Vol. 43 DECEMBER 15, 1931 No. 12

JOURNAL OF AGRICULTURAL RESEARCH

CONTENTS

ISSUED BY AUTHORITY OF THE SECRETARY OF AGRICULTURE
WITH THE COOPERATION OF THE ASSOCIATION
OF LAND-GRANT COLLEGES AND
UNIVERSITIES

For sale by the Superintendent of Documents, Washington, D. C. - See page 2 of cover for prices

JOURNAL OF AGRICULTURAL RESEARCH

VOL. 43 WASHINGTON, D. C., DECEMBER 15, 1931 No. 12

PLANT SUCCESSION AND GRAZING CAPACITY ON CLAY SOILS IN SOUTHERN NEW MEXICO [1]

By R. S. CAMPBELL [2]

Associate Forest Ecologist, Southwestern Forest and Range Experiment Station, Forest Service, United States Department of Agriculture

INTRODUCTION

It is common knowledge that continued overgrazing, such as is prevalent on the semidesert ranges of the Southwest, reduces the stand of desirable forage plants and leads to serious range depletion, especially during periods of drought. Such depletion allows erosion of the valuable topsoil layer and permits rainfall to run off in torrential floods, with consequent damage to agricultural lands and urban property in the valleys. Native vegetation, therefore, plays an important rôle not only in range conservation and improvement but also in the protection of watersheds.

This report is concerned with the vegetation and especially with the plant succession found on various types of clay soils occupying nearly 32,000 acres, or approximately one-sixth, of the entire Jornada Experimental Range, and covering large areas in the southern portions of Arizona and New Mexico and the western part of Texas. Different areas of the soils studied present every stage of vegetative development from complete denudation to the climax of dense tobosa grass (*Hilaria mutica*). The denuded and seriously depleted areas present the most critical problems on range units, and their restoration is of the greatest importance. They are practically worthless for grazing and furnish no watershed protection. They also complicate management of the whole unit and are a factor in the silt accumulation of flood waters. They support *Drymaria holosteoides* and *Astragalus* spp., poisonous plants which cause serious losses of livestock. Sampson (*6*) [3] has shown that the grazing value of the vegetative cover is determined essentially by the stage of succession. Plant succession was studied on the range to determine how natural revegetation occurs and the grazing values produced by each stage of development.

SOURCES OF DATA AND METHODS OF INVESTIGATION

In connection with the natural-revegetation and range-management studies on the Jornada range since 1915, many valuable climatic and

[1] Received for publication June 18, 1931; issued January, 1932. In order to establish a complete range unit on which to conduct experiments and demonstrations in range management under conditions existing in southern New Mexico and similar areas in adjoining States, and to find a solution to the problems of range maintenance and grazing capacity which confront the stockmen of the region, the Jornada Experimental Range was created by Executive order May 3, 1912, upon recommendation of the Secretary of Agriculture. This range, upon which the investigations here detailed were carried out, contains approximately 193,000 acres. It is located in Dona Ana County, N. Mex., 10 miles east of the Rio Grande and about 50 miles north of the Mexican boundary. On August 1, 1930, it was made a branch station of the Southwestern Forest and Range Experiment Station.

[2] Acknowledgment is due the earlier members of the Jornada Experimental Range staff for collection of data prior to 1925. Valuable help was rendered by L. C. Hurtt, who established several quadrats for the purpose of studying successional changes of vegetation on clay soils. Constructive criticism of the report was given by Gordon D. Merrick and several other members of the Forest Service.

[3] Reference is made by number (italic) to Literature Cited, p. 1051.

vegetative records have been accumulated. Such of these as yielded significant data were incorporated in this report. Additional studies covering phases of the problem needing special investigation included a close study of soil and vegetative conditions in the field and detailed study of representative areas.

Maximum and minimum air temperatures have been observed daily, and precipitation has been measured at the range headquarters since July 1, 1914, in cooperation with the United States Weather Bureau. Records of evaporation from a free water surface and wind-movement data are taken from the United States Weather Bureau reports for Elephant Butte Dam (*4*). The station is reasonably comparable in evaporation and wind movement to the Jornada Experimental Range, as is shown by measurements taken at the range during 1929 and 1930.

The descriptions of soil types and characteristics were adapted from a report (1918) by J. O. Veach, of the then Bureau of Soils, United States Department of Agriculture, based upon his soil survey of the Jornada range.

The quadrat data were obtained from representative plots, 1 meter square, which were mapped from 1915 to 1924, inclusive, by the strap method, and from 1925 to 1929 by the chartograph method, as outlined by McGinnies (*5*). Perennial-grass tufts were mapped at a height of 1 inch above the ground and were compiled in square centimeters, or ten-thousandths of a square meter.

The degrees of grazing use presented in the analysis of factors influencing vegetative spread were recorded in June at the close of each grazing year as a part of the regular grazing-capacity project. These data record in percentages the volume of range feed used by grazing animals and are based upon the palatability and growth requirements of the forage plants.

Germination tests of the various grass seeds were made from 1923 to 1925 by the agricultural experiment station of the New Mexico College of Agriculture and Mechanic Arts; in 1926 by Carola V. Jackson (*1*) at the University of Chicago; and from 1927 to 1929 by the Bureau of Plant Industry, United States Department of Agriculture. The tests of Drymaria seed were made at the Jornada range in 1930.

Between 1923 and 1928, numerous attempts were made to introduce exotic plant species on the Jornada range. Seedlings of Chinese pistache (*Pistacia chinensis*), dwarf Asiatic elm (*Ulmus pumila*), tamarisk or French tamarix (*Tamarix gallica*), Russian mulberry (*Morus alba tatarica*), ailanthus (*Ailanthus altissima*), and Osage-orange (*Toxylon pomiferum*) were set out in the spring and watered during the dry period. Alfileria (*Erodium cicutarium*) was broadcast over a quarter of an acre and harrowed into the soil just before the beginning of the rainy season in 1926, and tests of wallaby grass (*Danthonia semiannularis*) were made in pots and in small planted areas in 1927.

Livingston porous cup atmometers were run at two stations, in the denuded clay soil type and in the Hilaria association, from June 1 to October 7, 1927, in order to compare the evaporating power of the air during the summer in the two habitats.

Line transects were made through a number of tension zones on all the soil types, to determine accurately the changes in vegetation caused by variation in soils, and the distribution of species over the soil types.

In order to determine the actual conditions prevailing on the different clay soil areas and to indicate grazing values of the stages of succession, a careful record was made of the plant composition on representative areas in the fall of 1929. By using these records and palatability percentages, determined for each species under different range type conditions by other observations and detailed studies, grazing-capacity estimates of the representative types were made. The same vegetative type may vary considerably between years of drought and of favorable climate, but the data were collected after four years of above-average precipitation and present the various stages in their best vegetative development between 1916 and 1930.

The estimates of grazing capacity are based upon the grazing reconnaissance method developed by the Forest Service.[4] In using this method upon a fairly uniform type of vegetation, the following ocular observations are necessary:

(1) The average reconnaissance plant density, or the proportion of ground covered by vegetation, expressed in tenths, and (2) the percentage each species contributes to the whole vegetative cover, with the various species grouped under the three following heads: Grasses and grasslike plants, "forbs" or weeds,[5] and shrubs.

These data, together with data on palatability, were used to obtain (1) the palatability factor of the type, or the proportion of vegetation of value as forage; and (2) the forage factor, or the factor for converting surface acres into forage acres.

Palatability is considered to be the degree to which the herbage within easy reach of livestock is grazed when a range is properly utilized under the best practicable range management. Thus, the percentage of the readily accessible herbage of a species that is grazed when the range is properly utilized determines the palatability of the species. Palatabilities, expressed as percentages, for the various species in this study have been developed from a close observation of proper forage use on the Jornada range since 1915.

The palatability percentage for each species is multiplied by the percentage of the stand represented by that species. The sum of the products for all species involved is the palatability factor of the type.

The forage factor is the product of the average reconnaissance density of the type times the palatability factor. A forage acre represents an acre completely covered with vegetation wholly valuable as forage. Grazing-capacity experiments on the range have shown that approximately 0.8 forage acre is required to support a cow and her calf, until it is weaned, for one month in the type of range under study. To determine the approximate number of surface acres of a type required to support a cow for a month, then, the figure 0.8 is divided by the forage factor. Table 1 is an example of the method used to obtain the grazing-capacity data. For the purposes of this report, each stage in the succession is considered individually with respect to grazing capacity, regardless of whether or not it actually occurs in uniform areas large enough to furnish the estimated number of surface acres required to carry a cow for one month.

[4] For detailed information on this method, see Instructions for Grazing Reconnaissance on the National Forests, 1927, which may be obtained from the Forest Service, U. S. Department of Agriculture, Washington, D. C.

[5] The term "forb" is applied to herbaceous plants other than grasses and grasslike plants.

TABLE 1.—*Sample illustration of vegetative composition, palatability, density, and grazing capacity of a Hilaria association* [a]

Species by classes of forage	Species composition	Species palatability	Species palatability factor [b]
	Per cent	*Per cent*	
Grasses:			
Hilaria mutica	75	60	0.450
Scleropogon brevifolius	20	20	.040
Forbs:			
Sphaeralcea spp.	1	60	.006
Perezia nana	2	0	0
Shrubs:			
Ephedra trifurca	1	10	.001
Flourensia cernua	1	0	0
Total	100	------------	.497

[a] Reconnaissance plant density, 0.5. Forage factor (plant density × type palatability factor), 0.248. Approximate number of surface acres required to support 1 cow for a month on basis of 0.8 forage acre (0.8/0.248), 3.23.
[b] Species composition times species palatability.

FACTORS INFLUENCING VEGETATION ON CLAY SOILS

Since the vegetation on any area is controlled by habitat factors it is necessary to have a fairly complete picture of existing conditions and their causes. The factors influencing vegetative growth and change may be grouped under the following three main headings: Climatic, physiographic, and biotic.

CLIMATIC FACTORS

Because the culmination of favorable growth conditions occurs in the summer, climatic data for the Jornada range are more easily analyzed and correlated with vegetative response when considered by grazing years, or from July 1 to June 30 of the following calendar year. The principal measured climatic factors are thus summarized in Table 2, which shows the monthly means for temperature and precipitation at the Jornada range headquarters from July 1, 1914, to June 30, 1930, and for evaporation and wind movement at Elephant Butte Dam (*4*) from July 1, 1917, to June 30, 1930. On an average, these data show that although favorable growing temperatures may occur from March into October, yet on account of rainfall the growing season is limited mainly to three months, July to September, when slightly more than half of the total annual rainfall occurs. In some years the growing season may continue into early October, but low night temperatures usually render ineffective for the current season any rainfall after October 15. The culmination of unfavorable growth conditions is reached during the spring. Although temperatures become increasingly favorable during and following March, the precipitation is low, evaporation reaches its maximum in May and June, and wind movement is high during the entire spring period. Prevailing winds are from the west.

Evaporation varies considerably with the density of vegetation in different areas. As shown by Figure 1, evaporation from Livingston atmometers is consistently higher on a bare soil than in a Hilaria association. Thus the demands of the atmosphere upon seedlings in denuded soil are very severe, and only a limited number of species become established as pioneers.

TABLE 2.—*Means of principal measured climatic factors in experimental area*

Month	Temperature[a] Daily maximum	Temperature[a] Daily minimum	Precipitation[a]	Evaporation[b]	Wind movement[b]
	° F.	° F.	*Inches*	*Inches*	*Miles*
July	93.0	63.9	1.82	12.07	2,726
August	91.8	61.8	1.73	10.47	2,340
September	86.8	55.1	1.16	8.77	2,494
October	76.7	42.0	1.09	7.31	2,976
November	63.9	28.9	.42	3.98	2,453
December	53.1	22.2	.64	2.74	2,629
January	55.3	21.2	.28	2.78	2,638
February	62.5	26.4	.32	4.33	2,728
March	67.2	31.1	.48	7.46	3,544
April	74.0	39.1	.16	10.19	3,585
May	83.4	46.7	.64	12.86	3,583
June	94.7	56.2	.28	13.94	3,022
Average or total	75.2	41.2	9.02	96.81	2,893

[a] At Jornada Experimental Range headquarters, grazing years 1914–15 to 1929–30.
[b] At Elephant Butte Dam, grazing years 1917–18 to 1929–30.

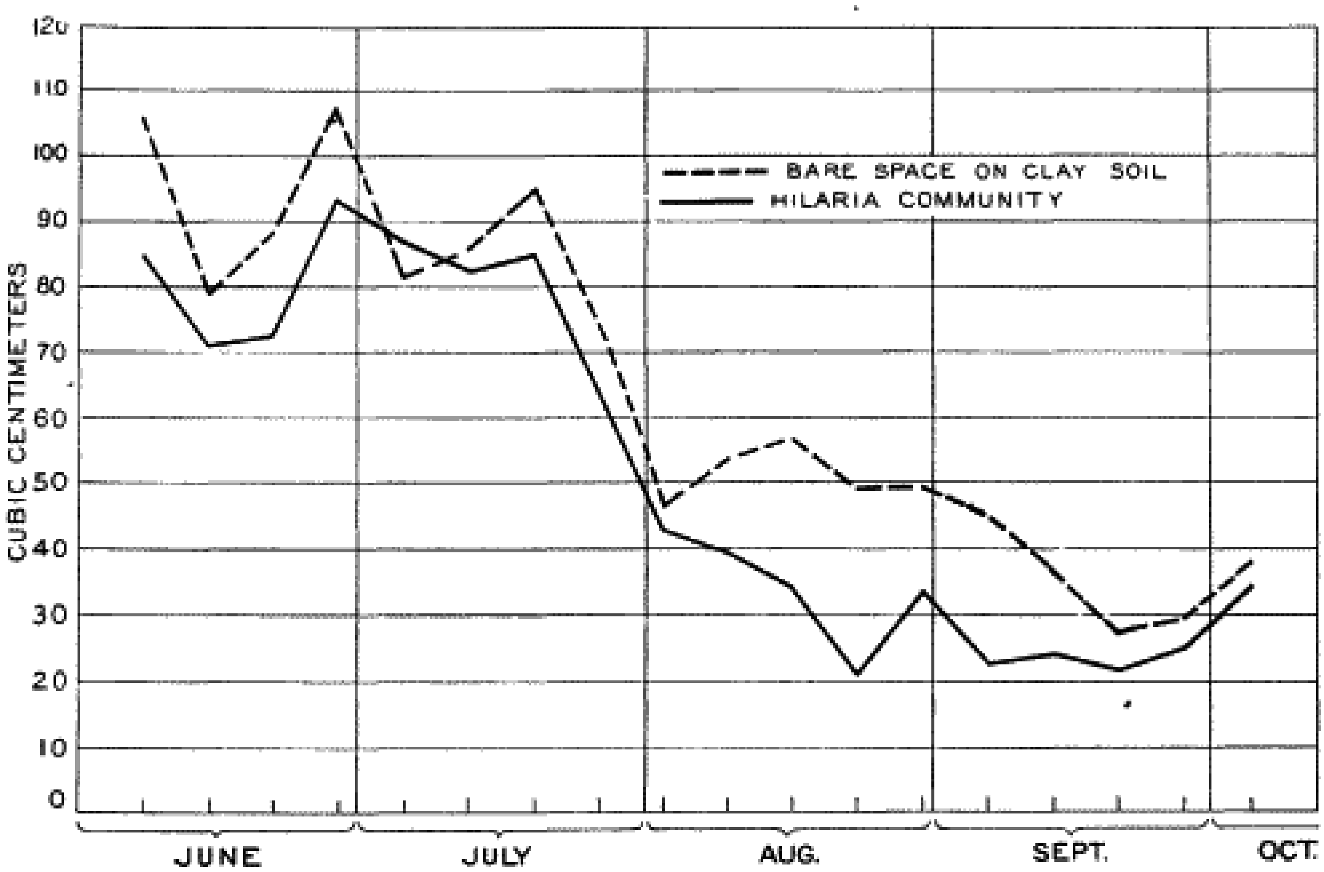

FIGURE 1.—Evaporation from Livingston atmometers, Jornada Experimental Range, 1927

PHYSIOGRAPHIC FACTORS

Since the vegetative composition of each stage of succession usually is different on different types of soil, it is necessary to consider the various clay soils found on the Jornada range. Within the limits of the range there are three topographic divisions, namely, the Jornada plain or mesa, the foothills, and the higher mountain slopes on the east.

The Jornada mesa is a gently undulating, featureless plain ranging between 4,000 and 4,600 feet above sea level. It is not occupied by any permanent stream and there is no surface outlet to the Rio Grande, which is 10 miles to the west. Arroyos extend from the foothills down the slopes of the plain for 1 to 5 miles. These are dry except after torrential showers, at which time the water debouching from them spreads out over the sand or clay flats at their mouths and rapidly disappears by percolation and evaporation.

The geologic formations in the Jornada plain consist of unconsolidated deposits of alluvial wash derived from the adjacent mountain masses. The upper part of the deposits at least are Pleistocene in age and for the most part consist of interbedded, comparatively thin layers of reddish sand, buff, grayish, or chocolate-colored clay, and gravel or bowlders. A highly calcareous substratum or caliche, occurring at depths ranging from 15 inches to 4 feet, is characteristic. This layer consists of a concentration of calcium carbonate and, very probably, other salts. Its development is greatest under sandy or gravelly soils and slightest under tight clay soils.

The clay soils on the Jornada range can be grouped into three main classes, although each class has rather wide variations between different areas. These main types are clay or adobe soil, clay loam, and lake-bed clay.

The adobe soil occurs as extensive flats at the mouths of arroyos or in the lower, flatter parts of alluvial aprons. Toward the foothills these aprons ascend by broad, flat steps. The rise from one flat to the next is marked by an abrupt clay bank from 3 to 8 feet high. Each bank or terrace scarp probably marks the extreme point to which successive sheets of alluvium were carried by storm waters at different periods. Since the distance to which the alluvium spread decreased as the slopes were built up and the velocity of the water decreased, the material was deposited in a succession of overlapping sheets. In many places the wind has worked in front of the scarps, which, owing to the prevailing slope, face the west, sweeping out the sediment until the surface is quite bare and depositing sand on the edge of the higher terrace, thus increasing the height of the rise from one flat to another. The clays in this type are tight, compact, and impervious. When dry, the soil is extremely hard. Water from light rains sinks in only a few inches or stands in puddles. These characteristics make difficult the establishment and maintenance of vegetation on adobe soils. These soils are mainly a chocolate or dark red, but in places are grayish or buff.

The clay loam types are intermediate in texture and structure between the clay flats just described and sandy or gravelly soils. Soils of this class also occupy an intermediate topographic position on the slopes of the foothills. They are not uniform in texture but are rather a composite of a number of intimately associated lithologic phases, among which red, compact sandy clay loam predominates. In other places the material is a compact fine sandy loam, and in many areas considerable gravel is to be seen on the surface. Nearly all the clay loam soils are more pervious and have soil moisture conditions more favorable for plant growth than those of the adobe flats.

The lake-bed clay classification includes land occupying beds of both present intermittent lakes and of old or extinct lakes. In the extinct lakes the outlines are still well preserved, and desiccation was comparatively recent. The soil in these situations may be either a chocolate-red or a grayish fine-grained structureless clay, which is sticky and plastic when wet and extremely hard and impenetrable when dry. It is usually highly calcareous and may contain scattered crystals of gypsum. In places a thin veneer of fine sand has blown over the surface of the clay.

BIOTIC FACTORS

As Taylor (*7*) points out, the problem of grazing management is one of proper handling of the complex biotic communities occurring on ranges. These communities include not only the forage plants and livestock, but all the plants and native animals. Except for data on grazing intensities, biotic factors on the Jornada range are largely unmeasured. In fact, until 1930, no attempt was made to estimate the proportion of forage use by rodents as distinct from use by livestock. However, observations in 1929 and 1930 showed that the rodents on the range—mainly jack rabbits, cottontails, and kangaroo rats—live almost entirely on sandy soils, and so are of little direct consequence in this study except in the sand dunes found on the terrace crests in the adobe type.

PLANT SUCCESSION ON DIFFERENT TYPES OF CLAY SOILS

In order to present a complete series of successional stages, some areas absolutely without vegetation must be studied for the pioneer stages. Bare clay areas exist on the Jornada and adjacent ranges, and both economic and ecological considerations require some explanation of them, especially those which once supported vegetation but are now denuded.

Among causes of denudation, rainfall, which is often in the form of torrential cloud-bursts, is often of primary importance. Surface run-off is rapid after heavy rains, especially near the foothills and mountains. Where naturally sparse vegetation permits water to drain quickly from steep slopes, the more fertile topsoil is carried away, and gullies cut in rapidly, undermining vegetation and draining moisture from the adjoining soil. Among other causes of denudation are localized overgrazing, trampling or loitering of stock near bushes, and trailing of stock, especially in localities exposed to erosion by wind action or flood waters. As has been stated, most rodents prefer the more sandy soils for their burrows, but prairie-dog workings, which contribute to denudation, occasionally are found in the clay soil types. Another common factor in range destruction through the Southwest is the plowed land exposed to erosion on abandoned homesteads.

Artificial revegetation is usually the first method suggested for restoring plant cover on denuded soil, but, as is shown in Table 3, attempts to introduce exotic shrubs on the range have met with little success, and plantings of alfileria and wallaby grass, also exotics, failed to survive. However, Wilson (*8*) reports that fourwing saltbush or "chamiza" (*Atriplex canescens*), a shrub, and blue grama (*Bouteloua gracilis*) are promising native species for artificial reseeding in New Mexico.

TABLE 3.—*Survival of exotic shrubs on Jornada Experimental Range*

Species	Shrubs planted		Survival in 1929		Average height, 1929
	Year	*Number*	*Number*	*Per cent*	*Inches*
Chinese pistache [a]	1923	53	2	3.8	12
Dwarf Asiatic elm [a]	1923	175	[b] 5	2.9	61
Tamarisk	1923	20	0	0	
Russian mulberry [a]	1927	2	0	0	
Ailanthus [c]	1928	5	1	20.0	32
Osage-orange [c]	1928	5	1	20.0	19

[a] Seedlings obtained through courtesy of Bureau of Plant Industry.
[b] Exclusive of one tree 185 inches high, grown over a cesspool.
[c] Seedlings obtained through courtesy of the regional forester, Albuquerque, N. Mex.

It appears that the revegetation of denuded areas will be, at best, a long process and that it must be accomplished by native plants adapted to climatic and physiographic conditions of the region, which must be grazed to a degree conservative enough to permit their revegetation and maintenance. The restoration of a suitable plant cover on areas in various stages of depletion may be greatly facilitated by improved range and livestock management based upon a better understanding of successional processes and stages. The actual length of time required to restore areas in various stages of depletion will depend in part upon the seriousness of depletion of the most important plants in the succession, and upon soil conditions. Because of the different conditions affecting natural succession and the variations in plant cover in the successional stages on the different clay soil types, plant succession has been discussed separately in this paper on adobe soils, sandy clay loam, gravelly clay loam, and lake-bed clay. Table 4 shows the grazing capacity of these soils at various stages of succession and the variation of grazing values within each stage.

TABLE 4.—*Comparison of grazing capacity in various stages of succession on clay soils*

Stage	Soil type	Surface acres required per cow per month	
		For representative area	Range within each stage
		Acres	*Acres*
Lichen	Adobe, gravelly clay loam, lake-bed clay		
Localized ruderal-weed	do	50	15.1 and over
Ruderal-weed	Sandy clay loam	25	15.1 to 35.
Scleropogon	All soil types	10.1	7.6 to 15.
Mixed-grass	Sandy clay loam	5.8	5 to 7.5.
Flourensia-hilaria	Gravelly clay loam	5.4	4.5 to 7.5.
Hilaria	Adobe, lake-bed clay	3.4	3 to 7.5.

PLANT SUCCESSION ON ADOBE SOILS

The adobe soils occur in alluvial aprons, which ascend from the Jornada plain toward the foothills in broad, flat steps. Each step is marked by an abrupt clay bank or terrace scarp. In many places the wind has worked in front of the scarps, simultaneously sweeping the surface bare and depositing sand on the edge of the higher terrace. Many of these sand deposits are true moving dunes, which shift very slowly toward the east, driven by the prevailing west winds. The average annual wind movement for 13 years, as recorded at Elephant Butte Dam, is approximately 4 miles an hour. This, in itself, does not seem excessive, but bare spaces are scoured and sand on the terrace edges is moved by strong, unabating semihurricanes which occur intermittently during the spring and early summer.

The relief of the terrace edges, with their scattered dunes, makes it difficult for plants to invade these areas. In many places the difference in soil level between terraces may be 5 to 8 feet; this leads to unfavorable moisture conditions on both sides of the bank. Rain falling on the lee side drains quickly to the lower level, often forming small arroyos and contributing to the erosion of soil from the upper level. (Fig. 2.) The water drains so quickly from the higher level of soil that it is not available to the plants there and consequently they are less vigorous than they would normally be. The water, after reaching the flat lower level, drains slowly and often stands in small puddles for several days before evaporating or sinking into the earth. Although drainage from above may promote seed dispersal of a few plants onto the lower clay flat, the standing water in the depression makes reseeding difficult.

Pioneer Lichen Stage

The first stage in the plant succession on adobe soils is the lichen stage. The uppermost 6 or more inches of bare clay soil are subject to greater fluctuations in moisture content than the corresponding layer in the same soil type in areas where there is a vegetative cover. The adobe softens quickly after rains, but the top layer, which is practically devoid of humus, hardens rapidly upon drying and con-

Figure 2.—Gullies on the outwash slope of an adobe terrace bank

tracts to form wide cracks. The soil is thus a poor habitat for most plants but an excellent base for the establishment and spread of a crustose lichen, *Lecidea crenata dealbata*, which is widespread in the region under study. This lichen scattered over the surface, although it has no forage value, protects the soil from wind erosion and builds up its humus content. (Fig. 3.)

Aside from lichens, scattered specimens of algae, *Nostoc commune flagelliforme*, and a few forbs, plants are scarce on bare adobe soils. The entire revegetation of such soils is characterized by the absence of a definite ruderal stage, except for a very limited number of species on the open flats and a fairly dense growth in drainage paths, where moisture is more abundant.

Localized Ruderal-Weed Stage

Although the bare adobe flats appear level, they have a slight degree of slope, and gravitational waters from heavy rains develop shallow drainage channels where seeds are easily disseminated and where moisture is more abundant than on the rest of the flat area. In such drainage paths a localized ruderal vegetation may develop, and some perennial grasses of considerable forage value may grow. The principal species found here are as follows, in order of their abundance: *Hoffmanseggia jamesii*, globemallow (*Sphaeralcea incana*), *Hymenopappus robustus*, *Drymaria holosteoides*, *Amaranthus graecizans*, *Sporobolus airoides*, and *Scleropogon brevifolius*. In some areas, the Drymaria may cover the soil after heavy rains in August and September. This plant, however, offers a special problem which complicates the situation from an economic viewpoint.

Drymaria holosteoides Benth. (*D. pachyphylla* Woot. and Standl.), as Lantow (*3*) points out, "has proved itself to be one of the most deadly of the poisonous plants and losses of cattle in New Mexico have often, within a few months' time, run into thousands of dollars." It is a menace especially during the late summer and fall. It is a low, nearly prostrate annual of the Silenaceae. The plant occurs only on the hard soils, where no other vegetation is present, and in drainage paths where seed dispersal is facilitated and moisture con-

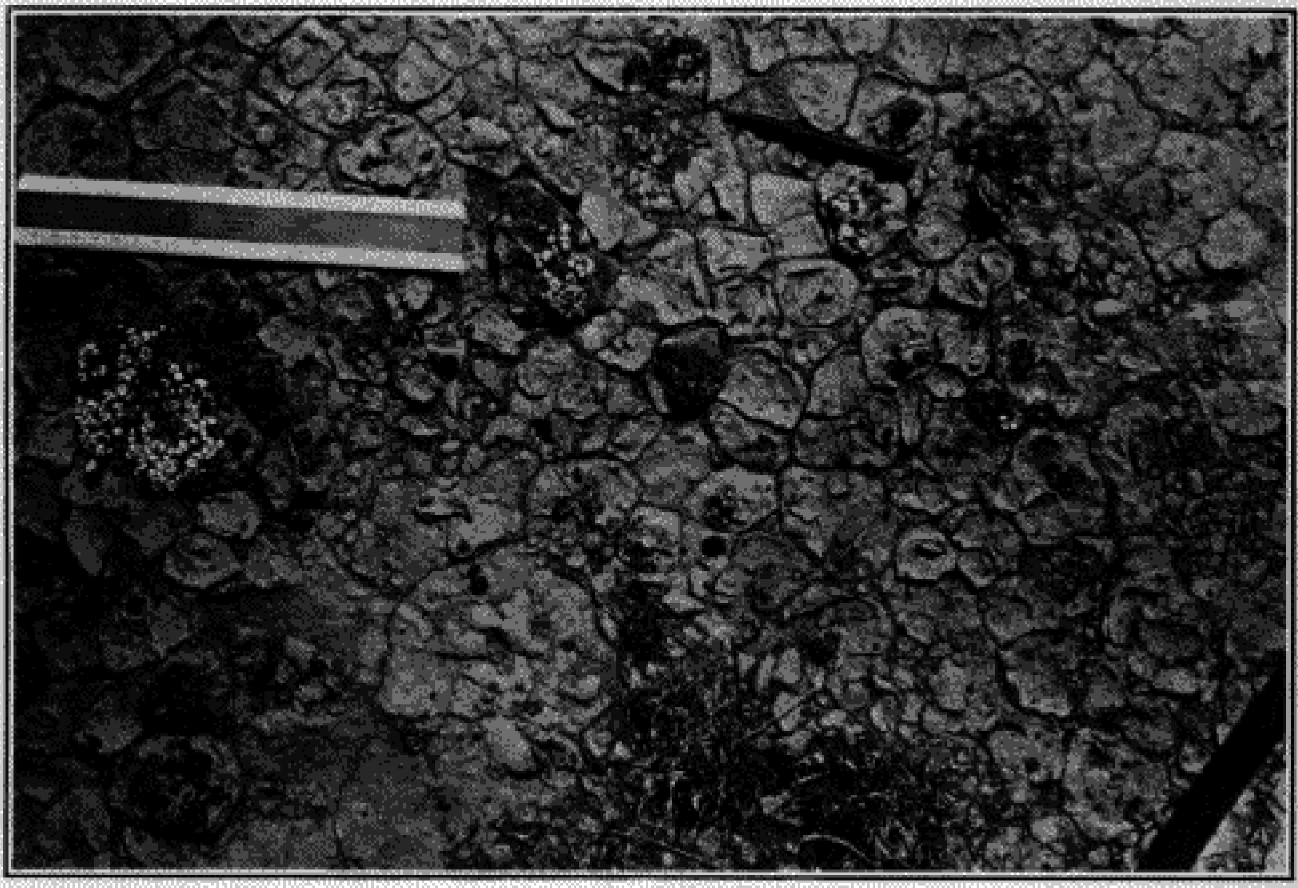

FIGURE 3.—Denuded adobe soil, with cracks in the surface crust. Nostoc is near the pencil point and Lecidea near the scale. Burro grass (*Scleropogon brevifolius*) is advancing onto the area

ditions are favorable. It grows very quickly and usually produces flowers and seeds within a few days after the seedling becomes established. Because of its abundant seed production it is extremely difficult to eradicate.

Drymaria holosteoides seed were collected in the fall of 1929 and germinated during the following winter. In a test made at room temperature during October, 1929, only 3 per cent germination was obtained. On January 12, 1930, two lots with 100 seeds in each were started, one at room temperature and one at about 40° F. On February 5, of those at room temperature 55 per cent had germinated. As none of the lot at 40° had started by January 22, these were allowed to dry out and (on February 2) 50 seeds were moved to room temperature and 50 left in the cold. No germination was observed in the latter lot, but on February 20 the lot at room temperature showed 66 per cent germination. On March 3, tests of seven additional lots of 100 seeds each were started at room temperature. On March 27, these showed germination ranging from 25 to 50 per cent, with an average of 38 per cent.

These tests show that *Drymaria holosteoides* seeds are viable and have sufficient endurance to withstand alternate wetting and drying and finally to germinate when favorable conditions occur. The existence of this noxious species as a potential pioneer and the possibility of every bare clay surface becoming a poison area from its growth makes it not only desirable but necessary to hasten revegetation of other species.

Although areas supporting the localized ruderal stage are not of sufficient size to be considered grazing units, their grazing capacity should be calculated in a manner similar to that used for the better forage types. The localized ruderal weed stage affords only enough vegetation to support a cow for one month on approximately 50 acres. This low grazing capacity is better than none, but it is not compatible with the most economical livestock production. Furthermore, these practically denuded spots have no value for watershed protection and, even when small, endanger the watershed value of better, adjacent areas. This is an added reason for hastening revegetation of other species.

The Scleropogon or First Grass Stage

The first successional stage of any real forage value to become established on adobe soils is the Scleropogon. Fourteen years' study on the Jornada range has shown that *Scleropogon brevifolius* is the most suitable grass for the early natural revegetation of depleted adobe soils, although other pioneering grasses occur in the type. *S. brevifolius* spreads both vegetatively and by reseeding.

Scleropogon brevifolius, which has a root system extending 8 to 16 inches into the soil, is well adapted to efficient absorption from heavy clay soils where the moisture seeps downward very slowly from the surface. The mature plant because of its ability to conserve the available water supply by small size, restricted growth, and wide spacing of tufts can survive several years of below-average rainfall.

Scleropogon brevifolius may produce horizontal stolons from 6 to 10 inches long in a single year. These stolons have rooting sets at the nodes, as shown in Figure 4. The number of unrooted sets produced on two Scleropogon quadrats as indicating the possible rate of spread, is set forth in Table 5, together with seasonal and annual rainfall data. From 1915 to 1927, the grass was spreading over both quadrats, hence the greater number of sets in most years prior to 1929. No very close correlation between rainfall and the number of unrooted sets can be developed from this table, but it is significant that the greatest number of unrooted sets on both quadrats should have been produced in 1919–20, which had excellent summer-seasonal rainfall, and was immediately preceded by a year with above-average precipitation. Further, no sets were produced in 1916–17, which had the minimum summer-seasonal rainfall for the 16-year period, and set production was very poor in 1922–23, which had only 3.18 inches of rainfall during the summer. These data show that summer rainfall probably is most important in set production. Set production is much more prolific on the young pioneering *S. brevifolius* tufts than in the well-established stand, as is shown by the fact that in 1929 quadrat L–3, with a tuft area of 2,631 sq. cm., produced only 7 sets, as compared with quadrat L–3a, which had a tuft area of only 176 sq. cm. and produced 15 sets. Quadrat L–3a adjoins L–3 and was established in 1929 in order to follow the vegetative spread of *S. brevifolius* after it had progressed beyond the limits of L–3.

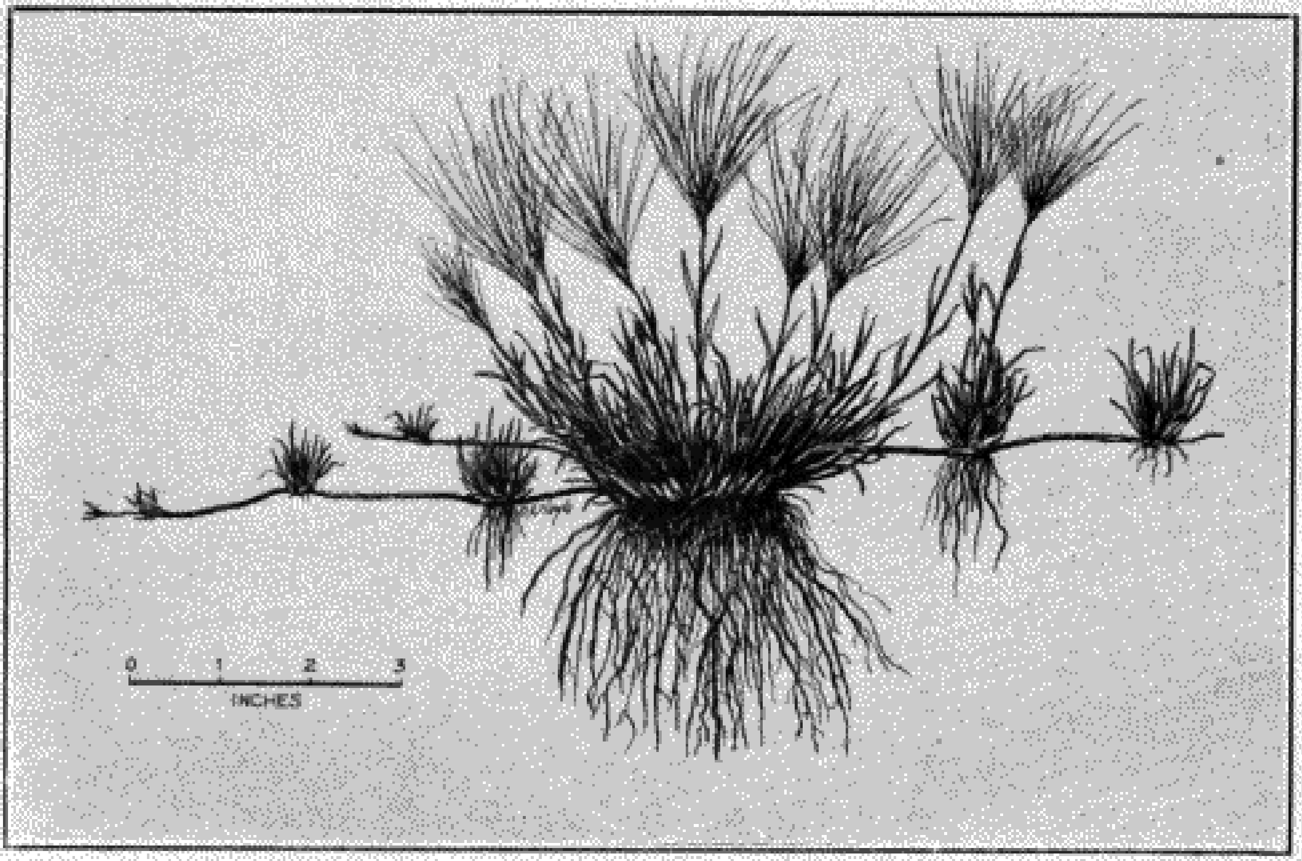

FIGURE 4.—Drawing of *Scleropogon brevifolius*, showing character of root system, foliage, stolons, and sets

TABLE 5.—*Rainfall and the production of unrooted sets by Scleropogon brevifolius*

Grazing year (July 1 to June 30)	Precipitation at Jornada headquarters		Unrooted Scleropogon sets [a]	
	Annual	Seasonal [b]	Quadrat L–3	Quadrat L–4
	Inches	*Inches*	*Number*	*Number*
1915–16	8.51	4.86	---	---
1916–17	6.80	2.58	0	0
1917–18	3.62	2.34	([c])	([c])
1918–19	10.47	4.41	36	1
1919–20	14.05	8.20	92	43
1920–21	9.72	5.67	28	18
1921–22	4.80	3.49	50	14
1922–23	9.18	3.18	11	2
1923–24	7.45	3.95	36	14
1924–25	6.10	3.87	38	10
1925–26	10.48	3.76	29	3
1926–27	13.64	8.53	([c])	([c])
1927–28	9.09	6.33	([c])	([c])
1928–29	10.47	3.92	28	33
1929–30	9.11	6.18	7	10

[a] Quadrats charted in September or October near end of growing season.
[b] July, August, and September.
[c] Not charted.

The quadrat charts shown in Figure 5 demonstrate the possibility of revegetation of adobe flats and show the rate of spread of Scleropogon under the various conditions mentioned in Table 6. From a comparison of tuft area with precipitation, it is evident that the Scleropogon changes of tuft area vary rather closely with the precipitation for the preceding year, unless the precipitation of the current or the preceding year is extreme enough to overbalance the vegetative changes which would ordinarily occur. It will also be noted that it was only after a period of several successive years, during which wind movement dropped to considerably below average, precipitation was favorable, evaporation below average, and grazing moderate to proper, that real progress was made in Scleropogon spread by stolons over

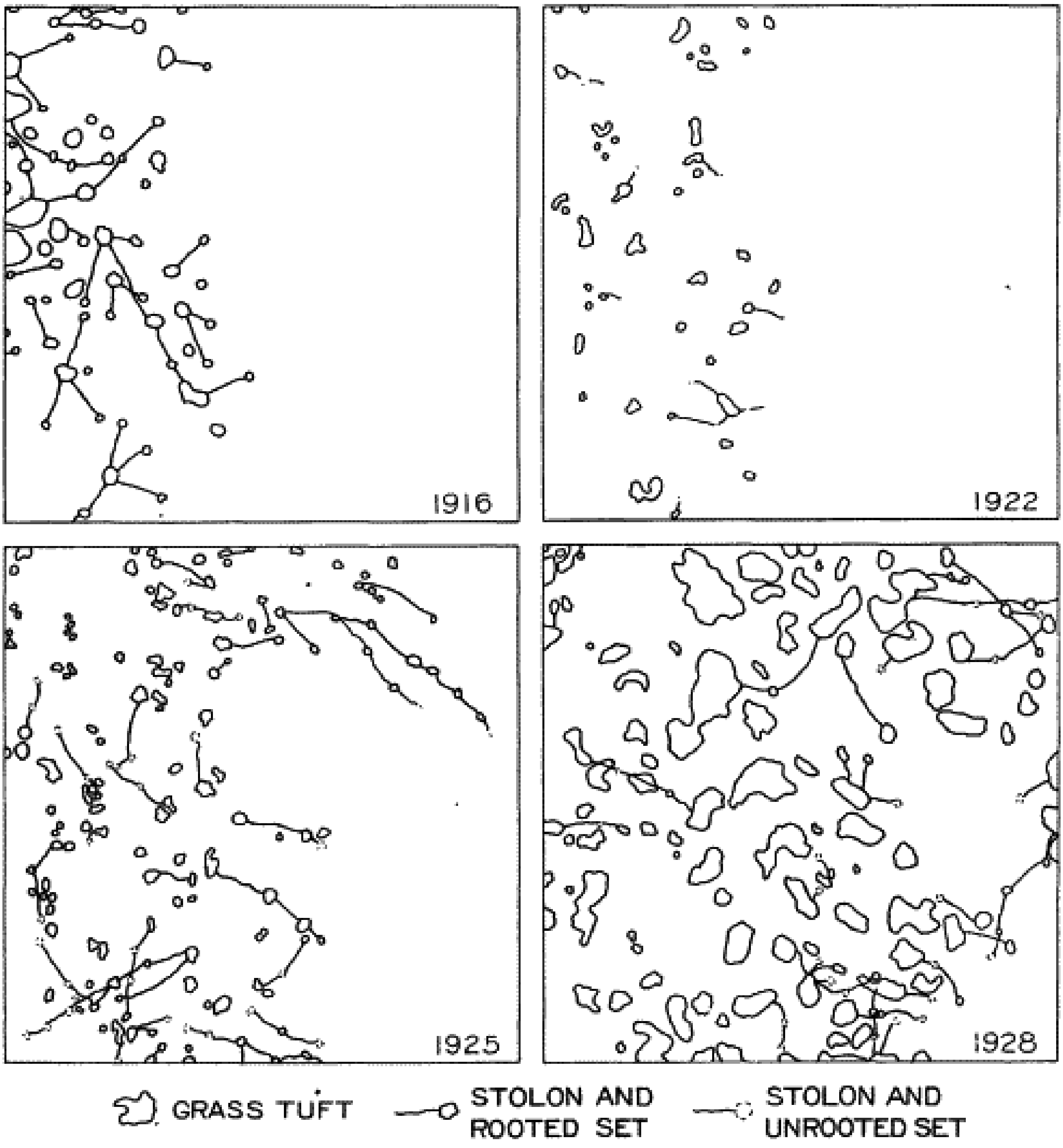

FIGURE 5.—Chartings of quadrat L–3, showing *Scleropogon brevifolius* tuft areas in 1916, 1922, 1925, and 1928

quadrats L–3 and L–4 and that substantial increases of tuft area were effected.

Definite conclusions concerning the effect of grazing on the Scleropogon spread can not be drawn from the data given in Table 6 because, during so much of the period under consideration, unfavorable climatic conditions caused poor forage production and consequently overgrazing prevailed in several years. The principal forage species in this stage of succession are palatable and nutritious to livestock only during the summer period. The Scleropogon tuft area responded favorably under moderate grazing, but the type as a whole was heavily grazed. Under light grazing from 1926 to 1929, when climatic conditions were also favorable, Scleropogon made very substantial gains. The grazing intensities indicated in Table 6 apply to large areas made up of intermingled units of all stages of succession. As Hilaria is three times as palatable as Scleropogon, the Hilaria associations which grow more or less intermingled with this stage may be used heavily, and actual grazing on the less palatable Scleropogon of the same range may be lighter. As Jardine and Forsling (*2, p. 10*) state: "The burro grass [Scleropogon] begins growth early and has its main value as forage before other vegetation has greened; after that time it is grazed but little." The difference in palatability permits full use of the Hilaria types and results in a minimum interference with Scleropogon spread. Thus the establishment of Scleropogon may be accomplished under moderate grazing or even under full use of the range, especially where there are adjacent Hilaria areas.

TABLE 6.—*Precipitation,*[a] *wind movement, and evaporation,*[b] *and grazing use as related to Scleropogon tuft areas on quadrats L–3 and L–4, grazing years (July 1 to June 30) 1914–15 to 1929–30*

Year	Precipitation		Wind movement	Evaporation	Grazing use [c]	Tuft areas on—	
	Annual	Seasonal				Quadrat L–3	Quadrat L–4
	Inches	*Inches*	*Miles*	*Inches*	*Per cent*	*Sq. cm.*	*Sq. cm.*
1914–15	10.77	4.09					
1915–16	8.51	4.86			100		
1916–17	6.80	2.58			115	327	416
1917–18	3.62	2.34	35,025	110.38	115	(d)	(d)
1918–19	10.47	4.41	34,392	93.32	100	216	141
1919–20	14.05	8.20	35,588	95.99	90	279	174
1920–21	9.72	5.67	42,260	104.78	125	428	135
1921–22	4.80	3.49	36,134	105.16	130	430	159
1922–23	9.18	3.18	48,236	105.77	120	137	33
1923–24	7.45	3.95	44,980	92.63	100	303	71
1924–25	6.10	3.87	39,370	102.71	100	717	128
1925–26	10.48	3.76	30,582	87.43	5	262	51
1926–27	13.64	8.53	29,398	96.50	65	(d)	(d)
1927–28	9.09	6.33	27,134	89.44	50	(d)	(d)
1928–29	10.47	3.92	27,279	93.12	75	1,682	543
1929–30	9.11	6.18	20,956	81.30	100	2,631	1,116
Average	9.02	4.71	34,718	96.81			

[a] At headquarters Jornada Experimental Range.
[b] At Elephant Butte Dam.
[c] 100 per cent is proper for type as a whole.
[d] Not charted.

Observations of the Scleropogon on several quadrats charted from 1915 to 1929 and ocular observations of other areas show the establishment of some seedlings in favorable years. Germination percentages of *S. brevifolius* seeds collected from the Jornada range are as follows:

	Per cent		Per cent
1923	18.6	1927	60.0
1925	0	1928	30.0
1926	46.0	1929	78.5

Scleropogon seeds are produced in abundance during favorable seasons. By means of their long awns they are disseminated easily by the wind. The florets are needlelike and slightly twisted and cling tenaciously in cracks of the clay soil and to the scattered filaments of Nostoc which adhere closely to the surface, even of dry soil. The germination tests demonstrate that the seeds are viable and field records show that seedlings become established. Because of its ability to reproduce both by means of stolons and of seed, Scleropogon is a very effective pioneer on denuded or depleted adobe soils.

One of the principal grass species associated with the Scleropogon is dwarf dropseed (*Sporobolus auriculatus*). The two species are so similar that they are often rather difficult to distinguish from one another unless their flower stalks are developed. They may be regarded as ecological equivalents, although the Sporobolus has underground rhizomes instead of aboveground stolons. These rhizomes grow horizontally just under the soil surface. They have numerous rooting nodes, and the new plants established from these nodes, unless they are exposed by soil erosion, are more stable than the aboveground sets of Scleropogon.

Sporobolus auriculatus produces small, hard seeds characteristic of the genus. Germination percentages of seeds collected on the range from 1925 to 1929 are as follows:

	Per cent		Per cent
1925	0.3	1928	7.0
1926	33.3	1929	43.5
1927	1.5		

The seeds collected in 1926 were tested by Jackson (*1*), who, in retesting seeds saved from the 1925 sample, obtained 100 per cent germination as compared with the 0.3 per cent when the seeds were tested the same year they were collected. This shows that Sporobolus seeds may germinate poorly the first season, but that they have good viability and will germinate well eventually. Thus it is found that Sporobolus as well as Scleropogon is well fitted for establishment vegetatively and by seeding.

TABLE 7.—*Estimated vegetative composition, palatability, and grazing capacity of a representative Scleropogon type on adobe soil* [a]

Species, by classes of forage	Composition	Palatability	Palatability factor
Grasses:	*Per cent*	*Per cent*	
Scleropogon brevifolius	55	20	0.110
Sporobolus auriculatus	23	20	.046
Sporobolus asperifolius	8	20	.016
Sporobolus airoides	6	50	.030
Hilaria mutica	2	60	.012
Forbs:			
Hoffmanseggia densiflora	2	50	.010
Eschenbachia coulteri	1	0	0
Chamaesaracha coronopus	.5	0	0
Solanum eleagnifolium	.5	0	0
Shrubs:			
Flourensia cernua	1	0	0
Ephedra trifurca	.5	20	.001
Koeberlinia spinosa	.5	0	0
Total	100		.225

[a] Reconnaissance plant density, 0.35; forage factor, 0.079; approximate number of surface acres required to support a cow for 1 month, 10.13.

The Scleropogon type, as found on the Jornada Experimental Range, includes scattered specimens of other grasses, with a few forbs and shrubs, as shown in Table 7. This type, when used during the proper season, requires approximately 10 surface acres to carry a cow for one month, as compared with approximately 50 acres required on the typical localized ruderal weed stage. Although the grazing capacity of the Scleropogon type is low, this stage represents a very tangible forage resource, especially in drought periods, and is infinitely superior to the scattered vegetation of the earlier stages of succession, both as range feed and as protection from erosion. In addition, this pioneer grass association plays a very definite rôle in building up the nutrient content and water-holding capacity of the soil, thus preparing it for the next stage of succession.

Hilaria Climax

The Hilaria or swale type, as it is commonly called, immediately succeeds the Scleropogon stage. *Hilaria mutica*, the dominant species of this climax stage, is a rather coarse sod grass which spreads vegetatively by means of large rhizomes. (Fig. 6.) The root system is

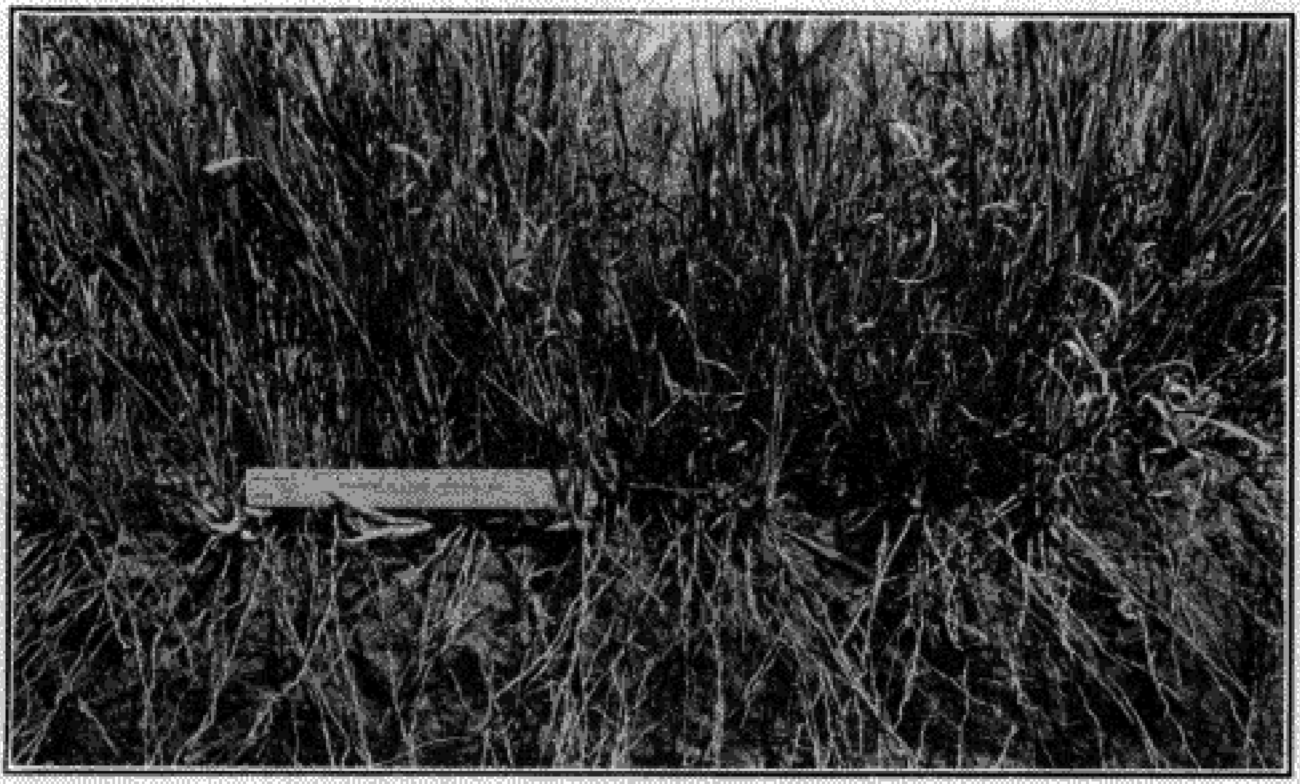

FIGURE 6.—Bisect of *Hilaria mutica*, showing the coarse root system and large rhizomes

coarse and poorly adapted to the most efficient absorption of moisture from the soil. The plants require flooding to make energetic growth, and for this reason the best developed stands of *H. mutica* always occur in depressions where surface run-off accumulates and stands for a few days. In fact, almost pure stands of *Hilaria mutica* form the semidesert climax on the adobe clay depressions.

The struggle between *Hilaria mutica* and *Scleropogon brevifolius* for dominance on adobe clay soils is shown rather strikingly by the results given in Table 8 for a quadrat, representative of an encroaching stand of tobosa grass. In 1915 the quantity of Hilaria on the plot was nearly three times that of the Scleropogon, although each largely occupied different parts of the quadrat. A material decrease in Hilaria tuft area occurred in 1919–20, as a belated result of the serious drought in 1917–18 and of overgrazing during the first five years of record. The Scleropogon responded more rapidly to the favorable growing conditions from the fall of 1918 to the spring of 1921, although the Hilaria had the greater density in the fall of 1921. Under overgrazing and drought both species lost density rapidly between the fall of 1921 and that of 1922, and the tufts of each were greatly reduced in size. Although growing conditions were not especially favorable from the fall of 1922 to the fall of 1924, low densities on soil which had supported much higher densities and more moderate grazing than had prevailed earlier favored rather rapid recovery, especially of the good seeding and stolon-producing Scleropogon. The rather dry year of 1924–25 and low rainfall in the summer of 1925 caused a moderate setback in the development of both species. Then a steady recovery started again, Scleropogon being the more rapid in its development and reaching a maximum tuft area in the fall of 1927. By the fall of 1929 the Scleropogon had dropped considerably below its maximum, and Hilaria clearly dominated the quadrat, having reached its maximum tuft area for the entire 15-year period.

TABLE 8.—*Tuft areas of Hilaria and Scleropogon, precipitation, and grazing use on quadrat I–3, Jornada Experimental Range, 1914–15 to 1929–30*

Year	Precipitation		Grazing use [a]	Tuft area of—	
	Annual	Seasonal		Hilaria	Scleropogon
	Inches	*Inches*	*Per cent*	*Sq. cm.*	*Sq. cm.*
1914–15	10.77	4.09			
1915–16	8.51	4.86	130	595	209
1916–17	6.80	2.58	115	545	226
1917–18	3.62	2.34	220	([b])	([b])
1918–19	10.47	4.41	150	621	205
1919–20	14.05	8.20	145	273	284
1920–21	9.72	5.67	160	369	605
1921–22	4.80	3.49	125	602	424
1922–23	9.18	3.18	110	50	66
1923–24	7.45	3.95	105	108	236
1924–25	6.10	3.87	100	330	685
1925–26	10.48	3.76	5	287	473
1926–27	13.64	8.53	15	482	1,043
1927–28	9.09	6.33	100	662	1,327
1928–29	10.47	3.92	20	821	1,203
1929–30	9.11	6.18	100	1,278	779
Average	9.02	4.71			

[a] 100 per cent is proper for type as a whole. [b] Not charted.

The Hilaria reacted more slowly to climatic conditions than did the Scleropogon, but after periods of favorable rainfall Hilaria predominated, as is shown by the tuft areas of the two species in the autumns of 1915, 1921, and 1929. The lack of flood water in drought years arrested the succession, and the Hilaria recuperated more slowly than the Scleropogon. In the charting in the fall of 1918 it was difficult to distinguish the dead tuft areas of both species because of the small amount of green material produced in that dry summer. This fact accounts in part for the sharp reduction in tuft areas recorded in 1919, when the live tufts were easily recognized by their green foliage. It must also be remembered in interpreting Table 8 that the Scleropogon on the plot was lightly grazed in most years, owing to the higher palatability of the Hilaria. The estimates of forage use were made in June at the close of each grazing year. Even the Hilaria was not seriously overgrazed except from 1917–18 to 1920–21, since its palatability of 60 per cent is based partly on the proper use of plants even more palatable than it is. Just as occurred in recent years on the quadrat recorded in Table 8, it has been observed on other areas that where a dense stand of *Hilaria mutica* encroaches upon a Scleropogon community the Scleropogon is the first species to give way. *Sporobolus auriculatus* gives way next, and *S. asperifolius* persists the longest, apparently because of its shade tolerance and a greater ability to withstand root competition.

The vegetative spread of *Hilaria mutica* is necessarily slow, but, as is true for most of the species of the region, vegetative reproduction is by far the surest method of migration. Very few seedlings of Hilaria have been charted on the Jornada range quadrats or recorded in the field notes, notwithstanding the generally high germination percentages (Table 9) obtained in the laboratory with seeds collected from the range.

TABLE 9.—*Germination percentage of seeds of Hilaria mutica collected from the Jornada experimental range*

Year	Germination in—		Year	Germination in—	
	Lot 1	Lot 2		Lot 1	Lot 2
	Per cent	*Per cent*		*Per cent*	*Per cent*
1923	66.3		1927	21.5	39.0
1924	5.0		1928	6.5	29.0
1925	66.0		1929	0	87.0
1926	34.0	91.0			

The variability in germination of seed in different samples is shown well by results when two lots were tested in the same year. The germination of the 1926 seeds indicated that higher germination percentage might be closely correlated with higher rainfall, as shown in Table 10. The seasonal precipitation was 4.82 inches in the region where lot 1 was collected and 7.51 inches in the lot 2 region. In preliminary tests, with seeds from the same samples, increased germination was generally obtained with successive trials.

TABLE 10.—*Percentage of germination obtained with Hilaria mutica seeds in successive trials, 1927*

Date	Germination in—		Date	Germination in—	
	Lot 1	Lot 2		Lot 1	Lot 2
	Per cent	*Per cent*		*Per cent*	*Per cent*
Jan. 19–Feb. 18	10	60	Feb. 12–Mar. 15	20	80
Feb. 4–25	20	100	Feb. 21–Mar. 16	34	91

From the germination results, it appears that seedling spread should be more important in the Hilaria invasion than it actually is. The fluctuating climatic conditions of late spring and early summer are undoubtedly responsible for lack of seedlings. Rains in May or June are often sufficient to cause germination, but both months regularly have long dry, windy periods during which it is almost impossible for seedlings to survive.

Because of its propagation by rhizomes, *Hilaria mutica* may be grazed during the summer season up to 60 per cent of its forage production without injury. In fact, studies by Canfield [6] on the Jornada range showed that frequent clipping of this species at 2 inches from the soil surface stimulated increased tuft area for the first two years of the experiment. However, the stimulation was not permanent and the increase in dry weight of forage produced was not proportionately as great as the increase in tuft area. On the other hand, frequent clipping at 4 inches or even a single clipping at the end of the growing season each year at 2 inches produced a steady increase in tuft area during the first five years of the experiment.

The vegetative composition of a representative Hilaria type is set forth in Table 11. This type when grazed properly during the summer and early fall will support a cow for one month on approximatey 3.4 surface acres. Here again the desirability of managing the range to bring about the higher stage of succession is very evident when the grazing capacity of this climax stage is compared with that of the Scleropogon stage, wherein 10.1 surface acres are required to carry a cow for one month.

TABLE 11.—*Estimated vegetative composition, palatability, and grazing capacity of a representative Hilaria mutica association on adobe soil* [a]

Species, by classes of forage	Composition	Palatability	Palatability factor
Grasses:	*Per cent*	*Per cent*	
Hilaria mutica	66	60	0.396
Scleropogon brevifolius	10	20	.020
Sporobolus airoides	6	50	.030
Sporobolus auriculatus	5	20	.010
Sporobolus asperifolius	4	20	.008
Bouteloua barbata	1	10	.001
Forbs:			
Gutierrezia sphaerocephala	2	0	0
Chamaesyce albomarginata	1	0	0
Perezia nana	1	0	0
Sphaeralcea incana	1	50	.005
Hoffmanseggia densiflora	.5	50	.002
Wedeliella incarnata	.5	20	.001
Shrubs:			
Flourensia cernua	1	0	0
Ephedra trifurca	.5	20	.001
Koeberlinia spinosa	.5	0	0
Total	100		.474

[a] Reconnaissance plant density, 0.5; forage factor, 0.237; approximate number of surface acres required to support a cow for 1 month, 3.38.

Although *Hilaria mutica* dominates this stage the principal grass species of the Scleropogon stage persist. *Sporobolus airoides* is one of the main associated species. Its seeds remain viable for several years, because of the hard, waxy seed coats. Seeds collected in 1925 and tested that year showed only 77 per cent germination, whereas 100 per cent germination was obtained from the same sample a year later. The plant migrates more quickly than *H. mutica,* especially in shallow drainage paths where seeds are dispersed easily and more moisture is available.

Experience on the Jornada range has shown that the Hilaria type must be used during the growing season if it is to be utilized when at its maximum grazing capacity. The grass is palatable to livestock only when it is green and succulent. It may be grazed to some

[6] CANFIELD, R. H. THE EFFECTS OF INTENSITY AND FREQUENCY OF CLIPPING BLACK GRAMA AND TOBOSA GRASS ON YIELD. 1930. (Thesis, Yale School of Forestry.)

advantage in the fall, but after growth has ceased the stems and leaves become so dry and tough that they retain little value and are refused by stock if other feed is available. An additional reason for using the Hilaria type during the summer is the opportunity thus afforded to defer grazing on the adjacent *Bouteloua eriopoda* range, so that the grass species growing in that type, which are palatable during the winter, may be allowed to produce the maximum volume of forage before being grazed.

Near the adobe terrace edges, where shifting sands encroach upon *Hilaria mutica* associations to the east, Hilaria is the first species to give way. It is replaced by a sparse stand of alkali sacaton (*Sporobolus airoides*). When the dune is quite large, the Sporobolus is killed by the advancing sands, and even the brush species die. Brush, however, often survives the sand deposition and perishes only after the soil is eroded from its roots. Such erosion occurs on the windward side of the terrace. *Flourensia cernua* may survive even a slow root exposure, as it is a very adaptable shrub which spreads by sprouts.

PLANT SUCCESSION ON CLAY LOAM SOILS

The clay loam types are intermediate in structure and geographic position between the adobe flats and adjacent sandy or gravelly soils. Through long periods of time the sandy or gravelly materials have gradually mixed with the clay where the soils overlap. The plant succession on the sandy clay loam is so distinct from that on the gravelly clay loam as to require a separate presentation.

Sandy Clay Loam

On sandy clay loam soils the lichen stage fails to develop. The ruderal-weed stage on this type of soil has both a more dense and a more diverse composition than the localized ruderal-weed stage on adobe soils. The more palatable forbs are *Hoffmanseggia densiflora*, *Sphaeralcea incana*, and *Lesquerella fendleri*, none of which occur commonly on the adobe soils. Scattered specimens of Scleropogon, *Muhlenbergia arenicola*, and *Sporobolus* spp. add to the forage value of the stage. The stage also includes some forbs worthless as forage, such as *Gutierrezia sphaerocephala*, *Croton corymbulosus*, and *Perezia nana*. This stage requires approximately 25 acres to support a cow for one month. The Scleropogon stage develops very much as on the adobe soils. Finally other grass species, growing more abundantly on near-by areas, become established to form a mixed-grass association, with a vegetative composition like that shown in Table 12. This is essentially a Scleropogon-Hilaria-Sporobolus association, but the main forage species is *Hilaria mutica*, although it is not dominant. This mixed-grass type must be grazed conservatively enough to encourage the growth of Hilaria, Aristida, Muhlenbergia, *Sporobolus airoides*, and *S. cryptandrus*.

All these species are palatable mainly during the summer and fall, and when feed is urgently needed grazing can hardly be deferred until winter to protect the scattered stand of highly palatable *Bouteloua eriopoda*. Where the soil contains a large percentage of sand and additional sand is deposited by the wind, the area eventually may develop into a Bouteloua association, but this succession is too long a process to accomplish within a single generation. For practical purposes, then, the mixed-grass type with its grazing capacity of 5.8 acres per cow per month, must be considered as the sandy clay loam climax. It should be stocked conservatively enough to maintain the more palatable species.

TABLE 12.—*Estimated vegetative composition, palatability, and grazing capacity of a representative mixed-grass type on sandy clay loam soils* [a]

Species, by classes of forage	Composition	Palatability	Palatability factor
Grasses:	*Per cent*	*Per cent*	
Scleropogon brevifolius	26	20	0.052
Hilaria mutica	17	60	.102
Sporobolus auriculatus	12	20	.024
Sporobolus asperifolius	7	20	.014
Sporobolus airoides	7	50	.035
Muhlenbergia arenicola	6	50	.030
Bouteloua eriopoda	5	80	.040
Aristida pansa	3	60	.018
Sporobolus cryptandrus	2	60	.012
Bouteloua barbata	1	10	.001
Forbs:			
Hoffmanseggia densiflora	1	50	.005
Sphaeralcea incana	1	50	.005
Lesquerella fendleri	1	20	.002
Chamaesaracha coronopus	1	0	0
Bahia dealbata	1	0	0
Aster leucelene	.5	0	0
Croton corymbulosus	.5	0	0
Perezia nana	.5	0	0
Aplopappus australis	.5	0	0
Shrubs:			
Gutierrezia sarothrae	3	0	0
Ephedra trifurca	2	20	.004
Prosopis glandulosa	1	10	.001
Yucca elata	1	10	.001
Total	100		.346

[a] Reconnaissance plant density, 0.4; forage factor, 0.138; approximate number of surface acres required to support a cow for 1 month, 5.80.

GRAVELLY CLAY LOAM

This soil phase contains only a small percentage of gravel, which is usually in a very scattered layer near the surface. The plant succession on gravelly clay loam is similar both in amount and composition of the plant cover in each of the early stages to that on adobe clays, the lichen, localized ruderal weed, and Scleropogon stages all occurring in the order named. The next step is the establishment of an open stand of brush, principally *Flourensia cernua*. This plant is a shrubby composite which seeds readily. When mature it is 3 to 4 feet high. Its growth rate is slow, but it spreads by vegetative means so that its advance over the Scleropogon stage (fig. 7) is very steady, once it becomes established.

The spacing of the Flourensia bushes is such that the Scleropogon plants are not immediately crowded out. The earliest phase is really a Flourensia-Scleropogon community, but the shrub, although not a forage plant, affords protection from grazing and improves soil conditions for the establishment of grasses which are palatable to livestock. These species, whose seeds are disseminated by wind and flood waters, are principally *Hilaria mutica*, *Muhlenbergia porteri* (a very edible grass that grows mainly in the shade of the shrubs), *Sporobolus airoides*, and *Bouteloua curtipendula*. With these new species established, the climax Flourensia-Hilaria association presents a vegetative composition as shown in Table 13. It will support a cow for one month on approximately 5.4 surface acres.

TABLE 13.—*Estimated vegetative composition, palatability, and grazing capacity of a representative Flourensia-Hilaria association on gravelly clay loam* [a]

Species, by classes of forage	Composition	Palatability	Palatability factor
	Per cent	*Per cent*	
Grasses:			
Hilaria mutica	26	60	0.156
Scleropogon brevifolius	11	20	.022
Muhlenbergia porteri	10	85	.085
Sporobolus auriculatus	10	20	.020
Sporobolus airoides	8	50	.040
Sporobolus asperifolius	5	20	.010
Bouteloua curtipendula	3	60	.018
Andropogon saccharoides	2	50	.010
Forbs:			
Perezia nana	2	0	0
Eschenbachia coulteri	1	0	0
Hoffmanseggia densiflora	1	50	.005
Chamaesyce albomarginata	.5	0	0
Eriogonum abertianum	.5	0	0
Shrubs:			
Flourensia cernua	17	0	0
Gutierrezia sarothrae	1	0	0
Lycium pallidum	1	0	0
Ephedra trifurca	.5	20	.001
Koeberlinia spinosa	.5	0	0
Total	100		.367

[a] Reconnaissance plant density, 0.4; forage factor, 0.147; approximate number of surface acres required to support a cow for 1 month, 5.44.

FIGURE 7.—The stages of succession on gravelly clay loams: Scleropogon advancing over a lichen stage in the foreground, with Flourensia shrubs encroaching from the background

PLANT SUCCESSION ON LAKE-BED CLAY

Lake-bed clay includes soils in lake beds, both present intermittent lakes and old or extinct lakes. In the extinct lakes the succession is identical with that on adobe soils, except where a thin layer of sand has blown over the surface. In this case, the lichen stage fails to develop, and the ruderal-weed stage is more clearly defined, with a good stand of *Hoffmanseggia densiflora*, *Evolvulus pilosus*, and *Actinea odorata*. Scleropogon and Hilaria stages then occur in regular order. *Hilaria mutica* develops in dense, almost pure stands where flood waters accumulate and remain for a few days but *Scleropogon brevi-*

folius remains dominant where moisture is less abundant. Where water stands for more than a few days, the area becomes an intermittent lake and is characterized by somewhat different vegetation.

On the Jornada range there are four intermittent lakes, which are completely dry during years with below-average rainfall but which hold water for three months to a year when rainfall is average or above. With the habitat varying between submerged and dry sun-baked conditions, it is almost impossible for a stable association to become established. For a period of several years the extreme edge of the water may remain low enough to permit the Hilaria climax to start, but one year with exceptionally high rainfall may see this association submerged for a prolonged period and killed. When the water level reaches an unusual height and remains there for several months, *Hilaria mutica* is the first plant to die; *Sporobolus airoides* persists longer but finally is killed. *Panicum obtusum* and *Distichlis spicata* thrive when submerged a few inches but grow very slowly after the water recedes. After the water percolates into the soil or evaporates, the ruderal-weed stage develops quickly where other vegetation has been killed.

SUMMARY AND CONCLUSIONS

In the semiarid Southwest it is extremely important to manage range units so as to maintain the best possible stand of vegetation, both for watershed protection and for sustained livestock production.

Drought, overgrazing, erosion by wind and water, and activity of rodents are all factors in range depletion. Grazing is the factor most easily regulated where the range is under some form of control.

Where depletion has become serious, the artificial reseeding of native forage plants during favorable climatic years offers some promise of success, but the introduction of known exotic species holds little promise. The satisfactory artificial reseeding of large areas of semidesert range in the Southwest would be a costly process. It is far better to maintain a good stand of forage through conservative grazing than to be forced to attempt artificial reseeding of the range after it has been depleted by overgrazing.

Seriously depleted clay soils may be restored by the natural succession of plants from pioneer stages, when the plants have little or no forage value, to climax stages in which only from 3.4 to 5.8 acres are required to support a cow for one month. A valuable cover does not become established immediately because the succession may require many years or even decades to complete.

The occurrence and plant composition of each stage in the succession is determined largely by the type of soil and its associated habitat factors. Each stage builds up the humus content and water-holding capacity of the soil, thus preparing it for the next stage until the climax is reached.

Drymaria holosteoides, a quickly developing annual herb which is poisonous to livestock, may occur in the pioneer ruderal-weed stages on adobe clay, gravelly clay loam, and lake-bed clay. It grows most abundantly on hard clay soils where no other vegetation occurs.

On all types of clay soils, the *Scleropogon brevifolius* association is the first grass type of any real or permanent forage value to become established. Scleropogon can survive several years of below-average rainfall.

Scleropogon spreads to new areas mainly by means of horizontal stolons which extend out over the soil surface from the parent plant and take root at the nodes. Summer rainfall is the most important single factor influencing the growth of stolons, although they are produced more abundantly by young Scleropogon plants than by plants several years old. The increase or decrease in size of the Scleropogon tufts is determined mainly by the rainfall of the preceding grazing year, unless the current summer-seasonal rainfall is sufficiently extreme to overbalance the changes that should have occurred.

Hilaria mutica, a sod grass, is either predominant or makes up a large proportion of the climax stage on all clay soil types.

When the climax Hilaria association encroaches upon the Scleropogon stage, the competition is very keen. Drought and overgrazing rapidly reduce the tuft areas of both the Hilaria and the Scleropogon, but during favorable climatic periods Scleropogon recovers rapidly. Hilaria recovers more slowly but eventually predominates in the competition.

The main spread of *Hilaria mutica* is by its rhizomes. It may be grazed up to 60 per cent of its herbage production each summer without injury or without materially hindering the succession on adjacent areas supporting lower stages. Hilaria should be grazed in the summer, because after maturity its foliage becomes so coarse that its palatability is practically nil.

Control and regulation of the range which would restrict livestock to the clay soil types during the summer, when their grazing value is greatest, would permit the plants in large *Bouteloua eriopoda* types on adjacent sandy or gravelly soils to mature unhindered. Thus the Bouteloua types could be reserved for use during the late fall, winter, and early spring, when they can be used to best advantage and when the clay soil types support little or no forage.

The main types of clay soils on the Jornada Experimental Range and adjacent ranges of the Southwest are adobe clay, clay loam, and lake-bed clay. The abode flats were formed by the deposition of alluvium at the mouths of arroyos; they occur as broad aprons with terrace scarps at the edges. In front of the scarps the wind sweeps out the soil and piles it on top of the terrace edges, thus further increasing their height.

There are four main stages of succession on adobe soils. The earliest pioneers are algae and lichens, which help to protect the soil surface from erosion and build up its humus content. The second pioneer stage is a localized ruderal-weed association which is confined mainly to shallow drainage paths but which often contains fairly dense stands of *Drymaria holosteoides*, a forb poisonous to livestock. The first stage of value as forage is the Scleropogon association, in which there is a good stand of grasses, with *Scleropogon brevifolius* predominant. The climax stage consists of *Hilaria mutica* with its associated species and furnishes more forage per unit of area than any of the preceding stages.

Clay loam soils are intermediate in texture and location between the adobe flats and either sandy or gravelly soils. The succession on gravelly clay loams is very similar to that on adobe clays, except that *Flourensia cernua*, a shrubby composite, is prominent in the climax. On sandy clay loams, the lichen stage is lacking, the ruderal-weed stage is better developed, the Scleropogon stage is not clearly defined, and the climax is more a mixed-grass association, with *Hilaria mutica*, *Scleropogon brevifolius*, and *Sporobolus* spp. predominating.

The succession in extinct lake beds is similar to that on adobe soils, with an almost pure stand of *Hilaria mutica* as the climax. In intermittent lake beds, the alternate flooding and drying are so detrimental to orderly succession that no definite sequence of stages occurs. The Hilaria climax may occur to some extent beyond the high-water mark, and *Sporobolus airoides* grows even farther into the lake bed. Both species, however, are killed by too long a period of submersion. When dry the lake beds support a good stand of ruderal weeds.

Range management is complicated by the necessity of using all the successional stages during the summer growing season and early fall if their maximum grazing capacity is to be obtained and if large adjacent Bouteloua types suitable for winter grazing are to be reserved for their proper season of use. This immediately brings up the question of how to manage the range in order to bring about the succession and maintain the climax after it has developed.

The problem becomes one mainly of accurately determining the actual grazing capacity of each range unit, together with the best season for use and extent of variation due to drought, and finally of stocking the range during a suitable season on a basis conservative enough and with sufficiently uniform distribution of stock to bring about the desired vegetative trend, keeping an accurate check on vegetative conditions through reliable quantitative measurements.

LITERATURE CITED

(1) JACKSON, C. V.
1928. SEED GERMINATION IN CERTAIN NEW MEXICO RANGE GRASSES. Bot. Gaz. 86: 270–294, illus.

(2) JARDINE, J. T., and FORSLING, C. L.
1922. RANGE AND CATTLE MANAGEMENT DURING DROUGHT. U. S. Dept. Agr. Bul. 1031, 83 p., illus.

(3) LANTOW, J. L.
1929. THE POISONING OF LIVESTOCK BY DRYMARIA PACHYPHYLLA. N. Mex. Agr. Expt. Sta. Bul. 173, 13 p., illus.

(4) LINNEY, C. E.
1917–1930. ANNUAL SUMMARIES. U. S. Dept. Agr., Weather Bur., Climatological Data, N. Mex. Sect. v. 21–34.

(5) MCGINNIES, W. G.
1930. THE QUADRAT. Jour. Forestry 28: 23–27.

(6) SAMPSON, A. W.
1919. PLANT SUCCESSION IN RELATION TO RANGE MANAGEMENT. U. S. Dept. Agr. Bul. 791, 76 p., illus.

(7) TAYLOR, W. P.
1930. METHODS OF DETERMINING RODENT PRESSURE ON THE RANGE. Ecology 11: 523–542, illus.

(8) WILSON, C. P.
1931. THE ARTIFICIAL RESEEDING OF NEW MEXICO RANGES. N. Mex. Agr. Expt. Sta. Bul. 189, 37 p., illus.