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CHANGES IN WEEDY PLANT COVER ON CLEARED SAGEBRUSH LAND AND THEIR

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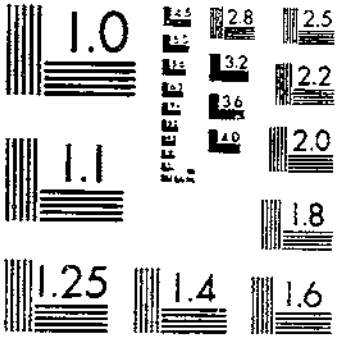

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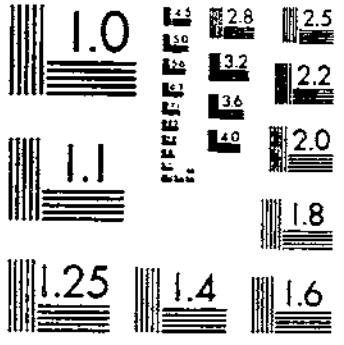

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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UNITED STATES DEPARTMENT OF AGRICULTURE
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CHANGES IN WEEDY PLANT COVER ON CLEARED SAGEBRUSH LAND AND THEIR PROBABLE CAUSES [1] [2]

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INTRODUCTION

Lands in the Snake River Plains of southern Idaho that have been cleared of their original cover of sagebrush and are not continuously farmed become covered with a weedy growth and afford large areas of breeding hosts of the beet leafhopper (*Eutettix tenellus* (Baker)), vector of the curly top disease of sugar beets, beans, tomatoes, and other plants. Since the areas of breeding hosts have a direct bearing on beet leafhopper populations and on the annual infestations of crops (*2*),[3] it was desirable to obtain information as to the size and the distribution of these areas and also as to their permanence; that is, whether there were notable changes in them from season to season or whether they were comparatively stable in size and composition. At least on some

[1] Submitted for publication January 4, 1938.

[2] Acknowledgment is made to Eubanks Carsner, senior pathologist, Division of Sugar Plant Investigations, for suggestions and criticisms in the course of the work and in the preparation of the manuscript; to Walter Carter, formerly in charge of the Bureau of Entomology station at Twin Falls, Idaho, for his assistance in beginning the work; to P. N. Annand and J. C. Chamberlin, both formerly in charge of the station just mentioned, for their help later in the progress of the work.

[3] Italic numbers in parentheses refer to Literature Cited, p. 43.

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of the abandoned fields the original cover of sagebrush (*Artemisia tridentata* Nutt.), with its associated perennial grasses and herbs, was reestablishing itself. What conditions favor such a reestablishment, and how much time is required for it to take place? These were other questions for which answers were sought.

Ecological investigations of the weed host areas were begun in 1928. A map of a portion of the Snake River Plains was published (*9*), giving the extent of the weedy areas and pointing out in general the changes in the weedy cover, the approximate time for the changes to take place, and some of the factors that favored or hindered the changes.

As the investigations proceeded, possibilities of a control of the beet leafhopper breeding areas became more evident. It was previously known (*2*, *5*) that grasses, annual and perennial, are not suitable as breeding hosts of the beet leafhopper, and neither are the native shrubs or perennial herbs. These plants occur on extensive areas as two kinds of plant cover. One is weedy, develops on cleared sagebrush lands, and is often composed of annual grasses to the exclusion of any of the breeding hosts. The other kind is the original cover of perennials mentioned above. It seemed likely that a method of control might be established if conditions were promoted to favor development of the two kinds of cover free of breeding hosts. In 1934, in cooperation with the Bureau of Entomology and Plant Quarantine, a survey of weed-host areas of southern Idaho was made and the results published (*10*). This included a map of southern Idaho, pointed out the means by which a control or a reduction of the area of breeding hosts might be achieved, and also classified the entire region as primary, secondary, or potential areas, according to the urgency of a need for control.

The present bulletin deals with the changes of plant cover for the period 1928–35 as recorded on a number of areas. Supplemented by other observations, these changes are discussed as they are affected by such "destructive agencies" as excessive grazing and burning. The information about the habits of the competitive plants and other ecological factors, especially precipitation, is brought together to indicate the causes of the changes in plant cover under protection from the destructive agencies.

Beginning with 1928, the Bureau of Entomology and Plant Quarantine carried on quantitative studies of the populations of the beet leafhopper and a number of other common insects on some of the same areas where changes of plant cover were recorded. The results of this work, showing the changes in the insect populations as the changes of plant cover took place, are given by Fox (*5*).

DESCRIPTION OF THE GENERAL AREA

The areas on which continuous observations of the weedy plant cover were carried on are situated in Twin Falls County, Idaho, on abandoned portions of the Salmon Irrigation Tract and south of a well-farmed irrigated area along the Snake River. This tract, which forms a southern portion of the Snake River Plains, was formerly covered by sagebrush, a type of cover that also formerly occupied most of the plains. In comparison, the area of alkali lands and wet, poorly drained lands with a salt desert-shrub type of cover is incon-

siderable. Bunch grass formerly covered the edges of the foothills, forming an irregular belt around the central sagebrush plains area and merged with it in an intermediate area of shrub savanna, that is, widely spaced sagebrush with an intervening grass cover.

The lands of the plains, including this southern portion, are sloping or rolling, with an average altitude of about 4,000 feet. The soils are for the most part those developed from wind-borne material (*1*) and underlain by a basaltic bedrock.

The climate is characterized by a low annual rainfall and dry summers, the precipitation, rain or snow, occurring in the fall, winter, and spring.

LOCATION AND DESCRIPTION OF AREAS UNDER OBSERVATION

A list of the areas under observation with their location, size, and other information is given in table 1. They are all within 11 miles of Hollister, Idaho. The areas are of two kinds. The larger units are called fields and correspond in their boundaries to the fields when under cultivation. The newly abandoned fields are also distinguished from the surrounding lands by the remnants of the crop immediately preceding abandonment, whereas the old abandoned fields usually differ from the surrounding area in the kind of weedy plant cover at the beginning of observations (1928). The fields are all subject to grazing by stock. The smaller units, called plots, are areas of 10 by 10 m, and each plot is situated within the field of a corresponding number (with the exception of plots 3 and 4, both in the same field and designated as field 4).[4] The unfenced plots (excepting 3A) were selected as representative of the field at the beginning of observations (1928) and received the same treatment as the fields, whereas the fenced plots differed in that they were protected from all grazing. In the latter the fence was set 1 m beyond the borders of the plot so as to afford a pathway around it and to avoid as much as possible walking over the portion under observation.

The fields are level, or nearly so, with the exception of No. 11, which slopes to the south. The soils of all of the fields are medium-textured and are considered to be of the Portneuf silt loam (shallow phase) or a closely related type. No. 11 is somewhat stony on the surface and No. 9 less so, while the others are free of surface stones or nearly so. These fields with their level or nearly level surfaces and with medium-textured soil are considered to be representative of a large portion of the abandoned lands in the Snake River Plains formerly covered by sagebrush. Abandoned lands formerly covered by the salt desert-shrub type of vegetation are not represented. These occur chiefly in the western part of the State on the lower benches of the Snake River, though some small areas also occur on the Raft and Lost Rivers. The total of these fields is comparatively small.

[4] The total number of fields was 13. Of these, Nos. 6 and 7 dealt largely with perennials and are not included. No. 10 was near the corner of a highway and was so interfered with by wagons and automobiles driving across it that it was shortly discontinued. In addition to the 13 fields there were fenced in 1931 three 40-acre tracts, each about one-half in sagebrush and one-half in weeds. The results from these are not as yet conclusive and are not included, though they are mentioned later where pertinent to the discussion. These are referred to as the Burley plot (SE¼SE¼ sec. 32, T. 10 S., R. 22 E., the Castleford plot (SE¼NW¼ and NE¼SW¼ sec. 4, T. 12 S., R. 15 E.), and the Wendell plot (NE¼NE¼ sec. 33, T. 7 S., R. 14 E.).

TABLE 1.—*Characteristics of the fields and plots under observation*

Fields							Plots in each field			
			Conditions under which changes in weedy plant cover took place					Conditions under which changes in weedy plant cover took place		
Field No.	Location	Approximate size	Length of time (in 1928) since abandonment	Surrounding vegetation	Grazing	Burning	Plot No.	Fenced or unfenced	Grazing	Burning
		Acres								
1	NW¼ SW¼ sec. 35, T. 12 S., R. 16 E.	40	First year	Weedy cover or field crops.	Excessive	None	1	Fenced	None	Partly burned, 1933.
2	NW ¼ NW¼ sec. 15, T. 13 S., R. 16 E.	40	do	do	do	do	2	do	do	None.
4	SE¼ SE¼ sec. 18, T. 12 S., R. 16 E.[1]	8	do	Sagebrush or weedy cover.	Moderate	do	3	do	do	Do.
							3A	Unfenced	Moderate	Do.
							4	Fenced	None	Do.
							4A	Unfenced	Moderate	Do.
5	SW¼ SW¼ sec. 17, T. 12 S., R. 16 E.[1]	30	do	do	do	do	5	Fenced	None	Do.
							5A	Unfenced	Moderate	Do.
8	S½ SE¼ sec. 20, T. 12 S., R. 16 E.	36	Sixth or seventh year.	do	do	do	8	do	do	Do.
9	E½ SE¼ sec. 4, T. 12 S., R. 16 E.	80	(2)	Sagebrush	do	do	9	do	do	Do.
11	SW¼ SW¼ sec. 34, T. 11 S., R. 17 E.[1]	23	(2)	Sagebrush or weedy cover.	do	do	11	do	do	Do.
12	NW¼ NW¼ sec. 3, T. 12 S., R. 17 E.[1]	32	(2)	do	do	In 1928, 1930, and 1932.	12	do	do	1928, 1930, and 1932.
13	NE¼ SW¼ sec. 21, T. 12 S., R. 16 E.	15	(2)	Weedy cover	Irregular	Late 1928 or early 1929.	13	do	Irregular	Late 1928 or early 1929.
14	SW¼ NE¼ sec. 21, T. 12 S., R. 16 E.	35	First year	do	Moderate	None	14	do	Moderate	None.

[1] Fields 4 and 5 are separated only by a dirt road, and so with fields 11 and 12.
[2] Time of abandonment is not known but probably ranges from 5 to 10 years.

The fields and plots listed in table 1 were chosen to give information along the following lines. It was desirable to record the development of the weedy cover from the time of abandonment, that is, beginning with the first season after the crop was removed and the land abandoned (fields 1, 2, 4, 5, and 14). At the time (1928) it was thought the crop immediately preceding abandonment might have some effect on the subsequent development of a weedy cover, so both grain stubble and alfalfa fields were included (grainfields 2 and 4, alfalfa fields 1, 5, and 14). Since most of the abandoned fields were subsequently subjected to grazing, it was desirable to know something of the effect of grazing on the development of the weedy cover, and therefore some small areas (plots) were fenced to keep out stock and to note development under such protected conditions (plots 1, 2, 3, 4, and 5). The protected areas are to be contrasted with the areas open to transient grazing and with two fenced fields (1 and 2) where stock was enclosed and the fields excessively grazed and trampled. The last two fields both contained small areas (plots 1 and 2) fenced to prevent all grazing or trampling by stock.

In addition to the above, a number of fields were chosen for the particular plant cover at the time (1928) without regard to the length of time after abandonment (fields 8, 9, and 11), to note whether the same cover reappeared year after year or whether there were changes from the cover of 1928 to some other. Two fields (12 and 13) show the effect of burning during the period of observations.

Finally it seemed desirable to obtain some information on the development of a weedy cover on land that was bare at the beginning of observations. No such fields were available, so two small areas in field 4 were hoed clean of all vegetation (1928) and kept free of weeds during that season. One of these plots (No. 3) was fenced and the other (No. 3A) was left unfenced.

METHODS

Because the plots were small more detailed methods of recording the plant cover were found feasible than for the large fields. The boundaries of the areas covered by the different weeds were located by laying tapes across the plots, and the boundaries were then plotted on charting paper. If the plant cover was very patchy and the areas small, each square meter was charted separately. From the charts the percentages of the area of the plot covered were calculated and the changes of plant cover could then be arrived at by comparing the percentages of one year with another.

For the fields a visual estimate was made by walking back and forth across them and noting the kind of plant cover that prevailed over a major part of each. This crude method did not permit the detection of slight differences in plant cover but was sufficient to show pronounced changes and therefore the trends in the changes from year to year for the period 1928 to 1935.

Often the areas covered by each of the weeds on the plots were well defined and there was no difficulty in charting them. Sometimes, however, an area outstandingly covered by one weed also had in it a scattering of individual plants of another. The amount of labor involved in getting at the area covered by the latter did not seem justifiable, and the area was accordingly designated by the name of the

first weed, and the scattering of the second was indicated by the word "with" preceding its name. If an area contained a mixture of two or more weeds in about equal proportions the cover was designated by the names of those present connected by the word "and." Thus, "a with b" denotes a scattering of "b", whereas "a and b" means a mixture in which the two are about equal. In a few cases where "a" or "b" is used it denotes numerous small areas of both not mixed but distinct.

For the most part the discussion of changes of plant cover is based on the percentage of area covered, arrived at by the methods just mentioned. However, it seemed desirable to obtain some information on the plots as to the numbers of plants appearing season after season on the same soil area, so a square meter was selected in some of the plots and the plants were counted each year. One of these, the one least disturbed by rodents and not burned or grazed, is given in a table later in the discussion of the causes of the changes in plant cover.

The plant species involved in the changes of plant cover under consideration are comparatively few. Those used in the tables and most frequently in the text are: Russian-thistle (*Salsola pestifer* A. Nels.); mustards, which include flixweed (*Sophia parviflora* (Lam.) Standl.) and tumblemustard (*Norta altissima* (L.) Britton); downy chess (*Bromus tectorum* L.); stickseed (*Lappula occidentalis* (S. Wats.) Greene and *L. texana* (Scheele) Greene). All but the last named are introduced plants. Tumbleweed (*Amaranthus graecizans* L.) is not common on dry abandoned fields but is given here because of its appearance in some of the records on the plots. Other plant names not referred to frequently are given in place in the text. The relation of the species given above to those of irrigated fields and to those of cleared sagebrush lands remote from cultivated sections is discussed in a previous publication (*9*).

CHANGES (1928–35) IN WEEDY PLANT COVER

The changes in weedy plant cover are affected by factors that can be grouped roughly under two headings, "destructive agencies," such as burning, excessive grazing, and wind erosion, and "natural" factors, such as climate (particularly precipitation) and plant characteristics (growth period and seed production and dispersal). Data regarding changes of plant cover on the fields and plots are presented in tables 2 to 7. These tables are grouped under subheadings and are followed by discussions. The discussions are limited here to the effect of destructive agencies, while the effect of precipitation and plant characteristics is dealt with later, after available information concerning the factors themselves has been presented. The later discussion of the causes of changes in plant cover under conditions free from destructive agencies also helps to understand why the changes are different or do not take place when destructive agencies are in operation.

NEWLY ABANDONED FIELDS

MODERATELY GRAZED FIELDS

The changes in weedy plant cover for the newly abandoned fields moderately grazed are given in table 2 and for the plots in these fields in table 3. The changes are described in some detail for field 4, and those of other fields or of plots are compared with this and the more outstanding differences are noted.

TABLE 2.—*Changes in weedy plant cover on three newly abandoned fields following barley and alfalfa crops*

Year	Field 4		Field 5		Field 14	
	Major portion	Minor portion	Major portion	Minor portion	Major portion	Minor portion
1927	Irrigated barley crop.	Irrigated barley crop.	Irrigated alfalfa crop.	Irrigated alfalfa crop.	Irrigated alfalfa crop.	Irrigated alfalfa crop.
1928	Russian-thistle.	Flixweed	Russian-thistle with flixweed.	Alfalfa	Alfalfa with flixweed.	Downy chess.
1929	Russian-thistle with flixweed.	Russian-thistle with flixweed.	Flixweed	Downy chess or alfalfa.	Alfalfa and flixweed.	Downy chess or nearly bare.
1930	Flixweed, or flixweed with tumble-mustard.	Downy chess, or flixweed with downy chess.	do	do	do	Downy chess.
1931	Flixweed, or flixweed with downy chess.	Downy chess or Russian-thistle with flixweed.	Flixweed and downy chess.	Sparse alfalfa or Russian-thistle.	do	Do.
1932	Downy chess	Nearly bare or sparse Russian-thistle.	Downy chess	Nearly bare or sparse Russian-thistle.	Sparse Russian-thistle and downy chess.	Do.
1933	do	Nearly bare or Russian-thistle with downy chess.	do	do	Downy chess.	Sparse Russian-thistle or flixweed.
1934	do	Nearly bare or sparse downy chess.	do	do	do	Russian-thistle and tumblemustard.
1935	do	Sparse Russian-thistle with downy chess	do	Sparse Russian-thistle and downy chess.	do	Do.

TABLE 3.—*Changes in weedy plant cover on plots in newly abandoned fields of barley and alfalfa*

Year	Plot 4, fenced (field 4)		Plot 4A, not fenced (field 4)		Plot 3, fenced (field 4)		Plot 3A, not fenced (field 4)	
	Plant cover	Area occupied	Plant cover	Area occupied	Plant cover	Area occupied	Plant cover	Area occupied
		Percent		*Percent*		*Percent*		*Percent*
1927	Irrigated barley crop		Irrigated barley crop		Irrigated barley crop		Irrigated barley crop	
1928	Stubble and Russian-thistle with scattered mustards.	70	Stubble with Russian-thistle	100	Plant cover removed, soil bare	100	Plant cover removed, soil bare	100
	Dense Russian-thistle patches	30						
1929	Russian-thistle with flixweed	99	Russian-thistle with flixweed	100	Russian-thistle with flixweed	100	Sparse Russian-thistle	50
	Downy chess	1					Russian-thistle with flixweed	50
1930	Flixweed	94	Flixweed	85	Flixweed	94	Flixweed with tumblemustard	84
	Downy chess	4	Flixweed and tumblemustard	14	Tumblemustard	4	Russian-thistle	16
	Tumblemustard	2	Downy chess	1	Russian-thistle	2		
1931	Flixweed	42	Flixweed	87	Flixweed	95	Flixweed	39
	Flixweed with scattered downy chess.	37	Flixweed with tumblemustard	4	Tumblemustard and flixweed	4	Flixweed with Russian-thistle	34
			Flixweed with downy chess	4	Downy chess	1	Flixweed with tumblemustard	22
	Downy chess	17	Downy chess	2			Downy chess	5
	Bare	4	Bare	3				
1932	Downy chess	99	Downy chess	21	Downy chess	9	Downy chess	11
	Bare	1	Bare	61	Bare	78	Bare	63
			Russian-thistle	11	Russian-thistle	11	Russian-thistle	23
			Tumbleweed	7	Tumbleweed	2	Tumbleweed	3
1933	Downy chess	98	Downy chess	59	Downy chess	80	Downy chess	54
	Bare	2	Nearly bare with sparse Russian-thistle and downy chess.	41	Nearly bare with sparse Russian-thistle and downy chess.	20	Nearly bare with sparse Russian-thistle and downy chess.	46
1934	Downy chess	99	Downy chess	96	Downy chess	98	Downy chess	87
	Bare	1	Bare	4	Bare	2	Nearly bare with sparse downy chess or tumblemustard.	13
1935	Downy chess	99	Downy chess	92	Downy chess	99	Downy chess	91
	Bare	1	Bare	8	Bare	1	Nearly bare with sparse downy chess.	9

Year	Plot 5, fenced (field 5)		Plot 5A, not fenced (field 5)		Plot 14, not fenced (field 14)	
	Plant cover	Area occupied	Plant cover	Area occupied	Plant cover	Area occupied
		Percent		*Percent*		*Percent*
1927	Irrigated alfalfa crop		Irrigated alfalfa crop		Irrigated alfalfa crop	
1928	Alfalfa	9	Alfalfa		Alfalfa and flixweed	100
	Russian-thistle with flixweed	91	Russian-thistle with flixweed			
1929	Alfalfa	8	Alfalfa		do	100
	Flixweed	90	Flixweed			
	Downy chess	2	Downy chess			
1930	Alfalfa	10	Flixweed and alfalfa	81	do	100
	Flixweed	85	Russian-thistle	8		
	Downy chess	5	Downy chess	6		
			Tumblemustard	2		
1931	Alfalfa	7	Alfalfa	13	Flixweed	100
	Downy chess	76	Downy chess	16		
	Flixweed with tumblemustard	10	Flixweed and Russian-thistle	68		
	Nearly bare	7	Russian-thistle	1		
			Nearly bare	2		
1932	Alfalfa	3	Alfalfa	5	Downy chess	2
	Downy chess	92	Downy chess	86	Russian-thistle and flixweed	98
	Bare	3	Nearly bare with sparse downy chess and Russian-thistle	9		
	Russian-thistle	2				
1933	Alfalfa	1	Alfalfa	3	Downy chess	3
	Downy chess	98	Downy chess	91	Downy chess and Russian-thistle	43
	Bare	1	Bare	6	Flixweed and Russian-thistle	38
					Flixweed	8
					Russian-thistle and tumblemustard	3
					Nearly bare	5
1934	Downy chess	99	Downy chess	96	Downy chess	16
	Bare	1	Bare	4	Downy chess and Russian-thistle	84
1935	Downy chess	98	Downy chess	96	Downy chess	66
	Bare	2	Bare	4	Russian-thistle	34

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FIELD 4

The development of the weedy plant cover on field 4 is shown year by year in table 2. The data represent all of the field open to grazing; that is, all of the field outside of the small fenced oblong containing plots 3 and 4. The changes in plant cover are as follows: Russian-thistle was the dominant plant and formed the cover over a major portion of the field the first 2 years (1928 and 1929). The first year the weedy cover in the barley stubble (fig. 1) consisted of irregular dense patches of Russian-thistle, especially along the corrugations, while between the dense patches there was a sparser growth with some mustards, chiefly flixweed, scattered in it. The second year Russian-thistle formed a uniform cover, denser but considerably shorter than in the preceding year. In this cover the flixweed still occurred as

FIGURE 1.—Field 4 in 1928, the first year after abandonment, and plots 3 and 4 2 weeks after being fenced. The bare soil (right) is plot 3, which was hoed clean. Plot 4 (left) was left intact, and here, as well as in the surrounding field, Russian-thistle was the dominant weed in the barley stubble. Flixweed and tumblemustard were scattered throughout the field and plot 4. Downy chess was also present, but comparatively rare. Photographed June 14, 1928.

individual plants rather than patches but much more closely spaced than in the preceding year. After these 2 years Russian-thistle formed only an insignificant part of the cover.

The next 2 years (1930 and 1931) flixweed was the dominant plant and covered the major portion of the field (fig. 2). In 1932 (figs. 3 and 4) and thereafter to 1935 (fig. 5) flixweed was rare and downy chess covered 95 percent (fig. 3) or more of the field. Downy chess had developed from a few widely scattered individuals in 1928 to small clusters of several plants in 1929, then to dense patches in 1930 and 1931 over a minor portion of the field, and in the latter year was also mixed with the flixweed in part of the major portion of the field. After 1931 downy chess formed a uniform cover.

Comparing the changes in plant cover of field 4 (table 2) and those of plot 4A (table 3), it is seen that they are very similar; that is, the end result is the same—a cover of downy chess preceded by one of flixweed and that by one of Russian-thistle. There is a difference in the 2 years 1932 and 1933, when one of the nearly bare areas covered a large portion of plot 4A (fig. 3), although the major part of the field was covered with downy chess (table 2 and fig. 3). Thus the plot represented a minor rather than a major portion of the field for these 2 years. In 1934 and 1935 the development on the plot had again reached a point equivalent to that on a large portion of the field.

The changes in plant cover in plot 4 (table 3) took place within a fence and so were protected from the grazing and trampling of stock. The development is the same as that summarized for field 4. Downy chess formed a somewhat more complete cover in plot 4 (99 percent) than in the field (95 percent) in 1932. In the years 1932-35 the plot was free of other weeds. In plot 4A there was not a cover as complete as this until 2 years later, 1934. Throughout the years after 1931 there was a smaller percentage of bare soil in plot 4 than in field 4, and many times smaller than in 4A.

Plots 3 and 3A, whose location in field 4 are shown in figure 3, represent areas laid bare in 1928. That year's growth was hoed off, and to make sure that all growth was killed the plots were kept free of all weeds for that season. The development of a plant cover begins then a year later (1929) than in the rest of the field. Plot 3 was fenced and near to plot 4, separated only by a meter strip, whereas 3A, unfenced, was similarly situated near 4A.

The development on plots 3 and 3A is similar in essentials to that of field 4 and plot 4, but there is the delay in the development of a downy chess cover as in 4A for the 2 years

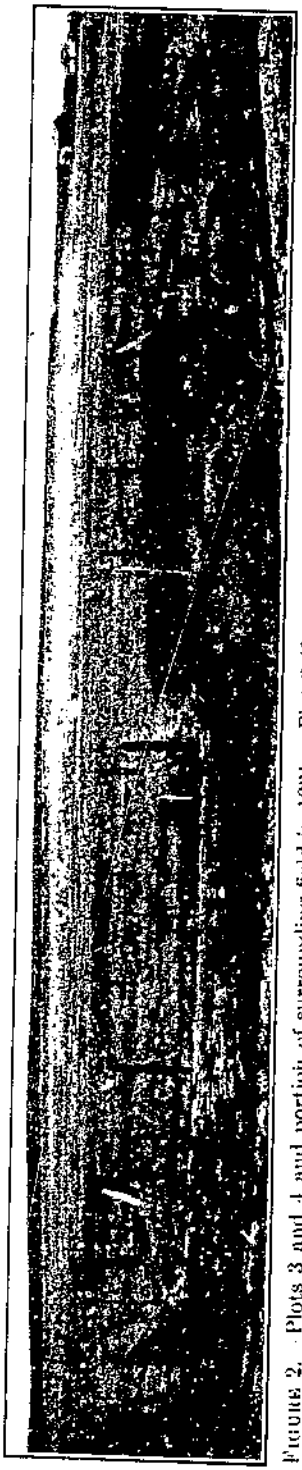

FIGURE 2.—Plots 3 and 4 and portion of surrounding field in 1931. Plot 3 (from right to white stake center) is covered with dense flixweed (dark). In plot 4 (left) and the surrounding field the light areas are downy chess or flixweed mixed with downy chess. Russian-thistle is lacking in both the plots, and only small patches of dwarfed plants occurred in the field, such as the patch just outside the fence at the lower left (darker than flixweed). Photographed September 18, 1931.

1932 and 1933, when the percentage of bare or nearly bare soil was high. In both plots 3 and 3A Russian-thistle formed the cover over the major portion for 1 year instead of 2 as in plot 4 or field 4.

FIELD 5

Field 5, separated from field 4 only by a road, differed from it in that an alfalfa crop preceded abandonment instead of a barley crop as in field 4. Development of the weedy plant cover in field 5 (table 3) was essentially the same as in field 4 except that the Russian-thistle cover was not pronounced the first year and lacking the second year, also bare or nearly bare areas occurred over a somewhat larger area than in field 4. The similarities and the differences just noted for the two fields apply as well to the two plots 4 and 5. Plot 5A (table 3), representative of field 5, showed a larger proportion of bare area than the fenced plot 5 but not the amount in 4A.

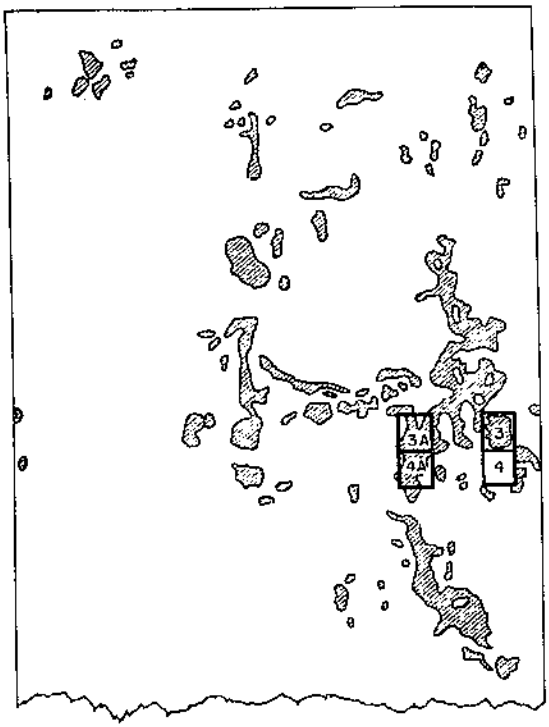

FIGURE 3.—Field 4 in 1932, the fifth year after abandonment. Downy chess (unshaded portion) covered 95 percent of the area. The remaining 5 percent (shaded portion) was either bare soil or covered with a tall scattered growth of Russian-thistle. The fenced plots, Nos. 3 and 4, are indicated by the oblong at the right. Photographed September 8, 1932.

FIELD 14

In field 14 (table 2), also with an alfalfa crop preceding abandonment (1928), the initial Russian-thistle cover was lacking, and instead there was a cover of flixweed among the alfalfa tufts. Russian-thistle appeared only as widely scattered plants. However, after the disappearance of flixweed in 1931, Russian-thistle was the next most abundant plant to downy chess, the two together forming a sparse cover. A downy chess cover was developed a year later (1933) than in field 4. This development was even later in plot 14 (table 3). Here downy chess first appeared in 1932 and did not develop to a point equivalent to the development over the major part of the field until 1935.

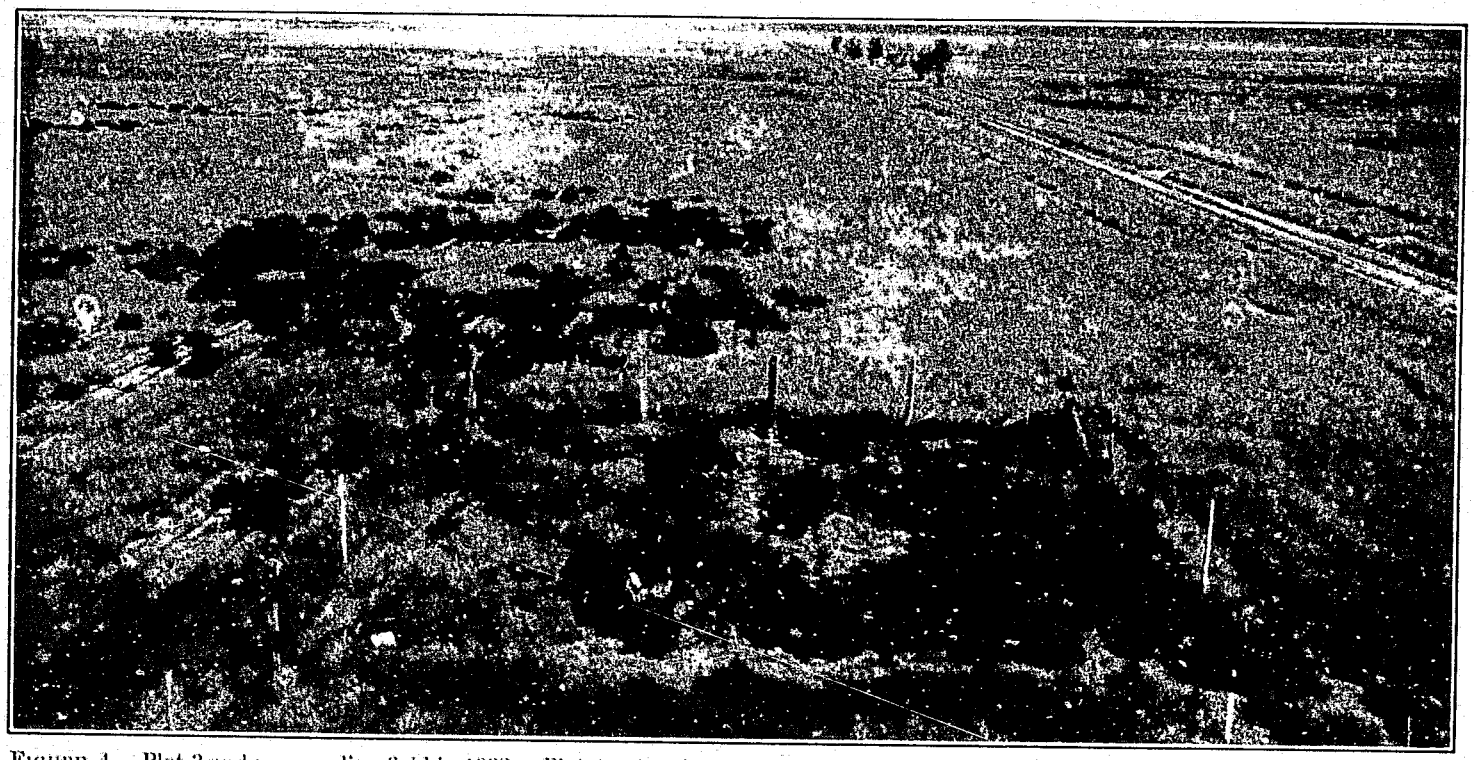

FIGURE 4.—Plot 3 and surrounding field in 1932. Plot 4 (edge shown in immediate foreground) has a practically complete cover of downy chess. Plot 3 (above path and from white stones back to fence) has a small area of downy chess (left) and some scattered tufts (right), but the greater portion has a scattered stand of large Russian-thistle (dark plants). The spaces between the Russian-thistle plants (center) are bare soil (light patches) or strewn with old plant debris of previous years (lightly shaded portions). Similar Russian-thistle patches occur in the surrounding field. Flixweed is lacking in the plot and rare in the field outside. Photographed September 7, 1932.

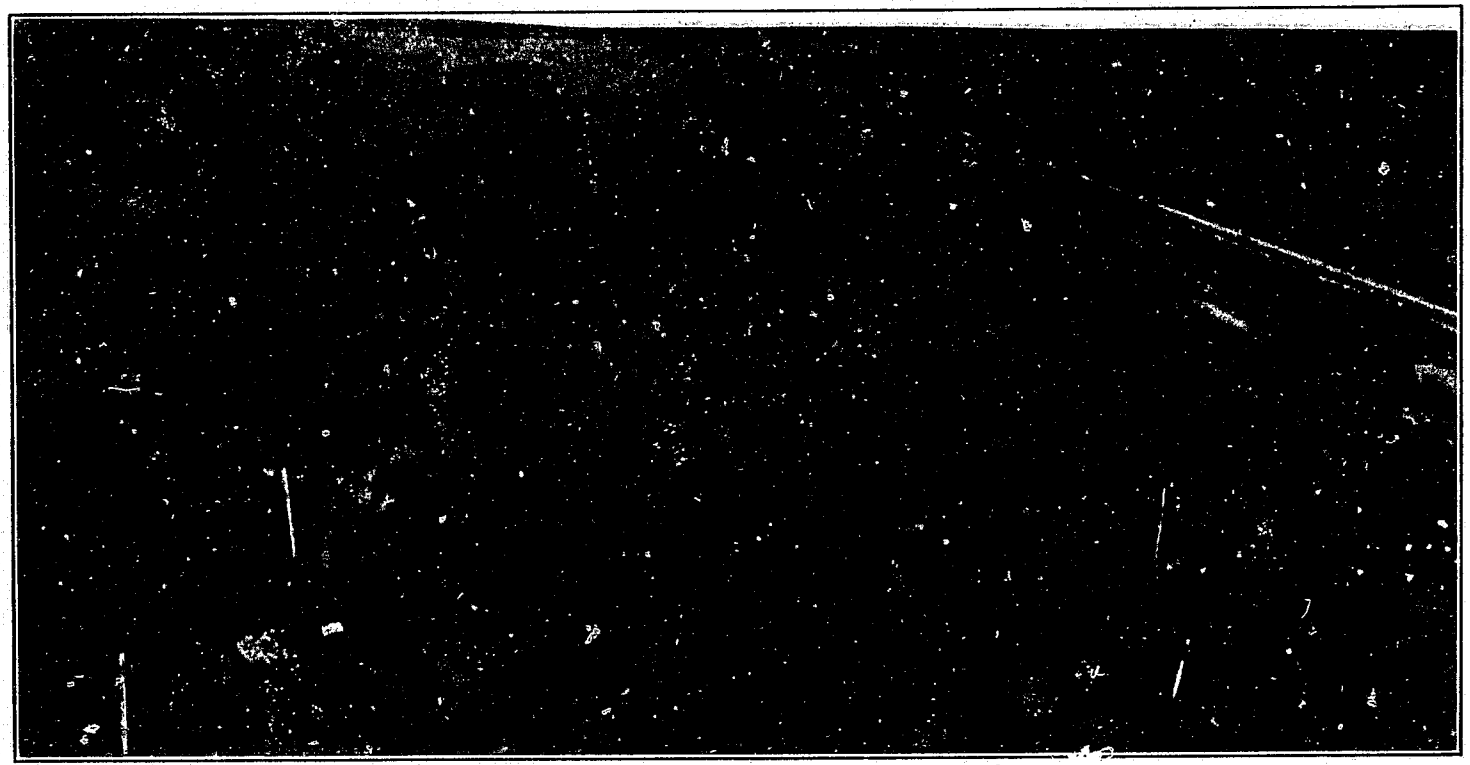

FIGURE 5.—Plot 3 and a portion of the surrounding field in 1935. The small downy chess area in plot 3 in 1932 (fig. 4) extended until now (1935) only one Russian-thistle plant appeared within the plot. The Russian-thistle areas of the surrounding field are also greatly reduced since 1932 (compare fig. 4). Plot 4 (edge shown in immediate foreground) has maintained its uniform cover of downy chess. Photographed September 20, 1935.

HEAVILY GRAZED FIELDS

The observations on two fenced fields with stock enclosed and hence heavily grazed and trampled are given in table 4. Both were newly abandoned fields (1928).

TABLE 4.—*Changes in weedy plant cover on two newly abandoned fields heavily grazed and trampled by enclosed stock*

Year	Field 1		Field 2	
	Major portion	Minor portion	Major portion	Minor portion
1927	Irrigated alfalfa crop.	Irrigated alfalfa crop.	Irrigated wheat crop.	Irrigated wheat crop.
1928	Downy chess	Alfalfa	Russian-thistle	Tumblemustard.
1929	Nearly bare or sparse Russian-thistle.	Alfalfa or downy chess.	do	Do.
1930	do	do	do	Do.
1931	do	Downy chess	do	Do.
1932	do[1]	Downy chess and Russian-thistle.	do	Tumblemustard with downy chess.
1933	Downy chess and Russian-thistle.	Russian-thistle	do	Downy chess and tumblemustard.
1934	Downy chess	do	do	Downy chess with tumblemustard.
1935	do	do	do	Tumblemustard and downy chess

[1] Part of the field fence down, May 1932.

FIELD 1

The alfalfa stand had already deteriorated at the time of abandonment and the spaces between the widely spaced alfalfa tufts were covered with downy chess. A portion of this field (plot 1) was fenced against all grazing (table 5).

TABLE 5.—*Changes in weedy plant cover on two plots fenced against the grazing of stock enclosed in the fields*

Year	Plot 1, fenced (field 1)		Plot 2, fenced (field 2)	
	Plant cover	Area occupied	Plant cover	Area occupied
		Percent		*Percent*
1927	Irrigated alfalfa crop	33	Irrigated wheat crop	100
1928	Alfalfa	5	Stubble with Russian-thistle	100
	Bare area	62		
	Downy chess	23		
1929	Alfalfa	11	Russian-thistle with tumblemustard	100
	Bare area	66		
	Downy chess	23		
1930	Downy chess and alfalfa	91	Tumblemustard	44
	Bare area	9	Tumblemustard and flixweed	25
			Russian-thistle	30
			Downy chess	1
1931	Alfalfa	4	Tumblemustard	48
	Bare area	13	Tumblemustard and Russian-thistle	38
	Downy chess	83	Russian-thistle	5
			Downy chess	2
			Tumblemustard with downy chess	1
			Flixweed with tumblemustard	6
1932	Alfalfa	4	Tumblemustard	72
	Bare area	1	Downy chess with tumblemustard	19
	Downy chess	95	Downy chess	9
1933	Nearly bare[1] (scattered Russian-thistle, tumblemustard, and downy chess).	63	Tumblemustard	1
		37	Downy chess with tumblemustard	40
	Downy chess		Downy chess	60
1934	Nearly bare	75		
	Russian-thistle and downy chess	2	Downy chess	99
	Downy chess	23	Tumblemustard	1
		75		
1935	Russian-thistle and downy chess	21	Downy chess	99
	Nearly bare	3	Tumblemustard	1
	Downy chess and tumblemustard	1		

[1] This portion burned Apr. 4, 1933.

As a result of the grazing and trampling, the field outside of the fenced plot developed a patchy cover. Near the gate, where trampling was heaviest, the soil was bare. Also throughout the rest of the field bare patches were everywhere, parts of them carrying a sparse short growth of Russian-thistle, and between the bare patches there were other small patches of downy chess or downy chess and Russian-thistle. This cover was characteristic of the years 1929, 1930, 1931, and 1932. In 1932 part of the field fences were taken down, and after that the grazing became more nearly that of the transient herds. By 1935 a good cover of downy chess had developed and at the time of maturity had been damaged very little by stock.

In the fenced plot (No. 1, table 5) downy chess maintained a cover in the intervening spaces between the alfalfa tufts and increased in area as the alfalfa disappeared. The plot was subjected to considerable disturbance of the soil as rodents burrowed to get at the alfalfa roots. The comparatively few other weeds present appeared on the newly disturbed soil. Much of the disturbed soil, where subsoil was not brought to the surface, was covered the following year by downy chess. On April 4, 1933, the owner accidentally burned part of the plot while burning weeds along a nearby field fence. The plant debris of the preceding year was still quite heavy, and the current season's growth of downy chess was green. The effect of the fire was to kill all of the growth on a little over one-third of the plot. Subsequent germination brought on a sparse growth of Russian-thistle, tumblemustard, and downy chess. The effect of the fire, though somewhat lessened, was noticeable in 1934 and 1935.

On the heavily grazed field, then, the downy chess cover deteriorated to a patchy cover, largely bare soil or Russian-thistle with some patches of downy chess. In the plot protected from grazing the downy chess maintained a cover nearly free of other weeds excepting the patches of soil newly disturbed by rodents.

FIELD 2

In 1928, the first year of abandonment, the plant cover of field 2 (table 4) was similar to that of field 4. The weeds in the grain stubble were largely Russian-thistle with both mustards (flixweed and tumblemustard) scattered throughout, while downy chess was rare. There were some patches in the field where tumblemustard predominated.

In the following years the changes in this field were slight. The most heavily trampled areas, such as near the gate and watering trough, were bare each year. The major portion of the field remained covered with a sparse growth of Russian-thistle (fig. 6). The tumblemustard area remained much the same, not over 5 percent of the field, up to 1932. After that year downy chess appeared with the tumblemustard, and the area of these increased in 1934 and 1935 to about 25 percent of the field.

In the plot (No. 2, table 5) fenced against grazing, the development was the same as in plot 4, that is, from a Russian-thistle cover to one of mustards and then to one of downy chess (fig. 6). The differences were a greater proportion of Russian-thistle persisting in plot 2 the third and fourth years (1930 and 1931), a longer period during which mustards (in this case tumblemustard instead of flixweed) covered a major part of the plot, and also the longer time (1934 instead of 1932) when downy chess formed as complete a cover as in plot 4.

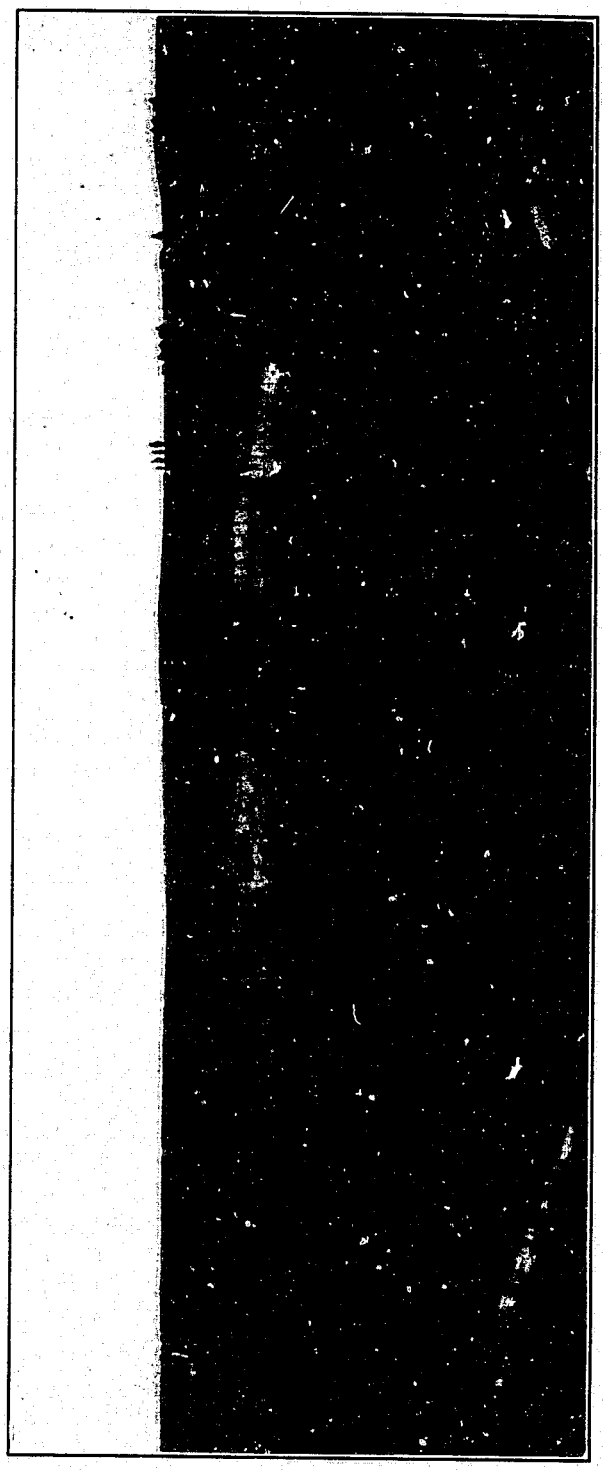

FIGURE 6.—Field 2 in 1935. Within the fenced plot, protected from grazing, there is a good cover of downy chess with some scattered Russian-thistle and tumblemustard (1 Russian-thistle for each 9 m^2, 1 tumblemustard for each 5 m^2, and more than 1,500 downy chess for each square meter). In the surrounding field Russian-thistle forms a sparse cover. Tumblemustard with downy chess occupies the light area in the background at the left. Photographed October 18, 1935.

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DISCUSSION OF CHANGES ON NEWLY ABANDONED FIELDS

The discussion here is limited to the changes in weedy plant cover that took place on newly abandoned fields (alfalfa and stubblefields) and to the effect that grazing had on the changes.

Russian-thistle was the first dominant and made a good growth in the abandoned stubblefields, 2 and 4, and so far as present information goes this is true generally. In alfalfa fields Russian-thistle may appear, as in field 5, make a poor growth the first year, and be sparse or lacking the second. The only fields seen where Russian-thistle made a good growth were those in which the alfalfa plants were in poor condition and very widely spaced. In some fields, such as No. 14, flixweed was present at the time of abandonment, and in field 1 there was downy chess. The difference is probably due to the fact that the stubblefield was plowed the year before and the weeds were the result of the first year's growth, whereas the alfalfa field may have been neglected so that the stand had deteriorated for 1 or more years preceding abandonment, and the weedy cover had had more than one season in which to develop. Aside from the difference in the growth of Russian-thistle and usually a more pronounced burrowing of animals in the alfalfa field, the changes in plant cover on the two types of newly abandoned fields were essentially alike.

The change from Russian-thistle to mustards may involve either flixweed, as in plot 4, or tumblemustard, as in plot 2. So far as present information goes the role of the two species in the changes of plant cover is similar and they are interchangeable.

In dealing with the effect of grazing, the extreme excessive grazing by enclosed stock may be contrasted with the other extreme, no grazing of the fenced plots, and with an intermediate moderate grazing [5] of the fields open to transient herds.

But for excessive grazing and trampling, the development in field 2 might have been expected to have followed a course similar to that in field 4; that is, a change from Russian-thistle to mustards and finally to downy chess. Such an expectation is supported by the development of a downy chess cover within the fenced area, plot 2, protected from grazing (fig. 6). Also the development in the field seemed proportionate to the amount of trampling and grazing, as indicated by the observations that where this was most severe, near gates and troughs, the soil was bare, and where there was somewhat less disturbance Russian-thistle appeared, whereas mustards or downy chess appeared eventually only in the remote, least disturbed portions.

Field 1 shows the effect of excessive grazing under somewhat similar conditions as field 2 but with a different initial cover. Here downy chess already formed a cover between the alfalfa tufts and the question was not of its development but of its maintenance. The cover of downy chess was destroyed, and there was instead a patchy cover in which Russian-thistle was the most important plant over a large part of the field. As a contrast to this, the downy chess cover within the fenced plot, protected from grazing, was maintained throughout the

[5] The amount of grazing was not uniform. It was slight on the newly abandoned fields up to 1930, as long as some fields in this portion of the irrigated tract were still being cultivated. In 1930 the lateral supplying this section was cut off and the remaining fields abandoned. Thereafter the grazing was heavier, especially from 1933 to 1936. Likewise the grazing in fields 1 and 2, while considered excessive for the period 1928–35, was less so from 1933 to 1935 after portions of the fences had been let down and the stock ranged over adjoining fields.

series of years with the exception of the portion of the plot that was burned in 1933.

This destruction of a downy chess cover occurs each season wherever a prolonged concentration of stock occurs. A similar effect may be seen when trails are made across a downy chess cover either by automobiles or by the trampling of animals.

Three newly abandoned fields (4, 5, and 14) were exposed to the grazing of transient herds. The development on these fields was essentially the same, resulting eventually in a downy chess cover similar to that of the fenced plots 4 and 5, though somewhat less complete and less uniform. However, such results cannot be expected on any particular field exposed to grazing, since the chances of destruction are always present, either during the process of development or after a downy chess cover has been formed.

On some of the newly abandoned fields in the vicinity of field 4, watering troughs were set up temporarily and water was hauled for sheep. One unfenced field one-half mile from field 4 had a considerable portion of its downy chess heavily trampled so that the soil was bare. Russian-thistle appeared the following year. Another field contiguous to field 8 but with an alfalfa and downy chess cover was also heavily trampled and the area covered with Russian-thistle the following season, and this was later followed by mustards. An unfenced, abandoned alfalfa field about a mile from field 1 had a stack of alfalfa hay on it that was fenced. The hay was later removed, but the fence was left intact. By 1935 practically all of the alfalfa plants were gone and Russian-thistle covered most of the field, as in field 2; but the small area within the stack fence, about equal to one of the fenced plots, had a good cover of downy chess in it.

It seems, then, that though development to a downy chess cover may take place on an abandoned field open to grazing, as it did on fields 4, 5, and 14, observations on other fields show there is no certainty that this will take place and results like that of fields 1 and 2 may be expected. Russian-thistle may persist from year to year or if a downy chess cover is developed it may be destroyed and Russian-thistle or mustards reappear.

No exact information is available on the part that trampling alone as separate from grazing takes in the destruction of the weedy plant covers. Downy chess is eaten quite readily in spring, so that it is subject to both eating and trampling. Neither Russian-thistle nor the mustards are eaten to any extent in spring, but the more wiry stems and branches of Russian-thistle survive trampling better than the broader-leaved and more brittle-stemmed mustards.

OLD ABANDONED FIELDS

The fields listed in table 6 were all abandoned 5 years preceding 1928 and some of them much longer. Perennials had appeared, chiefly young sagebrush in irregular strips on the west sides, but there were also some perennial grasses, though usually they were widely and unevenly scattered.

TABLE 6.—*Changes in the weedy plant cover on old abandoned fields*

Year	Field 8		Field 9		Field 11	
	Major portion	Minor portion	Major portion	Minor portion	Major portion	Minor portion
1928	Stickseed and flixweed	Downy chess	Stickseed and Russian-thistle.	Tumblemustard and downy chess.	Russian-thistle.	Downy chess.
1929	....do.....	....do.....	....do.....	Downy chess	Russian-thistle and stickseed.	Do.
1930	....do.....	....do.....	Russian-thistle with tumblemustard and stickseed.	....do.....	Downy chess.	Russian-thistle, stickseed, and tumblemustard.
1931	Downy chess	Flixweed ...	Russian-thistle.	....do.....	....do.....	Sparse Russian-thistle or nearly bare.
1932	....do.....	Russian-thistle.	Russian-thistle and stickseed.	....do.....	....do.....	Russian-thistle and stickseed.
1933	....do.....	Nearly bare or sparse stickseed or Russian-thistle.	Downy chess..	Russian-thistle.	....do.....	Russian-thistle.
1934	....do.....	Downy chess..	....do.....	Tumblemustard or Russian-thistle.	....do.....	Do.
1935	....do.....	Sparse Russian-thistle or stickseed with downy chess.	....do.....	Russian-thistle with tumblemustard.	....do.....	Do.

FIELD 8

Field 8 (table 6) in 1928 was covered with alternating patches of the three weeds. This patchy cover continued for 3 years with some changes in the proportions. In 1931 and thereafter downy chess covered the major portion of the field. A strip made up of a sparse growth of either Russian-thistle or stickseed reached across the plot (table 7) in 1935. In the other years the cover on the plot was similar to the cover on the major part of the field.

FIELD 9

Field 9 (table 6) was covered with stickseed and Russian-thistle in 1928, with a narrow strip of downy chess along one side bordering a highway and a strip along a shallow drainage channel. There were also some patches of tumblemustard scattered in the field. By 1935 the downy chess had extended from the strips and had covered a major part of the field. In the unfenced plot (table 7) there was little change and Russian-thistle was still the cover in 1933, though the portion of the field represented by the plot decreased from a large portion of the field in 1928 to a minor portion, slightly over one-fourth, in 1935.

FIELD 11

A small part of field 11 at the east end was covered with downy chess, and there were narrow strips running along the borders. By 1930 downy chess covered the larger part of the field (table 6). The unfenced plot (No. 11, table 7) was representative of a major portion of

the field during 1928 and 1929 and then to 1934 represented a minor part of the field. Russian-thistle continued to be the dominant plant in the plot, though downy chess increased in 1934 and there was a further increase in 1935.

TABLE 7.—*Changes in weedy plant cover on plots on three old abandoned fields*

Year	Plot 8, unfenced (field 8)		Plot 9, unfenced (field 9)		Plot 11, unfenced (field 11)	
	Plant cover	Area occupied	Plant cover	Area occupied	Plant cover	Area occupied
		Per cent		*Per cent*		*Per cent*
1928	Downy chess	18	Russian-thistle	79	Russian-thistle	100
	Flixweed	48	Stickseed	21		
	Stickseed	34				
1929	Downy chess	41	Russian-thistle	9		
	Downy chess and flixweed	6	Stickseed	22	Russian-thistle	99
	Flixweed	21	Russian-thistle and stickseed	69	Downy chess	1
	Flixweed and stickseed	22				
	Stickseed	10				
1930	Downy chess	52	Russian-thistle and stickseed with tumble-mustard	100	Downy chess	1
	Flixweed	43			Russian-thistle	70
	Stickseed	5			Stickseed	29
1931	Downy chess	64	Russian-thistle	100	Russian-thistle	99
	Flixweed and downy chess	29			Downy chess	1
	Flixweed and Russian-thistle	7				
1932	Downy chess	85			Downy chess	1
	Downy chess and stickseed	13			Stickseed and Russian-thistle	99
	Nearly bare	2				
1933	Downy chess	91	Russian-thistle	100	Downy chess	1
	Nearly bare	9			Russian-thistle	99
1934	Downy chess	99	...do	100	Downy chess	1
	Nearly bare	1			Russian-thistle with scattered downy chess	99
1935	Downy chess with Russian-thistle	99	...do	100	Downy chess	5
	Downy chess with flixweed	1			Russian-thistle with scattered downy chess	75
					Stickseed with Russian-thistle and downy chess	20

DISCUSSION OF CHANGES ON OLD ABANDONED FIELDS

All three of these old abandoned fields showed evidence of fire prior to 1928. Since neither a mustard nor a Russian-thistle cover will burn ordinarily, but a downy chess cover burns readily, it seems likely that fields 8, 9, and 11 had each been covered with downy chess prior to 1928 and that either burning or burning combined with excessive grazing destroyed the cover. Subsequently there appeared plant covers of Russian-thistle, stickseed, or flixweed, such as were found in 1928.

The plant cover on the major portion of each of these fields, at the beginning of observations in 1928, differed somewhat, though downy chess was present on a small portion of each. Eventually downy chess covered a major portion but not to such an extent as in fields 4 and 5. There was a greater irregularity of the cover. Breaks in its uniformity due to anthills and rodent mounds were more frequent. Portions in fields 9 and 11 showed signs of wind erosion prior to 1928 and bore quite sparse covers during the period of observation. The number of plant species was greater. Stickseed, not usually found on newly abandoned lands, formed a part of the cover on these old aban-

doned fields, and besides the scattered perennial grasses and sagebrush there were also a considerable number of species not an important feature of the cover but found only as widely scattered plants or localized in small patches.

The difference in the development on plots 9 and 11, representing minor portions of the fields, and in the development on the major portions cannot be explained with any certainty. It is ascribed to trampling or burning followed by wind erosion that took place prior to 1928.

The greater variation in both soil conditions and plant cover generally observed on old abandoned lands as compared with the newly abandoned lands is discussed further in the following sections dealing with burned-over fields and bare portions of fields.

BURNED-OVER FIELDS

FIELD 12

Field 12 (table 8) was selected in June 1928 just after the downy chess cover had been burned quite uniformly. The following year downy chess appeared as small colonies or scattered plants in a tumblemustard cover. In 1930 the field was burned over again, but patches of tumblemustard were left unburned where the downy chess was scant. The following spring dense patches of downy chess alternated with larger areas of sparse downy chess with tumblemustard. Much of the tumblemustard died prematurely and by the early part of June had disappeared from a large portion of the field and plot, leaving a downy chess cover of greatly varying density or bare soil. When the downy chess cover was burned in 1932 it was followed by a sparse cover of downy chess and Russian-thistle. By 1935 a downy chess cover had again developed over a major portion of the field.

The unfenced plot (No. 12, table 9) showed changes in plant cover similar to those in the field.

TABLE 8.—*Changes in weedy plant cover on two burned-over abandoned fields*

Year	Field 12		Field 13	
	Major portion	Minor portion	Major portion	Minor portion
1928	Burned downy chess.[1]	Sparse Russian-thistle and downy chess.	Dense downy chess[2]	Dense downy chess.[2]
1929	Tumblemustard with downy chess.	Russian-thistle	Sparse downy chess and tumblemustard.	Flixweed.
1930	Tumblemustard and downy chess.[1]	Downy chess	Downy chess and tumblemustard.	Sparse Russian-thistle.
1931	Downy chess	Tumblemustard or nearly bare.	Downy chess	Tumblemustard.
1932	do.[1]	Sparse tumblemustard with downy chess.	do	Do.
1933	Sparse downy chess and Russian-thistle.	Downy chess	Downy chess with tumblemustard.	Nearly bare.
1934	Russian-thistle with tumblemustard.	Russian-thistle and downy chess.	Downy chess	Do.
1935	Downy chess with tumblemustard and Russian-thistle.	Downy chess	do	Tumblemustard and downy chess.

[1] Burned uniformly in June 1928 and somewhat irregularly in August 1930 and again in August 1932.
[2] Burned between June 1928 and March 1929.

TABLE 9.—*Changes in weedy plant cover on plots in burned-over abandoned fields*

Year	Plot 12, unfenced (field 12)		Plot 13, unfenced (field 13)	
	Plant cover	Area occupied	Plant cover	Area occupied
		Percent		*Percent*
1928	Burned downy chess cover [1]	100	Downy chess [2]	100
1929	Tumblemustard and downy chess	100	Tumblemustard	4
			Downy chess and tumblemustard	96
1930	Downy chess [1]	14		
	Downy chess and tumblemustard	17	Tumblemustard	1
	Tumblemustard	29	Downy chess	18
	Tumblemustard with scattered downy chess	40	Downy chess and tumblemustard	81
1931	Downy chess	99	Downy chess and tumblemustard	100
	Nearly bare	1		
1932	Downy chess [1]		Downy chess	86
	Nearly bare		Downy chess and tumblemustard	13
			Nearly bare	1
1933	Downy chess	1		
	Sparse cover of downy chess, tumblemustard, and Russian-thistle	99	Downy chess	100
1934	Downy chess, tumblemustard, and Russian-thistle.	100	do	100
1935	Downy chess with scattered tumblemustard.	100	do	100

[1] Burned uniformly in June 1928 and somewhat irregularly in August 1930 and again in August 1932.
[2] Burned between June 1928 and March 1929.

FIELD 13

The grazing on this field was characterized as irregular in table 1. While none of the fields open to transient grazing can be said to have been grazed uniformly from year to year, the differences here were very great. The field was enclosed by a fence and there was no indication of grazing in 1928. In 1929 there was heavy grazing by enclosed horses for a short time in early spring, and so in 1930. In 1931 part of the field fence was broken down and there the field was subjected to grazing by transient herds.

Between June 1928 and March 1929 the downy chess cover was burned and this was followed by a mixture of downy chess and tumblemustard for 2 years (table 8). Thereafter downy chess again formed the cover.

DISCUSSION OF CHANGES ON BURNED-OVER FIELDS

Following the burning of the downy chess cover in 1928 there appeared a sparse stand of downy chess and tumblemustard in field 13 and a dense cover of tumblemustard with varying amounts of downy chess in field 12.

In another field one-half mile east of field 12 a portion of the downy chess cover was burned in December 1929. In 1930 there was no distinguishing line between the burned and unburned areas and an examination showed no change in the composition of the cover. Contrary to this condition, a number of fields scattered throughout this general area and burned in the very dry season 1931 were either bare or sparsely covered in 1932 and continued so in 1933 and 1934. On some of these fields the bare or nearly bare area increased.

The effect of burning alone, not complicated by other factors, following the burn on fenced plot 1 in early April 1933, is seen in table 5. Here the effect was immediate and severe, since under the debris of

the preceding season's growth downy chess had already germinated and the seedlings several centimeters in height were killed by the fire. In fields open to grazing there is less likelihood of sufficient debris in spring to support a fire, though occasionally there may be this type of injury in the fall if downy chess has already started new growth.

From what has been said it is obvious that the mere statement that a field has been burned is not sufficient information to foretell what the effect will be on the succeeding plant cover. It is necessary to know also whether the new growth of downy chess has started, whether subsequent grazing and trampling have been excessive, and whether the burning was followed by a very dry season accompanied by high winds. In the latter case the field may have been swept clean of seeds and possibly of the topsoil.

BARE PORTIONS OF FIELDS

WIND EROSION

Wind erosion as discussed in this bulletin is limited to that which affects the development of a weedy plant cover, usually on areas of soil where the cover has been previously removed by other agencies. The initial removal of the cover may be due to grazing and trampling or burning, but rarely plowing, since fields at the time of abandonment are usually covered with stubble or alfalfa. Those with newly turned soil are quite rare.[6] Pronounced wind erosion rarely affects entire fields, and no continuous records are available for them. The fields previously mentioned as being burned over in 1931 were practically bare over their entire extent the following season, but pronounced soil erosion that prevented a plant cover for a number of years was limited to portions of the fields and especially to those portions where stock or rodents disturbed the thin crust of the bare soil. The loosened soil was then readily blown away by the wind. Where a sparse growth occurred it was usually Russian-thistle, though tumble-mustard was often present.

The most pronounced wind erosion, where continuous records were kept, occurred at one of the fenced 40-acre tracts (Castleford plot) where the surface soil of a portion of the tract was churned to dust by stock early in the spring of 1931. There was very little or no cover on this portion that year, and during the exceedingly dry summer and fall the soil surface was badly wind-swept. The few plants present were either destroyed by rodents or broken off by the wind. There was very little improvement in 1932, and in the dry years 1933 and 1934 the area of bare or nearly bare soil was extended to several times the original size. While the initial area was largely outside of the fence, later by far the greater area was within the fence and not accessible to stock. Soil to the depth of 1 to 2 inches was blown away and deposited at the first barrier, tufts of weeds. Here hummocks of soil up to 4 inches deep were formed.

No noticeable effect was found on plots 3 and 3A, which were kept free of weeds so that the surface was bare during 1928. Both the plots were well covered in 1929. Portions of these plots and 4A were again bare of green growth in 1932, but these patches were covered with

[6] Fallow lands are excluded. Since these are again cultivated, there is little opportunity for any development of the weedy cover to take place. The most common growth on nonirrigated fallow lands in the Snake River Plains is one of Russian-thistle.

the debris of the preceding season's growth. The bare patches decreased in the next year and were completely covered in 1934. While the wind effect would be greater in larger areas, the lack of erosion here cannot be entirely ascribed to the smallness of the areas, since the small patches of soil around anthills in old abandoned fields were noticeably scoured by the wind in 1931.

Instead it seems that whether or not a bare soil area is eroded by the wind enough to affect appreciably the following season's cover is dependent on the length of the drought period, frequency of high winds, and to what extent the surface crust of soil is broken. Once the process is begun, many factors converge to prevent the reestablishment of a plant cover. The smooth, hard soil offers slight opportunity for seeds to lodge, whether from the few plants present or from the plants of the surrounding area. Conditions for germination for the few seeds that gain a lodging place are particularly unfavorable, since the bare soil dries out rapidly after a rain. Of the few that germinate, some during the seedling stage are badly frayed by the moving soil particles and finally disappear. Some are killed out by stock or rodents or are broken off by the wind. In the latter part of the season the soil is again bare or practically so and the erosion continues. In winter snow is blown off together with some of the surface soil, and a deposit of snow and soil particles is laid down beyond the first barrier.

OTHER AGENCIES CAUSING BARE PATCHES

Jack rabbits under certain conditions may profoundly affect both forage and vegetation in general on semiarid lands, as shown by Vorhies and Taylor (*13*). The interest here is limited to the effect the jack rabbits may have on the changes in weedy plant cover.

There was no noticeable effect on dense stands, for the changes took place on the abandoned fields and plots (listed in tables 2 to 9), though all of these were open to jack rabbits. The effect was marked on the sparse growth on the wind-eroded area previously mentioned at the edge of the Castleford plot. The widely spaced plants mature later than the surrounding dense growth and probably afford an added attraction to the rabbits. Downy chess was clipped to the ground and only the half-ripe heads were left lying about; and Russian-thistle was also clipped, though the entire plant was less frequently killed. The effect of this injury was to delay further the development of a cover, since the possibility of seeding the area was greatly reduced and the soil was again exposed to the full action of the wind.

A similar effect was observed on the portions of the field where plots 9 and 11 were situated (tables 6 and 7). The sparse cover on these portions was badly damaged by jack rabbits.

In the 40-acre Burley plot (fenced against stock) 5 years' records show practically no downy chess on the 20-acre weedy portion of the tract. Occasional plants were recorded, but these were eaten off early or at least before maturing. Downy chess was planted on 2 square rods in a small area (36 square rods) within fine-mesh fencing. The grass spread over all the rest of the area not occupied by perennials and contrasted sharply with the grass-free, sparse growth just outside the rodent exclosure.

More information is necessary to explain why jack rabbits prevented an increase of downy chess on the Burley plot but did not do so on

the abandoned fields, for which data are given in the tables. So far as the limited observations go, there was no marked difference in the numbers of jack rabbits in the two areas. A difference in the available food at the two places offers a better explanation. At Burley during the time when downy chess numbers were low the surrounding area was excessively grazed. In the Hollister area when downy chess numbers were low the surrounding area was moderately grazed and abandoned alfalfa and grainfields were frequent. There may have been, of course, a concentration of the jack rabbits on the affected areas, but it is thought that this is not necessary to produce the effect.

In each of the cases mentioned above the initial cause of the sparse growth is attributed to soil erosion preceded by burning or excessive trampling. The delay in covering the area is greatly increased by the rabbits. So far there is no evidence in the area considered here that the feeding of rabbits alone will affect a dense cover sufficiently to bring about a change in the weedy cover. The same statement applies to grasshoppers in this area, though in some years when they are abundant they may affect sparse growths somewhat as the jack rabbits do. But here it is obvious that the grasshoppers have moved in from the surrounding mature and dry cover and concentrated on widely spaced, still green plants.

Bare soil also results from the burrowing of animals. The patches of newly turned soil may be well covered the following year especially if they are surrounded by a dense cover, as of downy chess in plot 1. If by the burrowing the subsoil is brought to the surface, the patches may remain bare or very sparsely covered for a number of years. The individual patches are small, and usually the total of these in a field is not great. In field 4 it was not over 3 or 4 percent. In field 5 the area was greater, as it usually is in abandoned alfalfa fields, but less than 10 percent of the field. Only occasionally concentrations of the animals occur to such an extent that a large part of any field is affected, though the total in some sections may be great.

Small bare patches of soil also occur around anthills and remain bare until some time after the hill has been abandoned. These usually cover a very small part of the field, largely on the old abandoned fields. In fields 4 and 5 anthills were rare, though they were frequent in the strips along the road that had not been cultivated when the fields were cropped. In a strip 65 feet wide and 550 feet long, that was thought to be representative of the Castleford fenced plot, about 0.1 percent of the area was covered by anthills, but only 0.05 percent in the Burley plot in a strip approximately two and one-half times as large.

CAUSES OF THE CHANGES IN WEEDY PLANT COVER

Clements, Weaver, and Hanson (4), in the summarizing chapter of their work, Plant Competition, state:

> Much evidence has been secured of the importance of the three primary factors, water, light, and nutrients, in the various aspects of the present investigation. The results are in essential agreement throughout to the effect that water stands first, light next, and nutrients last, in native communities, with the order of light and nutrients reversed in the case of many intensive field-crops.

In the semiarid section of southern Idaho, water is an especially outstanding factor, since the amount is definitely limited to that

available in the upper layers of soil wetted by the current season's rains. Below this upper moist layer the soil is perennially dry. Thus the soil space on which the plant can draw for its water is limited in depth and, excepting very sparse covers, is also limited laterally in all directions by the surrounding plants.

For the present purpose the soil may be compared to a reservoir from which the plants draw their water. The capacity of the reservoir, if the same soil space is considered, will be the same from year to year. The amount of water each plant can get will depend (1) on how much will be put into the reservoir by precipitation, and (2) on how this will be shared; that is, on how many plants will draw on it. The amount of water available to each plant, then, will be affected by anything that will increase or decrease the numbers of plants per unit area. Destructive agencies such as fire and grazing affect the numbers of plants either the current or the following season. So do plant characteristics such as seed production and seed dispersal, and especially so since the plants dealt with here are annuals and there must be a new crop of plants from seed each year.

The amount of water available to individual plants of different species will be affected by another plant characteristic, the growth period, since this determines the time at which the water will be drawn upon—whether one species will draw on the water before another.

The available information on these factors as well as precipitation is presented in the following pages, and then an attempt is made to combine them so as to show why the changes in the weedy plant cover take place.

NUMBERS OF PLANTS EACH YEAR ON THE SAME SQUARE METER OF SOIL

The counts on the 1 m² in plot 4 were selected (table 10) because here the changes in plant cover were well represented and also because this square meter throughout the period of observation, besides being free of the disturbances due to burning and grazing, was not noticeably affected by rodents as were the counts on most of the square meters of the other fenced plots. Since the numbers of individual plants were enumerated each year on the same unit area of soil, the soil factors can be considered as constants.

TABLE 10.—*Numbers of plants on the same square meter of soil for each year, 1928–35*

Year	Russian-thistle		Flixweed		Downy chess		Tumble-mustard		Other plants		Total plants
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*
1928	[1] 26	54.2	4	8.3	0	0	11	22.9	7	14.6	48
1929	402	58.6	211	30.8	2	.3	17	2.5	53	7.7	685
1930	0	0	1,538	96.2	0	0	43	2.7	17	1.1	1,598
1931	0	0	936	92.2	47	4.6	30	3.0	2	.2	1,015
1932	0	0	0	0	305	100.0	0	0	0	0	305
1933	0	0	6	0	+1,800	100.0	0	0	0	0	+1,800
1934	0	0	0	0	1,484	100.0	0	0	0	0	1,484
1935	0	0	0	0	2,351	100.0	0	0	0	0	2,351

[1] The number of Russian-thistle plants given for each of the years was that obtained in the fall, when the plants were mature. The number of seedlings counted in the spring were as follows: 1928, 134; 1929, 687; 1930, 7; 1931, 40; and none in the years 1932–35

Most of the plants were mature or nearly so at the end of May, and a count of all the plants was made at that time. However, since living plants only were counted, this did not seem satisfactory for Russian-thistle, which at that time was still near the seedling stage. The mortality between the seedling stage and the nearly mature plants is high, and as this number was not included in the counts of the other plants, it seemed preferable to make a count of Russian-thistle in the fall at its maturity. Accordingly, the figures used in the following discussions are those obtained in the fall for Russian-thistle.

Aside from Russian-thistle, the two mustards, and downy chess, few other species were recorded. These were: *Collinsia tenella* (Pursh) Piper, *Gayophytum racemosum* Torr. and Gray, stickseed (*Lappula occidentalis* (S. Wats.) Greene), prickly lettuce (*Lactuca scariola integrata* Gren. and Godr.), and redscale (*Atriplex rosea* L.). These plants, native except the last two, were usually few in number.

The growth in 1928 was marked by the low number of individuals of all species, of which Russian-thistle had the highest number and downy chess had none (table 10). The other plants were five barley seedlings, one prickly lettuce, and one *Gayophytum*. The barley died prematurely before it had headed out.

In 1929 the total number of individuals had increased over 14 times. Russian-thistle had increased over 15 times, though the 687 seedlings in May were reduced to 402 by fall and only 9 produced some seed. Flixweed had increased nearly 50 times. Downy chess appeared for the first time. The other plants present were prickly lettuce, 21; *Collinsia*, 31; redscale, 1.

In 1930 the total number of individuals was more than twice that of 1929. Russian-thistle seedlings appeared, but did not mature. Flixweed increased to over seven times its previous number and was now the dominant plant. Tumblemustard numbers continued low. Downy chess did not reappear. The other plants present were prickly lettuce, 1; stickweed, 1; *Gayophytum*, 15.

In 1931 the total number of all plants decreased somewhat and so did the number of flixweed. Russian-thistle seedlings again appeared, but they did not mature. Downy chess, which had been present in the rest of the plot since 1929 (table 3), reappeared in the square meter. The only other plants were two of prickly lettuce. The year 1931, as shown later, was a very dry one, and none of the individuals of any of the species present, except downy chess, matured seed. Flixweed produced a few sterile flowers but no pods, whereas downy chess was well stooled and had several heads for each plant.

In 1932 downy chess appeared in a sparse stand with an increase of over six times, but there were no flixweed, Russian-thistle, or other plants.

Again in 1933 downy chess was the only species present. Its numbers increased over six times. The stand was dense and continued so for the next 2 years with no other species present.

The percentages of the total number given in table 10 indicate that there is an increase in the dominance of each succeeding species or a tendency toward a purer stand.

There is also an increase in the density of the plant cover, an increased occupancy of the soil space, as seen by comparing the figures in the last column of table 10. This increase in the number of indi-

viduals per unit area was not a gradual, steady one, but rose to peaks at irregular intervals.

COMPETITIVE EQUIPMENT OF THE SPECIES

The term "competitive equipment of the species" is equivalent to "biological equipment of species in relation to competition," used by Salisbury (*11*), and to the "competitive equipment of plants," used by Clements, Weaver, and Hanson (*4*). Under this heading are included plant characteristics that have been considered of special importance in competition, specifically in this bulletin, the supplanting of one dominant annual species by another.

SEED PRODUCTION

The principal species in the first two stages of the secondary successions produce large quantities of seed under favorable conditions. For fields in the northern Great Plains region Stevens (*12*) reports 80,400 seeds for a fair-sized tumblemustard, 75,650 seeds for flixweed, and 24,700 seeds for Russian-thistle. Considering only the plants growing on the dry lands of the Snake River Plains and excluding those on the waste places of irrigated land, the seed production of these three species is usually much less than that just given. Large plants selected on dry abandoned land and where plants were well spaced gave the following: For tumblemustard, 49,000 seeds; flixweed, 30,000; Russian-thistle, 6,100; and downy chess, 400. These are not the extreme. The two largest downy chess plants recorded had grown in a sheltered and partly shaded place and produced 6,120 and 4,200 seeds, respectively. A large, bushy flixweed grown on an old strawstack site and not crowded by other plants exceeded the seed production given by Stevens.

In the usual plant cover the individuals are crowded, and the seed production is far below that just given for large plants. On the 1 m² in 1929 when Russian-thistle was the dominant with flixweed as a secondary species and when the total number of all species was 685, an average-sized flixweed produced about 1,500 seeds. In 1930 with a higher rainfall, when the total number of plants, chiefly flixweed, was 1,598, the average-sized plant yielded only about 500 seeds. Even at the latter figure the seed production for the entire square meter was high, considering that it would be necessary for only one of several hundred seeds to grow to a mature plant to form a plant cover similar to that of the preceding year. The test came the next year, and the result was a dense stand of flixweed, although in number somewhat below that of 1930.

The importance of high seed production is seen in 1931, when the dense stand of flixweed produced no seed at all, with the result that thereafter flixweed did not occur in the square meter nor the plot and rarely in the entire field. The spaces occupied by dense growths of flixweed in 1931 were covered the following year partly by downy chess, partly by Russian-thistle, and a part was bare, as seen in plot 3 (table 3 and fig. 5). The percentages in this plot were downy chess 9, Russian-thistle 11, tumbleweed (*Amaranthus graecizans* L.) 2, and bare soil 73. A total of 87 percent of the plant cover of plot 3 in 1932 can be attributed to the preceding year's seed crop, either to its success

or to its failure; that is, the 9 percent of downy chess to an abundance of seed and 78 percent of bare soil to the lack of flixweed seed. Only the 2 percent with tumbleweed on it can be directly attributed to storage of seed in the soil. No plants of this species matured anywhere in the field or near it after 1927, so that its appearance can scarcely be accounted for by migration. Because of the efficiency with which Russian-thistle migrates, the remaining 11 percent may be attributed either to reseeding or to seed in the soil.

The point is that only 2 percent of the plant cover of the plot can be definitely ascribed to storage of seed in the soil and that 78 percent of the plot area remained bare throughout the season unaffected by the seed crops of earlier years. Since the fencing of the plot (1928) there had been at least one heavy crop of Russian-thistle seed (1928) and one of flixweed (1930), but not enough seed of either had remained to cover this 78 percent of the plot. If the 11 percent area of Russian-thistle is ascribed to stored seed, it may be that the seed had been plowed under in 1927, as that of the tumbleweed had been, and that it was not seed at or near the surface from the 1928 crop. Nevertheless, it is plain that there was not sufficient seed stored to form a cover for 78 percent of the area.

In field 4, as a whole, such areas formed a very small portion. Of the 5 percent not covered by downy chess (fig. 3) it was estimated, after excluding rodent mounds, that the type discussed above covered not over 1 percent.

It is very likely that the seeds of any of the species just discussed may remain buried in the soil for 5 years and retain their vitality (3), but it is not known to what extent seeds of the species concerned with here may retain their vitality when at or near the surface of the soil, as is necessarily the case where the soil is left undisturbed on the abandoned lands.

SEED DISPERSAL

A comparison of the methods of seed dispersal for the four species is as follows: Russian-thistle and tumblemustard are alike in that entire plants are broken off and tumbled about by the wind so that the seeds are widely scattered. However, Russian-thistle fruits are winged so that they are more easily carried farther by the wind, whereas tumblemustard seeds, because of their rounded forms, rest where they fall unless rolled along the ground or carried by water. Neither in flixweed nor in downy chess do the entire plants take a part in seed distribution. In downy chess the fruits are awned, and they may be attached to the coats of animals and thus carried about. Flixweed seeds are shed as they mature and fall about the parent plant. To some extent all of these species have their seeds distributed by being mixed in alfalfa seed and hay or in grain, but flixweed is most dependent on this method of transportation for any distance.

Of the four, Russian-thistle is perhaps best equipped to carry its seeds quickly and in quantity to nearby fields. Tumblemustard is a close second. However, although both are often cited as standard examples of tumbleweeds, this is true only of the individuals that are well spaced and thus grow to assume the dense, rounded form. If the plants are too crowded the individuals are of an open growth and slender, so that they are not easily broken off and do not have the proper form for tumbling readily with the wind. Therefore, the

tendency when the plants are crowded is to shed the seeds around the parent plants and so produce greater and greater crowding of the succeeding generations and make it less and less favorable for the individual to survive and produce seed.

Thus one of the principal characteristics (large seed production) that makes possible migrations in considerable numbers eventually thwarts such migration as the crowding becomes too severe and finally, when little or no seed is produced, prevents the species from continuing to occupy the ground. However, the function of carrying the species to new areas of bare soil had already been performed in the first year or two of its occupancy, so that the continuance of the species may be assured as long as new areas of bare soil are present, regardless of whether it continues to occupy a given area.

GROWTH PERIOD

GERMINATION

Downy chess, flixweed, and tumblemustard, in the order given, have already shed their seeds by about July 1, and they germinate as soon as sufficient rain has fallen. This is rarely before September and usually later, or, in other words, after the seeds of Russian-thistle are also shed. Here there is a distinct difference, in that downy chess, flixweed, and tumblemustard germinate immediately after there is sufficient moisture, whereas Russian-thistle does not do so until spring, or in the rather rare cases of fall germination, the seedlings are frozen in the severe winter weather. The time during which the first three species may germinate (fall to spring) is long and at some time during that period conditions are favorable for germination (of the three species mentioned, not of native desert annuals). Early light rains may bring on germination only in patches of old plant debris, shallow depressions, or old ditches, and the seedlings may not survive subsequent warm fall weather. Some years germination may not start at all before freezing, but takes place the following spring. For Russian-thistle the period is shorter (early spring to early summer), but either melting snows or later rains afford favorable conditions for germination.

GROWTH AND MATURITY

In the years when germination of downy chess, tumblemustard, and flixweed is very late, freezing weather is apt to follow shortly after and little growth is made. In such cases the last two pass the winter in the cotyledon stage or may develop small rosettes of about a centimeter in diameter. Downy chess may have one or two blades 1 to 2 cm in height. When germination is early, as in the fall of 1930, tumblemustard and flixweed may develop good-sized rosettes of 5 to 10 cm in diameter with dense leafage where the plants are well spaced. Downy chess, if germination is early and the plants are not too crowded, stools and is 5 cm or more in height. Usually these three species are well started by the time Russian-thistle begins its germination. In cases where germination of all of them takes place in spring and about the same time, the first three grow rapidly in the cool weather of spring, whereas Russian-thistle makes very little growth until the temperatures become relatively high. Downy chess develops

most rapidly. About the middle of May it is heading out. Figure 7 shows the comparative growth of the four species at this time. Flixweed and tumblemustard have no flower buds as yet, and Russian-thistle is a small tuft of bristlelike leaves barely past the seedling stage. About the middle of June, when flixweed and tumblemustard are in the flowering stage, downy chess is dry, or nearly so. Flixweed matures its seeds about a week or so before the first of July, and tumblemustard about that long after the first. By the time all of these three species have matured Russian-thistle has not yet made its greatest growth. It begins flowering in late July or August after having lived through the hottest and driest part of the year and finally matures not much ahead of the average date of the first killing frost.

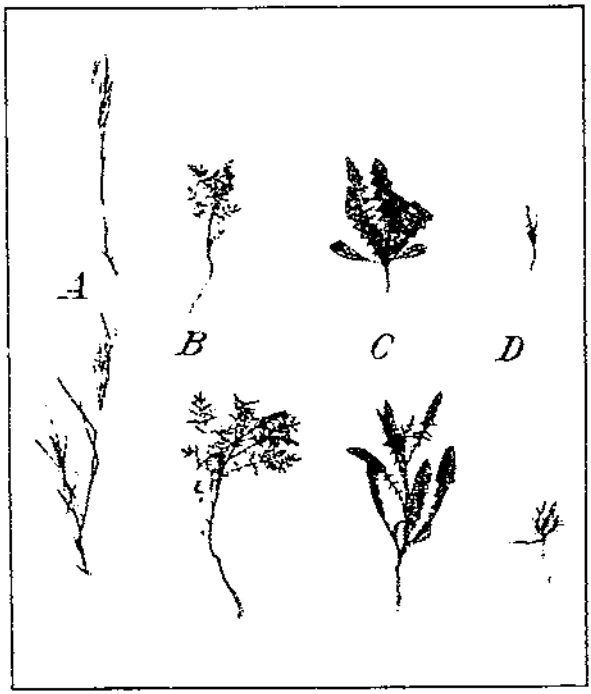

FIGURE 7. Comparative growth of the four principal species involved in the changes in weedy plant cover. These are: *A*, Downy chess; *B*, flixweed; *C*, tumblemustard; *D*, Russian-thistle. At the time downy chess is heading out Russian-thistle is still near the seedling stage.

The dates of maturity are approximate averages for the period of observations. In warm, dry springs downy chess may mature 2 to 3 weeks earlier, and in cool, wet springs 2 to 3 weeks later, with the dates for flixweed and tumblemustard earlier or later, respectively, though not necessarily in the same proportion.

The root development of the four species is briefly as follows: Russian-thistle forms the most extensive root system, reaching a depth of 18 or more inches, while downy chess has the shallowest, 6 to 12 inches. For large plants on good soil where there is a deeper moisture supply, the roots are correspondingly deeper and Russian-thistle roots

may reach several feet in depth. This species has the generalized type of root system with both taproot and laterals well developed. Downy chess has a finely divided fibrous root system which intensively occupies the soil space but is not of great depth nor of great lateral extent. Tumblemustard and flixweed are in intermediate positions between these two with shallower root systems than Russian-thistle and with laterals of less extent.

Thus, Russian-thistle, which grows throughout the hot, dry summer, is equipped to draw moisture from a wide space and a great depth, and downy chess, which matures at the beginning of the hot weather, draws moisture only from a localized area in the upper soil layers. The latter is least dependent on rains, other than those normally expected in spring. Also, maturing early as it does, downy chess takes the moisture required for the maturity of its seeds some time before any of the others. At the other extreme, Russian-thistle, if in competition with the other species, is forced to find sufficient soil moisture for its greatest growth long after the other species have matured and have fulfilled their needs from the limited water supply and when the chances for any additional rains are slight. Of the four species it would seem that Russian-thistle would need most space for the individual plant to develop and produce seed, and downy chess the least space.

CAPACITY TO WITHSTAND CROWDING

Crowding (high density) is determined by the plant characteristics just discussed; that is, it is chiefly a result of high seed production and slight dispersal. It may markedly affect the individuals of the current season's growth and yet not affect the dominance of the species the following season; that is, the plants may be reduced in size, and seed production per plant may be low but the total seed supply still high. It is only when crowding has increased to such an extent that the continued dominance of the species is at the point of being upset that the capacity to withstand crowding has been reached. An indication of this point is the amount of seed produced per unit area, and the final test is the next generation, the following season. The capacity of a species to withstand crowding then is the highest number of individuals per unit area compatible with the continued dominance of the species. It is considered as a plant characteristic that varies with species, is affected by such factors as soil conditions and precipitation just as other characteristics are, and is measurable if these factors are constant and only the numbers of individuals vary. This subject is discussed further under the heading "Combined Factors of Precipitation and of Crowding" (p. 36).

WATER

PRECIPITATION

The average annual precipitation for the 8 years of observation on plant cover (1928–35) was 7.62 inches, somewhat below that of the mean annual precipitation (9.24 inches) for the 24-year period beginning with 1912. The driest year of the 24 was 1933 with 3.79 inches. Two of the years, 1930 and 1932, were above normal (fig. 8). The mean for the six fall-winter months (September to February, inclusive), when there is little or no growth but when storage of moisture in the soil occurs, is 4.6 inches, about one-half of the mean annual.

The mean for the four spring and early summer months (March to June), when the greatest growth is made, is 3.78 inches. For the two summer months (July and August), when there is a dry-season dormancy for all of the four species except Russian-thistle, the mean is under 1 inch (0.85), or less than one-tenth of the mean annual.

For convenience in use with the particular set of plants the precipitation for the calendar year is not used, but the season is begun with

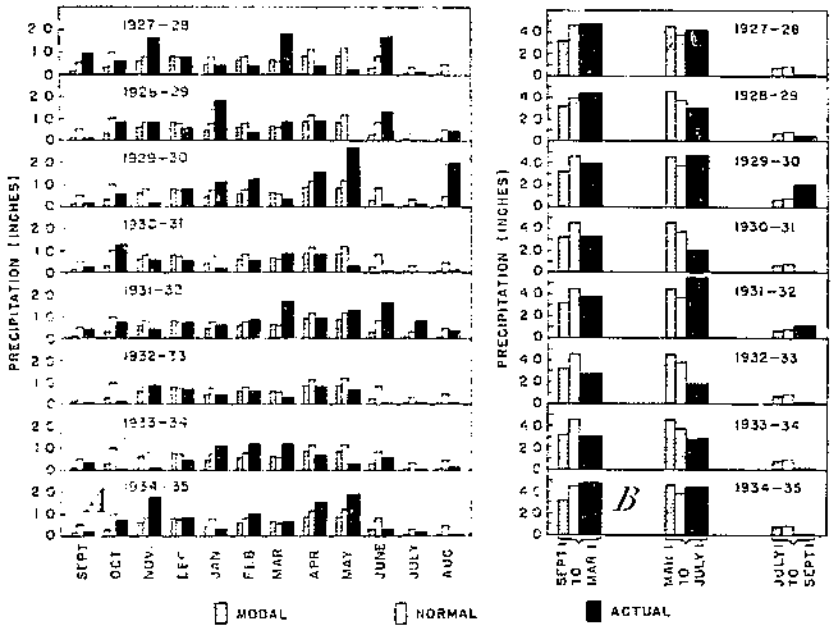

FIGURE 8.—Precipitation at Hollister, Idaho, 1928–35. The data are chiefly from United States Weather Bureau records; where data were missing, the figures were obtained from Hollister rainfall records of the Bureau of Entomology and Plant Quarantine through the courtesy of the Twin Falls station of that Bureau. *A*, Precipitation, in inches, by months; *B*, precipitation, in inches, for fall-winter, the spring, and the summer periods. Actual precipitation is represented by black bars, the normal by white, and the modal by bars marked with slanting lines.

September 1. Rains after the first of September are of no benefit to the current season's growth, since this is already completed; but if the precipitation is sufficient it brings on fall germination and begins storage of moisture in the soil. These fall and winter months are, therefore, more properly grouped with the following season's growth.

Comparing the changes in plant cover on the fenced plots (tables 3 and 5) with the precipitation (fig. 8) for the same period, it is seen that there are no marked changes in the plant cover on any of the plots the year following 1933, the driest year in 24, taken either by calendar year or the September-to-June period. Moreover, there were no consistent changes in the plant cover following 1932, the year when precipitation was above normal.

Precipitation, either its total amount or its distribution, cannot alone account for the survival of Russian-thistle dominance on plots 4 and 5 in 1928 or its failure to survive 1929, and this conclusion is strongly supported by the observations that in 1929, in the same area and on the same soil type, Russian-thistle, where the plants were well spaced, survived, and produced a good supply of seed. Moreover, on the same soil type and where the plants were well spaced, Russian-thistle survived the severe drought year 1931, as well as the most severe drought year of the 24-year record (1933), when the rainfall was only 60 percent of that in 1929. Similar observations were made with respect to flixweed and tumblemustard. Downy chess survived 1933 even in a dense cover (table 11).

TABLE 11.—*Factors in the survival of the plant cover*

Year	Plants per square meter	Soil space per plant	Precipitation [1] Sept. 1 to June 30 [2]		Survival index (based on soil space per plant and precipitation)	Dominant species	Failure or survival
			Actual	Percentage of normal (8.39 inches)			
	Number	*Square centimeters*	*Inches*	*Percent*			
1927-28	48	208.33	8.89	106	220.8	Russian-thistle	Survived.
1928-29	685	14.60	7.43	89	13.0	do	Failed.
1929-30	1,598	6.26	8.78	105	6.6	Flixweed	Survived.
1930-31	1,015	9.85	5.35	64	6.3	do	Failed.
1931-32	305	32.79	9.42	112	37.0	Downy chess.	Survived.
1932-33	1,800	5.56	4.48	53	2.9	do	Do.
1933-34	1,484	6.71	5.87	70	4.7	do	Do.
1934-35	2,376	4.25	9.21	110	4.7	do	Do.

[1] Precipitation compiled from U. S. Weather Bureau data for Hollister, Idaho. Where data were missing the figures were taken from Hollister records obtained by the station of the Bureau of Entomology and Plant Quarantine at Twin Falls, Idaho.

[2] If July and August are added to this period in 1928 and 1929 the precipitation is changed to 9.02 and 7.89 inches, respectively, and the survival indexes (based on normal of 9.21 for September-August) become 203.33 and 11.7, respectively. If June is excluded in 1931 the precipitation is changed to 4.96 inches and the survival index (based on 7.56 inches normal September-May) becomes 4.5. For 1936 the September-June precipitation was 10.02 inches and the index is 4.0 based on 3,218 plants and 3.11 cm.² soil space per plant. If June is excluded the precipitation becomes 7.17 inches and the index 3.1.

Accordingly, the premature drying of Russian-thistle and mustards on many abandoned fields in certain years usually attributed to "drought" can be better understood if the spacing of the plants is taken into account. As far as these four species are concerned, it seems that the individuals may produce seed in the worst of the drought years, if given sufficient soil space on reasonably good soil. In this respect these species are in marked contrast with species such as sunflower (*Helianthus annuus* L.), which grows to maturity and produces seed on ditch banks or wherever irrigation water has escaped, but can rarely do so, even if given an unlimited soil space, on the dry, cleared sagebrush lands that depend solely on precipitation for their water supply. As a contrast sunflower is often a common weed on abandoned lands in southern Idaho where the original cover was grass, brush, or forest and not sagebrush.

Though distribution of precipitation has been mentioned as not accounting for the changes in plant cover, it may, when very irregular,

have a marked effect on the plant cover, as seen in 1936.[7] The extent of this situation and the conditions under which it occurred are discussed further under General Discussion (p. 38).

SOIL MOISTURE

Hallsted and Mathews (7), working with records of soil moisture over long periods, have shown that there is a close relationship between the amount of soil moisture available to winter wheat at seeding time and the yields obtained. In their studies, it was possible to deal with soil moisture data directly without considering the number of plants per unit area since the variations in numbers, though not eliminated, are greatly minimized. At least the excessively high numbers are prevented, since in a wheatfield the numbers per unit area are definitely limited by the rate of seeding.

Some soil-moisture studies were carried on in the fenced plots from 1928 to 1932, but these are considered insufficient to make use of them at present. If accurate determinations of the capacity to withstand crowding (as mentioned in the next section) were attempted, it would be necessary either to make corrections for precipitation to offset the known sources of error or to use some soil-moisture method such as that of Hallsted and Mathews whereby the total available moisture for a unit soil space could be determined. For the present purpose, to illustrate the manner in which factors combine to effect changes in the weedy plant cover, precipitation data have been considered sufficient.

COMBINED FACTORS OF PRECIPITATION AND CROWDING

In a preceding section it was pointed out that the capacity to withstand crowding is a plant characteristic and that it is measurable. Thus under field conditions if a series of densities of a species were selected, were protected by proper fencing to insure development without disturbance, were situated on the same soil type so as to minimize soil differences, and were compared in the same season so as to avoid differences in precipitation, the capacity of a species to withstand crowding under the given conditions of soil and precipitation might be determined and expressed numerically, either by the numbers of plants or by the soil space per plant. Actually a series such as is needed for this comparison would perhaps never occur naturally in a circumscribed area, so that control of numbers by planting, weeding, or both may be necessary to get the proper series of densities in any one year. No such figures arrived at by experiment are available for the four species here considered. However, the figures obtained from the square meter on plot 4 may be used to illustrate the relation among the species in this respect (table 11).

The precipitation varied during this time, but assuming for the moment it had been the same for all the years, the capacity of downy chess to withstand crowding would be high based on soil space per plant, that of flixweed only about half as much, and of Russian-thistle considerably lower than that of flixweed. To get a better comparison

[7] The total precipitation for March, April, and May (normal 2.05 inches) was 1.24 inches in 1936, the lowest of the 1932–36 period, during which the downy chess cover was under observation, and lower than any other in the 25-year record at Hollister, Idaho, except the 2 years 1919 (0.90 inch) and 1924 (0.51 inch). June (normal 0.83 inch) had 2.55 inches in 1936, while July (normal 0.37 inch) and August (normal 0.41 inch) had 0.70 and 0.65 inch, respectively.

for the three species it is necessary to make some correction for the variation in precipitation during these years. For the sake of clearness, a fixed arbitrary period of September 1 to June 30 has been used uniformly throughout the years 1928-35. A more exact method would end the period with the maturing of the dominant plant.

While there is considerable variation in precipitation, it is slight as compared to the variations in numbers of plants per unit area. At precipitations above normal and with uncrowded conditions, the water available for individuals of the four species is not enough to bring about optimum growth as frequently seen when the plants receive water in addition to that of precipitation. With a limited amount of water to begin with, at even normal precipitations, and this amount subsequently divided up several hundred times where the numbers of plants per unit area are high, the chances for the continued dominance of the species are greatly reduced. If precipitation dropped to one-half of normal, the chances would be further reduced. How much this reduction would be has not been determined, but the determination might be made by continuing the experiments mentioned at the beginning of this section through a series of years with varying precipitation. In lieu of such determinations and to illustrate the method of combining the two factors, the soil space per plant, which represents the water available per plant, has been corrected proportionally to variation of the precipitation from normal.

It is obvious that such a relation cannot exist for all the conceivable variations in numbers of plants and in precipitation, but it is thought that the relation holds in the field, where variations of both of these are limited. The survival index (product of columns 3 and 5, table 11) then indicates the possibilities (favorable or unfavorable conditions) for the continued dominance of a species or the survival of dominance for a given area and soil. It is a correction of the capacity to withstand crowding so as to permit comparison of one year with another having a different precipitation. In a comparison of the three species (table 11), the survival index 13.0 indicates failure of Russian-thistle as a dominant (1929) and its absence as a dominant in the next year (1930); 6.3 indicates failure of flixweed in 1931 and its absence in 1932, but downy chess did not fail at the low index of 2.9 (1933) and reappeared the following year.

The figures are given only as rough approximations. The possible inexactness of the method of correcting for precipitation has already been cited. Moreover, some correction for distribution of precipitation would be necessary in some years at least. Also, the counts of the plants, although adequate for the original purpose for which they were used, are somewhat inexact here. The single count of only living plants does not account for all the plants that drew on the water supply, especially in a year such as 1931 when premature drying of nearly full-grown plants was very rapid. Also, the counts are treated as if there were pure stands of one species. This is true of the last 4 years (table 10). In 1930 and 1931 the admixture of other species was only slight, but it was considerable in 1928 and 1929. Very unequal spacing of the plants in the square meter would also have its effect. In 1928 the spacing was unequal, but it was fairly uniform over the square meter in the other years. The year 1928 is not a crucial year but is in fact the extreme for uncrowded conditions in this series.

In arriving at the survival index, simplification of the complex conditions under which changes of plant cover take place has been carried to a high degree. However, the statements are limited to a given soil and to an area protected from destructive agencies where the processes of seed production and crowding proceed undisturbed according to the capacities of each species. The selection of the capacity to withstand crowding and of precipitation as the two major factors does not imply that the other factors may be disregarded, but that the first two combined usually overshadow the effects of the others and can probably account for the changes in plant cover in a large number of cases in most of the years. The two factors, one biological and the other physical, converge to affect the factor most often at its minimum, water.

Even if the figures were arrived at experimentally, it is unlikely that all of the possible factors could be taken into account, and the result would be not an exact point of survival but a range of determinations, so that the figure at which Russian-thistle fails to continue its dominance would probably be not 13.0 but, say, 10 to 16; flixweed, 4 to 10, and downy chess, under 4. On this basis, with a rainfall equal to that of 1929, that is, 1.06 times normal, the number of Russian-thistle plants that would permit survival of its dominance on this soil type would be from 1,060 to 660 per square meter if the range of survival were 10 to 16. With the same precipitation the flixweed numbers would be from 2,650 to 1,060 if the range of survival for it were 4 to 10.

GENERAL DISCUSSION

SIGNIFICANCE OF CHANGES IN WEEDY PLANT COVER

The changes in the weedy plant cover as presented have been observed in Twin Falls County and in other portions of the Snake River Plains in southern Idaho (in abandoned areas in the vicinity of Mountain Home, Elmore County; Cotterell, Cassia County; Shoshone, Lincoln County; Aberdeen, Bingham County; and Minidoka, Minidoka County). In each of these localities some abandoned fields at first covered with Russian-thistle or mustards were found later to be covered with downy chess. Some indication of the extent of the downy chess cover, as well as of breeding hosts of the beet leafhopper, is given in the survey of a portion of Twin Falls County in 1929 (*9*) and in a general survey of southern Idaho in 1934 (*10*).

It is obvious that if the development toward a downy chess cover has taken place on many fields in a widespread area for some time, most of the old abandoned fields should now be covered with it. However, the downy chess cover is not stable in the sense that a sagebrush or perennial cover is, but it may deteriorate in a short time and breeding hosts again appear. The fact that a particular field develops to downy chess cover only to return later to one of breeding hosts (Russian-thistle or mustards) does not mean that downy chess does not play an important part in the beet leafhopper and curly-top problem. A sufficient number of fields remain covered with this grass so that the total acreage in most years is large, and this lessens by that much the total that may be covered by breeding hosts of the beet leafhopper.

COMPARISONS OF THE ORIGINAL SAGEBRUSH AND THE WEEDY PLANT COVER

The original sagebrush cover is exceedingly complex as compared with the simple annual communities that appear following destruction of the former. While sagebrush is the dominant plant and determines the appearance of the association, there are many species of plants (8) in the interspaces among the bushes that are an essential part of the whole. The life forms range from the woody sagebrush to the thallophytic forms of the mosses that cap the hummocks under the bushes. Between the extremes just mentioned there are perennials with bulbs, tuberous roots, and rhizomes, and perennials forming mats, rosettes, tussocks, and bunches. These species, with the exception of the biennials and annuals, are comparatively fixed as to location and numbers from year to year. When changes in numbers occur they take place slowly. The annuals occur for the most part in miniature areas where local disturbances have destroyed part of the perennial cover.

This wide range of life forms contrasts strikingly with the single life form, the annuals (either strict or winter annual) of the weedy plant cover on cleared lands. And since they are annuals, a new set of individuals appears each season, and their numbers, far from being fixed, fluctuate greatly from season to season, an important distinction from the comparatively fixed numbers of the sagebrush community.

The growing periods of the many species of the sagebrush association vary but agree in general to fit the following pattern: Most of the growth is made between the time of the beginning of the fall rains (about October) and the beginning of the succeeding hot, dry summer (July). It is interrupted by the winter cold weather, when little or no growth is made, and is terminated by the hot, dry weather. Occasionally in cases of very prolonged drought the dormancy of the hot, dry weather merges with that of winter so that there is no activity in the fall. The more usual course is for the perennials to show some activity, vegetative growth, or flowering and seeding, in the fall before freezing weather sets in. Once the summer drought is on, about the only native plants actively growing are those that are in reach of a water supply in addition to that obtained directly from precipitation. Such are the willows along streams and, in limited areas, the salt desert shrub within reach of a high water table.

Russian-thistle, usually the first to appear on abandoned land, contrasts sharply with the average growth period of the sagebrush cover and makes its greatest growth during the drought-period dormancy. The mustards (flixweed and tumblemustard) mature much earlier, near the beginning of the drought period, but it is downy chess, the latest of these to form the cover on abandoned lands, that matures the earliest. It seems, then, that as the changes of plant cover go on there is a nearer and nearer approach to the growing period that characterizes the original sagebrush cover.

Besides this difference in growing periods between the two types of communities there is also a difference in seed production. Constituents of the sagebrush association do not form seed, or do so sparingly, in the severe drought years, and the plant cover persists with little or no change the next year; whereas individuals in the communities

of introduced annuals must produce large quantities of seed even in the severe drought years, so that the current season's plant cover may be reproduced the following year.

The ecological requirements of neighboring plants in the sagebrush association differ widely. This is readily seen by comparing the extremes, mosses with the woody sagebrush and with the plants having bulbs or storage roots. An intensive occupancy of the soil by such diversified life forms is finally arrived at only after a long period of time, many decades or perhaps even centuries. In the communities of annuals there has not been time for the adjustments to climate, to soil, and to the competing species as in the community of perennials, so that the cover in any particular year is an assemblage of individuals of one or a few species, and the neighboring plants have identical, or at least quite similar, ecological requirements.

CAUSES OF THE CHANGES IN THE WEEDY PLANT COVER

The various factors affecting the changes in weedy plant cover have been presented in the foregoing pages, but more or less separately. Here the attempt is made to bring them together and with the help of general observations and occasionally specific additional information to show the relation of one to the other.

Russian-thistle usually appears as the first dominant on abandoned lands, owing chiefly to its efficiency in seed distribution. This efficiency may be outweighed by heavy seeding of any of the other weeds from adjacent covers, especially if the area to be seeded is small. Tumblemustard is often the first dominant in areas remote from cultivation, where it may be generally abundant and Russian-thistle rare. On a reasonably good soil no one of these needs to be first in the sense that the soil must be prepared, made habitable, for the next. In trial plantings any one of them was made to appear as the first dominant by heavy seeding. When an equal mixture of all of them was planted, downy chess became the dominant within the first year or at least the second.

In abandoned alfalfa fields Russian-thistle may be the first dominant weed, but if so, it does not make a good growth and may be lacking or rare the second year. Here Russian-thistle seedlings must establish themselves on soil already occupied by a deep-rooted perennial whose growth begins in early spring and continues through the dry summer. Even though the seedlings become established, if the alfalfa tufts are at all closely spaced so that the soil is pretty well occupied laterally as well as to a good depth, the chances for a good growth of Russian-thistle would seem to be poor. This view is supported by observations that the only good growth of Russian-thistle seen in abandoned alfalfa fields was in places where the alfalfa tufts were very widely spaced or in very poor condition. The same has been observed with respect to sagebrush and other native perennials, including the grasses.

If Russian-thistle were a perennial the advantage of prior occupancy on abandoned lands might be more lasting, since seedlings, either its own or of a competing species, would be at a very great disadvantage with the established parent plant. But as Russian-thistle is a strict annual, it is not on an equal footing with such of the competing winter annuals as may be present. The latter have the advantage

usually of prior germination and always of prior maturity. They have first chance at the water supply and fulfill their needs for growth and seed production before Russian-thistle is well started.

The growing period of Russian-thistle calls for water at a time of year when the water supply is at its lowest, so that the individual plant needs a large soil space to get sufficient water. A growth of tall, well-rounded plants of Russian-thistle, then, is an indication of uncrowded conditions. When crowding begins the individuals become smaller, and if crowding is excessive they produce no seeds. It is not necessary to assume competition of another species to account for the failure of either Russian-thistle or flixweed to continue as a dominant. Each of these may seed the ground so heavily that the individuals do not mature. However, it is more common for the competing species to be present, and these may thrive in a cover where the dominant fails. This was true of flixweed mixed in Russian-thistle in 1929 and of downy chess mixed in flixweed in 1931.

If the nature of the changes in the communities of annuals is sometimes stated as if fairly simple and predictable, it is understood that this can be true only if conditions are reasonably limited. It is obvious that if all the conceivable factors have in the past operated on a given field the changes will be exceedingly complex and that there can be scarcely any understanding of these even if there is available a fairly complete history of the field since abandonment. If the destructive agencies (fire, excessive grazing, rodents) are eliminated, the conditions are at once greatly simplified, since these in themselves may be quite complex in their combinations. Furthermore, if the conditions are limited to a reasonably good soil, there is fair assurance that the soil is habitable to all of the species concerned in the changes.

The change from Russian-thistle to flixweed and then to downy chess may proceed under transient grazing, but it is uncertain for any particular field. The certainty is greatly increased if grazing is excluded and, again, if rodents are excluded. If grazing is permitted at a time when Russian-thistle or mustards form the cover and downy chess plants are few, these few plants must survive both trampling and eating by stock. A reduction of the numbers of downy chess, few to begin with, retards or prevents its increase, whereas the thinning, if not too drastic, by trampling of Russian-thistle or mustard covers with high numbers, retards crowding and so favors the continuance of these species as the cover. If the trampling is excessive, Russian-thistle will survive, but not the mustards. If continued, the soil becomes bare and wind erosion sets in.

Once the downy chess cover is formed, its maintenance is likewise dependent on protection from too great disturbance. It may be destroyed by excessive grazing and also by burning, while either may be followed by worse— wind erosion. Once the stand of any one of these weeds becomes sparse, from whatever cause, the effect of jack rabbits and other agencies not noticeable on the dense cover becomes pronounced, and the tendency, especially in dry years, is for an area of erosion to increase and the erosion to be prolonged. The reestablishment of a downy chess cover may be difficult, at least on portions of an old abandoned field after it is affected by the factors just mentioned. Moreover, the development for the field as a whole

may be quite irregular as compared with that on a newly abandoned field.

How long a cover of downy chess may maintain itself in strictly protected situations is not known. For the series of years of observations, the conditions in 1933 and 1936 were the severest. Of the two, the early spring drought was severer in 1936, with 1.24 inches of precipitation for March-April-May, as against 1.77 inches in 1933. Dense downy chess covers survived 1933, and though the growth was slight in 1936, seed was produced. There are, however, in the 25-year weather record at Hollister, Idaho, 2 years that show much severer droughts than that of 1936. Such a spring drought as 1924, with only 0.50 inch, may conceivably cause a lack of seed production and leave the ground open to the entrance of mustards or Russian-thistle. In such a season it would seem that a cover of downy chess strictly protected against disturbance would have less chance of surviving than one grazed sufficiently to thin the cover.

The conditions in 1936 were further complicated by the heavy June rainfall, the heaviest in 25 years. This brought on a germination of Russian-thistle, which, with more than normal summer rains, made a good growth. There was a great increase in the total Russian-thistle area. In some cases it meant two weedy plant covers on the same area in the same season. This occurred where there had been heavy grazing and where there was reseeding of the downy chess area by Russian-thistle from highways or nearby areas. In remote areas surrounded by sagebrush where the downy chess cover had prevailed for some years, so that the Russian-thistle seed supply was low and there was no opportunity for reseeding from other areas, the Russian-thistle appeared only as a few scattered plants or not at all, in spite of the favorable rains.

A high rainfall in June in 1932 did not bring on a similar growth of Russian-thistle, partly because of the later maturing of downy chess and partly because of its tall, heavy growth. In such a heavy cover of downy chess, Russian-thistle was found frequently dried up in the seedling stage.

With a precipitation such as that in 1936, the two covers, Russian-thistle and downy chess, do not come into competition with one another. If such precipitation continued it would change the relationship of the kinds of weedy cover, and if long-continued it might eventually change the character of the native perennial cover as well.

So far as known there is no information available in the literature on either the nature of the changes or the causes of the changes in annual communities such as are treated here. The lack of information on competition involving successive generations of plants has been pointed out by Gause (*6, p. 4*):

> The experiments so far made by botanists are devoted to the analysis of plant competition from the viewpoint of ontogenic development. The competition began when the young plantlets came in contact with one another and all the decisive stages of the competition took place in the course of development of the same plants.

Not only is the information on the communities of annuals meager, but so is that on the original sagebrush community. There is no detailed picture of the relations among the varied species, much less any measure determined by experiment of the competition among them. In many cases it is becoming increasingly difficult to say

what the original vegetation was, except for the dominants, and in some cases even this information is lacking. Moreover, there are no known long-time protected areas of even small acreages to turn to for comparison or study, as there are in forest lands.

SUMMARY

The nature of the changes in weedy plant cover that take place on abandoned fields in southern Idaho, the rate of change, and the species involved are given for a number of fields and plots for the period 1928–35. On newly abandoned fields the successive plant covers were, first, Russian-thistle; then mustards, either flixweed or tumble-mustard; and next, downy chess. Under favorable conditions flixweed supplanted Russian-thistle the third season, and downy chess supplanted flixweed the fifth. In abandoned alfalfa fields the Russian-thistle cover was poorly developed or lacking. Though Russian-thistle forms the first cover, because of its efficient seed distribution, it fails to continue to hold the ground. The numbers of plants per unit area of this species and of flixweed may become so high and the individuals so crowded that they fail to produce seed. Low precipitation accentuates the effect of crowding.

Downy chess and flixweed have the advantage over Russian-thistle usually of prior germination and always of prior maturity. The first two have first chance at the water supply and fulfill their needs for growth and seed production before Russian-thistle is well started. Downy chess has the greatest advantage in this respect, since it matures the earliest. In dense mixed stands where Russian-thistle is the dominant, individuals of flixweed and of downy chess may thrive and produce seed when Russian-thistle fails.

The capacity of a species to withstand crowding and the chances for its continuance as a dominant are illustrated by means of counts made on a square meter in one of the plots. The degree of crowding can be expressed in terms of soil space, in square centimeters per plant, based on the number of plants per unit area, and the figure can then be corrected for precipitation.

The capacity of Russian-thistle to withstand crowding is least, and flixweed is next. The conditions of crowding and drought under which downy chess may fail as a dominant have not yet been observed, though during the period of observation dense covers have survived severe drought.

Destructive agencies such as excessive grazing and burning may either destroy a downy chess cover or prevent its development. Any factor that will cause marked thinning of the cover and so prevent crowding may permit a Russian-thistle cover to persist year after year, as it does in fields excessively grazed by enclosed stock.

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