SOIL CONDITIONS OF THE JORNADA RED LOAMY SAND OF SOUTHERN NEW MEXICO, AS RELATED TO THE DEGREE OF INVASION BY MESQUITE, PROSOPIS GLANDULOSA

by

Kenneth A. Valentine

A Thesis

submitted to the faculty of the

Department of Botany

in partial fulfillment of

the requirements for the degree of

Master of Science

in the Graduate College

University of Arizona

1941

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INTRODUCTION

The Jornada Red Loamy Sand is a local soil occurring on the Jornada Experimental Range in southern New Mexico and on nearby areas. The undisturbed vegetation associated with this soil is a desert grassland consisting principally of black grama, Bouteloua eriopoda, which is one of the most valuable range types on the Experimental Range. Lying contiguous to and partly interspersed with the Jornada Red Loamy Sand is another local soil, the Jornada Red Loamy Sand-Windblown Phase. This soil, as its name implies, was considered by Veatch (22), in the report of his survey of the Soils of the Jornada Experimental Range, to be a deteriorated phase of the Jornada Red Loamy Sand. The vegetation on this soil consists almost entirely of mesquite, Prosopis glandulosa. The grazing value of this range type is very low by comparison with the black grama range. Jardine and Hurtt (7) have estimated the grazing capacity of the mesquite, or mesquite sandhills range as it is called locally, to be slightly less than a third that of the black grama grassland. Conversion of the grassland to the mesquite sandhills thus results in the loss of the greater part of the original grazing capacity. The soil protection value of the vegetation cover on the Windblown Phase of the Jornada Red Loamy Sand is also very much less than the

desert grassland on the stable phase and wind and deposition is severe. Water erosion, though less general, is severe over limited areas.

Because of the low grazing and soil protection value of the vegetation on the Windblown Phase of the Jornada Red Loamy Sand, considerable work has been done on the Experimental Range aimed at improvement of the cover. This work has consisted in the main of protection from grazing by livestock, rabbits, and other rodents. Little or no improvement in the vegetation cover has attended these treatments. As a result of this lack of improvement, it has been suggested that the character of the soil is such as to be limiting to the success of the desirable grasses found on the adjacent grassland on the Jornada Red Loamy Sand.

Two possibilities are suggested as to the manner in which the soil of the Jornada Red Loamy Sand-Windblown Phase may be limiting or partly limiting to the growth of desirable forage plants. One of these is the effect of wind erosion and deposition of the sandy soil about plants and abrasion of plants by wind-borne sand. The other has to do with the water and nutrient holding and supplying capacity of the soil. It is with this latter possibility that the present study is concerned.

Review of Literature

Differences in natural vegetation cover have been correlated with differences in associated soil types (2) (8)

(16) (17) (18). Successional changes in the vegetation cover are accompanied by changes in soil conditions as has been noted in a limited number of studies. Cooper, Wilson, and Barron (4) describe a definite succession of pasture plants which accompanies decreasing soil fertility in the northeastern United States. Stewart (20), working in New York State, made a comprehensive study of physical, microbiological, and chemical conditions of the soils of forest and of pastures exhibiting five degrees of quality, ranging from good blue grass pasture down to deteriorated pasture heavily invaded by moss and ferns. He found that the change from trees to grass was accompanied by loss of permeability to water, lessened water holding capacity, and reduced air space; and that the forest and better pasture soils have deeper and more humified A and B horizons than do the soils of the poorer pastures. Plant residues were found to accumulate on the surface of the poorer pasture soils, which were more acid in reaction than the soils of the forest and better pastures. It was found that the forest soils ranked highest in initial nitrate content and in accumulation of nitrates during storage, followed by the soils of blue grass pasture, Rhode Island bent grass pasture, and with the poor pasture soils showing the lowest initial content and accumulation during storage. Lime was found to be highest in the blue grass pasture soils. Azotobacter were found only in the blue grass soils and legume bacteria only in

soils in which legumes had been growing. Sinclair and Sampson (19) studied the influences of the A, B, and C horizons of soils of the Holland, Aiken, and Olympic series in California on the development of early-successional annual and later-successional perennial plants. In all cases greater growth and earlier development were obtained in the A horizon than in the B or C horizons. Water requirement was found to be higher for plants grown in the B and C horizons than for plants grown in the A horizon. Aikman (1) studying the relation of the stages of plant succession to erosion in central Iowa, found that depth of soil increases and erosion losses decrease as the succession proceeds from the initial foliose lichen stage to the linden-maple community. Water-holding capacity was found to be about as great for the early formed soil as for the soil of the later stages. Wilting coefficient and organic matter content were found to increase slightly from the lower to the higher successional stages.

Millar (11) studied 48 crop-depleted Michigan soils and the undepleted virgin soils nearby. He found that the virgin soils had a greater rate of solubility upon standing after being washed practically free of soluble salts and concludes that decreasing rate of solubility is one of the important changes a soil undergoes in passing from a virgin to a depleted condition.

Murphy and Daniel (13) in a comparative study of the normal soil of the short grass plains in central Oklahoma with adjacent solenetz soils found that the natural vegetation consisting of blue grama and buffalo grass afforded a vital protection to the thin A horizon of the solonetz as shown by rapid rate of erosion following any removal of plant cover. The original cover of blue grama and buffalo grass failed to grow when the A horizon was depleted and three-awn grass, Aristida oligantha, occupied the deteriorated soil. The B horizon of the solonetz did not support a vegetation cover sufficient to prevent its rapid erosion.

Shantz and Piemeisel (18) in a study of the vegetation of Escalante Valley, Utah, described and figured a vegetation type consisting chiefly of big rabbit bush, Chrysothamnus spp., growing on the top of sand dunes with the interdunal areas barren. This type of vegetation in the Escalante Valley is stated to result from abandonment after farming. In their study of the vegetation in the Imperial Valley in California, these same workers (17) described and pictured a sand dune vegetation consisting of mesquite, Prosopis glandulosa, and chamisa, Atriplex canescens, which is very much like the mesquite community on the Windblown Phase of the Jornada Red Loamy Sand. Here they report that the dunes consist of pure sand with little sand in the interdunal areas. Water holding capacity and wilting coefficient of the soil is low; rainfall enters the surface of the soil readily and

run-off is low. The soil is well supplied with water after the winter rains, but this water is rapidly removed by plants and evaporation during the early summer. Salt content was found to be low, running less than .01 percent, dry soil basis, in most cases in the first and second foot and from .01 to .03 percent in the third and fourth foot.

These workers have shown some of the changes that soils undergo with changing conditions of the vegetation cover. Some of these changes have been so marked that plants characteristic of the virgin or undeteriorated soils are not capable of growing successfully on the corresponding deteriorated soils. In view of these findings and of the lack of success of the treatments made on the Experimental Range, the present study was undertaken to discover any differences between the stable Jornada Red Loamy Sand and the Windblown Phase of this soil which might account for the failure of the plants characteristic of the stable phase to become established on the windblown phase of the soil. The present experiment consists of physical, chemical, and microbiological analysis and pot tests of samples taken from each of these soils and from locations intermediate between the two which represent transition conditions.

EXPERIMENTAL AREA

Location

The Jornada Experimental Range is located in Dona Ana County, New Mexico at the southern end of the Jornada plain, a basin without drainage outlet between the San Andreas and Oscura Mountains on the east and the valley of the Rio Grande River on the west.

Soil and Vegetation

The Jornada Red Loamy Sand and the windblown phase of this soil occupy the greater part of the west part of the Experimental Range. Veatch (22) described these soils as being among the older soils of the Jornada plain, all of which consist of comparatively recent deposits of unconsolidated alluvium not later than Pleistocene in age, derived from the nearby mountains. As to the general nature of the soils of the Jornada plain, Veatch states that they are not at all comparable to the soil mantle which is found in more humid climates but are little more than various lithologic phases of the surface of a recent geologic formation. The soils of the whole Jornada plain are shown in the Atlas of American Agriculture (21) to fall in the Southern Red Desert Soil group and to consist largely of the Reeves series, though some areas of Sand are shown to occur interspersed with this series locally. Standard soil survey of the Jornada plain has not been made in sufficient detail to place

the soil in the Experimental Range in either the Reeves series or Sand.

The Jornada Red Loamy Sand is described by Veatch as being a uniformly medium to fine sand with gravel and stones absent, exhibiting the following profile:

Superficial veneer of grayish, loose, incoherent sand; 2 to 6 or 8 inches.

Reddish, slightly compact loamy sand; 24 to 30 inches; gradation to:

Salmon colored sand, slightly cemented, streaked and splotched with accumulation of lime carbonate; 18 inches; gradation to:

Hard, whitish, mortar-like caliche, consisting of fine and medium sand cemented by lime carbonate, 6 feet; abrupt change to:

Medium and coarse granitic sand, unconsolidated and not highly calcareous, 1 foot.

The land occupied by the soil is nearly level or gently rolling and the surface is smooth. Black grama grass is dominant in the undisturbed natural vegetation on this soil. Other grasses, chiefly mesa dropseed, Sporobolus flexuosus, spike dropseed, S. contractus, poverty grass, Aristida divaricata, and red three-awn grass, A. pansa, occur in minor proportions. Soaptree yucca, Yucca elata, a stalked yucca of some 4 to 6 feet in height characterizes this grassland. Broad-leaved herbs, especially perennials, are uncommon.

The Jornada Red Loamy Sand--Windblown Phase is described by Veatch as being similar to the Jornada Red Loamy Sand but differing from the latter soil in surface structure. Over much of the area occupied by the Windblown Phase, the surface has been shifted by the wind into low hummocks and dunes. A hard whitish caliche substratum is present, as in the stable phase of the soil, but at variable depths, depending on the degree of wind erosion and deposition. Between the higher dunes this substratum is sometimes exposed. The surface of the bare soil between the dunes is subject to the full force of the wind and is consequently very unstable. Changes in level of the surface of nearly two inches over a 21-month period have been observed. The original surface of this soil is considered by Veatch to have been smooth as is the present surface of the stable Jornada Red Loamy Sand. All stages of transition between the two soils are observable. The vegetation associated with the windblown soil consists largely of mesquite. This plant occupies the sand dunes and its habit of growth is modified by the association with the dunes. Instead of exhibiting an upright growth of a few stems, one to three or four inches in diameter, as it does when growing on compact soil, the plant has hundreds of small stems of about one-fourth to one-half inch diameter projecting but a foot or so from the dune tops. Other shrubs, chief among which are chamiza, snakeweed, Gutierrezia sarothrae, soaptree yucca,

sandsage, Artemisia filifolia, and wild alfalfa, Dalea scoparia, contribute in a lesser degree to the perennial plant cover of this community. Except for the light stand of shrubby species, the interdunal areas or blowouts are quite barren for the greater part of the year. In summer and fall of years favored by heavy, well-distributed rainfall, a stand of annuals develops on the blowouts. Most common among these are: big sandburr, Franseria acanthicarpa, sunflower, Helianthus canus, chamaesyce, Chamaesyce albomarginata, reverchonia, Reverchonia arenaria, and big mallow, Sphaeralcea incana. Grasses are very uncommon in this community, the two most common species, mesa dropseed and plains bristle grass, Setaria macrostachya, constituting only a trace in the total vegetation cover, if present to that degree. As in the case with the two soils, all stages in the transition between grassland and mesquite communities exist. So closely are the two soil types and their respective plant communities associated that the major portion of their respective boundaries practically coincide. These two soils and associated plant communities and intermediate transition conditions are represented in Figures 1, 2, and 3.

Climate

The climate of the Jornada plain, like that of other southwestern lowland areas is severe for several months of the year as regards growing conditions. Table 1 presents a

Figure 1. Desert grassland consisting of black grama grass on the Jornada Red Loamy Sand, Jornada Experimental Range.

Figure 2. Mesquite community on the Windblown Phase of the Jornada Red Loamy Sand, Jornada Experimental Range.

Figure 3. Intermediate transition conditions between the desert grassland community on the Jornada Red Loamy Sand and mesquite community on the Windblown Phase of the Jornada Red Loamy Sand, Jornada Experimental Range.

Table 1. Mean monthly temperature, (1928-1940), evaporation (1929-1940), precipitation (1914-1940), and wind movement (1929-1940) as recorded at the Jornada Experimental Range Headquarters.

Month	Mean monthly temperature	Mean monthly evaporation	Mean monthly precipitation	Mean monthly wind movement
	°F	Inches	Inches	Miles
January	38.7	2.87	.41	2909.3
February	43.7	4.13	.39	2911.5
March	49.5	7.50	.37	3756.7
April	57.9	9.98	.19	3843.8
May	65.8	12.39	.47	3571.7
June	75.2	13.63	.58	3480.4
July	78.3	11.82	1.72	3192.1
August	77.1	10.36	1.70	2657.0
September	72.2	8.68	1.47	2387.9
October	60.9	6.29	.85	2278.7
November	46.7	3.88	.43	2144.7
December	39.5	2.54	.63	2070.7

summary of mean monthly temperatures, evaporation from a free water surface, precipitation, and wind movement as observed at the Jornada Experimental Range Headquarters. Inspection of this table reveals a combination of relatively high temperature, high evaporation, low precipitation, and high wind movement occurring in the months of April, May, and June which renders this period one of considerable stress for vegetation. Rainfall coming in late June or early July breaks this stress period and opens the growing season on the range which continues until low temperatures check growth in October. The combination of climatic factors which makes spring and early summer a stress period for vegetation on the Jornada range is increased in severity on the Windblown Phase of the Jornada Red Loamy Sand. Here the high wind movement over the nearly barren soil operates to rapidly remove moisture from the surface of the soil and to transport much of the loose sandy soil from place to place, thus drying the soil more completely than by surface evaporation alone. In addition the wind does further damage by erosion and deposition of sand about plants growing on the nearly barren site.

METHODS

Collection of Samples

Soil samples were collected at three series of stations located along the boundary between the Jornada Red Loamy

Sand and its Windblown Phase as shown on the outline map of the Jornada Experimental Range, Figure 4. Each series included one station in the desert grassland on the stable Jornada Red Loamy Sand, one in the mesquite community on the Windblown Phase of the soil and a third station intermediate between these two and representing transition conditions between the two soils and vegetation types. Samples were taken at two points at the Grassland Station: near a small inconspicuous mesquite plant and at a point 10 or 15 feet distant where no mesquite plant was present. Three points were sampled in the Transition and Mesquite Stations: on the top of the dune, in the blowout next the dune, and in the grassland near the mesquite community. The sampling depth at all these locations included the surface 8 inches. In addition, samples were taken at greater depths on the dunes and in the grassland near the blowouts. On the dunes, samples were taken at successive 8-inch intervals from the surface down to approximately 8 inches below the original soil surface. In the grassland near the blowouts, samples were taken in successive 8-inch intervals downward to approximately the same depth as the surface sample in the adjacent blowout. Relative location of the stations in a series and points and depths of sampling at the stations are shown diagramatically in Figure 5. Sampling was done by digging with a shovel. A larger quantity of soil was dug than was needed for the sample and the soil well mixed

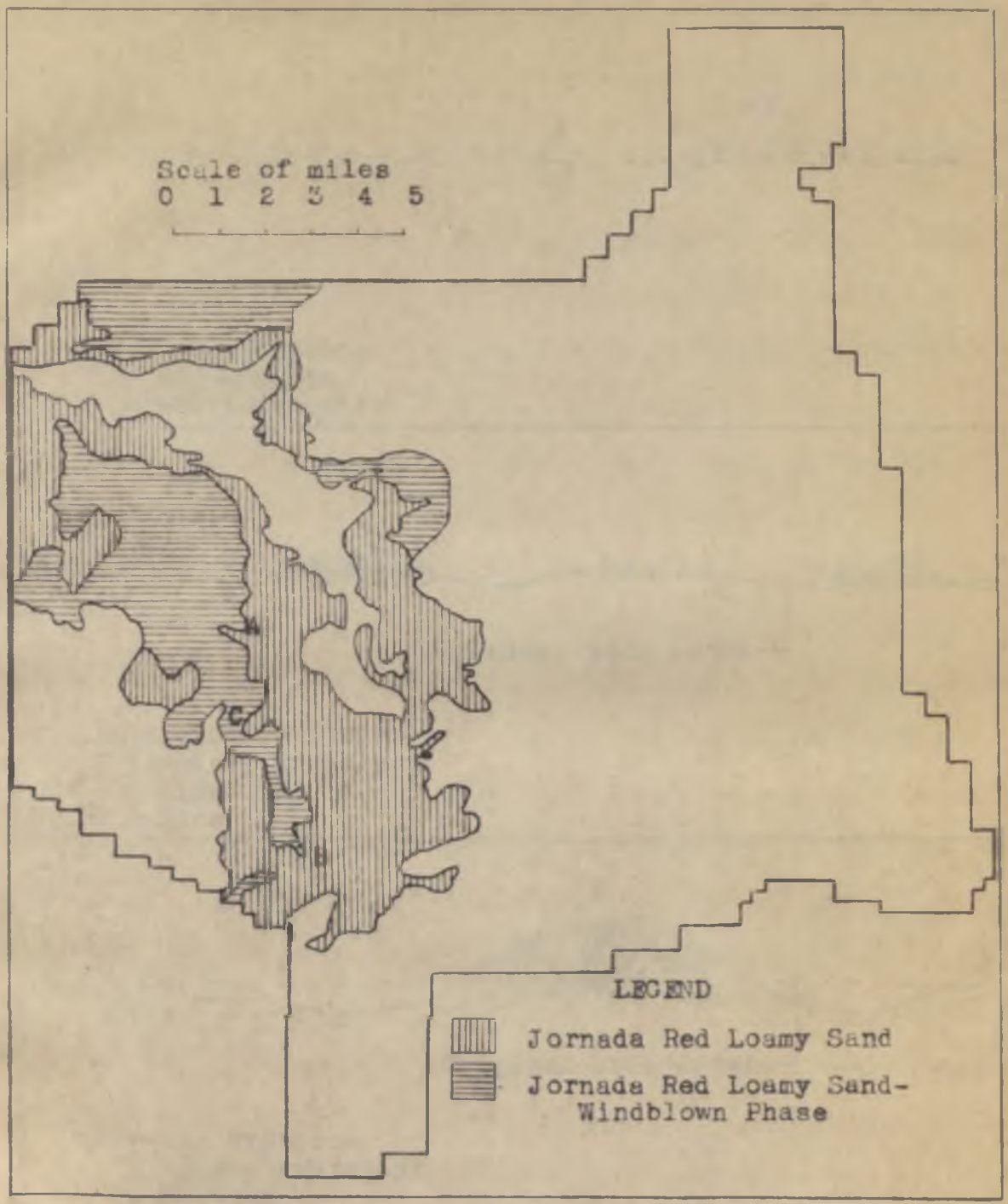

Figure 4. Outline map of the Jornada Experimental Range showing the location of the Jornada Red Loamy Sand, the Jornada Red Loamy Sand-Windblown Phase, and the A, B, and C series of stations at which soil samples were taken.

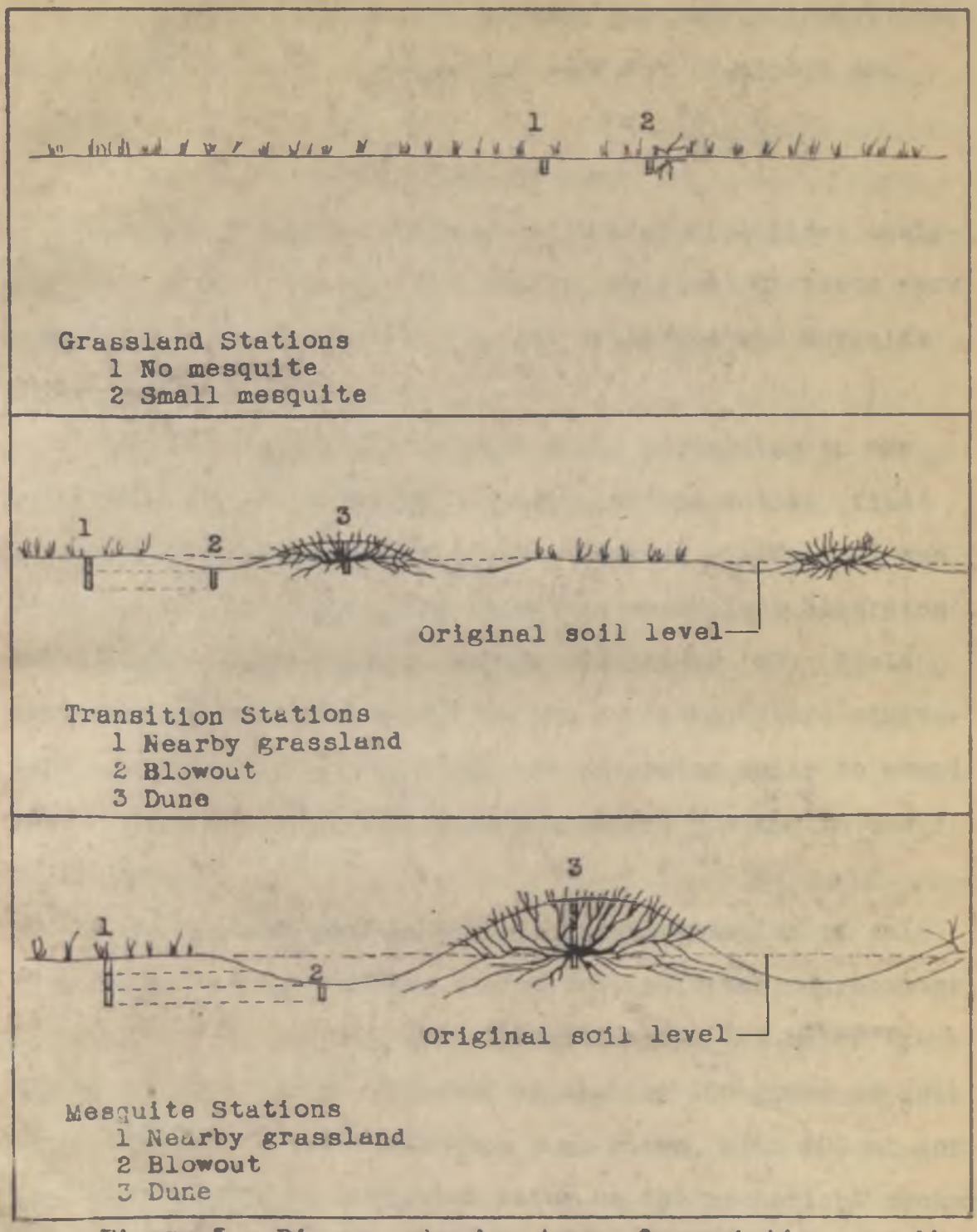

Figure 5. Diagram showing type of vegetation, condition of the soil surface, original soil level, and relation of sampling depths at the different locations at the Grassland, Transition and Mesquite Stations.

on a wooden platform before removing the sample quantities, which were placed in Kraft paper bags for transport and storage.

Analytical Methods

Certain physical, chemical, and microbiological analyses were made of the samples and in addition pot tests were made of the surface soils from the Grassland and Mesquite Stations.

Physical analyses made were those pertaining to the water holding and supplying capacity of the soils: field capacity and wilting coefficient. Wilting coefficient was obtained indirectly from the moisture equivalent according to the method described by Briggs and Shantz (3). Field capacity was obtained in the course of the moisture equivalent determination by allowing the saturated soils to stand until drainage ceased and weighing before placing in the centrifuge.

Chemical analyses consisted of determination of calcium, magnesium, potassium, chlorides, sulfates, carbonates, bicarbonates, nitrates, and phosphates in a 1:5 water extract. Extracts were prepared by shaking 100 grams of soil, which had been passed through a 2 mm. sieve, with 500 ml. of cool freshly-boiled distilled water on the mechanical shaker for 30 minutes and then filtering by gravity through paper and the soil colloids until a clear extract was obtained.

Calcium and magnesium were determined by titration with standard soap solution. Potassium was determined volumetrically by precipitating as di-potassium sodium cobalti-nitrite with acidified tri-sodium cobalti-nitrite reagent, dissolving in standard potassium permanganate adding excess standard sodium oxalate and titrating the excess oxalate with standard potassium permanganate. Organic matter was first removed by oxidation with concentrated nitric acid. Chlorides were determined by titration with standard silver nitrate using potassium dichromate indicator. Carbonates and bicarbonates were determined by titration with standard sulfuric acid, carbonates being computed from the phenolpthalein end point and bicarbonates from the methyl orange end point. Sulfates were determined turbidimetrically by comparison with prepared standards. Nitrates were determined colorimetrically by the phenoldisulfonic acid method, values being computed by comparison with standard nitrate solutions on the colorimeter. Soluble organic matter was first removed by precipitation with copper sulfate. Phosphates were determined colorimetrically by the Deniges method. pH values were obtained in unfiltered 1:5 suspensions by means of the Beckman pH meter. Total soluble salts were determined by conductivity.

Microbiological analysis of the soils was made by determining the capacity of the soils to oxidize the nitrogen of ammonium sulfate. A 50-gram portion of each soil sample

was moistened with ammonium sulfate solution containing 12 mgms. of nitrogen. Distilled water was added to bring the water content up to optimum. After an incubation period of 23 days at room temperature, nitrate determinations were made of a 1:5 water extract of these samples.

Pot tests were made in the University of Arizona Botany Department greenhouse of the surface samples from the Grassland and Mesquite Stations. Two sets of pot tests were made: one in which Rothrock grama, Bouteloua Rothrockii Vasey (6), was used as the culture plant, and another in which one of the six-weeks gramas, Bouteloua Parryi (Fourn.) Griffiths (6), was used. The plants were grown in two-gallon glazed pots with drainage holes at the bottom. In the Rothrock grama set, a pint wide-mouth Mason fruit jar was inverted over the hole in each pot to take up space and thus reduce the quantity of soil needed since the supply was limited. Pots were then filled with the dry soil and watered with 2 liters of distilled water, the quantity computed to almost satisfy the field capacity of the soil used. After allowing the soil to dry sufficiently to avoid puddling upon being worked, a uniform quantity of clean seed was sown in each pot. Pots were then covered with paper discs to keep the surface of the soil moist during seed germination and emergence. Planting was done on December 2, 1940. Owing to caterpillar damage, the pots of blow-out soil of the B and C Series had to be replanted on

December 9. After seedlings were established, they were thinned down to 35 or 40 plants per pot. Measured amounts of distilled water were used to water the pots. Water additions were made at the same time and in equal amounts to all pots in the Rothrock grama set, except during the early period of growth when additional small quantities of water were added to the pots of blowout soil in the B and C Series to keep the surface moist during emergence of the second crop seedlings, and later when water was withheld from the pot of blowout soil of the C Series to avoid over watering. Amounts of water applied and dates of watering are shown in Table 2. On April 30, 1941, the plants were washed out of the pots, partially dried in a plant press, and photographed. After photographing, the tops and roots were separated, dried at 105° C, and weighed.

The set of pot tests using six-weeks grama as the culture plant included, in addition to pots of the two surface samples from the Grassland Stations and the three from the Mesquite Stations, pots of blowout soil from the Mesquite Stations to which nitrogen, phosphorus, and potassium amendments were independently added by watering with solutions instead of distilled water. Owing to the lack of sufficient soil of the A Series, Mesquite Station blowout, potassium amendment of the soil was omitted. Solutions containing the primary amendments (nitrogen, phosphorus, or potassium) also

Table 2. Record of water applied on pots of Rothrock grama plants grown in surface soils from Grassland and Mesquite Stations, in milliliters.

Date	Pots watered	Amount	Remarks
Nov. 23	All	2000	Initial watering prior to planting
Dec. 7	All	10	To keep surface moist during emergence of seedlings
9	C Series, Mesquite-blowout	150	To keep replanted seed moist
11	B and C Series, Mesquite-blowout	50	To keep replanted seed moist
12	All	100	
16	B and C Series, Mesquite-blowout	100	
22	All	500	
Jan. 2	All	250	
6	All	250	
12	B and C Series, Mesquite-blowout	200	
13	All	500	
20	All	500	
27	All	500	
Feb. 7	All	1000	
17	All	1000	
Mar. 3	All except C Series, Mesquite-blowout*	1000	
5	C Series, Mesquite-blowout	1000	
13	All except C Series, Mesquite-blowout*	1000	
17	C Series, Mesquite-blowout	1000	
22	All except C Series, Mesquite-blowout*	1000	
25	C Series, Mesquite-blowout	1000	
28	All except C Series, Mesquite-blowout*	1000	
Apr. 4	All	1000	
14	All except C Series, Mesquite-blowout*	1000	
17	C Series, Mesquite-blowout	1000	
26	All except C Series, Mesquite blowout*	500	

*Water withheld from C Series, Mesquite-blowout pot to avoid keeping soil too wet.

contained .24 gram per liter of magnesium sulfate and .55 gram per liter of calcium chloride in order that calcium, magnesium, and sulfur be present in each amendment pot. Water and amendment solutions were added in equal amounts and at the same time throughout the six-weeks grama set as shown by Table 3.

Table 3. Record of water or amendment solutions applied on pots of six-weeks grama plants grown in surface soils from Grassland and Mesquite Stations and in Mesquite-blowout soils amended with nitrogen, phosphorus, and potassium, in milliliters.

Date	Pots watered	Amount	Remarks
Feb. 13	All	500	Initial watering prior to planting
Mar. 6	All	500	Water or amendment solution
13	All	500	Water or amendment solution
21	All	250	Water only
Apr. 1	All	500	Water or amendment solution
7	All	500	Water or amendment solution
17	All	500	Water or amendment solution

Each of the amendment solutions carried their respective primary amendments in the following concentrations: nitrogen as NO_3, 0.62 gram per liter; phosphorus as HPO_4, 0.097 gram per liter; and potassium as K, 0.195 gram per liter. Amounts of these nutrients added in the 500 milliliters of solution applied at each watering were: nitrate, 310 milligrams; phosphate, 47.5 milligrams; and potassium, 97.5 milligrams. Converted to parts per million of the dry soil in each pot (about 7 kilograms), these amounts are 44, 6.8, and 13.9, respectively. Seed was not sown directly in

the six-weeks grama pots but was sprouted from the chaff in sand and the seedlings then transplanted to the culture pots, four to a pot. Seedlings were first transplanted on February 17 and replacements were made of those not surviving transplanting for several days following. On May 1, 1941, the plants of this set were carefully washed from the soil, partially dried in a plant press, and photographed. After photographing, they were dried at 105° C and weighed. Separation of tops from roots of these plants for the purpose of determining top/root ratios was not made owing to the unavoidable loss of parts of the very fragile root systems while washing them from the soil.

RESULTS

Physical Analysis

The results of the field capacity determinations are presented in Table 4. In each series the field capacity values of the surface soil at the Grassland Stations and the grassland of the Transition and Mesquite Stations are seen to be generally lower than the surface soil of the adjacent blowouts and dunes. The soil of the grassland of the Transition Station of the A Series is an exception to this general relationship. The Transition-grassland soil in each series has a slightly higher field capacity than the other grassland soil. The sub-surface soil of the A Series, Transition-grassland has a field capacity almost equal to

that of the soil in the adjacent blowout; and at the Mesquite Stations in all series the field capacity of the sub-surface soil in the grassland is higher than that of the blowout soil. The soil in the dunes, although variable within a single dune, generally exhibits intermediate field capacity values. None of the differences found are large.

Wilting coefficient data are presented in Table 5. Here the relationship of values is generally similar to that of the field capacity data. The surface grassland soil shows the lower values and the sub-surface grassland and blowout soils exhibit the higher values. Wilting coefficients of the dune soil show slight irregular variation with depth but are usually higher than that of the surface grassland soil and lower than the sub-surface grassland soil and blowout soil.

Chemical Analysis

The pH values of the soil samples are presented in Table 6. These values range from mildly alkaline to alkaline and show no consistent variation between grassland, blowout, and dune.

Data obtained by chemical analysis are presented in Tables 7 to 14 and are summarized in Table 15. Total soluble salts as determined by conductivity are also shown in Table 15. Results of calcium analysis are presented in Table 7. Calcium content is shown to be consistently higher in the soil of the dunes than the other soils. The other

soils show irregular variation between series and between grassland and blowout samples. Magnesium content of the samples are shown by Table 8. Here the values, though smaller in magnitude, show the same trend as calcium values, generally higher in the dunes and lower in the other soils.

Potassium concentrations of the soils are presented in Table 9. Content of potassium is seen to be higher in the soil of the dunes than the soil of the blowouts or grassland. It is of interest to note that potassium content of the dunes of the Transition Stations tends to be considerably higher than that of the older and larger dunes of the Mesquite Stations. Consistent differences do not appear between the soils of the blowout and grassland with regard to potassium content. The surface soil of the grassland at the Transition Stations in the A and B Series exhibits a greater potassium concentration than does the soil of the adjacent blowouts. In the C Series, however, the Transition Station grassland is lower in potassium than the blowout. At the A Series Mesquite Station, the grassland is also lower in potassium than the blowout, but in the B and C Series the grassland soil of the Mesquite Stations show higher potassium content than do the blowouts. Sodium content of the soil is presented in Table 10. These values do not, in general, vary widely from place to place, either within a series or between series. Relatively low concentrations appear

in the lower portions of the Mesquite Station dunes of the B and C Series and in the Transition Station dunes of the A and B Series.

The results of chloride analysis are presented in Table 11. Here the data do not show consistent variation between grassland and blowouts; but with the exception of the soil from the B Series, Transition-dune, they do show greater amounts of chloride in the dune soil than in the soil of grassland or blowout. Neither sulfates nor carbonates were found in any of the extracts. Results of the bicarbonate analysis are shown in Table 12. Bicarbonate values do not show consistent differences between soil of the grassland, blowouts, and dunes.

The results of the nitrate analysis are presented in Table 13. The data show marked differences in nitrate concentrations between the grassland and blowout soils on one hand and the dune soil on the other, the values for the dune soil of both Transition and Mesquite Stations in all series running uniformly high. Concentrations were found to be higher in general beneath the surface on the dunes than at the surface. Consistent differences between grassland and blowout soils are not shown by the data. Soil from both Transition and Mesquite-blowout of the A Series shows lower nitrate content than the soil of the adjacent grassland. At the Transition Station of the B Series, nitrate content of the blowout and grassland soil is nearly

the same. In the C Series both Transition-blowout and Mesquite-blowout soil is higher in nitrate content than the soil of the adjacent grassland. It is of interest to note that in all series the soil of the Grassland Station from next the small mesquite plant has a higher nitrate content than the Grassland soil where mesquite was not present.

The results of phosphate analysis are presented in Table 14. The data show almost the same phosphate content for all the grassland soils. Phosphate concentrations exhibit a sharp increase in the blowout soil of the Transition Stations in all series, and decrease almost as sharply in the blowout soils at the Mesquite Stations. The dune soil of both Transition and Mesquite Stations exhibit phosphate concentrations considerably above the amounts found in the grassland soil. It is very interesting to observe that the dune soil of the Transition and Mesquite Stations show the same relationship with regard to phosphate content that they do for potassium. The smaller, younger dunes of the Transition Station have a higher content of phosphorus than the dunes at the Mesquite Stations. Results of all the chemical analyses are summarized in Table 15.

Microbiological Analysis

The results of the nitrification tests are presented in Table 16, in terms of the nitrate concentration in parts per million in excess of that found in the untreated, unincubated soil. Nitrification proceeded with considerable magnitude

in most of the dune soil and to a lesser extent in the grassland and blowout soils. In general, the blowout soil has shown slightly lower nitrifying capacity than the grassland soil. It is interesting to observe that although the ammonia added to the soils was equivalent to 1063 parts per million nitrate nitrogen, several of the dune soils converted the greater part of this during the period of incubation.

Pot Tests

The growth of tops and roots made by the Rothrock grama plants grown in the Grassland and Mesquite soils of Series A, B, and C from December 2, 1940 to April 30, 1941 is shown by Figures 6, 7, and 8, respectively. The average weights of tops and roots and top/root ratios of the Rothrock grama plants are presented in Table 17. These data reveal a greater production of tops in the grassland soils than in the blowout soil of the A Series, only a slightly greater production in the grassland soils than in the blowout soil of the B Series, and a much greater production in the grassland soils than in the blowout soil of the C Series. The dune soil of the A and C Series is considerably more productive of top growth than grassland soils of these series but there is less difference in productiveness of dune and grassland soils of the B Series. Root production of Rothrock grama plants roughly parallels top production in most

cases but exhibits inversion in the case of the dune soil of the A and B Series. Production was greater in the grassland soils than in the blowout soil of the A Series, about the same in the grassland soils as in the blowout soil of the B Series, and very much greater in grassland soils than in blowout soil of the C Series. Root production is about the same in dune and grassland soils of the A Series, much less in the dune soil than the grassland soil of the B Series, and somewhat greater in the dune than in the grassland soils of the C Series.

Top/root ratios of the Rothrock grama plants are not uniform from series to series but the general trend is intermediate for the grassland soils, low for the blowout soils, and high for the dune soil. Variation of top/root ratio between series is least for the grassland soils and greatest for the blowout and dune soils.

The growth of the six-weeks grama plants made in the Grassland and Mesquite soils and amended mesquite blowout soils of the A, B, and C Series from February 17 to May 1, 1941 is shown in Figures 9, 10, and 11, respectively. Average weights of the six-weeks grama plants are presented in Table 18. These annuals showed greater variation in size within a pot than was exhibited by Rothrock grama. This table reveals the smallest yield in the unamended blowout soils in each series and largest yields in the Mesquite-grassland and Mesquite-dune soils. The nitrogen amendment

of the blowout soil resulted in but little production in excess of that of the unamended soil. Phosphorus amendment, however, resulted in the production of a noteworthy excess over the unamended soil. Potassium amendment, in one of the two instances in which it was made, resulted in a considerable increase. In the other case the potassium amended soil gave lower yield than the unamended soil; this lower yield is, however, hardly attributable to the amendment.

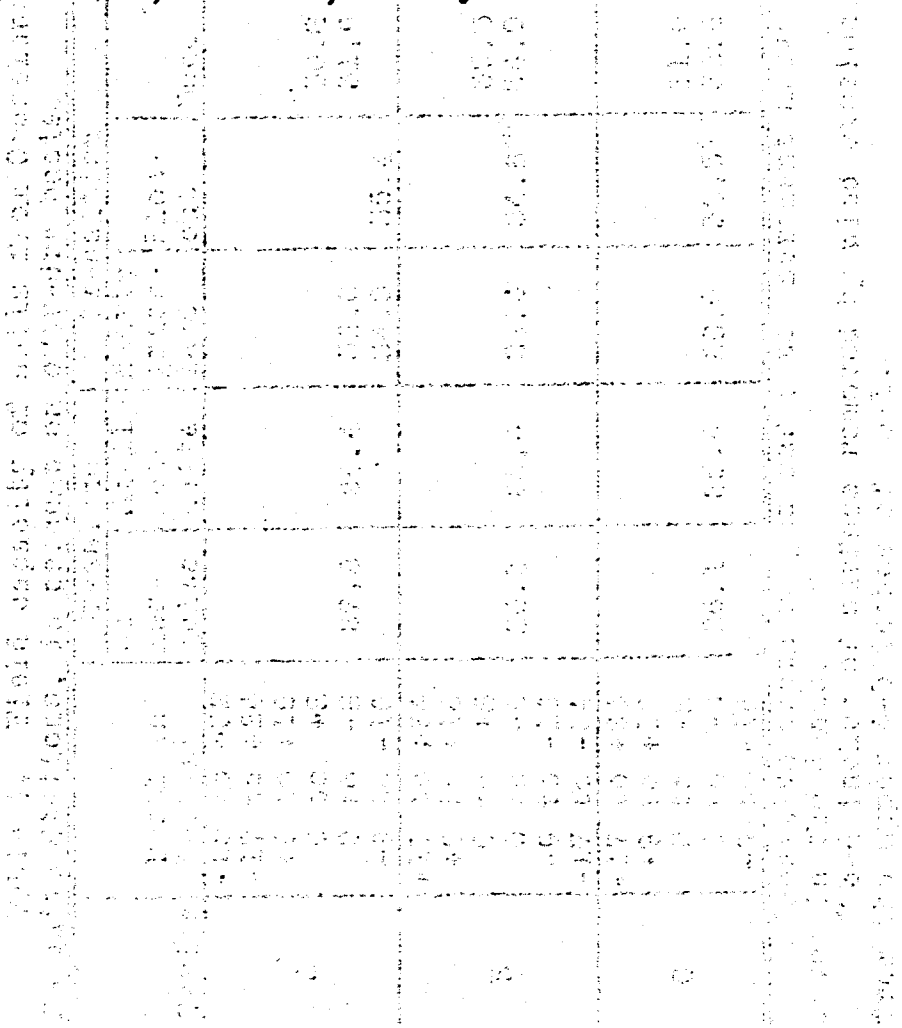

Table 4. Field capacity of soils from Grassland, Transition, and Mesquite Stations, in percent on over-dry basis.

Series	Depth in inches*	Grassland		Transition			Mesquite		
		No mesquite	Small mesquite	Nearby grassland	Blowout	Dune	Nearby grassland	Blowout	Dune
A	+25 to +32								30.2
	+17 to +24								31.6
	+9 to +16								33.2
	0 to +8					30.8			31.5
	0 to -8	27.8	26.4	32.0		31.9	27.2		31.6
	-9 to -16			34.0	35.4		34.8	27.7	
B	+17 to +24								29.5
	+9 to +16								33.7
	0 to +8					35.3			33.2
	0 to -8	26.3	25.4	29.6	34.8**	34.0	25.4		32.4
	-9 to -16						34.3		
	-17 to -24						37.4	30.7	
C	+17 to +24								29.0
	+9 to +16								30.9
	0 to +8					31.0			30.9
	0 to -8	26.1	25.4	28.0	32.5**	32.6	26.2		33.8
	-9 to -16						32.6	28.2	

*Positive depth ranges refer to increment above original surface level in the dunes.

**3-4 inches of surface removed by wind erosion. Samples were taken from the upper 4-5 inches of soil.

Table 5. Wilting coefficient of soils from Grassland, Transition, and Mesquite Stations, in percent on oven-dry basis.

Series	Depth in inches*	Grassland		Transition			Mesquite		
		No mesquite	Small mesquite	Nearby grassland	Blowout	Dune	Nearby grassland	Blowout	Dune
A	+25 to +32								3.0
	+17 to +24								3.2
	+9 to +16								3.1
	0 to +8					2.9			2.6
	0 to -8	3.0	2.8	3.6		2.9	2.6		3.2
	-9 to -16			4.3	4.6		4.2	3.0	
B	+17 to +24								3.2
	+9 to +16								3.3
	0 to +8					3.8			3.2
	0 to -8	3.0	2.6	3.0	4.4**	3.7	2.4		3.4
	-9 to -16						3.8		
	-17 to -24						4.5	4.0	
C	+17 to +24								3.2
	+9 to +16								2.7
	0 to +8					2.8			2.8
	0 to -8	3.4	3.1	2.6	4.4**	3.3	2.7		3.5
	-9 to -16						4.2	3.4	

*Positive depth ranges refer to increment above original surface level in the dunes.

**3-4 inches of surface removed by wind erosion. Samples were taken from the upper 4-5 inches of soil.

Table 6. pH values of 1:5 water suspensions of soils from Grassland, Transition, and Mesquite Stations.

Series	Depth in inches*	Grassland		Transition			Mesquite		
		No mesquite	Small mesquite	Nearby grassland	Blowout	Dune	Nearby grassland	Blowout	Dune
A	+25 to +32								7.85
	+17 to +24								7.85
	+9 to +16								7.75
	0 to +8					8.30			8.00
	0 to -8	7.65	7.85	8.35		8.05	7.85		8.05
	-9 to -16			8.55	8.20		8.50	8.00	
B	+17 to +24								8.70
	+9 to +16								8.25
	0 to +8					8.10			8.25
	0 to -8	8.65	7.95	8.60	8.60**	8.10	8.80		8.25
	-9 to -16						8.65		
	-17 to -24						8.55	8.55	
C	+17 to +24								8.35
	+9 to +16								8.60
	0 to +8					8.10			8.15
	0 to -8	8.60	8.30	7.95	7.65**	7.50	8.35		8.15
	-9 to -16						8.35	8.75	

*Positive depth ranges refer to increment above original surface level in the dunes.

**3-4 inches of surface removed by wind erosion. Samples were taken from the upper 4-5 inches of soil.

Table 7. Calcium content of soils from Grassland, Transition, and Mesquite Stations; 1:5 water extract; in parts per million on dry-soil basis

Series	Depth in inches*	Grassland		Transition			Mesquite		
		No mesquite	Small mesquite	Nearby grassland	Blowout	Dune	Nearby grassland	Blowout	Dune
A	+25 to +32								75.8
	+17 to +24								83.8
	+9 to +16								136.2
	0 to +8					128.7			158.9
	0 to -8	37.9	30.3	60.6		166.5	53.0		113.5
	-9 to -16			60.6	30.3		68.2	53.0	
B	+17 to +24								105.9
	+9 to +16								204.5
	0 to +8					106.0			174.2
	0 to -8	60.6	30.3	90.9	83.2**	75.8	106.0		204.5
	-9 to -16						83.3		
	-17 to -24						83.3	90.9	
C	+17 to +24								98.5
	+9 to +16								98.5
	0 to +8					60.6			159.0
	0 to -8	75.8	68.2	45.4	30.3**	121.2	53.0		143.9
	-9 to -16						83.3	106.0	

*Positive depth ranges refer to increment above original surface level in the dunes.

**3-4 inches of surface removed by wind erosion. Samples were taken from the upper 4-5 inches of soil.

Table 8. Magnesium content of soils from Grassland, Transition, and Mesquite Stations; 1:5 water extract; in parts per million on oven-dry basis.

Series	Depth in inches*	Grassland		Transition			Mesquite		
		No mesquite	Small mesquite	Nearby grassland	Blowout	Dune	Nearby grassland	Blowout	Dune
A	+25 to +32								.0
	+17 to +24								.0
	+9 to +16								7.6
	0 to +8					.0			.0
	0 to -8	3.8	.0	.0		3.8	.0		3.8
	-9 to -16			3.8	7.6		.0	.0	
B	+17 to +24								3.8
	+9 to +16								3.8
	0 to +8					.0			3.8
	0 to -8	.0	.0	.0	.0**	.0	.0		3.8
	-9 to -16						.0	.0	
	-17 to -24						7.6		
C	+17 to +24								3.8
	+9 to +16								3.8
	0 to +8					3.8			3.8
	0 to -8	3.8	.0	.0	.0**	15.1	3.8		3.8
	-9 to -16						3.8	.0	

*Positive depth ranges refer to increment above original surface level in the dunes.

**3-4 inches of surface removed by wind erosion. Samples were taken from the upper 4-5 inches of soil.

Table 9. Potassium content of soils from Grassland, Transition, and Mesquite Stations; 1:5 water extract; in parts per million on oven-dry basis.

Series	Depth in inches*	Grassland		Transition			Mesquite		
		No mesquite	Small mesquite	Nearby grassland	Blowout	Dune	Nearby grassland	Blowout	Dune
A	+25 to +32								11.1
	+17 to +24								19.2
	+9 to +16								50.1
	0 to +8					75.7			60.5
	0 to -8	3.5	9.6	3.0		65.6	2.0		52.0
	-9 to -16			.0	2.0		4.0	7.6	
B	+17 to +24								27.7
	+9 to +16								43.9
	0 to +8					88.3			12.1
	0 to -8	8.6	5.5	16.6	7.1**	64.1	8.1		26.2
	-9 to -16						6.6		
	-17 to -24						4.0	2.0	
C	+17 to +24								19.7
	+9 to +16								27.7
	0 to +8					67.1			57.5
	0 to -8	11.1	8.1	4.0	6.6**	155.9	15.1		27.7
	-9 to -16						15.6	7.6	

*Positive depth ranges refer to increment above original surface level in the dunes.

**3-4 inches of surface removed by wind erosion. Samples were taken from the upper 4-5 inches of soil.

Table 10. Sodium content of soils from Grassland, Transition, and Mesquite Stations; 1:5 water extract; in parts per million on oven-dry basis.

Series	Depth in inches*	Grassland		Transition			Mesquite		
		No mesquite	Small mesquite	Nearby grassland	Blowout	Dune	Nearby grassland	Blowout	Dune
A	+25 to +32								23.6
	+17 to +24								37.4
	+9 to +16								32.9
	0 to +8					9.9			66.7
	0 to -8	15.1	22.0	32.6		3.7	43.8		20.7
	-9 to -16			21.8	20.4		32.3	11.1	
B	+17 to +24								18.1
	+9 to +16								37.8
	0 to +8					9.5			52.1
	0 to -8	20.2	35.9	25.1	32.0**	22.7	32.7		7.7
	-9 to -16						30.8		
	-17 to -24						32.6	18.6	
C	+17 to +24								34.6
	+9 to +16								9.5
	0 to +8					37.4			.0
	0 to -8	42.1	44.3	27.2	21.6**	36.8	37.8		23.8
	-9 to -16						29.2	31.9	

*Positive depth ranges refer to increment above original surface level in the dunes.

**3-4 inches of surface removed by wind erosion. Samples were taken from the upper 4-5 inches of soil.

Table 11. Chloride content of soils from Grassland, Transition, and Mesquite Stations; 1:5 water extract; in parts per million on oven-dry basis.

Series	Depth in inches*	Grassland		Transition			Mesquite		
		No mesquite	Small mesquite	Nearby grassland	Blowout	Dune	Nearby grassland	Blowout	Dune
A	+25 to +32								25.2
	+17 to +24								50.4
	+9 to +16								90.8
	0 to +8					30.3			166.5
	0 to -8	20.2	10.1	15.1		65.6	15.1		80.7
	-9 to -16			10.1	10.1		15.1	15.1	
B	+17 to +24								20.2
	+9 to +16								90.8
	0 to +8					15.1			75.7
	0 to -8	15.1	15.1	10.1	15.1**	10.1	10.1		75.7
	-9 to -16						15.1		
	-17 to -24						25.2	10.1	
C	+17 to +24								15.1
	+9 to +16								40.4
	0 to +8					25.2			80.7
	0 to -8	15.1	5.0	25.2	20.2**	85.8	5.0		105.9
	-9 to -16						20.2	10.1	

*Positive depth ranges refer to increment above original surface level in the dunes.

**3-4 inches of surface removed by wind erosion. Samples were taken from the upper 4-5 inches of soil.

Table 12. Bicarbonate content of soils from Grassland, Transition, and Mesquite Stations; 1:5 water extract; in parts per million on oven-dry basis.

Series	Depth in inches*	Grassland		Transition			Mesquite		
		No mesquite	Small mesquite	Nearby grassland	Blowout	Dune	Nearby grassland	Blowout	Dune
A	+25 to +32								184.6
	+17 to +24								160.4
	+9 to +16								246.2
	0 to +8					339.0			264.3
	0 to -8	141.3	141.3	240.1		319.8	246.2		216.9
	-9 to -16			234.1	166.5		258.0	172.5	
B	+17 to +24								375.3
	+9 to +16								196.8
	0 to +8					400.6			184.6
	0 to -8	222.0	166.5	345.1	313.8**	351.1	400.6		222.0
	-9 to -16						307.7		
	-17 to -24						332.0	307.7	
C	+17 to +24								399.6
	+9 to +16								289.6
	0 to +8					313.8			240.1
	0 to -8	345.1	319.8	166.5	111.0**	277.5	289.6		216.0
	-9 to -16						307.7	394.5	

*Positive depth ranges refer to increment above original surface level in the dunes.

**3-4 inches of surface removed by wind erosion. Samples were taken from the upper 4-5 inches of soil.

Table 13. Nitrate content of soils from Grassland, Transition, and Mesquite Stations; 1:5 water extract; in parts per million on oven-dry basis.

Series	Depth in inches*	Grassland		Transition			Mesquite		
		No mesquite	Small mesquite	Nearby grassland	Blowout	Dune	Nearby grassland	Blowout	Dune
A	+25 to +32								82.4
	+17 to +24								135.5
	+9 to +16								227.2
	0 to +8					143.7			206.3
	0 to -8	2.4	5.3	8.0		205.8	7.1		146.5
	-9 to -16			8.1	1.8		13.6	2.4	
B	+17 to +24								21.6
	+9 to +16								461.6
	0 to +8					54.8			395.0
	0 to -8	1.8	2.1	4.8	6.9**	17.0	2.6		353.2
	-9 to -16						10.1		
	-17 to -24						7.7	2.5	
C	+17 to +24								13.3
	+9 to +16								26.3
	0 to +8					45.8			111.0
	0 to -8	4.8	6.9	5.0	11.3**	358.5	4.1		166.9
	-9 to -16						30.7	6.2	

*Positive depth ranges refer to increment above original surface level in the dunes.

**3-4 inches of surface removed by wind erosion. Samples were taken from the upper 4-5 inches of soil.

Table 14. Phosphate content of soils from Grassland, Transition, and Mesquite Stations; 1:5 water extract; in parts per million on oven-dry basis.

Series	Depth in inches*	Grassland		Transition			Mesquite		
		No mesquite	Small mesquite	Nearby grassland	Blowout	Dune	Nearby grassland	Blowout	Dune
A	+25 to +32								.6
	+17 to +24								.9
	+9 to +16								1.3
	0 to +8					1.8			1.0
	0 to -8	.8	.8	.6		1.4	.7		.8
	-9 to -16			.6	.9		.6	.6	
B	+17 to +24								.9
	+9 to +16								1.2
	0 to +8					4.0			1.2
	0 to -8	.6	.8	.8	1.3**	2.6	.8		1.1
	-9 to -16						.7		
	-17 to -24						.6	.5	
C	+17 to +24								1.2
	+9 to +16								.9
	0 to +8					2.3			1.6
	0 to -8	.9	.8	.9	1.4**	3.6	.7		.7
	-9 to -16						.7	.5	

*Positive depth ranges refer to increment above original surface level in the dunes.

**3-4 inches of surface removed by wind erosion. Samples were taken from the upper 4-5 inches of soil.

Table 15. Summary of chemical analysis of soils from Grassland, Transition, and Mesquite Stations; 1:5 water extract; in parts per million on oven-dry basis.

Location	Depth*	Ca	Mg	K	Na	Cl	HCO_3	NO_3	PO_4	Total by analysis	Total by conductivity
A Series											
Grassland											
No mesquite	0 to -8	37.9	3.8	3.5	15.1	20.2	141.3	2.4	.8	225.0	378
Small mesquite	0 to -8	30.3	.0	9.6	22.0	10.1	141.3	5.3	.8	219.4	222
Transition											
Nearby grassland	0 to -8	60.6	.0	3.0	32.6	15.1	240.1	8.0	.6	360.0	161
Nearby grassland	-9 to -16	60.6	3.8	.0	21.6	10.1	234.1	8.1	.6	339.1	222
Blowout	-9 to -16	30.3	7.6	2.0	20.4	10.1	166.5	1.8	.9	239.6	172
Dune	0 to +8	128.7	.0	75.7	9.9	30.3	339.0	143.7	1.8	729.1	555
Dune	0 to -8	166.5	3.8	65.6	3.7	65.6	319.8	205.8	1.4	832.2	767
Mesquite											
Nearby grassland	0 to -8	53.0	.0	2.0	43.8	15.1	246.2	7.1	.7	367.9	283
Nearby grassland	-9 to -16	68.2	.0	4.0	32.3	15.1	258.0	13.6	.6	391.8	247
Blowout	-9 to -16	53.0	.0	7.6	11.1	15.1	172.5	2.4	.6	262.3	242
Dune	+25 to +32	75.8	.0	11.1	23.6	25.2	184.6	82.4	.6	403.3	590
Dune	+17 to +24	83.8	.0	19.2	37.4	50.4	160.4	135.5	.9	487.6	863
Dune	+9 to +16	136.2	7.6	50.1	32.9	90.8	246.2	227.2	1.3	792.3	3451
Dune	0 to +8	158.9	.0	60.5	66.7	166.5	264.3	206.3	1.0	924.2	898
Dune	0 to -8	113.5	3.8	52.0	20.7	80.7	216.9	146.5	.8	734.9	666
B Series											
Grassland											
No mesquite	0 to -8	60.6	.0	8.6	20.2	15.1	222.0	1.8	.6	328.9	237
Small mesquite	0 to -8	30.3	.0	5.5	35.9	15.1	166.5	2.1	.8	256.2	545
Transition											
Nearby grassland	0 to -8	90.9	.0	16.6	25.1	10.1	345.1	4.8	.8	493.4	267
Blowout	0 to -8	83.2	.0	7.1	32.0	15.1	313.8	6.9	1.3	459.4	232
Dune	0 to +8	106.0	.0	88.3	9.5	15.1	400.6	54.8	4.0	678.3	494
Dune	0 to -8	75.8	.0	64.1	22.7	10.1	351.1	17.0	2.6	543.2	414

*Positive depth ranges refer to increment above original surface level in the dunes.

Table 15. (Continued) Summary of chemical analysis of soils from Grassland, Transition, and Mesquite Stations; 1:5 water extract; in parts per million on oven-dry basis.

Location	Depth*	Ca	Mg	K	Na	Cl	HCO_3	NO_3	PO_4	Total by analysis	Total by conductivity
B Series, continued											
Mesquite											
Nearby grassland	0 to -8	106.0	.0	8.1	32.7	10.1	400.6	2.6	.8	560.9	318
Nearby grassland	-9 to -16	83.3	.0	6.6	30.8	15.1	307.7	10.1	.7	454.3	277
Nearby grassland	-17 to -24	83.3	7.6	4.0	32.6	25.2	332.0	7.7	.6	493.0	348
Blowout	-17 to -24	90.9	.0	2.0	18.6	10.1	307.7	2.5	.5	432.3	303
Dune	+17 to +24	105.9	3.8	27.5	18.1	20.2	375.3	21.6	.9	573.5	409
Dune	+9 to +16	204.5	3.8	43.9	37.8	90.8	196.8	461.6	1.2	1040.4	984
Dune	0 to +8	174.2	3.8	12.1	52.1	75.7	184.6	395.0	1.2	898.7	918
Dune	0 to -8	204.5	3.8	26.2	7.7	75.7	122.0	353.2	1.1	892.5	969
C Series											
Grassland											
No mesquite	0 to -8	75.8	3.8	11.1	42.1	15.1	345.1	4.8	.9	508.7	262
Small mesquite	0 to -8	68.2	.0	8.1	44.3	5.0	319.8	6.9	.8	453.1	600
Transition											
Nearby grassland	0 to -8	45.4	.0	4.0	27.2	25.2	166.5	5.0	.9	276.1	111
Blowout	0 to -8	30.3	.0	6.6	21.6	20.2	111.0	11.3	1.4	202.4	131
Dune	0 to +8	60.6	3.8	67.1	37.4	25.2	313.8	45.8	2.3	556.0	383
Dune	0 to -8	121.2	15.1	155.9	36.8	85.8	277.5	358.5	3.6	1054.4	1070
Mesquite											
Nearby grassland	0 to -8	53.0	3.8	15.1	37.8	5.0	289.6	4.1	.7	409.1	383
Nearby grassland	-9 to -16	83.3	3.8	15.6	29.2	20.2	307.7	30.7	.7	491.2	313
Blowout	-9 to -16	106.0	.0	7.6	31.9	10.1	394.5	6.2	.5	556.7	232
Dune	+17 to +24	98.5	3.8	19.7	34.6	15.1	399.6	13.3	1.2	585.8	671
Dune	+9 to +16	98.5	3.8	27.7	9.5	40.4	289.6	26.3	.9	496.7	399
Dune	0 to +8	159.0	3.8	57.5	.0	80.7	240.1	111.0	1.6	653.7	827
Dune	0 to -8	143.9	3.8	27.7	23.8	105.9	216.0	166.9	.7	688.7	681

*Positive depth ranges refer to increment above original surface level in the dunes.

Table 16. Nitrification capacity of soil from Grassland, Transition, and Mesquite Stations as indicated by nitrification of ammonia applied as ammonia sulfate in 23-day period of incubation; 1:5 water extract; in parts per million on oven-dry basis.

Series	Depth in inches*	Grassland		Transition			Mesquite		
		No mesquite	Small mesquite	Nearby grassland	Blowout	Dune	Nearby grassland	Blowout	Dune
A	+25 to +32								190.0
	+17 to +24								187.4
	+9 to +16								216.8
	0 to +8					78.3			156.9
	0 to -8	65.7	70.4	10.2		228.1	53.4		70.4
	-9 to -16			60.0	68.8		16.7	93.5	
B	+17 to +24								886.5
	+9 to +16								809.7
	0 to +8					510.2			316.3
	0 to -8	35.5	98.8	86.0	7.7**	406.8	108.4		312.7
	-9 to -16						58.0		
	-17 to -24						50.3	11.6	
C	+17 to +24								471.0
	+9 to +16								175.5
	0 to +8					347.7			242.2
	0 to -8	620.8	76.3	95.9	51.8**	75.4	69.1		95.4
	-9 to -16						4.6	36.7	

*Positive depth ranges refer to increment above original surface level in the dunes.

**3-4 inches of surface removed by wind erosion. Samples were taken from the upper 4-5 inches of soil.

Table 17. Average weight of tops and roots and top/root ratio of Rothrock grama plants grown in surface soil from Grassland and Mesquite Stations, in grams.

Series	Grassland		Mesquite		
	No mesquite	Small mesquite	Nearby grassland	Blowout	Dune
			Tops		
A	.13	.18	.18	.09	.35
B	.12	.15	.12	.10	.19
C	.13	.19	.13	.015	.26
			Roots		
A	.21	.22	.24	.13	.20
B	.20	.21	.15	.19	.07
C	.23	.24	.15	.037	.28
			Top/root ratio		
A	.62	.82	.75	.69	1.75
B	.60	.71	.80	.53	2.72
C	.57	.79	.87	.41	.93

Table 18. Average weight of six-weeks grama plants grown in surface soil from Grassland and Mesquite Stations and in Mesquite-blowout soils amended with nitrogen, phosphorus, and potassium, in grams.

Series	Grassland		Mesquite					
	No mesquite	Small mesquite	Nearby grassland	Blowout	Blowout - nitrogen	Blowout - phosphorus	Blowout - potassium	Dune
A	.72	.43	1.02	.29	.30	.47	*	.93
B	.44	.45	.59	.068	.072	.21	.13	.44
C	.46	.74	.64	.018	.022	.045	.008	.94

*Pot test with amendment was not made because of lack of soil.

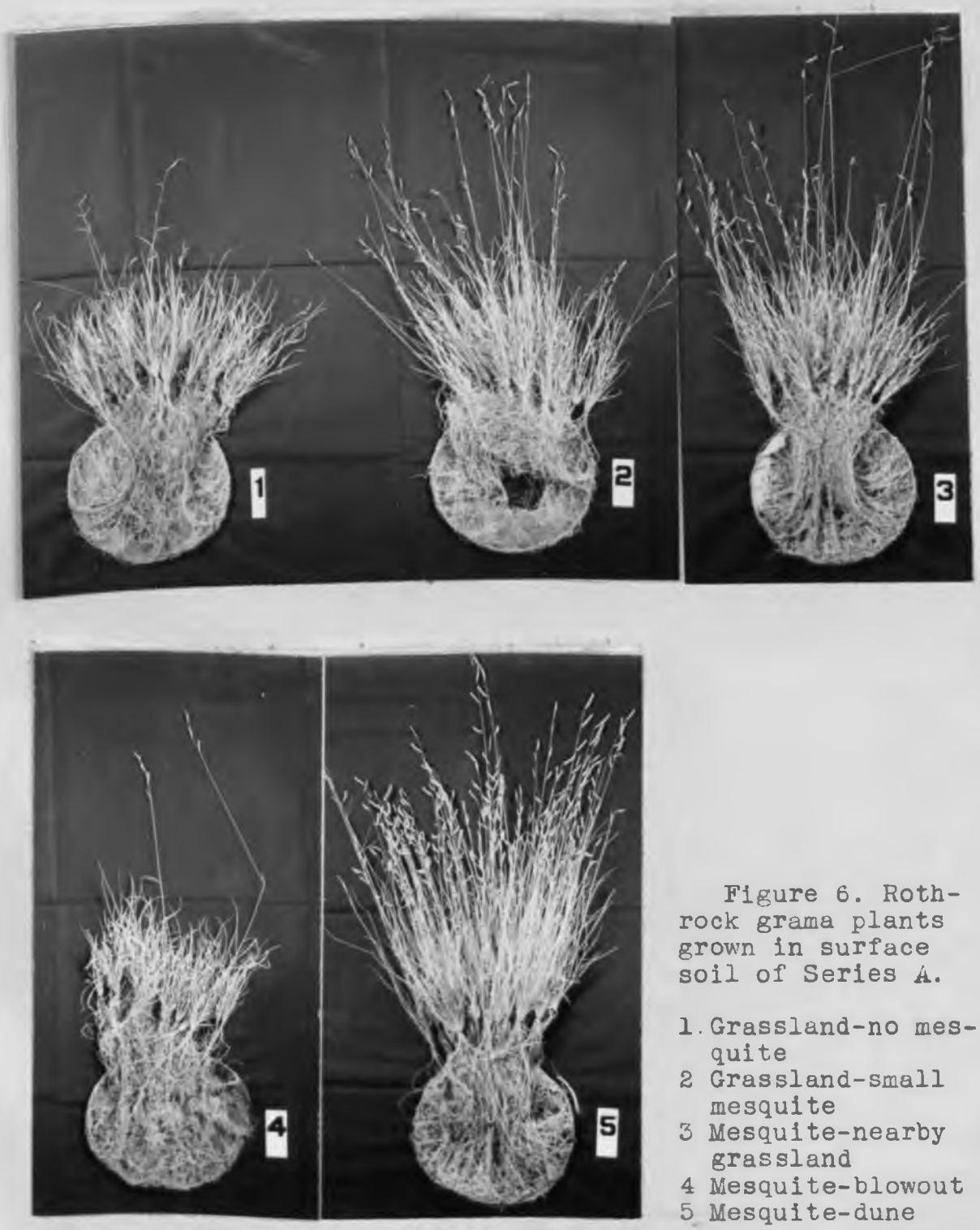

Figure 6. Rothrock grama plants grown in surface soil of Series A.

1. Grassland-no mesquite
2 Grassland-small mesquite
3 Mesquite-nearby grassland
4 Mesquite-blowout
5 Mesquite-dune

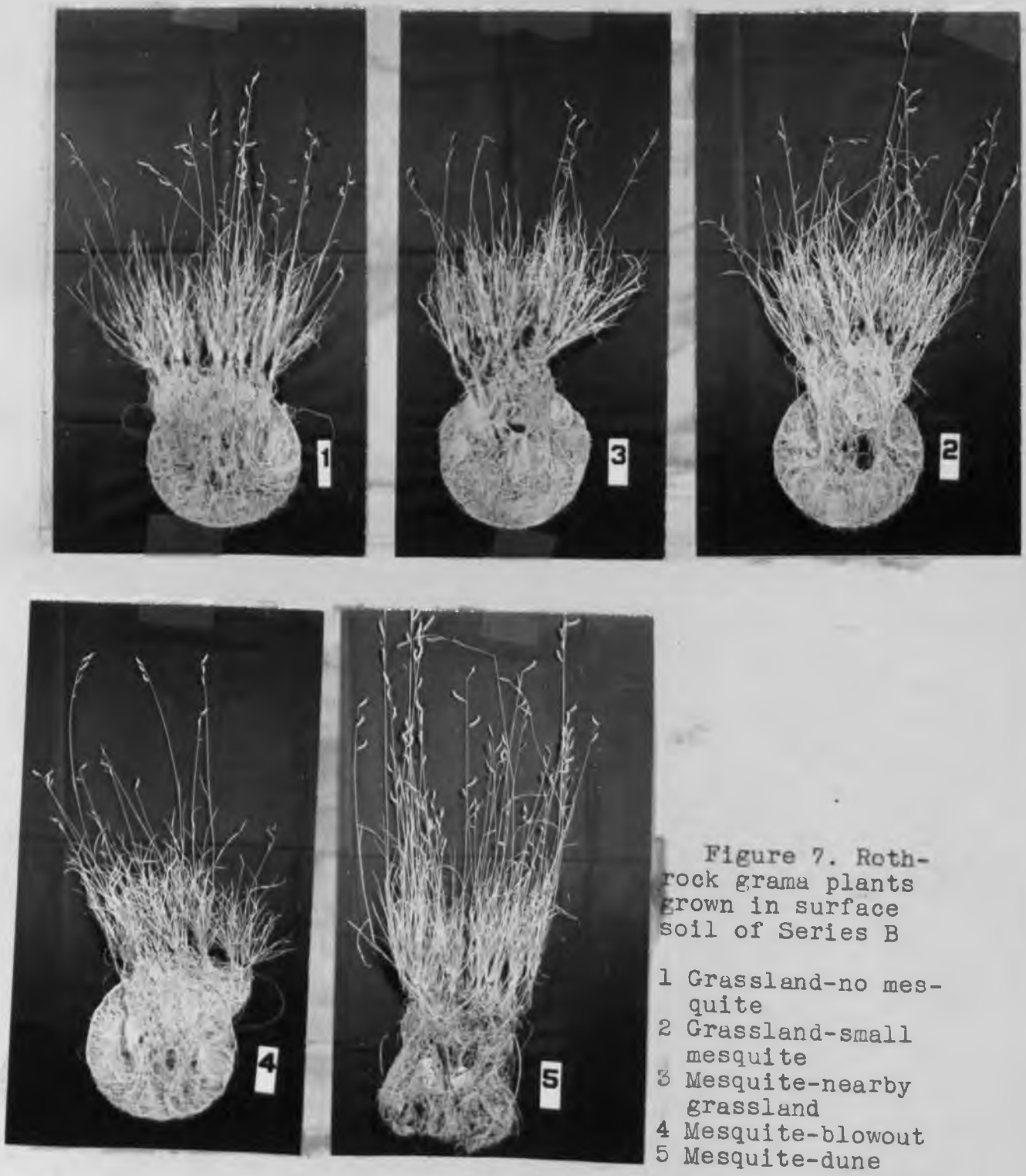

Figure 7. Rothrock grama plants grown in surface soil of Series B

1 Grassland-no mesquite
2 Grassland-small mesquite
3 Mesquite-nearby grassland
4 Mesquite-blowout
5 Mesquite-dune

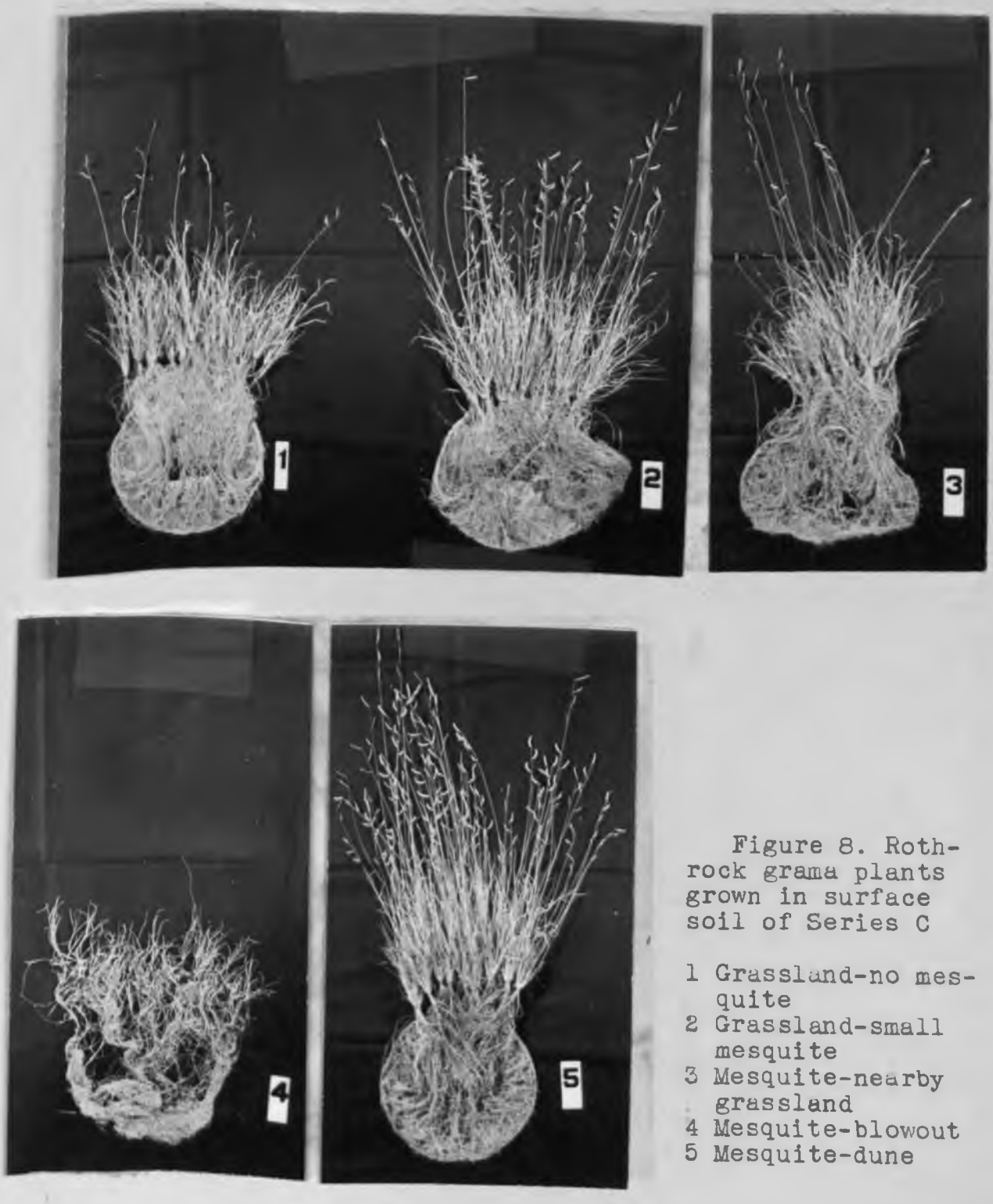

Figure 8. Rothrock grama plants grown in surface soil of Series C

1 Grassland-no mesquite
2 Grassland-small mesquite
3 Mesquite-nearby grassland
4 Mesquite-blowout
5 Mesquite-dune

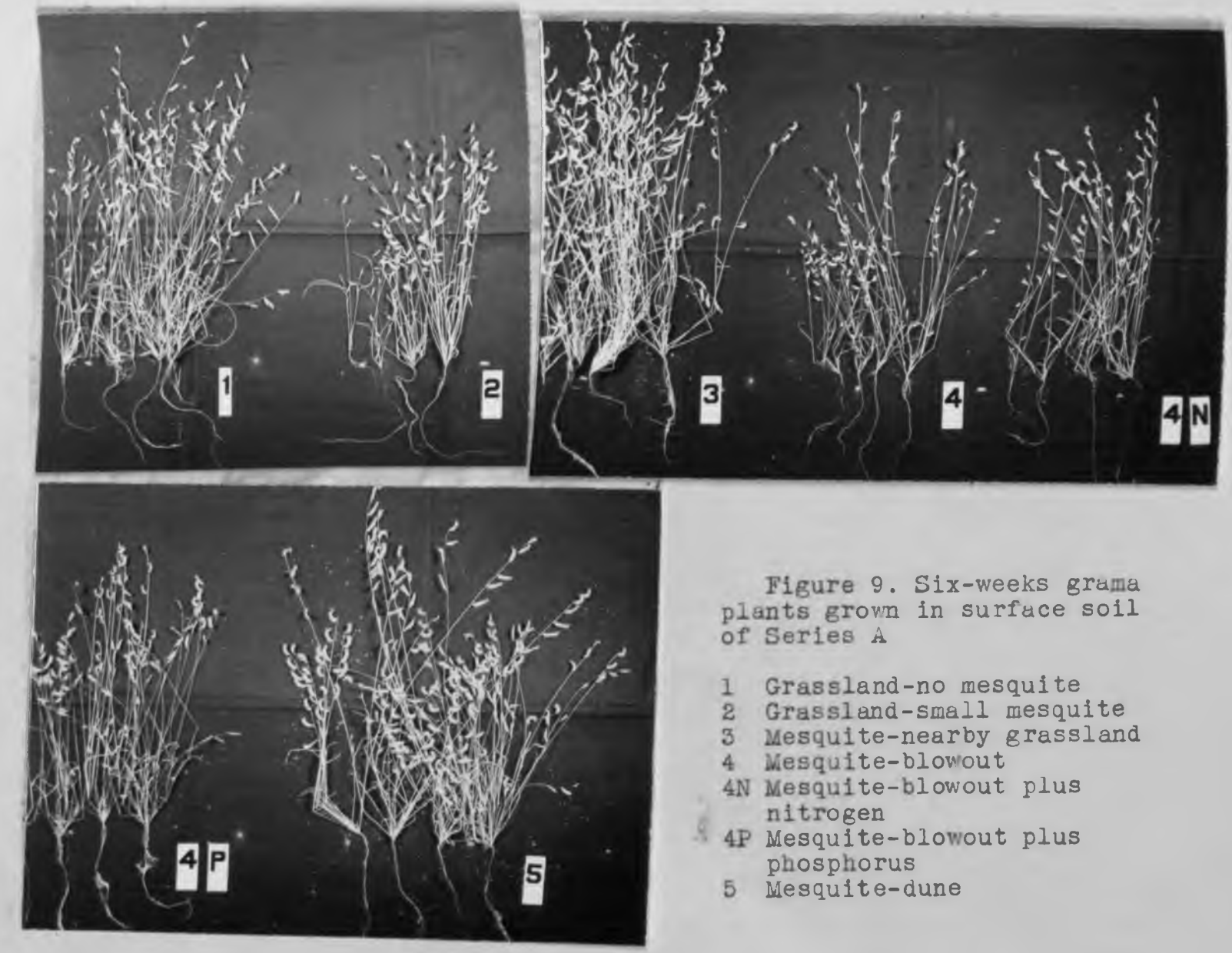

Figure 9. Six-weeks grama plants grown in surface soil of Series A

1 Grassland-no mesquite
2 Grassland-small mesquite
3 Mesquite-nearby grassland
4 Mesquite-blowout
4N Mesquite-blowout plus nitrogen
4P Mesquite-blowout plus phosphorus
5 Mesquite-dune

Figure 10. Six-weeks grama plants grown in surface soil of Series B

1 Grassland-no mesquite
2 Grassland-small mesquite
3 Mesquite-nearby grassland
4 Mesquite-blowout
4N Mesquite-blowout plus nitrogen
4P Mesquite-blowout plus phosphorus
4K Mesquite-blowout plus potassium
5 Mesquite-dune

Figure 11. Six-weeks grama plants grown in surface soil of Series C

1 Grassland-no mesquite
2 Grassland-small mesquite
3 Mesquite-nearby grassland
4 Mesquite-blowout
4N Mesquite-blowout plus nitrogen
4P Mesquite-blowout plus phosphorus
4K Mesquite-blowout plus potassium
5 Mesquite-dune

DISCUSSION

Physical Analysis

Physical analysis of the soils has not disclosed any significant differences with respect to water supplying capacity between grassland and blowout soil. The slight increase in field capacity of the soils of the blowouts and dunes over the grassland soils may be explained by reference to Veatch's profile description (see page 8). The uppermost layer of the Jornada Red Loamy Sand of the grassland consists of loose incoherent sand, 2 to 6 or 8 inches in depth and beneath this lies a layer of compact loamy sand. The layer containing the finer-textured material, giving rise to the loamy nature of the soil, would be expected to exhibit a higher field capacity than the coarser-textured surface soil. The data for the A Series, Transition-grassland substantiate this expectation. The blowout soils of the Windblown Phase, having lost much of this coarser upper layer by wind erosion, exhibit the same high capacities as the sub-surface soils of the nearby grassland because a certain amount of the coarse surface sand has remained in the blowouts during the process of erosion. The dunes owe their greater field capacity, by comparison with the grassland soils, to the fact that they are composed largely of the fine soil fraction which eroded from the blowouts. Another factor which operates to raise the field capacity of the dune soils is the presence of much plant

debris throughout the dune soils.

The increases in wilting coefficient from grassland to blowout and dune soils probably arise in the same way as the field capacity increases. Parallel trends are to be expected since both constants are expressions of the same phenomenon at different intensity levels. When both field capacity and wilting coefficient values are taken into consideration, the grassland and blowout soils are seen to be similar as regards the property of water supply to plants. The soils of the dunes have a slightly greater capacity for supplying water to plants than the soils of grassland and blowouts owing to the greater range between field capacity and wilting coefficient of the dune soils.

Chemical Analysis

Certain of the chemical analyses have revealed significant differences between the stable Jornada Red Loamy Sand and the Windblown Phase of this soil, with marked differences between the dune and blowout soils of the Windblown Phase. Before proceeding with the discussion of the chemical analysis, it will be well to point out that the soil of the dunes contains much more plant debris than either the interdunal or grassland soil. Organic matter was not determined quantitatively but the high organic matter content of the dune soil is indicated by the soluble organic matter which colored the extracts of the dune soil. The

greater microbiological activity exhibited by the dune soil also reflects a greater content of organic matter.

No consistent differences in pH were found between the soils of the grassland and the mesquite community. The soil of both communities varies irregularly from mildly alkaline to alkaline.

Calcium content of grassland and blowout soils was found to vary irregularly. The generally greater amounts of calcium found in the dunes appear to be related to their higher nitrate content, the calcium being brought into solution by the nitric acid produced in the nitrification process. Russell (15) points out this effect of nitrification on the solubility of calcium. The much greater amount of plant debris present in the dunes by comparison with that present in the soils of the grassland and the blowouts, resulting in greater production of carbonic acid, may account for part of the observed differences in calcium content. Magnesium also exhibits higher values in the dune soil than in the grassland and blowout soils. Here again higher content of nitrate and plant litter appear to account for the difference.

Potassium values show irregular variation among the soils of the grassland and blowouts as did the calcium and magnesium values. At the Transition Stations in the A and B Series and the Mesquite Stations in the B and C Series, the grassland next the blowouts shows higher potassium

values than the blowouts; while at the Transition Station in the C Series and the Mesquite Station in the A Series, the blowouts have a higher potassium content than the adjacent grassland. In the dunes, however, considerably higher potassium values were uniformly found. As in the case of calcium, the higher potassium concentration may be related in part to the greater magnitude of nitrate formation in the dunes and in part to carbonic acid produced by decay of the plant residues in the dunes. McGeorge (10) has shown that the solubility of potassium is considerably increased in carbon dioxide-saturated water by comparison with carbon dioxide-free water.

Another interesting condition is brought out by the potassium analysis. The soil of the smaller and younger dunes in the transition between grassland and mesquite in each series consistently exhibits higher potassium content than does that of the larger and older dunes of the fully developed mesquite community. This difference appears to be related to difference in intensity of rodent activities between the younger and older dunes. Nearly every one of the dunes developing in the grassland is heavily infested with kangaroo rats, Dipodomys spectabilis, D. merriami, and D. ordii, while the older dunes are much less frequently occupied. The good supply of food and nest materials near the younger dunes accounts for the higher frequency of occupation of the dunes by the rodents. Long occupation of

these growing dunes by rodents results in the enrichment of the soil by incorporation of quantities of nest materials, food stores, and feces. This organic matter not only enriches the soil because of the nutrients contained in it but brings about increased solubility of plant nutrients native to the soil. This interpretation of the high potassium content of the Transition dunes is in close agreement with the work of Green and Reynard (5) who found that the soils of kangaroo rat burrows on the Santa Rita Experimental Range in southern Arizona contained much higher concentrations of calcium, magnesium, bicarbonates, nitrates, and total soluble salts than the soil a few feet distant from the burrows. They attribute the higher nitrate content of the burrows to the nitrification of the organic nitrogen added to the soil of the burrows as nest material, food stores, and feces, and the higher bicarbonate content to the carbon dioxide produced by respiration of the rodents. Calcium and magnesium increases came about through solution in the nitric and carbonic acids. Potassium was not determined in the study but conditions which were revealed were such as would make for accumulation and increased solubility of potassium as well as of calcium and magnesium.

The burrowing and soil-scattering activities of rodents around the Transition Station dunes may account for the higher potassium concentration in the C Series, Transition-blowout soil than in the soil of the adjacent grassland.

It is of interest to note that the potassium content of the soil of the Grassland Stations from near the small mesquite plants is but little lower in two cases and higher in the third than that of the same stations where no mesquite grew. Sodium, chloride, and bicarbonate concentrations do not exhibit consistent differences between grassland and blowout soils. The generally slightly higher concentration of these ions in the dune soils correlate with the greater amount of plant residues and nitrates in the dune soils.

The nitrate analysis has revealed irregular nitrate content of the grassland and blowout soils and uniformly high concentrations in the dunes. These high concentrations in the dune soil are well related to the accumulation of plant residues in the dunes and in the case of the Transition dunes are probably influenced by the accumulation of organic matter of animal origin. Since the soil of the barren blowouts is so low in plant residues and thus presents conditions unfavorable for nitrification, it seems unlikely that the higher concentrations in certain of the blowouts has its origin in bacterial activity. It appears reasonable to relate the high nitrate content of the B and C Series, Transition-blowouts to the much higher concentration in the adjacent dunes and to the earth-scattering activities of the rodents inhabiting the dunes. In the C Series, Mesquite-blowout soil the high nitrate content seems

to be a residual effect of high nitrate content of the 9-16 inch layer of soil as is shown by the nitrate content of the corresponding layer in the adjacent grassland. A definite decrease in nitrate concentration in the blowout soil with loss of the vegetation cover is indicated despite the similar nitrate content of the blowout soil and the surface soil of the grassland. The higher nitrate content of the Grassland Station soil next the small mesquite plants by comparison with the soil of these stations where no mesquite is present is of interest. The larger nitrate concentrations, and the fact that the mesquite is a number of Leguminosae suggest that symbiotic nitrogen-fixing bacteria may be responsible for the increase. However, studies being conducted by the Arizona Agricultural Experiment Station* have not revealed the presence of symbiotic nitrogen-fixers on the roots of mesquite plants. Additional soil nitrogen in the vicinity of mesquite plants may have been derived from decay of mesquite leaf and fruit litter.

Results of the nitrification study have shown an irregular variability from place to place in grassland and blowout soils, but with the blowout soils generally exhibiting lower values. Nitrifying capacity has not been found to parallel nitrate content closely except in the dunes

*Information communicated verbally by Dr. W. P. Martin, Assistant Soil Microbiologist, Arizona Agricultural Experiment Station.

where high nitrate content and high nitrification both obtain. Russell (15) indicates that general fertility conditions of soil are reflected by its nitrifying capacity as well as conditions with regard to nitrate supply. Nitrification capacity used as an index of the general fertility thus would indicate lower productivity in the blowouts than in the grassland soils. Lower nitrification capacity of the blowout soil in the B and C Series Transition Stations lends support to the view that the good condition of these blowouts as regards potassium, nitrate, and phosphorus content is not inherent in these blowouts but is attributable to the burrowing and earth-scattering activities of rodents about the dunes, where these nutrients occur in higher concentrations.

Phosphates were found to vary more consistently between grassland, blowout, and dune soils than any of the other ions. The Mesquite Station blowout soil has shown the lowest phosphate concentrations, the grassland soils intermediate concentrations, and the dune soils at the Mesquite Stations and the dune and blowout soils at the Transition Stations the greatest concentrations. As has been suggested with respect to potassium and nitrates, the greater phosphorus concentrations in the blowouts of the Transition Stations may well be a result of relatively high phosphate concentrations in the surface layer of the nearby dunes. The high phosphate concentration of these dunes may be

built up under the influence of intensive rodent activity in the dunes. The lower intensity of rodent occupation of the more mature dunes is reflected in lower phosphate concentrations than in the younger dunes. The blowouts of the Mesquite Station do not receive phosphates from the dunes and consequently exhibit lower phosphate content than the surface soils of the nearby grassland. Their phosphate concentrations are more nearly comparable to the phosphate concentrations of the sub-surface grassland soil nearby. The greater phosphate concentrations in the dunes may be explained by the presence of plant residues and the non-calcareous nature of the dune soil, which has been shown by field tests with dilute hydrochloric acid. This view is in accord with the work of Rhoades (14) who found that in non-calcareous soils the addition of crop residues resulted in increased soluble phosphates; while in calcareous soils crop residues failed to bring about an increase in soluble phosphates. He attributed the difference, not to increased solubility of the native soil phosphorus in the non-calcareous soil, but rather to lower reversion of phosphate derived from the crop residues in the non-calcareous soils as contrasted with high reversion in the calcareous soils. McGeorge and Brazeale (9), however, found that saturating water suspensions of soils with carbon dioxide increased the solubility of native phosphates even though calcium solubility was increased at the same time. This latter

work may be taken to indicate that higher phosphate concentrations in the dune soils may be due to solution of native soil phosphates as well as to phosphates derived from the plant residues. No difference in phosphate content of soils at the Grassland Stations was noted with respect to position of sample to mesquite plants.

Pot Tests

The results of pot tests correlate closely with the analytical results in most cases. Yield and development of plants were poorest in the blowout soil, intermediate in the grassland soil, and best in the dune soil. Low yields and development in the blowout soil are in general accord with the work of Sinclair and Sampson (19) who found that development and production of plants were better in the A horizon than in the B horizon, and slightly better in the B horizon than in the C horizon. In the present study, however, better yields and development were made in the soil of the B Series blowout, which was more deeply eroded, than in the soil of the A and C Series blowouts, which were not so deeply eroded.

The yields of Rothrock grama in the Grassland Station soil from near the small mesquite plants has been found to be greater than the yields from the Grassland Station soil away from the mesquite plants. These yield data reflect the findings with regard to the concentrations of potassium, phosphates, and particularly nitrates, since nitrate concentrations were found to be somewhat greater in the soil near

the small mesquite plants. Top/root ratios of the Rothrock grama plants also reflect the analytical results. Miller (12) in summarizing the relationship of plant nutrients to top/root ratio, states that top/root ratios are greater in fertile soils than in infertile soils and that, as a rule, the effect of nitrogen is to increase top/root ratio, while phosphorus decreases the ratio. In this study the highest ratios are attained in the dune soil, while the lowest ratios occur in the blowout soil. The grassland soils exhibit intermediate ratios. Certain of the wider irregularities in top/root ratio appear to be explained by the results of chemical analysis. The lowest ratio attained in the dune soil is in the C Series where the lowest nitrate content and the highest phosphate content (in dune soils) occur in combination. The comparatively low ratio attained in the C Series Grassland Station soil not near a mesquite plant may be in part a result of the slightly higher phosphate concentration of that soil.

The yields of the six-weeks grama plants manifest similar relationships between soils to those of the Rothrock grama plants. The growth of the annuals was less uniform among the plants in a single pot and among the pots containing soil from the same stations in the different series than was the case with the perennials. The yields in both dune and blowout soils were lower by comparison with the yields in the grassland soils than noted for the perennials.

Responses to the amendment treatments as measured by increased yield by comparison with the unamended blowout soil were uniformly high for the phosphate amendment, uniformly low for the nitrate amendment, high in the one case of potassium amendment and none in the other potassium amendment. These responses relate well to the amounts of phosphate, nitrate, and potassium found by analysis. The blowout soil of the Mesquite Stations exhibit uniformly low phosphate values by comparison with the other soils. Phosphate amendment increased the yields 62, 245, and 150 percent in the A, B, and C Series, respectively. Nitrate concentrations in the Mesquite Station blowout soils, although generally lower than the concentrations in the grassland soils, are equal or higher than grassland soils which have shown comparatively good yields. Increase in yield under the nitrate amendments was 3.5, 5.9, and 22 percent, respectively, in the A, B, and C Series blowout soil. The potassium amendment of the B Series blowout soil, in which potassium concentration is low, increased the yield 91 erecent. In the C Series blowout soil, where potassium concentrations were found to compare favorably with the potassium concentrations in the other soils, potassium amendment produced no increased yield.

CONCLUSIONS

The study has brought out the following points with regard to the soil conditions attending the invasion of the desert grassland community on the Jornada Red Loamy Sand by mesquite:

1. During the period immediately after the establishment of mesquite plants in the grassland before dunes begin to form over the plants and barren blowouts develop around them, no deterioration in soil conditions takes place as a result of the invasion.

2. Under intermediate conditions of the transition from grassland to the mesquite community, when dunes have started to form over the mesquite plants and barren blowouts have begun to develop around them, the soil of the dunes is more fertile than that of the surrounding grassland, being enriched by organic residues of plant and animal origin added to the dune soil by rodents. The blowout soil in this transitory stage is inherently less fertile than the grassland soil as indicated by paucity of plant residues and reduced microbiological activity, but it may be enriched by the earth-scattering activities of rodents occupying the dunes so that it may be equal to or greater in fertility than the soil of the grassland. No deterioration of the soil with regard to water holding or supplying capacity attends the formation of the blowout; water retention and

supplying power of the dune soil is greater than that of the grassland.

3. With the complete conversion of the grassland to the mesquite community, when mesquite fully dominates the site and grasses are almost entirely absent, the soil in the blowout is less fertile than that of the surrounding grassland, having decreased in soluble potassium, nitrates, and soluble phosphates. The dune soil of the fully-developed mesquite community is more fertile than the soil of the nearby grassland. The water retention and supplying capacities of blowout and dune soil is equal to or better than that of the grassland.

4. The deterioration of the soil of the blowout in the fully developed mesquite community is such as to severely limit the growth of plants in this soil.

SUMMARY

1. A study has been made of the soil conditions of the Jornada Red Loamy Sand on the Jornada Experimental Range in Dona Ana County, New Mexico as they are affected by the degree of invasion by mesquite, Prosopis glandulosa.

2. The study has consisted of physical, chemical, and microbiological analysis of the Jornada Red Loamy Sand, of the Windblown Phase of this soil on which mesquite, Prosopis glandulosa, has replaced the desert

grassland characteristic of the stable phase, and of soil representing transition conditions between these two. In addition, pot tests were made of the soil from the stable Jornada Red Loamy Sand and from the Windblown Phase.

3. Physical analysis did not reveal any significant change in soil conditions with regard to water holding and water supplying capacity of the soil accompanying the invasion by mesquite.

4. Chemical analysis revealed no reduction in fertility of the soil around the mesquite plant in the early stage of the invasion.

5. The developing dunes characteristic of the intermediate stages in the invasion exhibit higher concentrations of potassium, nitrate, and phosphate than the surrounding grassland.

6. The blowouts around these dunes may exhibit higher concentration of potassium, nitrate, and phosphorus than the surrounding grassland. These higher concentrations, when they occur, are believed to be a result of the scattering of the fertile soil from the transition stage dunes by the relatively heavy rodent population.

7. The dunes of the fully developed mesquite community, in which the grasses of the desert grassland are almost entirely lacking, are higher in potassium, nitrate, and phosphate, while the blowouts surrounding these dunes are lower in these nutrients than the adjacent grassland.

8. Nitrification capacity was found to be generally lower in the blowout soil than in the grassland soil and much lower in the blowout soil than in the dune soil.

9. Pot tests of the soils of the grassland and the fully developed mesquite community showed lowest yields in the blowout soil, intermediate yields in the grassland soil, and highest yields in the dune soil.

10. Phosphate amendment of the blowout soil gave greatest response in yield; potassium amendment gave response in soil which was lower in potassium than the grassland soil; and no response in soil as high in potassium as the grassland soil. No response was made to nitrate amendment.

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