
5	" " "	224	272	1	4,333	---
6	" " "	108	33	10	8,383	74
7	4 mi N. Shaniko	49	76	34	2,996	257
8	" " "	1	0	292	9,385	223
13	2 mi. So. Grass Valley	250	194	3	6,595**	180
12	" " " "	238	183	6	4,000	---
11	" " " "	142	1	6	4,515	124
10	" " " "	35	2	18	11,710	---

TABLE 1 continued

Plot No.	Location	Bunchgrass and Rabbitbrush Frequency A. spicatum	F. idahoensis	C. nauseosus	Av. No. of Flowers Per Plant 1954	1955
9	2 mi. So. Grass Valley	3	0	27	11,680	468
14	6 mi. So. Pine City	253	0	6	519	2
15	" " " "	130	0	32	265	none
16	" " " "	84	0	76	369	none
17	1.5 mi. SW Pilot Rock	255	0	2	none	none
19	" " " "	194	0	23	151	none
18	" " " "	91	0	26	806	none

* Plots arranged in decreasing A. spicatum frequency in each location.

** Predominantly older plants.

The observed decrease in flower production from west to east in 1954 was repeated in 1955 to the point that no flowers were produced on any of the plants in the Pine City and Pilot Rock area regardless of size or age. There is some evidence from these data that not all of the C. nauseosus plots are in the Agropyron-Poa Zone because of greater flower production in the Shaniko-Grass Valley area. Possibly this area is on the border of a Fescue Zone. A very striking observation in 1955 on plots at Shaniko and Grass Valley was the high level of flower production on extremely old plants in the 25-year age class. These old plants on plots in depleted areas appeared to be almost independent of weather conditions or competition from bunchgrass or smaller rabbitbrush plants.

On sandy soils in many areas of the Basin and Range Province the principal competitor of C. viscidiflorus is sagebrush, even though grasses and forbs constitute an important part of the vegetation. Sagebrush appears to be especially competitive with C. viscidiflorus in the latter half of the growing season and during flower development. Table 2 provides some indication of this competitive relationship as flower production is affected.

Two peaks in flower production are indicated by the arrows in Table 2. One peak is on plots which have a moderate sagebrush frequency and fairly high C. viscidiflorus frequency. Sagebrush plants are moderately large and exceed the size of C. viscidiflorus plants as indicated by the crown/stem ratios. Very low stem borer

TABLE 2

Flower Production of C. viscidiflorus on Selected Plots in the Millican Area.*

Plot No.	Sagebrush and Rabbitbrush Occurrence: A. tridentata frequency: Stems	Crown	Crown/stem ratio	C. viscidiflorus frequency: Stems	Crown	Crown/stem ratio	Av. No. of Flowers Per Plant: 1954	1955	Direction of Flower Increase
1	120	304	2.53	46	68	1.47	1,875	---	Low
3	76	145	1.91	52	17	1.48	2,012	642	
9	65	212	3.26	70	157	1.24	7,720	---	
8	54	244	4.52	64	102	1.59	16,533	2,839	High
6	52	161	3.09	69	56	1.81	4,621	---	
5	48	138	2.87	45	56	1.24	2,070	---	
7	32	203	6.35	1	1	1.00	528	208	Low
11	31	200	6.45	10	13	1.30	3,811	---	
2	21	98	3.79	88	174	1.97	2,450	678	
12	23	106	4.60	164	164	1.45	9,272	---	
13	22	103	4.68	11	26	2.36	10,810	---	
10	18	96	5.33	5	20	4.00	10,522	---	High
4	17	58	3.41	72	215	3.00	19,528	6,886	

* Plots arranged according to decreasing sagebrush frequency.

damage on plot No. 8 might be a significant factor. Another peak in flower production occurred on plots supporting only a few sagebrush and a few to many C. viscidiflorus plants. Sagebrush and C. viscidiflorus plants are rather large on these plots. Conversely, the lowest C. viscidiflorus flower production occurred on plots where sagebrush plants appeared in rather high frequency.

Plots with sufficiently high sagebrush frequency to dominate the area indicated a low C. viscidiflorus flower production. Flower production was also limited in areas with a low number of large sagebrush plants. Plot No. 2 illustrates another cause of reduced flower production which resulted from close competition between C. viscidiflorus plants.

At this point in the study, conclusions are difficult to make, but the data tend to support the hypothesis that the greatest seed source of C. viscidiflorus plants is from an area where rabbitbrush is higher than sagebrush in frequency and where rabbitbrush flower production is not reduced by intraspecific competition.

Temperature and precipitation for 1954 and 1955 at Squaw Butte Experiment Station which represents the C. viscidiflorus plots in the Millican area, and Kent which characterizes weather for the C. nauseosus plots in the Columbia Basin. (Tables 3, 4.) The area surrounding Kent is warmer and receives more precipitation than does Squaw Butte. In a general way these data might explain the relatively greater abundance of C. nauseosus in the

TABLE 3

Precipitation at Squaw Butte Experiment Station and Kent, Oregon during 1954 and 1955

		Precipitation													
Location	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total for Year	Departure from Normal
Kent	1954	2.07	.54	.58	.20	.93	.78	.05	.63	1.05	.80	.80	.71	9.14	- 1.19
	1955	.50	.31	.70	1.21	.94	.52	.81	.00	.67	.78	1.69	2.64	10.77	+ .44
Squaw Butte	1954	1.20	.35	.91	.78	.93	1.03	T	.23	.09	.10	.45	.70	6.77	- 5.10
	1955	.70	.50	.70	1.91	.32	.41	.57	T	1.02	.49	1.80	2.05	10.47	- 1.40

TABLE 4

Temperature at Squaw Butte Experiment Station and Kent, Oregon During 1954 and 1955

		Average Month Temperature											
Location	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Kent	1954	30.6	36.5	36.0	45.5	53.9	56.8	64.8	61.8	57.9	46.4	43.5	31.2
	1955	31.5	32.9	34.3	39.8	49.2	60.1	63.1	67.3	60.5	50.1	33.3	30.7

TABLE 4 continued

Average Month Temperature

Location	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Squaw Butte	1954	29.9	36.1	33.9	44.8	53.4	53.6	67.7	61.7	56.5	47.9	42.3	26.7
	1955	23.5	27.9	34.9	36.2	47.8	61.1	63.1	69.2	58.2	48.9	34.2	31.0

grasslands of the Columbia Basin and C. *viscidiflorus* in the bottomlands of the Great Basin. The difference between 1954 and 1955 for both areas is striking in that the early spring of 1954 was wetter and warmer than the corresponding period in 1955. The relatively dry winter of 1954-55 could have reduced the number of flowers produced in the summer of 1955.

Obviously more information is necessary to clarify the relationships between bunchgrass frequency or sagebrush frequency and the reproduction of rabbitbrush plants. Such factors as size and age of plants in relation to flower production also need to be further studied. To determine the influence of size and age of plants and of weather conditions on flower production, different age classes should be studied over a period of years. More observations will be required before the controlling factors in rabbitbrush flower and seed production can be adequately understood.

Response of Rabbitbrush Following Removal of Competing Vegetation

Rabbitbrush plants growing in areas lacking or low in competition from other plants are larger and produce more flowers than rabbitbrush plants in competition with surrounding vegetation. To study the magnitude and rate of flower production increase and stem growth as a result of removing competing vegetation a controlled experiment was established.

Methods. Ten pairs of C. nauseosus plants and ten pairs of C. viscidiflorus plants were marked in the field at Millican. A different location was chosen for each five pairs of plants.

On March 26, 1955, one plant of each pair was randomly selected and all competing shrubs and herbaceous vegetation within a radius of 10 feet were removed. Care was exercised to avoid damage to the root system of the test plant.

Flower counts were obtained by using the same procedure as outlined in the preceding study.

Data on growth in one season were obtained by randomly selecting and measuring the current year's growth of 25 stems of each rabbitbrush plant in the study.

Mature seeds were collected from the plants in this study to determine if any difference existed between the number of viable seeds on plants with competition as compared to plants without competition. Twenty-five seed heads containing a possible 4 to 5 mature seeds were collected from each plant. Seeds were removed from the enclosing involucre and planted on moist blotter paper in seed germination dishes. Germinations were recorded every two weeks for eight weeks.

Results and Discussion. Plants released from competition were partly in flower as early as August 4 and were fully in flower by August 22. Plants competing with surrounding vegetation were approximately three weeks later in flowering. This response is similar to the earlier flowering of rabbitbrush observed along highways, back roads, and fence rows where competition from other plants is at a minimum.

In only one season of growth, flower production on cleared plants was approximately 300% greater in C. nauseosus and 500% greater in C. viscidiflorus following removal of competing vegetation. (Figures 4, 5, 6 and 7).

Significance was indicated at the .01 level for F values of 10.04 for C. viscidiflorus and 17.88 for C. nauseosus obtained in an analysis of variance between plants with competing vegetation removed and plants with competing vegetation present. The conclusion may be drawn that removing competing vegetation does result in an increase in rabbitbrush flower production at least 99% of the time. In no instance was there a decrease in flower production. (Table 5). However, paired plants in another location at Dry Canyon between Redmond and Sisters failed to show any difference in flowering when competing vegetation was removed. A possible explanation for this lack of response might be due to removal of surrounding vegetation a month later in this location. Clearing took place a few days after precipitation in April and probably came too late to conserve any supplies of soil moisture. For this reason the Dry Canyon location was not included in the statistical analysis.

Field observations in the fall of 1955 recorded shoots growing from crowns of rabbitbrush plants cut off in the process of clearing study plots. Many of these shoots attained a length of 4 to 6 inches and produced flowers.

Figure 4. Flower production of C. nauseosus in competition with surrounding vegetation.

Figure 5. Flower production of C. nauseosus released from competition.

Figure 6. Flower production of C. viscidiflorus in competition with surrounding vegetation.

Figure 7. Flower production of C. viscidiflorus released from competition.

TABLE 5

Average Rabbitbrush Flower Production on Plants Growing With, and Without Competition from Other Plants

Species	Location	Av. Flower Production for Five Plants With Competition	Without Competition
C. nauseosus			
	Location #1	1,393 $\pm s_{\bar{x}}$ 374	3,561 $\pm s_{\bar{x}}$ 514
	Location #2	63 $\pm s_{\bar{x}}$ 45	680 $\pm s_{\bar{x}}$ 165
C. viscidiflorus			
	Location #3	25 $\pm s_{\bar{x}}$ 15	2,034 $\pm s_{\bar{x}}$ 436
	Location #4	1,019 $\pm s_{\bar{x}}$ 394	3,857 $\pm s_{\bar{x}}$ 1,411

No significant difference was indicated between germination of seeds from rabbitbrush plants with competing vegetation present, and with competing vegetation absent. (Table 6). This agrees with the statement made by Salisbury (43) that the effect on plants grown in adverse conditions is to cause a diminution in the number of seeds per plant rather than to affect the quality of the seeds. The number of flowers produced per plant (Table 5) further supports Salisbury's statement in that the response of plants following removal of plant competition is to increase the number of flower heads while the number of flowers per head and the viability of the seeds matured from these flowers remains constant.

In addition to increased flower production, rabbitbrush

TABLE 6

Germination of *C. viscidiflorus* and *C. nauseosus* Seeds Collected From Plants in Removal of Competing Vegetation Study

C. nauseosus

Pair no.	With Competition	Without Competition
1	---	7
2	14	24
3	15	46
4	16	44
5	39	20
6	13	25
7	14	4
8	15	6
9	16	12
10	28	---
Total	170	188
Average	17	18.8

C. viscidiflorus

Pair no.	With Competition	Without Competition
1	43	78
2	41	28
3	22	30
4	26	58
5	91	9
6	5	6
7	66	39
8	20	20
9	44	25
10	14	40
Total	372	333
Average	37.2	33.3

plants not in competition with surrounding vegetation also had a considerable amount of stem growth during the growing season. C. viscidiflorus plants without competition averaged 2.86 inches greater stem elongation than did plants with competition. The same pattern also held true with C. nauseosus where an average of 2.74 inches greater stem elongation was recorded.

An analysis of variance was performed on the sum of stem growth for the 25 randomly selected stems on each plant. The F value for 1 and 9 degrees of freedom for the test of stem growth on C. nauseosus was 25.2. This value is significant at the .01 level. An F value of 9.03 was obtained in the test of stem growth of C. viscidiflorus which is significant at the .05 level. The conclusion may therefore be drawn that at least 99% of the time with C. nauseosus and 95% of the time with C. viscidiflorus one might expect to obtain a significant increase in stem elongation the first growing season following the removal of competing vegetation.

The implications of the preceding study in relation to current brush-control measures should be amplified. At the present time brush-control measures are reasonably effective in controlling sagebrush and other plants, but are ineffective in controlling rabbitbrush. Therefore, range improvement programs which remove vegetation competing with rabbitbrush encourage the reproduction and growth of this undesirable shrub. This situation is particularly true on ranges dominated by rabbitbrush but low in grass density. As has been mentioned previously, rabbitbrush plants have an advantage in such locations because they resprout from the crown following fire, drought, and cutting and because of the marked increase in flower (seed) production and growth.

Age of Plants Producing Seed

Most rabbitbrush plants do not begin to produce flowers and seeds until they are four to six years old. Three-year-old _C. nauseosus_ plants in flower were collected at Fort Rock in 1954. These plants were growing in a bare spot in a rangeland pasture and were not in competition with other plants. Seed production has been observed to be greater in proportion to size of old plants which appear to be less affected by competing vegetation. Further observations are necessary to clearly define the age at which most rabbitbrush plants begin to produce seed.

Seed Characteristics

The mature fruit in _Chrysothamnus_ is a cypsela which is an achenium with an adherent calyx. An average of 4 or 5 cypselas are produced on each head in _C. nauseosus_ and _C. viscidiflorus_. Findings of this study are generally in agreement with _The Woody-Plant Seed Manual_ (53) which briefly lists seed characteristics for _C. nauseosus_. Seeds of this species are from 5 to 7 mm. long, pappus is in a single series and may be as long as, or slightly longer than the seed. The seed coat has prominent ribs, and pubescence of approximately .5 mm. in length. _C. viscidiflorus_ seed length averages 3 to 3.5 mm. with a correspondingly shorter pappus. General characteristics are quite similar for both species. The percentage of empty seeds in field collections is very high.

Seed Viability

Viability of seeds under field conditions appears to be of short duration. This is suggested by an experiment with one-year-old samples of litter taken from the area surrounding mature one-year-old _C. viscidiflorus_ and _C. nauseosus_ plants in the vicinity of Redmond.

Methods. Litter samples were taken prior to the maturation of a new seed crop in 1955 and placed on moist pumice soil in the greenhouse to determine what plants would develop from seeds in the litter.

Results and Discussion. Only cheat grass (_Bromus tectorum_ L.) and a few sagebrush seeds germinated. This evidence so far is inconclusive and further trials should be made. Other experiments were established in the fall of 1954, but failed because no provision was made for protecting seeds from seed-eating wildlife.

Seeds cleaned and stored in glass containers at room temperature in the laboratory remained viable for a period of two years, although the rate of germination decreased with age. Other samples stored in the laboratory but not cleaned and protected from temperature, humidity, and plant pathogens were not viable after one year.

Seed Dissemination

Seeds are loosened from the involucre by the reflexing action of the pappus as it dries. Dissemination occurs with the action of the slightest breeze on the capillary pappus. In eastern Oregon these seeds are usually scattered from west to east due to the direction of the prevailing wind.

Methods. Distance of dissemination has been calculated in cultivated fields at Fort Rock and at the Land Utilization Project near Madras. The distance that seeds have traveled may be inferred by the location of established plants in relation to the nearest seed source.

Results and Discussion. A field at Fort Rock planted to cereal rye (*Secale cereale* L.) bordered on the southwest by a stand of mature *C. nauseosus* and *C. viscidiflorus* had *C. viscidiflorus* and *C. nauseosus* plants scattered into the field as far as 165 yards. Another field in this same area had *C. nauseosus* plants growing seedlings on a slight elevation above the level of the bottomland 500 yards from the nearest seed source. At the Madras Land Utilization Project on Grizzly pasture, young *C. nauseosus* plants were established in the pasture as far as 153 yards from the nearest seed source. At Willow Creek pasture, distances of 140 and 130 yards respectively, were measured between seed source and seedlings in two different locations.

Sagebrush seedlings did not appear any farther away from a seed source than 25 yards in any of the pastures surveyed.

No rule can be established concerning the distance of seed dispersal because of the many factors involved. The most important considerations in determining dissemination distance appear to be wind velocity and direction, topography, humidity, microrelief or soil surface conditions and quantity of seed available.

In view of the data comparing rabbitbrush and sagebrush seed-dispersal distances, the ability of rabbitbrush to provide for dissemination of seeds over greater distances gives it an advantage over sagebrush in revegetating abandoned or depleted areas.

Seed Cleaning

Collection and cleaning of seed for laboratory and greenhouse study proved to be a laborious process. The best time to collect seed is during the last week of September and the first two weeks in October. Rabbitbrush seed production in colder regions, such as the Fort Rock area, is from two to three weeks earlier.

Methods. One of the most successful methods used in obtaining seed was to hold a corrugated paper box close to the top of a rabbitbrush plant and then gently brush the mature seeds into the box. This method eliminates the collection of a large amount of undesirable plant parts, such as bracts, leaves, twigs and receptacles and provides a high percentage of matured seeds.

Cleaning seed involves the separation of pappus, other plant parts, and empty seeds from the filled, mature seeds. The collected material should be reasonably dry before threshing in order to insure best results. Threshing was performed in a modified Waring Blendor equipped with a four-inch long central shaft of $\frac{1}{4}$" diameter which supported two $1\frac{1}{2}$" long arms covered with rubber tubing. The blendor was regulated with a Powerstat control that was set at 60 to provide for a slower speed. Other equipment used in seed cleaning included a set of screens and a South Dakota Seed Blower.

After several trials the following procedure produced the best results:

1. Thresh approximately 500 cc. of plant material in modified Waring Blendor at a powerstat setting of 60 for 3-minutes.

2. Screen out stems and larger matter with a 1/16" x 1/4" or larger screen. This step also breaks up any wads of pappus material and facilitates separation in the seed blower.

3. Place material in a South Dakota Seed Blower and blow for 25 seconds at a setting of 8. This removes very light trash.

4. Repeat step 3 with a setting of 10. Discard pappus, lighter bracts and other trash.

5. Repeat step 3 with a setting of 15. Discard bracts and small stems.

6. Screen material with a 1/4" x 1/22" screen. This removes bracts and small stems of weight equal to the mature seeds, but of a larger size.

7. Repeat step 3 with a setting of 20. This separates under-developed and empty seeds from the mature seeds.

8. An additional blowing at a setting of 22 may be used to insure better seed for experimentation. Viable seed of low quality will be blown over.

Results and Discussion. Seeds removed at settings of 18 and 19 in a South Dakota Seed Blower did not germinate, but the seeds that remained after settings of 20 and 22 showed 50-80% germination.

SEED GERMINATION

Introduction

A knowledge of the particular requirements for germination is important to an understanding of the field conditions under which rabbitbrush becomes established and of the ecological status of these shrubs in range vegetation. Nothing is known about the optimum temperature requirements for germination. Seeds should be able to germinate at low temperatures so that seedlings may become established before soil moisture is depleted. If freezing temperatures occur early, seedlings might be killed if they are not frost resistant. Germination percentages may be different in seeds collected from various locations. These and many other problems need to be answered, and some of them are considered in the following discussion.

The germination responses of different desert plants according to Went (58), suggests that much detailed information may be obtained about the growth requirements of desert plants. He concluded that the distribution of two closely related species appeared to be based on a slight differential in night germination temperature. Such an observation suggests that the distribution of *C. nauseosus* and *C. viscidiflorus* could be due to a small differential in germination response.

The available literature suggests that no particular temperature is optimum for the seed germination of all semi-desert shrubs. Trumble (51), reported that native Australian saltbrushes

(<u>Atriplex</u> spp.) germinated best at 16°C., although a range of 10°-22°C. produced fairly high germination. Benedict and Robinson (3), (in an exhaustive study of seed germination of guayule (<u>Parthenium argentatum</u> A. Gray), concluded that the highest germination response occurred at a constant temperature of 25°C. or an alternating 20° and 30°C. Big sagebrush (<u>Artemisia tridentata</u> Nutt.) has received some attention recently by Goodwin (22) and Alley, Bohmont, and Weldon (1). Goodwin (22) reported that the optimum temperature for sagebrush germination was between 17°C. and 19°C. and that temperatures above 24°C. reduce germination. Although no dormancy was reported, he stated that a pretreatment of extended cold temperature resulted in an immediate germination response. The latter authors found that 90% germination occurred under light at 70°F. (21°C.) with 0 atmosphere moisture tension.

Limited field observations indicate that optimum germination of rabbitbrush seeds might occur at rather low temperatures. An inch of snow and cold conditions followed the planting of seeds at Millican on March 26, 1955. Within three weeks seeds had germinated. The average temperature during this time was about 35°F., according to U. S. Weather Bureau records. (Table 4).

The first evidence of germination is the emergence of the radicle tip. Radicle and hypocotyl continue to elongate and after approximately 7 days the cotyledons emerge from the testa. (Figures 8 and 9). An important feature of rabbitbrush germination

Figure 8. Germination of seeds and development of C. nauseosus seedlings.

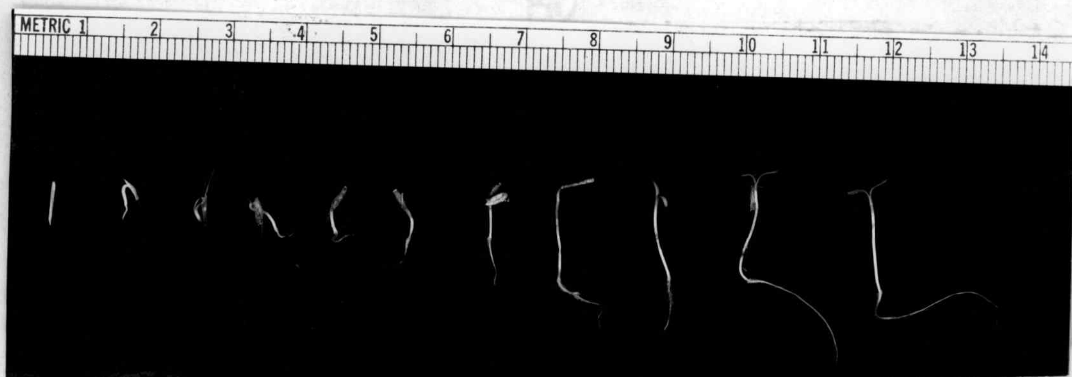

Figure 9. Germination of seeds and development of C. viscidiflorus seedlings.

and seedling development is the epigeous growth habit whereby the cotyledons do not remain below ground, but are pushed up through the soil.

Immediate Germination

Seeds of *C. nauseosus* and *C. viscidiflorus* will germinate as soon as they are ripened in the fall if proper conditions are present. *The Woody-Plant Seed Manual* states that *C. nauseosus* seeds germinate without treatment a few days after sowing. This statement should be amended to include the fact that seeds will germinate immediately after dissemination and that no maturation period is necessary.

Methods. In an effort to check on the germination of newly produced rabbitbrush seed collections were made near Redmond on October 3, 1955, by shaking seeds from mature plants. Seeds were then returned to the seed laboratory where they were cleaned and empty seeds were discarded. Seeds were scattered on moist paper toweling in germination dishes and at 10:00 a.m., October 9, they were placed in seed germinators. Germination conditions included 15°C. dark, 20°C. dark, 15-25°C. light, 20-30°C. light, and 20-30°C. dark.

Results and Discussion. Germination was noted as early as October 11 at 9:00 a.m.; a period of 47 hours. (Table 7).

Although germination was rather low for *C. viscidiflorus* there is sufficient evidence to conclude that seeds will germinate as soon as they are produced if temperature and moisture

TABLE 7

Germination of Newly Matured *C. nauseosus* and *C. viscidiflorus* Seeds in Light and Darkness at Different Temperatures *

Light and Temp. Treatment	*C. nauseosus* 47 hrs.	17 days	Total	*C. viscidiflorus* 47 hrs.	17 days	Total
15°C. Darkness	2	26	28	1	11	12
20°C. Darkness	3	26	29	1	12	13
15-25°C. Light	7	25	32	6	5	11
20-30°C. Light	11	20	31	7	7	14
20-30°C. Darkness	18	19	37	1	12	13
		Species Total	157		Species Total	63
		Germination	62%		Germination	25%

* Fifty seeds of each species at each treatment.

conditions are favorable. No difference in germination was indicated between treatments of light and darkness. Dormancy did not appear to be present, but there may be a high degree of variability between seeds which results in some seeds germinating at a later date.

1954 Seed Germination Study

An experiment in the seed laboratory was designed to investigate the optimum temperature for germination, the rate of germination, and to obtain a comparison of germination among *C. nauseosus*, *C. viscidiflorus* and *A. tridentata* seeds.

Methods. Seeds for the 1954 germination study were collected seven miles east of Bend along U. S. Highway 20 and in the valley near Millican on November 7, 1953. At this time most seeds had already been disseminated and as a result, even though a large volume of plant material was obtained, the yield of viable seed was low.

Seeds were cleaned and stored at room temperature for 9 months.

Germination temperatures included 5°C., 10°C., 15°C., 20°C., alternating 16 hours of 20°C. and 8 hours of 30°C., and 30°C. Fifty seeds of each species were placed on moist paper toweling in individual standard seed germinating dishes that then were distributed to seed germinators set for the temperatures selected. Replication was provided by a repetition of the experiment after two weeks and again at four weeks. Since there was a smaller amount of *C. nauseosus* seed available from the collections made near Bend, seeds from Millican were used in the third replication. Most of the seeds at Millican were already disseminated when collections were made and the ones collected not top quality.

Observations were made every twelve hours for the first three days of each replication and were subsequently reduced to once each day. Seeds that remained in the germination dishes after six weeks were cut to see if they were filled.

Results and Discussion. Seed germination was summarized by considering the average amount of germination that occurred within each of four time periods. These periods were from 0 to 48 hours, between 48 hours and 7 days, between 7 days and 14 days, and from 14 days to 42 days. (Table 8, Figures 10, 11, 12).

Data obtained in this study were statistically analyzed according to a split plot statistical design. (Table 9).

Further interpretation of the data and of Table 9 may be essential for a better understanding of the experimental results. The .05 level of significance is chosen as being sufficient to compare means of the various factors and interactions.

The significance indicated for replications is probably a result of using _C. nauseosus_ seeds from a different seed source in the third replication, since the number of _C. nauseosus_ seeds that germinated in the first and second replication is 273 and 249 respectively, and only 75 in the third replication. No serious error is committed, however, as the variation due to this different seed source is easily identified and provided for in the analysis of variance calculations.

Time required for germination is a very important consideration. The overall means for time may be seen along the right side of Table 10.

A comparison of the time interval means in their chronological order indicates that germination during the period from 48 hours to 7 days is significantly different from either the first 48 hours or the second week of germination.

The difference between species means in Table 10 supports the conclusion that there is a significant difference in overall

TABLE 8

Average Number of C. viscidiflorus, C. nauseosus, and A. tridentata Seeds That Germinated at 5°C., 10°C., 15°C., 20°C., 20-30°C., and 30°C. During Four Different Time Periods

	C. nauseosus				C. viscidiflorus				A. tridentata			
Temp.	0-48 hrs.	7 days	14 days	14 days +	0-48 hrs.	7 days	14 days	14 days +	0-48 hrs.	7 days	14 days	14 days +
5°	0	3	18.3	14.0	0	4.0	27.7	10.7	0	0	1.0	12.0
10°	0	20.7	9.0	2.7	0	16.0	9.7	10.3	0	.3	8.0	11.0
15°	10.0	18.3	4.7	2.3	2.7	13.7	8.0	6.0	1.3	20.3	9.3	1.7
20°	12.7	14.3	5.3	2.7	2.3	12.7	7.7	7.3	4.7	18.7	8.0	1.3
20-30°	23.3	6.0	1.0	0	2.7	16.3	3.3	7.3	2.0	12.7	1.7	0
30°	21.7	9.0	0	0	0	13.0	3.0	6.3	7.0	4.7	0	.3

(Number of filled ungerminated seeds = 9) (Number of filled ungerminated seeds = 45) (Number of filled ungerminated seeds = 27)

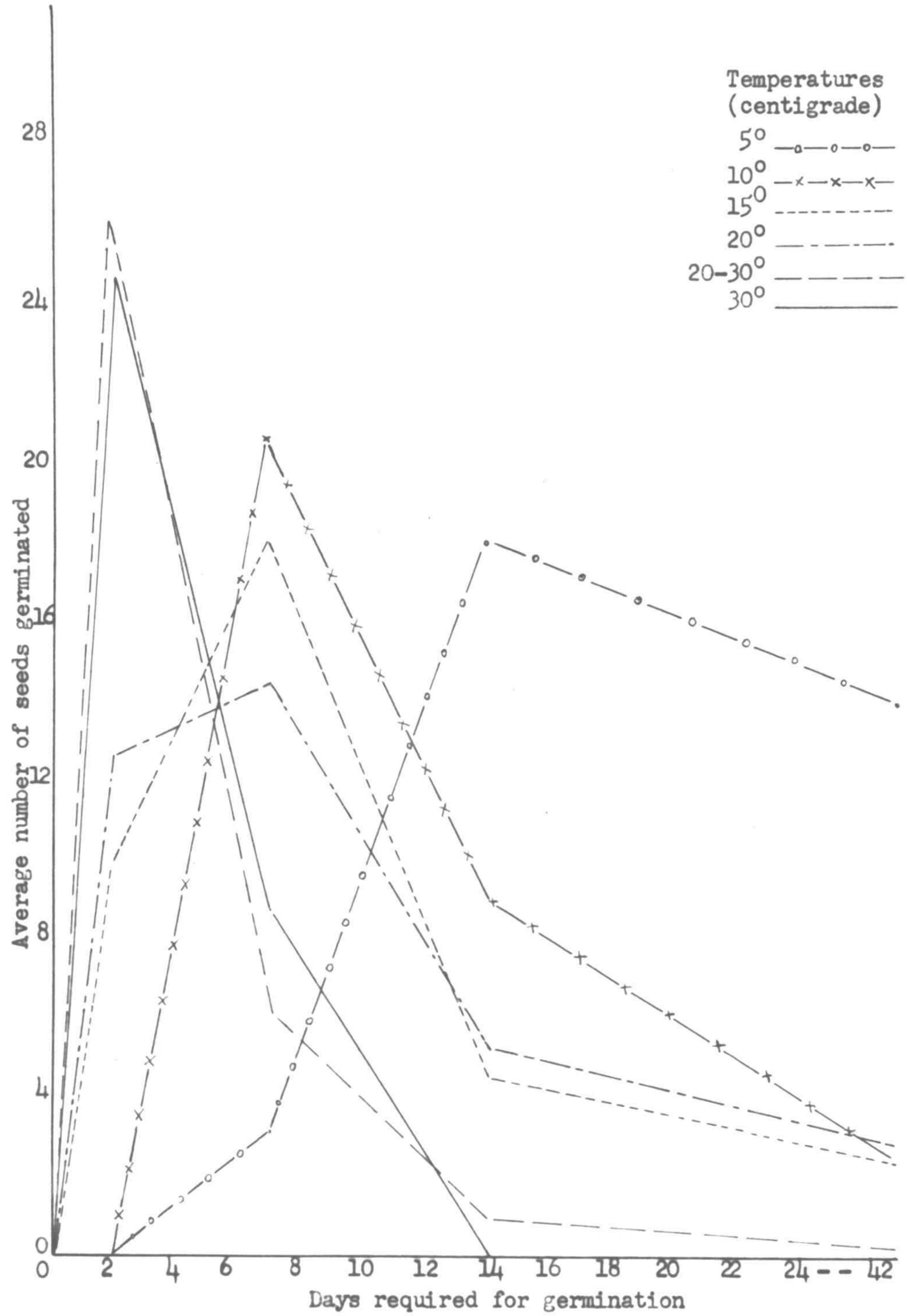

Figure 10. Average Germination of C. nauseosus Seeds as Affected by Time and Temperature.

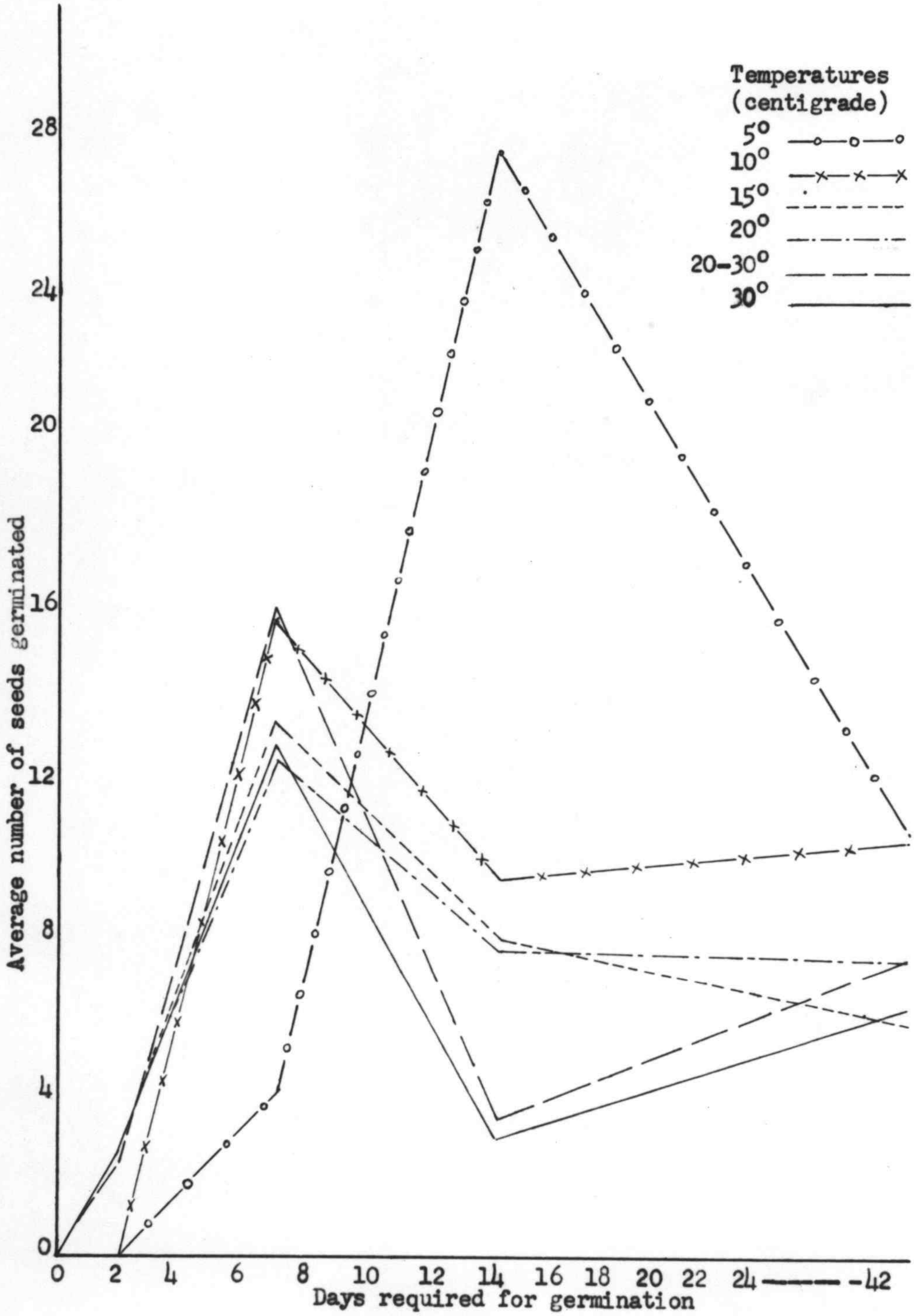

Figure 11. Average Germination of *C. viscidiflorus* Seeds as Affected by Time and Temperature.

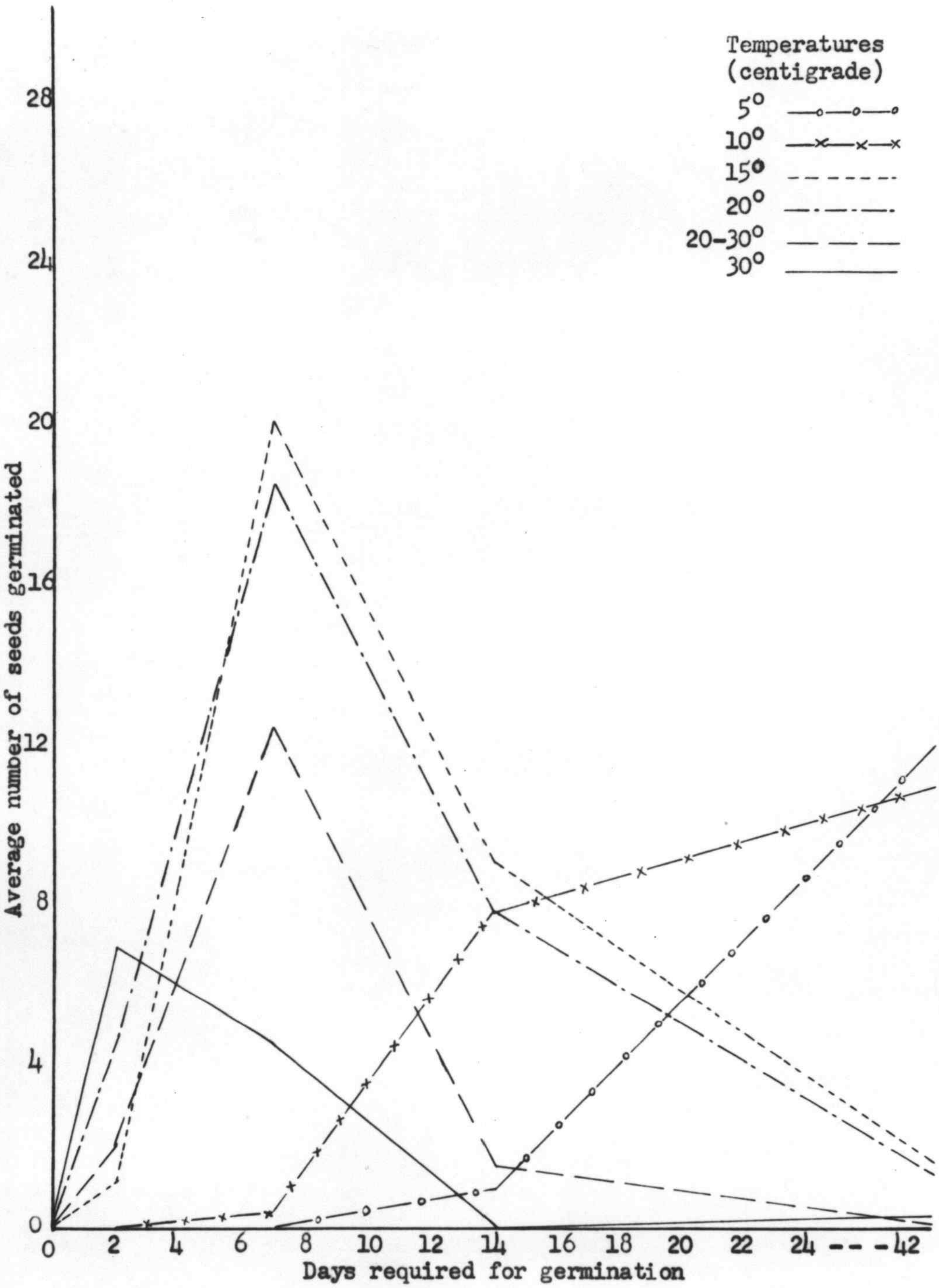

Figure 12. Average Germination of A. tridentata Seeds as Affected by Time and Temperature.

TABLE 9

Summary of Analysis of Variance of C. nauseosus, C. viscidiflorus, and A. tridentata Seed Germination

Source of Variation	Degrees of Freedom	Significance
Replications	2	*
Time	3	**
Reps x Time (error a)	6	
Species	2	**
Temperatures	5	
Species x Temp.	10	
Time x Species	6	**
Time x Temp.	15	**
Time x Species x Temp.	30	**
Error b	136	

* Significant at the .05 level.

** Significant at the .01 level.

TABLE 10

Average Germination of C. nauseosus, C. viscidiflorus, and A. tridentata Seeds During Four Time Intervals, 1954

Time interval	C. nauseosus	C. viscidiflorus	A. tridentata	Av. for Time interval
0-48 hrs.	11.3	1.7 *	2.5 *	5.2 *
48 hrs.-7 days	11.9 *	12.6 *	9.4 *	11.3 *
7 days - 14 days	6.4 *	9.9 *	4.7	7.0
14 days - 42 days	3.6	8.0	4.4	5.3
Species Means	8.3	8.1 *	5.2	

Time L.S.D. = 2.66 at .05 level
Species L.S.D. = 1.70 at .05 level
Time x Species L.S.D. = .85 at .05 level

* Denotes that the difference between the means indicated is greater than the L.S.D. value.

germination between sagebrush and rabbitbrush, but that no significant difference exists between _C. nauseosus_ and _C. viscidiflorus_. The inclusion of _C. nauseosus_ seeds having a lower germination percentage in the third replication may be responsible for this apparent lack of difference between rabbitbrush species.

The temperatures used in the experiment are not limiting to the germination of rabbitbrush and sagebrush seeds. In addition there is no significant difference in the average number of seeds germinating at each temperature for each species where time is not a factor.

When considering time in relation to the germination response of each species, there is a significantly different germination pattern for these brush seeds. (Table 11). Most _C. nauseosus_ seeds germinate as soon as 48 hours and during the first week, as compared to _C. viscidiflorus_ and sagebrush which do not have an early flush of germination within the first two days. These differences are significant on the basis of the L.S.D. values.

The general effect of time and temperature interaction can be seen in Table 11. Obviously a longer time is required at low temperatures than at higher temperatures. By the time germination is completed at 30°C., seeds are just starting to germinate at 5°C. L.S.D. values indicate a support of this conclusion.

The important interaction between time, species, and temperature can best be interpreted by a visual inspection of Figures 10 and 11 which graphically illustrate the rate of germination

TABLE 11

Average Seed Germination as Affected by

Time and Temperatures

Time periods	Temperatures 5°	10°	15°	20°	20-30°	30°
0 to 48 hrs.	0	0	4.7	6.7	9.2	10.4
48 hrs. to 7 days	2.3	*12.3	*17.4	*15.2	*11.7	8.9
7 to 14 days	*15.7	*8.9	*7.3	*7.0	*2.0	*1.0
14 to 42 days	*12.2	8.0	*3.3	*3.8	2.4	2.2
Temperature Means	7.6	7.3	8.2	8.2	6.3	5.6

Time x Temperature L.S.D. = 1.83 at .05 level.

* Signifies that the difference between the means indicated is greater than the L.S.D.

at each temperature for C. nauseosus and C. viscidiflorus. C. nauseosus seeds germinate faster than C. viscidiflorus or sagebrush seeds at 20-30°C., and at 30°C. temperatures. In contrast to this germination response, sagebrush and C. viscidiflorus seeds reach their maximum rate of germination between 48 hours and 7 days at the higher temperatures. At the lower temperatures there appears to be no real difference in rate of germination between C. nauseosus and C. viscidiflorus since both reach a peak in 7 days at 10°C. and in 14 days at 5°C. Apparently some dormancy exists in sagebrush seed as evidenced by the increasing germination rate after 14 days at 5°C. and 10°C. (Table 8 and Figure 12). *A. tridentata* seeds placed in -5°C. for 24 hours before planting in greenhouse experiments indicated higher germination figures than did seeds not cold treated. However, Goodwin (22) reported no dormancy in *A. tridentata*, but did make the statement that, "Even though stratification may not be essential to germination, such treatment did result in higher total germination". Apparently, terminology is more in conflict in this problem than are the data.

1955 Seed Germination Study

Several problems were suggested by the 1954 germination trials. The first question, of course, was whether the general conclusions reached in 1954 would hold true with seeds produced in a different year. Another problem concerned the possibility that a difference in germination might exist between *C. nauseosus* and *C. viscidiflorus* if seed sources for both species were from the same locality, and whether a difference existed between seeds collected at different locations. Sagebrush seeds were not included in this study, as most of the above problems were considered by Goodwin (22).

Methods. Seeds were collected in the last week of September 1954. This time was at the peak of seed dissemination at the first two collection locations at the Land Utilization Project near Madras, and at three miles south of Redmond in a large clearing in the Juniper forest. Seed dissemination was advanced at the third collection location in an abandoned homestead 1 mile west of Fort Rock.

Seeds were cleaned according to the described technique and stored in glass vials at room temperature for nine months. Fifty seeds were used in each germination dish and the same six temperatures used in the 1954 tests were also used. Seeds were lightly dusted with Captan, a commercial fungicide, before placing dishes in germinators. This treatment was used in an effort to test whether greater germination could occur in the last time period if the effects of seed-borne fungi were reduced.

Results and Discussion. The resulting data were statistically analyzed by means of an analysis of variance with a split plot statistical design. (Table 12).

In a general way these data are in agreement with conclusions reached from the preceding seed germination study, although several points are further clarified.

Seeds collected at different locations did not show any significant difference in total germination, although seeds from Fort Rock had the lowest percentage germination. This information helps to explain why a lower germination percentage was obtained in the third replication of the 1954 germination study. Apparently the conclusion that no difference in seed germination

TABLE 12

Summary of Statistical Analysis of Germination of <u>C. nauseosus</u> and <u>C. viscidiflorus</u> Seeds at Four Time Periods and Six Temperatures. Seeds were collected from three locations.

Source of Variation	Degrees of Freedom	Significance
Locations	2	
Time	3	**
Locations x Time (error a)	6	—
Species	1	*
Temperature	5	
Species x Temp.	5	
Time x Species	3	**
Time x Temp.	15	**
Locations x Species	2	
Locations x Temp.	10	
(error b)	91	—

* Significance at .05 level.

** Significance at .01 level.

exists between locations should be modified to include the requirement that the stage of seed development must be somewhat similar for each location.

Time is important as would be expected. A germination pattern somewhat similar to the 1954 experiment resulted with the exception that a greater amount of seeds germinated in the final time period. (Table 13).

TABLE 13

Average Germination of *C. viscidiflorus* and *C. nauseosus* Seeds During Four Time Intervals, 1955

Time interval	*C. nauseosus*	*C. viscidiflorus*	Mean for time interval
0-48 hrs.	6.2	.9	3.5
	*	*	
48 hrs.-7 days	12.8	4.8	8.8
	*	*	
7 days-14 days	7.6	8.3	7.9
	*	*	*
14 days-42 days	15.8	16.9	16.4
	10.6 *	7.7	

Time L.S.D. = 5.79 at .05 level.
Time x Species L.S.D. = 1.09 at .05 level.

* Denotes that the difference between the means indicated is greater than the L.S.D.

A significant difference in seed germination exists between C. nauseosus and C. viscidiflorus. This conclusion was suggested in the previous study, but was unsupported by conclusive evidence. One caution should be attached to this conclusion, however, that each species used in this study were given an identical cleaning treatment to remove all empty or low density seeds and any deviation from this schedule could possibly produce different results.

As was the case in the 1954 study, germination temperatures and the interaction between germination temperatures and species showed no significance. This again substantiates the conclusion that the experimental temperatures were not limiting to germination, provided that ample time was available.

The relationship between time and species is further clarified by this study, as there is a significant difference between each of the time intervals. However, the same germination pattern observed in 1954 is evident whereby C. nauseosus germinates faster than does C. viscidiflorus. Greater germination than in the 1954 study appeared in the time period between 14 and 42 days because of the application of a fungicide. This suggests that many seeds in the field may be destroyed by seed-borne pathogens.

Time and temperature relationships in this experiment are essentially the same as reported previously with the exception that a slightly longer period of time appeared to be necessary at each temperature in the entire experiment.

Inasmuch as no significance was indicated for locations, there is correspondingly no relationship indicated between locations and species or between locations and temperatures.

Effects of Freezing and Soaking Upon Germination

Rabbitbrush seeds normally undergo a certain amount of freezing temperatures during the winter months and seeds might be either moist or dry at the time of freezing. Inasmuch as *C. viscidiflorus* seeds appeared to be somewhat lower in germination as compared to *C. nauseosus*, a study was designed to test germination after soaking and freezing pregermination treatments.

Methods. Combinations of soaking and temperature treatment were; seeds soaked and frozen 72 hours, seeds dry frozen 72 hours, seeds dry frozen 16 hours, and a control having no soaking or freezing. Fifty seeds of each species were germinated for 8 weeks at three temperature levels and under each pregermination treatment.

Results and Discussion. Data were statistically analyzed by means of an analysis of variance with a randomized block design. Significance was indicated for treatments at the .05 level and for the interaction of species and treatments at the .05 and .01 levels. Values of L.S.D. may be used to compare differences between the average number of seeds of each species that germinated after each pregermination treatment. (Table 14).

C. viscidiflorus seeds soaked and frozen for 72 hours had

TABLE 14

Average C. nauseosus and C. viscidiflorus Seed Germination as Related to Soaking and Freezing Prior to Germination

Pregermination Treatment	C. nauseosus	C. viscidiflorus	Treatment Means
Control (no pretreatment)	44.3	24.3	68.6
Soaked, frozen 72 hrs.	17.0*	35.3*	52.3
Dry-frozen 72 hrs.	40.3	28.3	68.6
Dry-frozen 16 hrs.	38.0	29.6	67.6

Treatment L.S.D. = 3.48 at .05 level.
Species x Treatment L.S.D. = 9.03 at .05 level.
" " " = 16.58 at .01 level.

* Indicates a significant difference between means.

a significantly higher germination average than the control. (Table 14). Freezing for 16 or 72 hours without soaking did not result in any significant differences although the data suggest that a slight increase may have resulted. C. nauseosus seeds appear to suffer a reduction in germination as a result of soaking and freezing. Freezing alone may reduce germination slightly but not enough to be significant. From these data then, the conclusion may be reached that a pregermination treatment of soaking and freezing for 72 hours results in increased germination of C. viscidiflorus seeds, but a decrease in C. nauseosus. No change in germination results from freezing if seeds are not soaked.

Freezing Temperatures During Germination

C. viscidiflorus and C. nauseosus seedlings should be resistant to freezing temperatures during germination. As a general rule, night temperatures drop below freezing during the period of seed germination under field conditions.

Methods. A small experiment was designed to study the effect of freezing on seeds germinated at $5^{o}C.$, $15^{o}C.$, and $30^{o}C.$

Fifty seeds of each species were placed on moist filter paper in separate germination dishes. One dish of each species was placed at each temperature. After seven days the number of germinated seeds were noted and all six dishes were placed in $-5^{o}C.$ temperature for 24 hours. At the end of this period the dishes were returned to their original temperatures. Survival was based on the appearance of seedlings at the end of one week. By this time life or death was readily apparent. Subsequent germination was recorded at the end of 6 weeks.

Results and Discussion. Although limited data are provided, there is some evidence that very young seedlings are able to survive freezing temperatures if they have germinated under conditions of low temperature. (Table 15). In addition, these data bear out the conclusion that germination of C. viscidiflorus seeds is increased by a pretreatment of soaking and freezing which was essentially what happened to the C. viscidiflorus seeds that germinated after the 24 hour freeze.

TABLE 15

Effect of Freezing Temperatures on Young Seedlings

and Subsequent Germination

	Germination Temperatures					
	5°C.		15°C.		30°C.	
Conditions	*C. nauseosus*	*C. viscidiflorus*	*C. nauseosus*	*C. viscidiflorus*	*C. nauseosus*	*C. viscidiflorus*
No seeds germ. in 7 days	32	15	35	17	40	7
No seedlings survived after 24 hr. freeze	5	5	0	0	0	0
Subsequent germination	10	32	3	28	0	15

Inhibition of Germination

No formal experiment was set up to investigate inhibition, although some observations of germination suggest that under certain conditions inhibition may be operating.

In an effort to germinate all of the viable seeds in some *C. nauseosus* seed collections in which the extraneous plant material was not removed, but was present in the germination dish, the germination percentage was extremely low. At the same time these seeds were in the germinator, another experiment was being conducted with seeds of the same species but from another location. The extraneous material consisting of involucral bracts, pappus, and dried corollas had been removed. In the latter experiment a much higher germination response was obtained. Certainly this evidence is not conclusive, but interesting enough that further investigations should be made.

SEEDLING ESTABLISHMENT

Introduction

Seedling establishment is the critical period in the life cycle of a plant. During this period many important environmental factors have to be met or tolerated for the seedling to survive. Many ecologists are of the opinion that the seedling stage is the deciding point in important ecological relationships such as succession, competition, invasion, and dominance.

Successful invasion of rabbitbrush into improved pastures and depleted rangelands depends upon the ability of rabbitbrush seedlings to become established under field conditions which may often be less than optimum. Characteristics which may enable seedlings to survive under the harsh semi-desert environment may include a high rate of radicle and root growth, a tolerance to high and low temperatures, an endurance of drought, a tolerance of soil conditions, which might include a range from coarse to finely textured heavy soils, and be able to germinate and grow at various depths of planting.

The adverse field conditions described above may be a barrier to establishment in most years, but there are some years in which field conditions are not as limiting. The presence of groups of even-aged rabbitbrush stands indicate that it was in these favorable years that many of the present day colonies of rabbitbrush became established.

Experimentation to determine some of the conditions under which rabbitbrush becomes established was carried out in the greenhouse and where possible, in the field. Sagebrush seedlings were included in many of the studies for comparison.

Data from these experiments indicate to a degree some of the capabilities of rabbitbrush for establishment.

Seedbed Condition

The condition of the seedbed is an important factor in seedling establishment and many species have been investigated from this point of view. Glendening and Paulson (21) found that most velvet mesquite (*Prosopsis juliflora* var. *velutina* (Woot.) Sarg.) seeds failed to germinate on the surface of bare mineral soil. Although a few seeds did germinate, the radicles failed to penetrate the soil. They concluded that maximum germination occurred on coarse, sandy soil at a planting depth of one inch. Wilson (60) found that seedlings of chamiza (*Atriplex canescens* James) became established from fall germinations in the shade of other bushes. Highest germinations of *A. canescens* occurred from seeds lying near the surface of the soil for a few months before cool weather arrived. He concluded that the best planting depth depended upon the soil texture. Field observations of guayule made in Brewster County, Texas, by Muller (35) indicated that seedlings were found principally on minor level spots with a fair mantle of soil. A small amount of duff did not appear to affect germination, but thick duff layers reduced germination by excluding seeds from contact with the soil.

The foregoing references merely point out some of the seedbed conditions required for the establishment of various semidesert plant species. Inasmuch as rabbitbrush appears to be most competitive on disturbed areas the question arises as to what necessary seedbed condition, if any, is supplied by disturbances.

A comparative study in the greenhouse considered the seedbed conditions required by A. tridentata, C. nauseosus and C. viscidiflorus.

Methods. Fifty seeds of each species were planted in 12" x 18" greenhouse flats filled with pumice soil under each of the following conditions:

1. On bare soil surface.
2. On soil surface covered with grass and shrub litter.
3. On soil surface covered with powdered sagebrush leaves and stems.
4. Covered with 1/8" of pumice soil.
5. Covered with 1/4" of pumice soil.

Conditions No. 1 and No. 2 were selected because of the natural or undisturbed conditions they suggest. Condition No. 3 was used to test for possible inhibition of germination and establishment because of the presence of sagebrush. Conditions No. 4 and 5 were selected on the assumption that disturbance would result in a cover of soil by reason of trampling animal feet and wind blown soil particles. Seeding depths of 1/8" and 1/4" were maintained by leveling the soil surface in the greenhouse flats. Wooden toothpicks with two marks 1/8" or 1/4" apart were then inserted in the soil up to the first mark. Seeds were sown and soil was then scattered over the flat until the second mark on the toothpick was covered.

Flats were lightly watered twice weekly which allowed the soil surface to dry out between each watering. Seedlings were counted as being established and were removed from the flat one week after cotyledons had expanded and become functional. The experiment was carried on for five weeks to allow for delayed germination. Reliability of experimental results was increased by repeating the experiment three times.

Results and Discussion. Data from this experiment was analyzed as a split plot statistical design. Significance was indicated at the .05 level for seedbed conditions, but not for species. The interaction between seedbed condition and species also failed to indicate any significance.

Very little seedling establishment of any species occurred on the bare soil surface or on the soil surface covered with a thin layer of sagebrush powder. No conclusion can be reached concerning inhibition of germination or seedling growth by the sagebrush powder. This condition was too similar to the bare soil conditions and yielded results too variable for any clear interpretation. On the other hand, moderately high establishment of all seedlings occurred under grass and shrub litter cover, 1/8" soil cover, and 1/4" soil cover. A significant difference was indicated between surface plantings without any litter cover or with a thin layer of sagebrush powder and the other seedbed conditions. Seedling establishment is greatest where there is some type of cover, either litter or soil.

The experimental results of the interaction between species and seedbed condition justify the conclusion that there is no difference in seedbed requirements on this soil type between the three shrub species considered. Apparently rabbitbrush and sagebrush have a fairly wide tolerance for various seedbed conditions. The ability to become established under various seedbed conditions would seem to be an important contributing factor to the success of these shrubs in assuming dominance in plant communities.

Because this experiment was conducted on one soil type, conclusions are rather limited in their scope. Further trials were initiated with soils from several locations and the results appear in the following section.

Depth of Seeding in Various Soils

Little work has been done on the response of shrubs from arid regions to soils and depth of seeding. Most literature on the subject concerns cultivated crops on productive soils. Data reported by Murphy and Arny (36) indicate a differential response of grasses and legumes to depth of planting on five soils. A greater planting depth in heavier soils gave less seedlings emergence. A study of depth of seeding timothy (*Phleum pratense* L.) by Williams (59) in relation to different moisture levels indicated that deeper planting gave best results under low moisture. When considered in terms of rabbitbrush this may be very important under dry range conditions on sandy soils.

Rabbitbrush has been reported by Daubenmire (15) in climax association on sandy soils, but field observations in many areas indicate that it occupies other soil types under disturbed conditions. To determine whether this occurrence is due to some response in the seedling stage, six soils from various locations in eastern Oregon were used in greenhouse experiments.

Methods. Selection of soils for the experiment was based on location and presence or absence of rabbitbrush. A brief description of the location and type of vegetation of the soils chosen for experimentation follows:

No. 1. Millican valley bottomland. Windblown pumice soil supporting a dense stand of *C. viscidiflorus* with some *A. tridentata* and *Sitanion hystrix*. Sample taken at 0" - 6".

No. 2. Five miles east of Millican on higher ground, and of a finer texture than No. 1. Vegetation present included *A. tridentata* and *C. viscidiflorus* in equal dominance, plus *Festuca idahoensis* Elm., *Poa secunda* Presl. and *Eriogonum* spp. Sample taken 0" - 6".

No. 3. Squaw Butte Experiment Station. South Range. Sandy in appearance. *C. viscidiflorus* abundant. Other species mentioned for No. 2 were present in this area. Impervious caliche layer at 18"-20". Sample taken 0" - 6".

No. 4. Near entrance to Squaw Butte Experiment Station on gentle north facing slope. Shallow rocky soil supporting a stand of *Artemisia arbuscula* and *C. viscidiflorus*. Other plants present included *Festuca idahoensis*, *Sitanion hystrix*, *Koeleria cristata*, *Eriogonum sphaerocephalum*. Sample taken 0" - 4".

No. 5. One mile from entrance to Squaw Butte Experiment Station. Alkaline bottomland area vegetated primarily with *Artemisia cana* and *Muhlenbergia* spp. No rabbitbrush present. Sample taken from 0" - 3".

No. 6. Two miles east of Clarno in a dry canyon bottomland. A red clay soil. Soil appeared to be "self-mulching" with the two surface inches cracked and broken up by contraction upon drying. No vegetation present except for a few weedy annuals. Sample taken 0" - 3".

These soils were further characterized by laboratory determination of pH, particle size, cations and cation exchange capacity. (Table 15). Data on cations and cation exchange capacity were provided by the Soils Testing Laboratory, Oregon State College.

Soils were prepared for the experiment by breaking up clods and sieving through a 1/4" mesh screen. Three greenhouse flats were filled to within an inch from the top with each soil. Each flat was sub-divided into three sections and the following species and depths were completely randomized over the nine sub-divisions for each soil type:

Three species. *C. nauseosus*, *C. viscidiflorus* and *A. tridentata*.
50 seeds for each.

Three depths. Surface with litter, 1/8" and 1/4".

Proper depth was maintained by marked toothpicks as described in the previous experiment with seedbed condition. A 1/8" layer of peat moss was scattered over the surface planting to provide better moisture relations and to simulate to litter condition in the field. This was necessary in view of the extremely low germination obtained in the previous experiment where seeds were placed only on the bare soil surface. Flats were sprinkled equally twice weekly for a period of five weeks at which time the number of seedlings established was recorded and the experiment was repeated. A total of three replicates was carried out.

Results and Discussion. The six soils in the experiment appear to fall into three groups. (Table 16). The first group includes Soils No. 1, 2, and 3, which, according to Textural classification of the Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. D. A., are loamy sands. They have a low cation exchange capacity and support rabbitbrush and sagebrush vegetation. The second group of soils includes Nos. 4 and 5 and covers a wider range of variability. These soils classify as sandy loam and loam soils respectively. Only the sandy loam soil had *C. viscidiflorus* growing on it. A third category consists only of No. 6, a clay soil which is very different from the other five soils in many respects, most important of which is its "self-mulching" characteristic. This characteristic may be due to the flocculating action of its high sodium content or to the presence of 2:1 expanding lattice clays. The absence of any permanent vegetation on this soil seems to be a result of arid conditions and the loss of water by cracking and baking.

TABLE 16

Certain Characteristics of Six Soils From Eastern Oregon

Soil No.	Mechanical analysis % Sand	% Silt	% Clay	Textural class	pH	Parts per million Ca	K	Mg	Na	C. E. C. me/100 g.
1	84	13	3	Loamy sand	6.8	1200	770	640	15	11.09
2	84	11	5	Loamy sand	6.3	1290	515	515	22	11.59
3	81	14	5	Loamy sand	6.7	1000	440	730	17	11.26
4	59	30	11	Sandy loam	6.8	1670	770	1500	52	19.53
5	48	32	20	Loam	5.8	1660	770	1170	62	19.15
6	30	28	42	Clay	7.1	7500	665	980	710	47.46

Data on seedling establishment was statistically analyzed by a randomized block design. (Table 17).

TABLE 17

Summary of Statistical Analysis of Seedling Establishment at Different Depths on Six Soils of Eastern Oregon

Source of Variation	Degrees of Freedom	Significance
Replication	2	**
Soil	5	**
Species	2	
Soil x Species	10	*
Depth	2	**
Soil x Depth	10	
Species x Depth	4	**
Soil x Species x Depth	20	

* Indicates significance at the .05 level.

** Indicates significance at the .01 level.

The average number of seedlings established in the entire experiment was similar when considered independent from interactions with particular soils and planting depths. (Table 18). However, there are differences between the response of these species at different depths and on different soils. By means of L.S.D. values conclusions may be drawn as to whether there is a

TABLE 18

Average Seedling Establishment on Six Soils

from Eastern Oregon

Soil No.	Average Seedling Establishment *C. nauseosus*	*C. viscidiflorus*	*A. tridentata*	Soil mean
1	10.6	7.0	12.0	9.9
2	10.3	5.4	9.4	8.4
3	4.9	.7	4.4	3.3
4	5.8	6.0	2.9	4.9
5	2.2	.7	2.9	1.9
6	2.3	10.00	7.1	6.5
Species Mean	6.0	5.0	6.5	

Soil L.S.D. = 2.87 at .05 level, 3.80 at .01 level.

Soil x Species L.S.D. = 4.98 at .05 level.

real difference between various soils, depths, Soil x Species interactions or Species x Depth interactions.

Seedling establishment on the six soils appears to be related to the texture (Table 18). A difference of 3.8 between the average of the means of the first three soils and the average of the means for Soil No. 4 and 5 is greater than the L.S.D. The three plant species used in the experiment are more successful on loamy sand soils similar to Nos. 1, 2, and 3 than on sandy loam and loam soils similar to No. 4 and 5. Establishment of seedlings on the heavy red clay soil was much higher than would be expected and may be related to flocculation and self-mulching of this soil upon drying.

Even though a high degree of variability exists for the response of these species on the six soils, a trend is readily apparent by looking at the various species means on each soil type. (Table 18). The difference between the species means on No. 1, the sandiest soil, and on No. 5, the heaviest soil, is greater than the L.S.D. However, there is not a significant difference between the general response on the three sandy soils and on the two heavy soils. Again Soil No. 6 should not be compared with the other five soils, because it does not behave exactly as a heavy soil, due to self-mulching which allows seedling emergence up through many small cracks in the surface.

Even though soil No. 6 had no rabbitbrush or sagebrush growing on it, the results of this experiment suggest that under moist conditions seedlings of woody species could become established. Whether seedlings would be permanent on this type of soil would depend on other factors, such as frost heaving and high surface temperature.

C. viscidiflorus appears to be highly variable in its response which may be interpreted as an indication of the wide ecologic amplitude this species possesses. No definite conclusion can be made regarding seedling establishment on various soils, although there is some evidence suggesting that part of the success of rabbitbrush may be attributed to the easier seedling emergence possible in sandy soils.

Selection of 1/8" and 1/4" planting depths was based on the observation that very little opportunity exists in the field for a soil cover much greater than 1/4", except in special cases of disturbance. However, the responses to the depths used in the greenhouse flats are not directly transferable to the field mainly because of different moisture relations. Under conditions experienced in the greenhouse, planting depth appears to be very important. The conclusion that there is a difference between seedling establishment at various planting depths is justified and in agreement with most findings in relation to this subject. (Table 19). In addition, these data further clarify the results obtained in the seedbed-condition experiment, which, because of limited observations did not indicate any significant difference between species under the various seedbed treatments. Here is seen at least a difference between surface, 1/8" and 1/4" planting depth for all species. No significance was indicated for the interaction, soil x depth, which should yield pertinent data, but was either masked by the low seedling establishment on heavy soils and the relatively high seedling establishment on sandy soils regardless of depth, or by modification of soil relationships by greenhouse conditions.

TABLE 19

Average Seedling Establishment in Relation to

Depth of Planting

Planting depth	Average Number of Seedlings Per Species					Depth mean
	C. nauseosus		*C. viscidiflorus*		*A. tridentata*	
Surface	9.1	*	5.5	*	14.4	9.7
					*	*
1/8"	6.4		6.1		4.3	5.6
	*				*	*
1/4"	2.6		3.3		.6	2.2

Depth L.S.D. = 2.69 at .05 level, 2.03 at .01 level.

Species x Depth L.S.D. = 3.52 at .05 level, 4.66 at .01 level.

* Indicates significance between means.

Further information is available in considering individual species response at the various planting depths. (Table 19). There appears to be no difference between surface and 1/8" planting for *C. nauseosus*, but there is a difference at the .05 level between 1/8" and 1/4". *C. viscidiflorus* indicated no significant difference between any of the planting depths which again may be a further suggestion of its wide range of tolerance. *A. tridentata* seedling establishment appears to be significantly greater at the surface and at 1/8" depth than at 1/4" depth, which leads to the conclusion that sagebrush requires a shallow planting depth. In the experiment with seedbed condition the hypothesis was advanced that seedling establishment at a shallow seeding depth indicated undisturbed conditions. Thus, sagebrush could be characterized as being most successful as a climax species as compared to rabbitbrush which increases its range and invades new areas as a result of disturbance.

The second order interaction, species x soil x depth, did not indicate any significance. Interactions of this type are difficult to interpret and, considering the high degree of variability in the data, no attempt will be made to explain this result.

Success of seedling establishment on arid sandy soils evokes speculation as to why and how these soils provide essential conditions. These sandy soils are low in their nutrient holding ability as indicated by a cation exchange capacity. (Table 15). Correspondingly, base saturation is high. Sandy soils have a low specific surface which results in a low water holding capacity. In addition, they experience rapid percolation, making soil moisture unavailable to shallow-rooted plants. However, these disadvantages are balanced by favorable features. Root penetration is greater in sandy soils. Veihmeyer and Hendrickson (54) found that the size of the pore spaces was limiting to the penetration of grape roots, which would not penetrate soils with an apparent density of 1.9 or above. Seedling emergence is also greater in sandy soils due to the lack of crust formation. Shaw (47) states that the most important effect of crusts is the prevention of seedling emergence. Excavations at the end of the experiment revealed that many seedlings were unable to penetrate the crust formed on soils No. 4 and 5.

This study suggests that the greater occurrence of rabbitbrush on coarse textured soils of eastern Oregon may be partly related to certain factors in the seedling stage. Coarse textured or flocculated soils appear to permit greater rabbitbrush seedling emergence and root growth.

Initial Seedling Establishment in the Field

Experimental work in the greenhouse indicated a large number of seedlings associated with a litter or soil cover. Even though greenhouse studies supply valuable information and clarify some plant relationships, such studies need to be verified in the field.

Field observations indicated that most seedlings established in previous years could be found in grass and shrub litter on the north and northeast sides of older rabbitbrush and sagebrush plants. In addition to finding seedlings around the base of older plants, they were also found in areas associated with microrelief on the north facing slopes of small mounds of wind blown soil particles and on the north facing rims of small indentations made by animal feet.

Muller makes the observation (35) that the presence of a nurse plant seemed most effective in the establishment of guayule seedlings. He reported that almost every plant capable of casting a shadow was sheltering a few seedlings.

<u>Description</u> <u>of</u> <u>Study</u> <u>Area.</u> Field studies were conducted at Millican which is on the margin of the Harney section defined by Fenneman (19), approximately 20 miles east of Bend and 32 miles directly south of Prineville.

Fenneman noted that the Harney section has internal drainage with the soils made up wholly or in part by broken up pumice that ranges in particle size from dust to lapilli. This area is characterized as a "Great Sandy Desert". Millican was chosen as a site for field experiments because both <u>C. nauseosus</u> and <u>C. viscidiflorus</u> are present in abundance and because this area typifies many of the rangelands on which rabbitbrush is a problem. Although weather data are not recorded at Millican, the approximate weather conditions for the area may be determined from climatic maps of Oregon located in the U. S. D. A. Yearbook for 1941 (57). January temperatures average between 24°F. and 28°F. The July temperatures average between 60°F. and 62°F.

The growing season averages about 80 days in duration; the average day for the last killing frost in the spring occurs between May 10 and June 20, and the first killing frost in the fall occurs about August 30. However, Bend and other Central Oregon areas have recorded freezing temperatures on every day of the year and the same could be expected for Millican.

Annual precipitation is variable from year to year, but generally amounts to between 8 and 10 inches, which occurs mostly during winter months in the form of snow or in spring thundershowers. For more detailed information reference should be made to Tables 3 and 4 concerning precipitation at Squaw Butte Experiment Station which is quite comparable in climate.

Soils of the area are built up from parent material consisting of gray dacite pumice particles of the size of medium sand. Valley bottoms, such as in the Millican basin, have been covered with pumice alluvium from the surrounding hills. The depths of this pumice layer are variable, but generally ranges from 30 to 40 inches and rests on a layer of gravel. There appears to be little organic matter in the A_1 horizon.

Apparently as a result of percolation into the gravel layer, no lime accumulation zone has been found in the valley bottom at Millican.

Soils of the slopes surrounding the Millican basin and soils of similar slopes in the general area are more shallow, possibly because of erosion and loss of the pumice mantle to the valley bottom. Pumice particles are present in lesser concentration in the soil profiles of these slopes.

In the valley bottom at Millican the following profile may be characterized:

A_1 0-1"	Light brown. Medium sandy soil, slight surface crust in spring that disappears upon drying. Organic matter lacking or very low.
C 1-36"	Gray brown. Medium sandy soil. Some finer particles accumulated in this horizon. Has a general uniform appearance.
D 36"-	Medium gravel.

Soils of this area are droughty soils because of the pumice. Therefore, they look more like the Grey Desert soils than they actually are. The Prineville and the Deschutes soil surveys[2] list soils in adjacent areas as Brown soils or Chestnut soils. This suggests that the soils in the Millican area might not be as closely related to desert soils as was described in the 1938 Yearbook of Agriculture (48).

Soil moisture determinations were made in the summer of 1954 and 1955 by means of electrical resistance readings of plaster-of-paris blocks. Ten moisture sampling stations were located 0.2 of a mile apart along the graded road that leads to the Cabin Lake ranger station. Blocks were placed 6 inches away from the north east side of a mature rabbitbrush plant at four depths; 36 inches, 18 inches, 12 inches, and 4 inches. Readings were taken approximately every two weeks from the last of April to the last of August each year. (Table 20).

Since Table 20 does not indicate the amount of variability for the mean ohms resistance at the various depths, this information is provided in the appendix. In the sagebrush and rabbitbrush covered valley at Millican there appears to be little variation in the bottomland area. However, electrical resistance readings for this area indicate a high degree of soil moisture variability between locations. As an example, most of the

2. Soil Conservation Service, U. S. Dept. of Agriculture. Descriptive Legends in Unpublished Soil Surveys of the Prineville and the Deschutes areas.

TABLE 20

Mean of Ohm Readings Obtained by Bouyoucos Bridge at Four Depths for Ten Field Locations Near Millican, Oregon - 1954 and 1955

Date	Depth 4"	12"	18"	36"
1954				
May 2	1,550	1,390	1,380	1,230
May 8	1,611	1,686	1,266	1,230
June 12	1,800	1,300	2,180	1,520
July 10	364,814	275,890	74,730	33,700
Aug. 3	53,000*	408,375	71,906	40,218
Aug. 29	972,222	241,560	210,380	130,155
1955				
April 23	16,770	66,690	79,780	78,730
May 14	26,710	57,190	64,350	60,870
May 28	12,750	49,480	62,000	50,568
June 12	336,470	96,240	101,400	72,140
June 30	647,060	201,200	194,780	122,360
July 9	248,100	195,000	187,100	99,600
July 26	1,084,000	248,300	226,150	144,850
Aug. 5	1,550,000	540,900	304,000	190,630
Aug. 22	1,396,000	510,500	371,800	185,650

* Readings were not obtained on 5 plots.

readings on August 22, 1955 for the 36" depth were about 200,000 ohms, but the range was from 7,900 to 500,000 even though blocks at each of the depths sampled were within a range of 100 ohms variability when calibrated in distilled water in the laboratory. The data collected during the years 1954 and 1955 indicate that these areas would require a considerable number of soil-moisture observation stations to adequately sample the range of variability that exists in an otherwise uniform looking area.

The admittedly inadequate sampling does indicate, however, that depletion of soil moisture in the general area occurred at a fairly rapid rate in 1955 and by June 30 most locations had an extremely low amount of available water remaining. This makes a very striking comparison with the same period in 1954. (Figure 13). Obviously, there is quite a difference between the available moisture remaining at the end of the growing season, even when two comparatively dry summers are considered. (Table 3). These data are particularly significant because of the location of the plaster-of-paris blocks near the base of mature rabbitbrush plants where seedlings have been observed to be most successfully established in previous years.

Calibration of ohms resistance in terms of percent moisture of the pumice soil from this area is discussed in a later section dealing with drought endurance of seedlings in pumice soil. For information dealing with the relationship of ohms resistance to percent moisture reference should be made to Figure 18.

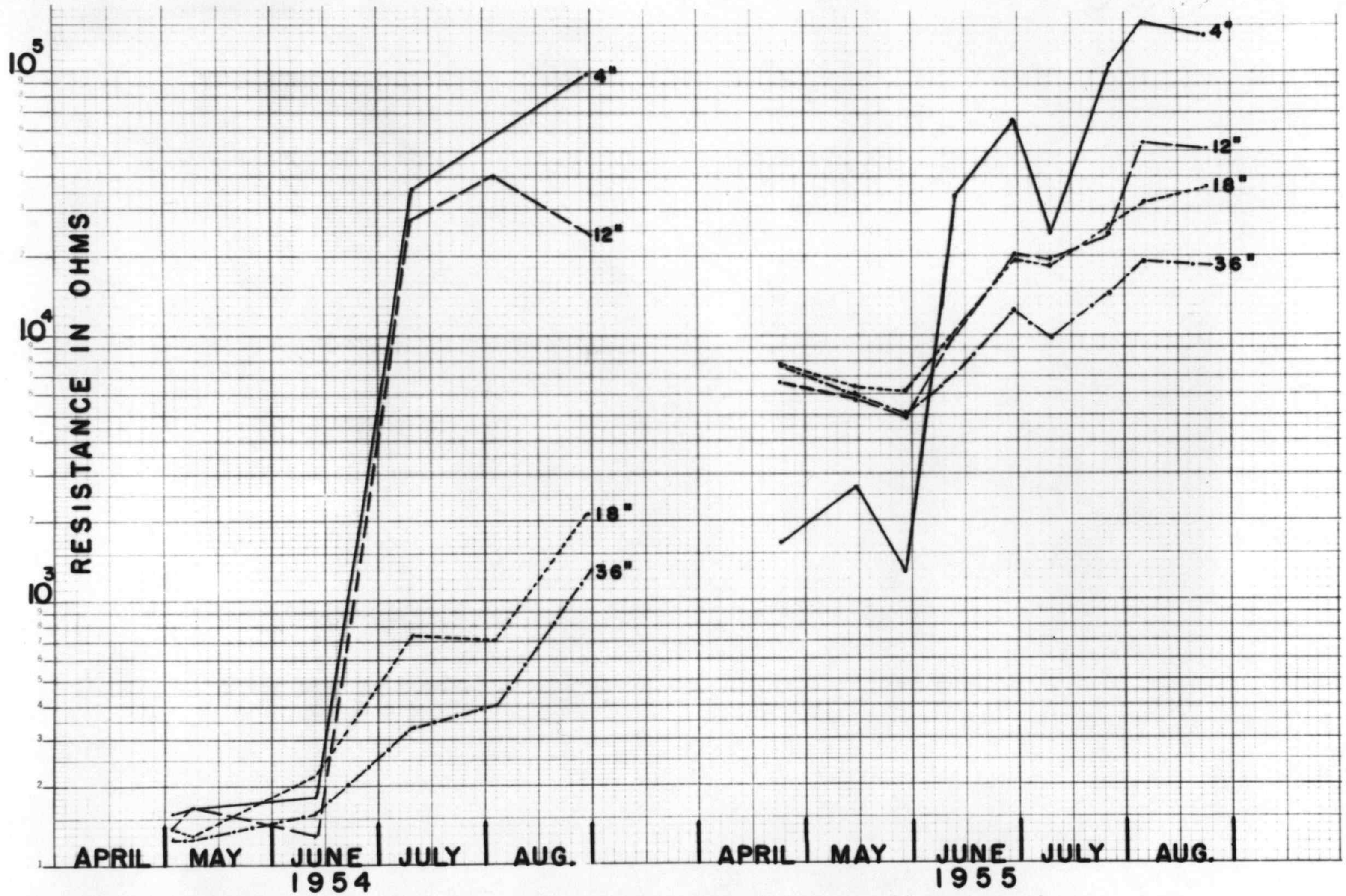

Figure 13. Average ohms Resistance at 4 depths for 10 field locations near Millican, 1954-55.

Methods. Field study plots on seedling establishment were set up in areas adjacent to the ten soil moisture sampling stations. All vegetation was removed for an area of approximately 100 square feet to avoid the effects of competing vegetation. The purpose of these plots was to evaluate *C. nauseosus*, *C. viscidiflorus* and *A. tridentata* seedling establishment under combinations of shade, no shade, litter, and no litter. To avoid the possible introduction of seeds contained in natural litter in the area, dry greenhouse peat moss was substituted. A lath shade frame three feet square provided approximately 50% shade. (Figure 14).

On March 26, 1955, 100 seeds of each shrub species were planted at approximately 1/4" depth under each of the following conditions:

1. Under shade frame with peat moss litter.
2. Under shade frame without peat moss litter.
3. No shade with peat moss litter.
4. No shade without peat moss litter.

Visits were made to the plots every two weeks to make observations on seedlings, temperature, and moisture. Soil surface temperatures under the shade frame and in the open were recorded by maximum thermometers. Soil moisture at 4" soil depth was measured by a plaster-of-paris block.

Results and Discussion. Immediately after seeds were planted the area was covered with about one inch of snow. Temperatures remained fairly low for over two weeks, thus permitting some semblence of a normal cold treatment for the planted seeds.

Figure 14. A view of field experimental design for seedling establishment study.

Very few of the 4,000 seeds of each species germinated. By April 23 some seedlings had developed, but on May 14 a few additional seedlings were recorded. A greater number of *C. nauseosus* seedlings were recorded in initial establishment than were *C. viscidiflorus* seedlings. (Table 21). Apparently the conditions for pretreatment of sagebrush seeds, storage temperatures, and field temperatures after seeding were not satisfactory for germination of sagebrush as indicated by the complete lack of any sagebrush seedlings.

TABLE 21

Total Number of Seedlings Initially Established Under Field Conditions of Shade and Litter

	Number seedlings established		
	C. nauseosus	*C. viscidiflorus*	*A. tridentata*
Shade with litter	34	39	0
Shade without litter	52	35	0
No shade with litter	22	4	0
No shade, no litter	12	1	0
Total seedlings	~~12.0~~ 120	79	0

Data on initial seedling establishment were not statistically analyzed because of the variability of the data and because of the comparatively low number of seedlings involved, especially where no shade was provided. The experiment is valuable, however, because it emphasizes the large number of viable seeds required for initial seedling establishment, and because there are at least some suggested requirements for seedling establishment in the field. Shade appears to be important, especially in a dry year, as indicated by the establishment of 160 seedlings under shade as compared with 39 seedlings established out in the open. Ninety-nine seedlings were observed under a litter cover as compared to 100 seedlings on plots without a litter cover, which suggests that a litter cover is not an essential factor as long as shade and soil cover is provided. Another interesting point is the higher number of C. nauseosus seedlings that became established in the experimental plots which are on a typically C. viscidiflorus habitat. Evidently the reason for the absence of mature C. nauseosus plants in the bottomland area at Millican is due to some factor other than initial seedling establishment.

More conclusive evidence probably could be obtained in a future study concerning rabbitbrush seedling establishment by obtaining more seedlings through fall planting or the good fortune of receiving more favorable spring weather conditions, whatever they may be.

Seedling Mortality in the Field

To obtain an estimate of field conditions under which seedlings exist or die, observations were made of seedlings initially established in the preceding study.

Methods. Mortality of seedlings was recorded at successive two-week intervals. Soil surface temperatures on shaded and unshaded areas were recorded along with soil moisture readings for each cleared experimental area.

Results and Discussion. By June 12 over half of the seedlings had died. The actual cause of seedling mortality is difficult to ascertain from the data obtained. (Table 22). In addition to low moisture and high soil surface temperature one would expect that rate of temperature rise and rate of soil moisture depletion would be interacting to produce an unfavorable environment. Field observations suggest that root development was retarded by unfavorable conditions and as a result roots did not grow fast enough to keep up with soil moisture depletion. Further evidence is given to this hypothesis by root excavations on June 12. (Figures 15, 16). Without disturbing young plants still living, many of the dead seedlings were carefully removed from the soil. The average root length of 23 *C. nauseosus* seedlings was 18.4 mm., as compared with an average root length of 19.8 mm. for 17 *C. viscidiflorus* seedlings.

The conclusion appears justified that even though *C. nauseosus* and *C. viscidiflorus* seeds are able to germinate and the seedlings are established, they will not persist if spring rains are not forthcoming during May and June to maintain adequate soil moisture near the surface.

TABLE 22

Seedling Mortality, Soil Surface Temperature, and Soil Moisture at 4" Depth

Date	No. dead *C. nauseosus* seedlings Shade	No. dead *C. nauseosus* seedlings No Shade	No. dead *C. viscidiflorus* seedlings Shade	No. dead *C. viscidiflorus* seedlings No Shade	Average soil Surface temp. Shade	Average soil Surface temp. No Shade	Mean ohm reading at 4"
May 28	15	13	6	0	114.0	131.0	1,240
June 12	51	13	43	0	130.8	146.3	66,580
June 30	12	8	15	4	136.3	151.4	157,639
July 9	8	0	10	1	108.1	127.0	35,520
	86	34	74	5			

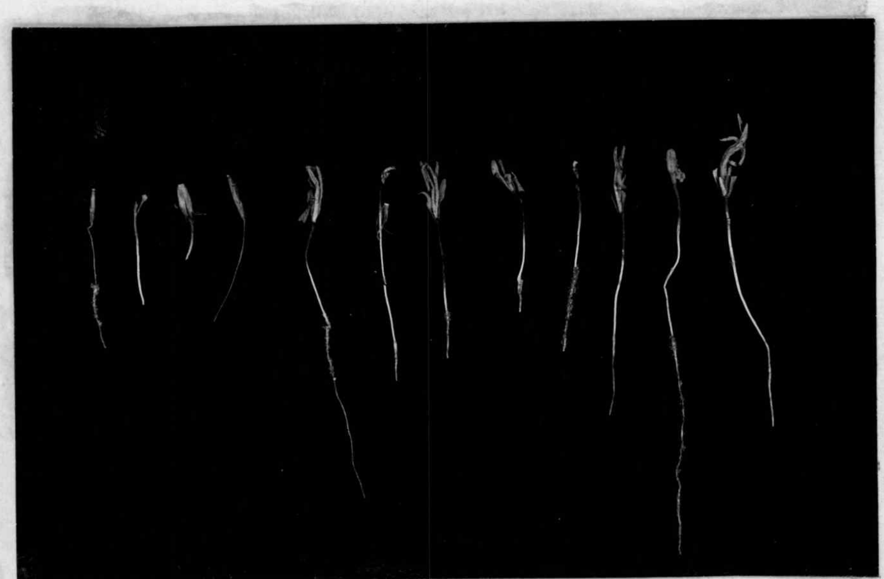

Figure 15. Dead C. nauseosus seedlings excavated on June 12, 1955.

Figure 16. Dead C. viscidiflorus seedlings excavated on June 12, 1955.

Radicle Elongation

One of the most important features of rabbitbrush seedlings is a rapid elongation of radicles and young roots. This characteristic is extremely advantageous in the dry sandy soils of eastern Oregon where roots must grow fast enough to keep pace with soil moisture depletion in the upper soil profile.

Methods. To study the rate of radicle and root elongation, 12 to 24-hour-old seedlings of *C. nauseosus*, *C. viscidiflorus*, and *A. tridentata* from the seed germination experiment were used. These seedlings were taken from the germination dishes and placed on moist paper toweling, which was rolled and placed in an upright position in the seed germinators at the same temperatures used in the germination experiment. Because of the problem of differentiating between hypocotyl and radicle in some seedlings, only total elongation was considered. Millimeters of elongation was measured every 12 hours for the first three days and then the time interval was extended to every 24 hours.

Results and Discussion. A comparison of the rate of radicle elongation of rabbitbrush and sagebrush reveals that rabbitbrush seedlings have an elongation rate approximately twice that of sagebrush seedlings. (Table 23). Unless this difference is later modified by more rapid growth or different character of growth, *C. nauseosus* and *C. viscidiflorus* seedlings appear to have an advantage over *A. tridentata*. Data from other experiments clarify this point.

TABLE 23

Radicle Elongation of Ten Seedlings of C. nauseosus, C. viscidiflorus and A. tridentata

for 36 Hours at Six Temperatures

		Temperatures in degrees centigrade					
Species	Replication	30°	20°-30°	20°	15°	10°	5°
C. nauseosus	1	9.9 mm	9.9 mm	10.7 mm	7.45 mm	2.4 mm	1.43 mm
	2	10.2 mm	14.3 mm	8.4 mm	6.9 mm	2.8 mm	1.1 mm
C. viscidiflorus	1	9.7 mm	7.0 mm	8.7 mm	5.15 mm	2.3 mm	2.18 mm
	2	7.9 mm	7.5 mm	9.2 mm	7.5 mm	2.4 mm	1.15 mm
A. tridentata	1	3.2 mm*	4.0 mm**	6.8 mm	4.4 mm	1.2 mm**	.43 mm***
	2	4.5 mm*	3.5 mm	5.3 mm	4.0 mm	(did not germinate)	

* Average of 5
** Average of 2
*** Average of 3

The highest rate of radicle elongation occurs either at 20°, 20°-30°, or 30°. An examination of the data indicates that variation exists, but there appears to be no difference between these temperatures. Most interesting is the fact that elongation still takes place at temperatures as low as 5°C.

Root Growth

Root penetration and habit of growth have been considered by many researchers as the key to a better understanding of the basic relationships between competing plant species. Some interesting studies on root development have been made by Weaver (55,56), Cannon (9), Hendrickson and Veihmeyer (26) and Muller (35). Muller's work on guayule (*Parthenium argentatum* A. Gray) is a classic in its complete treatment of root development under native conditions in the field and as a cultivated crop. The guayule study has particular significance to this study because of the arid conditions under which both guayule and rabbitbrush grow.

A high rate of root growth has been observed in the seedling stages of rabbitbrush and sagebrush in the field and in greenhouse studies. One-year-old seedlings of *C. viscidiflorus* and *C. nauseosus* excavated in the field had roots over 30 inches long.

Methods. Root studies in the greenhouse were made in three specially constructed root observation columns. These columns were 36 inches tall and 12 inches square, but the front side consisted of a plate glass slanted inward toward the bottom of the column. Sandy pumice soil from Millican was used as a rooting medium which provided a uniform but natural condition.

Ten small seedlings of each shrub species were transplanted to the front of each column where the roots could be observed and measured as they grew down along the slanted glass. After each weekly measurement a fiberboard cover was placed over the glass front to maintain darkness. Plants in each column were equally watered once a week for the first four weeks of the four month long experiment.

To obtain measurements from more than the ten seedlings that could be lined up along the glass front of the column, another experiment was set up in which all of the square foot surface area of each column was seeded with seeds of the three species. Plants were grown for two months and then one side of each column was removed to permit the soil to be carefully washed away from the roots.

Results and Discussion. At the end of four months *C. nauseosus* roots were longest and *C. viscidiflorus* roots were shortest with *A. tridentata* roots being approximately intermediate in length. (Table 24). Another difference was that the rate of elongation for the first two months was slower than for the last two months.

Seedlings of all three species have a very obvious taproot in the early growth stages. No lateral roots were produced by any seedling until the end of the third week. At this time one or two lateral roots about 10 mm. long were found on many of the

TABLE 24

Centimeters of Root Elongation of C. nauseosus, C. viscidiflorus, and A. tridentata Seedlings as Measured in Glass Front Root Study Columns

	C. nauseosus	C. viscidiflorus	A. tridentata
Average length of roots in 2 weeks	11.2 cm	11.3 cm	9.0 cm
Average length of roots in 4 weeks	16.4 cm	13.7 cm	13.0 cm
Average length of roots in 8 weeks	27.8 cm	17.45 cm	22.3 cm
Average length of roots in 12 weeks	105.0 cm	56.0 cm	85.0 cm

A. tridentata seedlings and a like number about 3 mm. long were observed on most C. nauseosus seedlings. No lateral roots were produced on C. viscidiflorus until the end of one month. The development of small lateral roots illustrates what has been described as a two layered root system which is particularly characteristic of sagebrush. This modification of the root system has also been described by Muller (35) in guayule where the tap root habit is lost as guayule plants approach maturity. Instead of a tap root, a large number of principal lateral roots are developed and eventually resembles a fibrous root system.

C. nauseosus roots grow faster than either C. viscidiflorus roots or A. tridentata roots. A. tridentata roots develop slower initially, but by the end of the fourth week are equal to

C. viscidiflorus. After four months of growth, C. nauseosus roots are longer than C. viscidiflorus roots, but A. tridentata roots are intermediate in length between the two rabbitbrush species. (Table 24).

When many seeds were planted in each glass fronted column root growth of each species was less than in the experiment where only ten seedlings were grown in the columns. This could possibly be due to competition for moisture. Nevertheless, approximately the same relationship holds true for the three species with C. viscidiflorus showing less root growth than A. tridentata and C. nauseosus. (Table 25).

A. tridentata had a rate of elongation slower than rabbitbrush, but this relationship appears to change by the time seedlings are four weeks old.

TABLE 25

Length of Two-Month-Old Seedling Roots in Mass Planting of Root Study Columns

Species	No. of seedlings	Average length	Range
C. nauseosus	65	13.6 inches	4.0-38 in.
C. viscidiflorus	67	9.2 inches	4.0-27 in.
A. tridentata	94	13.7 inches	4.0-32 in.

Total elongation attained should not be considered to be the same as in the field inasmuch as the greenhouse conditions were not the same as in the field. The main value of this study should be to determine the relationship between species which may be expected to hold fairly constant whether in the field or in the greenhouse.

To better understand how a high rate of root penetration serves rabbitbrush as an advantage in establishment or how sagebrush is able to compete by reason of also having a rapid rate of root development further experimentation on various soil types would be desirable. According to Muller (35) the root zone may vary widely within a given species with differences in soil conditions. The facility with which roots are able to penetrate the soil may have a major effect on the extent of the soil-moisture reservoir that may be used.

Drought Endurance

The degree to which rabbitbrush seedlings and mature plants withstand periods of drought is important in their successful domination of many sandy rangeland soils. Particularly in the seedling stage are soil moisture relations critical. Since little information is available on drought resistance of brush seedlings, a greenhouse study was initiated to clarify certain aspects of this problem. Of special interest was the possible existence of a difference in drought tolerance between *C. nauseosus*, *C. viscidiflorus* and *A. tridentata*.

Observations of mature *C. nauseosus* in the bunchgrass region during the dry summer of 1955 suggest that this species is a second-best competitor on bunchgrass ranges under dry conditions. On rangelands in fair and good condition near Buttercreek, Pilot Rock, and Grass Valley, C. nauseosus plants observed in the last week of August were producing few, or no flowers, leaves were curled up and dry and stem growth for the current year was extremely limited. About 25% of the younger plants in these areas had dropped most of their leaves. A few C. viscidiflorus plants in these areas also appeared to be equally under moisture stress. Further observations should be made in 1956 to determine if permanent damage resulted.

Apparently conditions in the Basin and Range area were not quite as critical in 1955 as for the areas described above. However, flower and seed production was smaller in 1955 than in 1954. In local areas where close competition existed between mature green rabbitbrush plants there was ample evidence of reduced shoot growth and early leaf drop. Only in a few protected microhabitats were any seedlings found, but by the middle of August these small plants were dead. Other observations of C. viscidiflorus and C. nauseosus seedlings in the field experiment with shade and litter during the course of the 1955 growing season suggest that even though seedlings are able to survive drying out of the soil surface by a rapid rate of root elongation they may still become a casualty later on in the summer if rains are not forthcoming.

Plants growing in regions subject to drought are able to succeed by many different means. Livingston (34) observed that seedling roots elongated directly downward rapidly enough to reach an adequate water supply before the upper soil layer could produce injury by drought. Shantz (45) pointed out that desert shrubs should be considered as drought enduring rather than drought resisting, a term he reserved for cacti and other desert succulents. As a result of many soil moisture determinations Shantz concluded that desert shrubs could reduce the water content of the soil below the hygroscopic coefficient. Even so, some desert shrubs may be killed by protracted dry spells and Shantz (46) later reported that little rabbitbrush (<u>Chrysothamnus stenophyllis</u>) grows in Utah and Nevada on dry soils similar to sagebrush lands, but where sagebrush has been driven out by drought or burning. Alway (2) in a study of desert legumes, described leaf abscission, death of shoot tips and growth cessation that resulted from soil drought below the wilting point, even though plants remained alive for a considerable period. In view of the varied results obtained in determining a wilting point for different types of plants, Furr and Reave (20) proposed that a wilting range existed in which water is not available for continued growth, but is sufficient for mere maintenance of life. They stated that plants die not because water absorption has finally ceased, but because the rate of absorption finally has lagged too far behind the rate of loss to support life. This observation certainly appears to describe the situation with respect to young rabbitbrush seedlings which may have their root tips in slightly moist soil but the majority of the root system is in soil with moisture below the available range.

<u>Methods</u>. Drought studies of rabbitbrush and sagebrush seedlings were conducted on loamy sand pumice soil from Millican valley. Some characteristics of soils in the Millican area were reported in Table 16. The percent moisture present in terms of ohms resistance for this soil has been calibrated. (Figure 17). Data for this curve were provided from ten #10 cans filled with pumice soil in which a plaster-of-paris block was buried at a depth of 3.5 inches. All cans were brought up to field capacity and five barley seeds were planted in each can to deplete soil moisture. In addition, several <u>C</u>. <u>nauseosus</u> and <u>C</u>. <u>viscidiflorus</u> seeds were also planted. Values for the calibration curve were provided by simultaneous weighings and ohms resistance readings as soil moisture in the cans became progressively depleted. The barley plants were dead in most cans by the time the ohm readings reached 1,000,000, but the few shrub seedlings, although rather small, were still alive and drawing some moisture from the cans. Final weights were recorded when most of the cans failed to lose more than 1 to 2 grams in a 24-hour period. The cans were then placed in a drying oven for 3 days. Oven-dry weights were recorded and the weight of each empty can and plaster-of-paris block was subtracted from all weights, both oven-dry and moist. Moisture percentages were then figured on an oven-dry basis. The gradual loss in weight of plants was not considered. Compared to the magnitude of the weight of the soil in the can, approximately 3

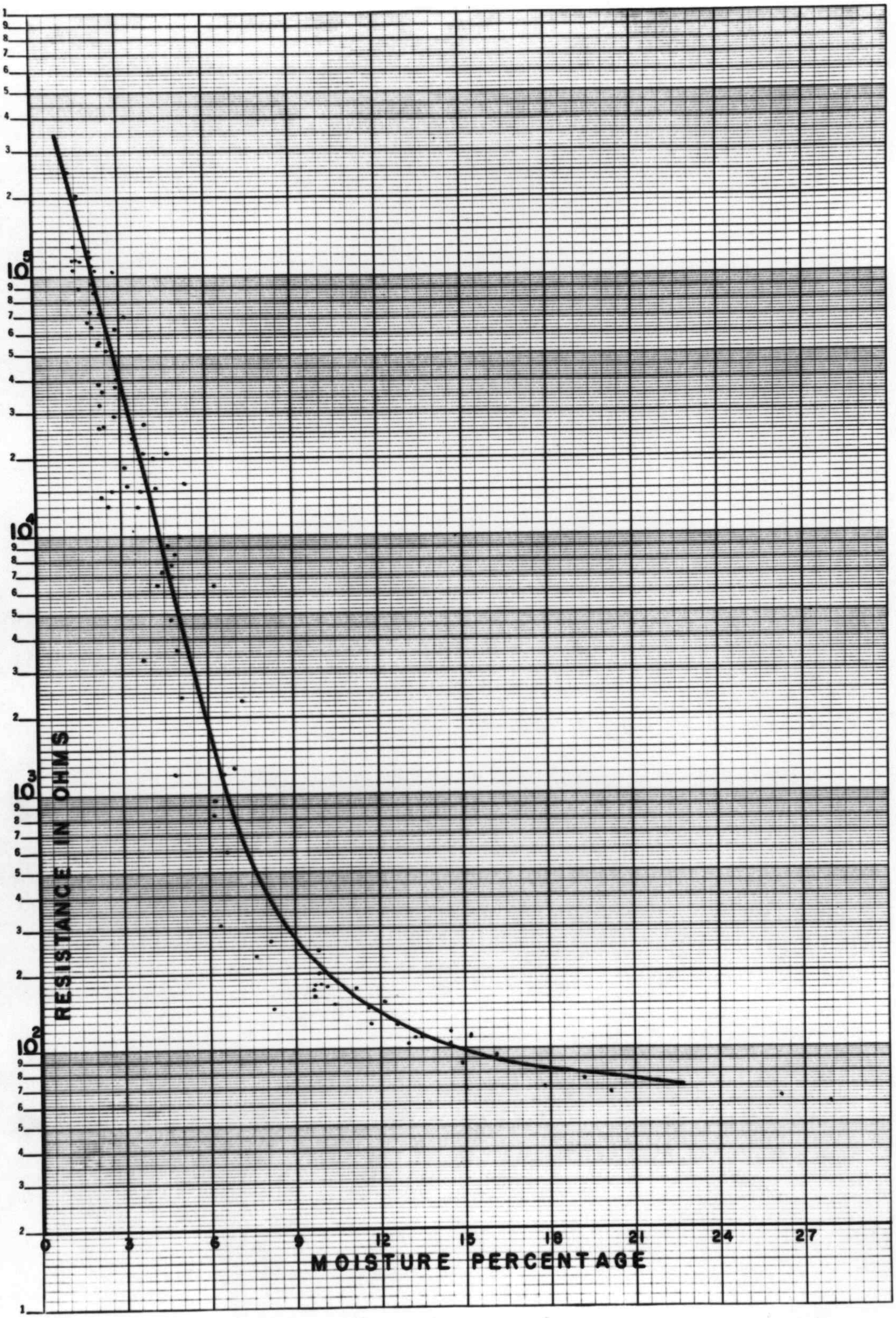

Figure 17. Calibration curve for pumice loamy sand soil in terms of percent moisture for ohms resistance.

kilograms, the effect of the slight weight loss as plants dried out was considered to be negligible.

For drought studies on shrub seedlings thirty #10 cans with drainage holes in the bottom were filled with loamy sand pumice soil. (Figure 18). Plaster-of-paris electrical resistance blocks calibrated within 100 ohms variability were buried at a depth of 3.5 inches. Twenty-five seeds each of _C. nauseosus_, _C. viscidiflorus_ and _A. tridentata_ were seeded at a depth of 1/8 inches. The soil was brought up to field capacity and was lightly sprinkled every other day until some germination was noted. No further water was added during the experiment.

Ohm readings were made as the seedlings developed and changes in appearance were noted. When the seedlings appeared to be dead, a final ohm reading was made and the can was placed in a shallow pan of water for 3 days to bring the soil moisture back up to field capacity. Cans were then placed back on the greenhouse bench and at the end of two weeks plants still alive had sufficiently recovered to be easily distinguished from the dead plants. Inasmuch as many dormant seeds germinated after bringing the cans back up to field capacity, all old plants were removed after results were recorded and the experiment was repeated for most of the cans. However, six cans were used to check on roots in order to make certain they were distributed all through the soil in the cans. In all six cans roots were found throughout the soil, in the vicinity of the block, and at the bottom of the can.

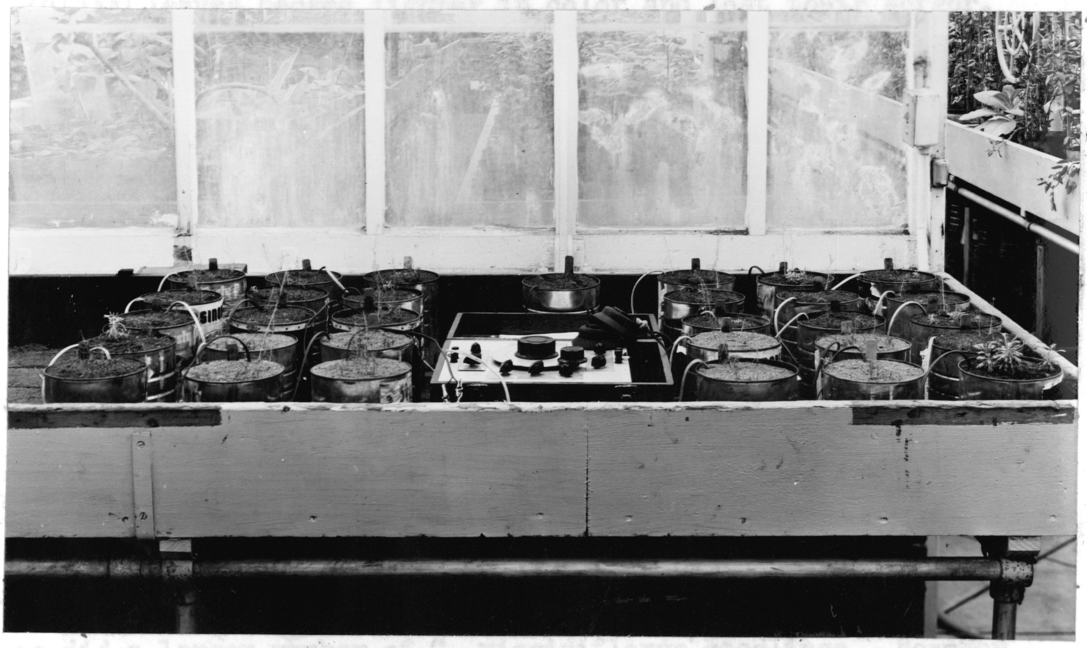

Figure 18. Experiment for drought endurance. C. nauseosus, C. viscidiflorus and A. tridentata seedlings are planted in #10 cans filled with loamy sand pumice soil. Plaster-of-paris blocks are buried at three and one-half inches depth in each can.

Results and Discussion. Very few *A. tridentata* seeds germinated, but adequate germination of rabbitbrush occurred and an average of 5 seedlings of both species were grown in each can. As moisture became depleted and ohm readings reached approximately 270,000 leaves became lighter in color and lost their turgor. The elongated stem tip of *C. nauseosus* bent over in an apparent permanent wilt. *C. viscidiflorus* seedling growth more resembled a rosette shape and as a result the stem tip apparently was not as damaged at this point. Ohm readings increased rapidly in the high resistance ranges until readings were around 1,200,000 and plants appeared dead.

Plants that survived after soil moisture was returned to field capacity were very striking in their response. A limited number of *C. nauseosus* plants continued growth from the stem tip as did a larger number of *C. viscidiflorus* seedlings. However, the development of side branches at or above the crown on many of these 3-month-old seedlings was the most common means of regrowth. (Figure 19).

Fifty-five percent of the *C. viscidiflorus* seedlings survived as compared to 20 percent of the *C. nauseosus* seedlings.

Final results of seedling response to drought in the fifty-four cans of the experiment are summarized in Table 26.

C. viscidiflorus seedlings may be able to endure greater moisture stress than *C. nauseosus* seedlings as indicated by a higher mean ohm reading and by a higher percent of seedlings

Figure 19. Seedling regrowth of C. *viscidiflorus* and C. *nauseosus* after drought.

TABLE 26

Drought Endurance of Seedlings in Fifty-four #10 Cans as Indicated by Mean Ohms Resistance and Number of Cans Observed With Living or Dead Seedlings

Species response to drought	Mean ohms resistance	No. of cans observed	Percent seedling survival
_C_. _nauseosus_ and _C_. _viscidiflorus_ survive	1,103,000	12	
_C_. _nauseosus_ survives	1,266,000	5	20
_C_. _viscidiflorus_ survives	1,490,000	13	55
_C_. _nauseosus_ and _C_. _viscidiflorus_ dead	1,517,000	24	
_A_. _tridentata_ survives	1,290,000	5 *	32
_A_. _tridentata_ dead	1,383,000	6 *	

*Planted in cans with rabbitbrush.

surviving. There is also an indication that _A_. _tridentata_ might be intermediate in its tolerance to drought. A word of caution should be entered at this point, however, in that the data for sagebrush are too limited to serve as a base for any final conclusion. The same may be said for the other data, although there is much stronger evidence that _C_. _viscidiflorus_ is superior in its drought enduring ability. This experiment should be repeated with a greater number of observations and further attempts should be made to reduce any source of undesirable variation.

Competition Between Rabbitbrush Seedlings and Crested Wheatgrass Seedlings

Seedling establishment and survival in competition with other species is an important consideration in determining the ability of any particular species to invade a new area or to maintain itself in its present distribution. One of the main problems in managing improved pastures is to maintain the pasture in the most productive state. Certainly the development of rabbitbrush in such an area reduces grazing yield considerably.

The key to the problem appears to be a better understanding of the seedling stage and proper management in light of this information. Schultz, Launchbaugh, and Biswell (44), concluded that a dense stand of grass seeded after burning brush in the fall could be sufficiently developed to deplete soil moisture below the amount required for brush seedling survival. Essentially the same conclusion was reached by Blaisdell (5) in working with sagebrush and reseeded grasses. Seeding grasses one year or more in advance permitted very little sagebrush establishment as compared to concurrent grass and sagebrush seeding or seeding grass into an established stand of sagebrush which resulted in a greater number of sagebrush seedlings.

A study between crested wheatgrass and rabbitbrush seedlings was conducted in the greenhouse during the fall of 1955.

Methods. To provide sufficient depth for root development the last 4½ feet of a greenhouse bench were built up with sides three feet high. (Figure 20). The resulting deep bench was subdivided into eight 2¼' x 1' sections by means of masonite panels that extended through the depth of the bench. These panels were designed to permit removal of two sections at a time for studies of development at four different times. Two cubic yards of pumice soil from Millican were screened and packed into the bench. Electrical resistance blocks were placed at 8" and 15" in all but the two front sections.

One-half of the box was seeded with crested wheatgrass. Concurrently, each section in the entire experiment was seeded with 100 C. nauseosus and 100 C. viscidiflorus seeds. The soil was lightly sprinkled for 2 weeks until some seedling emergence was noted.

Results and Discussion. At the end of three weeks 79 C. nauseosus and 45 C. viscidiflorus seedlings were recorded on the sections not seeded with crested wheatgrass as compared to 3 C. nauseosus and 0 C. viscidiflorus seedlings on sections with crested wheatgrass. Plants in the first two sections were excavated at the end of eight weeks. Further excavations were made at 12 and 15 weeks. The last two sections were not considered for root studies because of a leak in the greenhouse roof, resulting in water on these sections. The wheatgrass roots were, on the

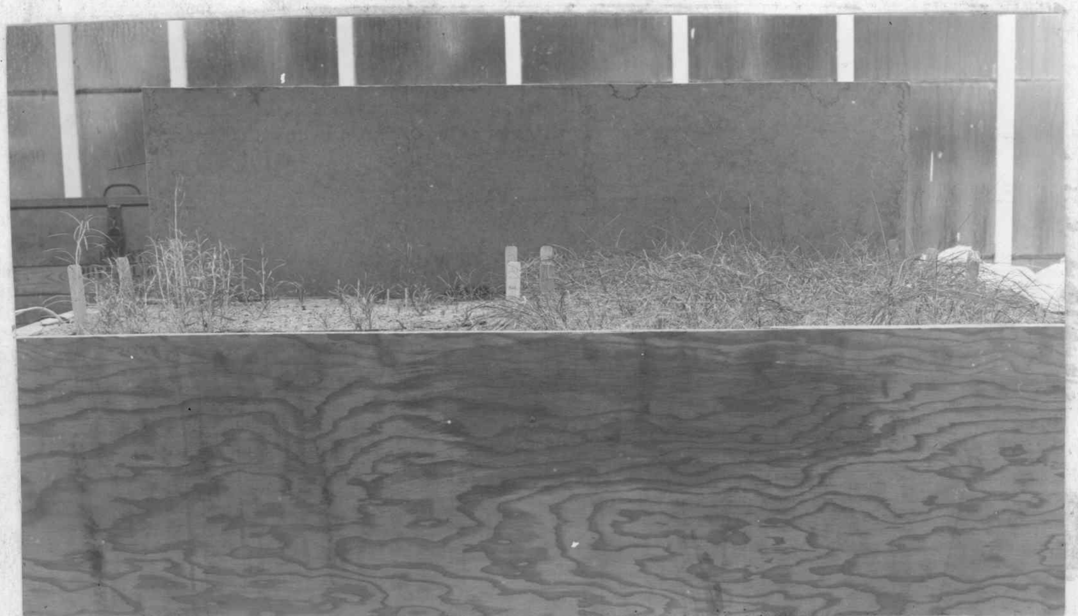

Figure 20. Experiment on competition between C. viscidiflorus, C. nauseosus and Agropyron desertorum seedlings. Rabbitbrush seeds were planted on each half of the area. Crested wheatgrass seeds were sown only on the right side.

average, more shallow, (Table 27), even though some extremely long roots were measured which were longer than the average length of C. nauseosus roots. The fact that wheatgrass roots were so extensive through the depth indicated, presents a real problem for rabbitbrush seedling survival. The distribution pattern for roots is further accentuated by the depletion of soil moisture in this region. (Table 28).

TABLE 27

Average Centimeters of Root Growth in Deep Greenhouse Bench Measured at Eight, Twelve, and Fifteen Weeks *

	C. nauseosus		C. viscidiflorus		A. desertorum
Time	No. of plants	Av. root length	No. of plants	Av. root length	Av. root length
8 weeks	17	7.9 cm	6	4.4 cm	7 cm
12 weeks	17	13.3 cm	10	9.9 cm	12 cm
15 weeks	23	25.0 cm	11	21.9 cm	15 cm

* Shrub seedlings grown independently of crested wheatgrass.

TABLE 28

Mean Ohms Resistance at 12 and 15 Weeks at Depths of 8 and 15 Inches, With and Without a Cover of Crested Wheatgrass

Time	Without Crested Wheatgrass		With Crested Wheatgrass	
	8"	15"	8"	15"
12 weeks	53,000	200,000	1,120,000	550,000
15 weeks	215,000	255,000	1,250,000	780,000

Under a cover of grass seedlings the moisture level appears to be below the amount required for rabbitbrush seedling survival. This is also true of the grass seedlings as most of them appeared to be permanently wilted or dead by the 15th week.

From the results of this experiment and field observations and also from the available literature, the best way to manage improved pastures to prevent the invasion of rabbitbrush is to maintain a rapidly transpiring plant cover of grasses. In dry years the danger of brush seedling establishment does not appear to be very great and usual grazing management programs would be satisfactory. However, in moist years grazing should be deferred until soil moisture in the upper horizon is depleted and unavailable to brush seedlings that have germinated under the favorable moisture conditions in the earlier weeks. This conclusion is not entirely supported by greenhouse data, but field observations and literature do suggest that this might be a solution.

SUMMARY

Chrysothamnus nauseosus and *Chrysothamnus viscidiflorus* are undesirable shrubs common to the rangelands of eastern Oregon. On many depleted ranges the number of rabbitbrush shrubs has greatly increased at the expense of valuable forage plants.

An autecological study of rabbitbrush indicates that characteristics such as resprouting from the crown, seed production, seed dissemination, germination, seedling establishment, radicle and root growth, and drought endurance contribute to establishment in various range communities.

An important characteristic of rabbitbrush is the habit of resprouting from the crown following burning and many commonly used brush control measures. However, the habit of regrowth is not limited to the mature plant. Two and three month-old seedlings have also been observed to produce new sprouts from the crown after subjection to extreme drought.

Seed production of *C. nauseosus* and *C. viscidiflorus* appears to be relatively high but may be markedly reduced in dry years as indicated by a study of flower production over a period of two years.

C. nauseosus plants on rangelands with low bunchgrass frequency produce a greater number of flowers than on ranges with high bunchgrass frequency. Plants are larger and produce more flowers in the Shaniko and Grass Valley area than to the east in

the area around Pine City and Pilot Rock. Bunchgrass appears to be a better competitor in the latter area.

Sagebrush is the principal competitor with C. viscidiflorus in many areas of the Basin and Range province of Oregon. Flower production of C. viscidiflorus appears to decrease with increased sagebrush frequency although intra-specific competition will also reduce the number of flowers per plant.

Removal of competing vegetation in the early spring results in an increase in flower production and shoot growth of C. viscidiflorus and C. nauseosus within one growing season. In addition, plants are three weeks earlier to flower. No difference in germination was noted for seeds collected from plants with competition and plants without competition.

The majority of rabbitbrush seeds are wind disseminated. Dissemination distances ranging from 130 to 165 yards were recorded. In comparison, sagebrush seeds appeared to be disseminated only 25 yards. The rapid invasion of rabbitbrush plants into agricultural lands may be partly explained on the basis of dissemination distance.

Germination of seeds from both species of rabbitbrush studied may occur immediately upon maturity under proper temperature and moisture conditions. Neither C. nauseosus nor C. viscidiflorus indicates a significant difference in total germination at temperatures ranging from 5^{o}C. to 30^{o}C., although a longer time is required for germination at the lower temperatures. A considerable number of C. nauseosus seeds germinated within 24 hours, which is much faster than seeds of C. viscidiflorus or A. tridentata. No significant difference was indicated in germination of rabbitbrush seeds collected from three locations.

A pretreatment of soaking and freezing seeds for 72 hours produced a significant increase in germination of C. viscidiflorus seeds but reduced germination of C. nauseosus seeds.

Rabbitbrush seedlings three to seven days old that were germinated at 5°C. withstood freezing temperatures of -5°C. for 24 hours as compared to no survival of seedlings germinated at 15°C. or 30°C.

Establishment of C. nauseosus and C. viscidiflorus seedlings was high on loamy sand soils in greenhouse experiments. A relatively high number of C. viscidiflorus seedlings also became established on a self-mulching clay soil. No significant difference in C. viscidiflorus establishment was noted between 1/4", 1/8" and surface plantings. However, a significant difference was observed between planting depths of 1/4", 1/8" and surface for C. nauseosus and A. tridentata seedlings, with progressively greater seedling establishment indicated at the shallow plantings.

Initial seedling establishment in the field during the spring of 1955 was very low and suggests that a large number of viable seed may be required to produce a few seedlings. Greater initial seedling establishment occurred under a shade canopy. Presence or absence of litter did not affect initial establishment.

Rate of moisture depletion in the upper two centimeters of the soil appeared to be an important factor in seedling mortality. Four-week-old seedlings of both rabbitbrush species appeared to withstand soil surface temperatures of about 145°F. as long as roots were in moist soil.

The rate of radicle elongation 24 to 60 hours after germination was greatest for *C. nauseosus*, intermediate for *C. viscidiflorus* and least for *A. tridentata*.

Seedling root growth at the end of two months was greater for *C. nauseosus* than for *C. viscidiflorus*. *A. tridentata* seedlings had roots intermediate in length between the two species of rabbitbrush.

Drought endurance developes early in the seedling stage of *C. nauseosus*, *C. viscidiflorus* and *A. tridentata*. A higher percentage of *C. viscidiflorus* seedlings survived extreme drought than did *C. nauseosus* seedlings. *C. viscidiflorus* seedlings three months old endured lower soil moisture percentages than either *C. nauseosus* or *A. tridentata*.

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APPENDIX

Appendix 1. Rabbitbrush flower production on plants growing with, and without competition from other plants.

C. nauseosus - Location No. 1

With competition Plant No.	No. of flowers		Without competition Plant No.	No. of flowers	
1	1320		1a	4488	
2	1207		2a	4248	
3	1562		3a	3673	
4	272		4a	1589	
5	2605		5a	3808	
Average	1393	37.3	Average	3561	59.6

C. nauseosus - Location No. 2

With competition Plant No.	No. of flowers		Without competition Plant No.	No. of flowers	
6	0		6a	88	
7	0		7a	864	
8	24		8a	1004	
9	239		9a	560	
10	54		10a	884	
Average	63.4	7.9	Average	680	26

C. viscidiflorus - Location No. 1

With competition Plant No.	No. of flowers		Without competition Plant No.	No. of flowers	
1	2		1a	2552	
2	73		2a	1226	
3	51		3a	1095	
4	0		4a	1858	
5	2		5a	3439	
Average	25	34	Average	2034	975

C. viscidiflorus - Location No. 2

With competition Plant No.	No. of flowers		Without competition Plant No.	No. of flowers	
6	630		6a	5628	
7	1884		7a	4309	
8	405		8a	699	
9	134		9a	714	
10	2042		10a	7936	
Average	1019	881	Average	3857	3155

Appendix 2. Ohms resistance for ten locations, four depths at Millican, Oregon, 1954.

Date	4"	12"	18"	36"
May 2	1925	1200	——	1200
	1425	1350	1300	1450
	1275	1325	1225	1225
	1550	1325	1800	1300
	1625	1625	1575	1100
	1325	1225	1025	1100
	1600	1450	1400	1400
	1740	1680	1220	1100
Mean	1550	1390	1380	1230
May 8	1820	1450	1120	1040
	1350	1200	1160	1320
	1210	1180	1200	1200
	1515	1200	1850	1285
	1580	1415	1120	1545
	1190	1085	1015	1080
	1560	1440	1400	1200
	1740	1680	1220	1100
	1350	1200	1100	1180
	2700	1810	1475	1375
Mean	1611	1686	1266	1232
June 12	1450	7000	7500	1240
	1900	1200	1200	1160
	1240	1175	1175	1100
	1280	1250	1440	1660
	940	1500	1500	1450
	1020	1050	1140	1500
	1200	1600	1740	1420
	6500	1300	1840	1680
	1160	1210	1300	1100
	1620	2400	3000	2950
Mean	1800	1300	2180	1520

Date	4"	12"	18"	36"
July 10	1850000	225000	230000	89000
	1200000	1000	1120	1100
	29750	1190	1100	1130
	66800	3700	1360	1570
	16800	3080	1770	1310
	29250	970	1000	900
	30000	7800	3500	2500
	55000	27250	5650	1880
	5730	1300	1230	980
	----	46000	35000	12800
Mean	364814	275890	74730	33070
Aug. 3	----	300000	300000	350000
	----	2600	1600	1100
	19000	3800	9500	22500
	----	15000	2400	3800
	11000	31000	16800	2100
	85000	2275	1260	1180
	----	12500	8200	3500
	50000	6800	7600	5000
	100000	4400	1800	1000
	----	30000	22000	12000
Mean	53000 *	408375	71906 *	40218
August 29	1550000	840000	800000	500000
	1200000	1600	1900	1230
	750000	25000	38000	14000
	750000	85000	8000	35000
	1500000	200000	92000	23000
	1000000	6000	5900	1720
	500000	380000	310000	195000
	1000000	205000	270000	250000
	400000	53000	48000	1600
	----	620000	530000	280000
Mean	972222	241560	210380	130155

* Five plots missing.