5-1956

Ecology of Plant Distribution on the Salt-Deserts of Utah

Dillard H. Gates

Utah State University

ECOLOGY OF PLANT DISTRIBUTION

ON THE SALT-DESERTS OF UTAH

by

Dillard H. Gates

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

Doctor of Philosophy

in

Range Management

UTAH STATE AGRICULTURAL COLLEGE
Logan, Utah

1956

ACKNOWLEDGEMENTS

I wish to express my appreciation to Professor L. A. Stoddart and Professor C. Wayne Cook for their helpful suggestions and advice during this study and for their assistance in the preparation of this manuscript. Appreciation is also expressed to Mr. J. P. Thorne of the Soil Conservation Service laboratory for the soil analyses, to Mr. Lynn Olsen of the U. S. Bureau of Reclamation for use of the soil testing equipment, and to the U. S. Bureau of Land Management for financial aid as part of the Experiment Station Project 411.

CONTENTS

LIST OF TABLES

LIST OF APPENDIX TABLES

LIST OF APPENDIX TABLES (cont.)

Table | Page

LIST OF FIGURES

INTRODUCTION

The reciprocal effects of vegetation and soils have long been a subject of speculation and conjecture. In the management of any natural land area the problem of interpreting vegetational expression is especially important. The effects of native vegetation on soils and the effects of the soil on the vegetation have been studied and observed for many years. The arid-desert range lands have been studied least and as a result are not well understood.

As human populations increase there will be additional need for agricultural production, and these lands may be put to higher use, perhaps even to irrigated crop production. Basic to increasing the productivity of these lands is an understanding of the vegetation they are now supporting, what they supported prior to their use by domestic livestock, and why the present vegetation grows to the exclusion of other vegetation types.

The areas under study were confined to the shadscale and sagebrush-grass zones of Utah (7). In these zones the desert shrub types form the matrix of climax vegetation. Embedded in this matrix are what appears to be edaphically controlled climax communities.

Grazing in the past 60 to 70 years is believed responsible for considerable change in floristic cover on the salt-desert. Some perennial herbaceous species belonging to the climax have decreased or over extensive areas perhaps disappeared. Some of the more desirable shrubs also have been reduced by grazing. In many cases annual herbs have become established in vacated areas. The result of these changes in floristic composition is a less desirable forage and consequently a decline in grazing capacity.

The invasion of halogeton (Halogeton glomeratus) on abused range lands of the intermountain west has done much to bring the retrogradation of these ranges to public attention. Hundreds of thousands of dollars have already been spent for study and control of this plant. Money is still being appropriated for these purposes.

Native vegetation in a vigorous state of productivity apparently controls local invasion or suppresses extensive occupation by halogeton. Most attempts at seeding arid salt-desert ranges have been unsuccessful, therefore, a knowledge of vegetation composition obtainable under good management is of primary importance in land administration. Most problems of range deterioration must be answered through natural rehabilitation and wise use of natural forage species.

Classification of these range lands is an important function of the administering agencies. Proper carrying capacities and management practices should be based on correct classification of the lands. In order to appraise present condition of these range lands the normal condition or climax must be understood. The Bureau of Land Management which controls most of this salt-desert land must classify it as to whether it is potentially arable or not. The question arises as to whether vegetation now present on these salt-desert ranges is an adequate index to their capabilities.

Plant indicators have been used to a limited extent for classifying areas for cultivated crop production and for grazing. The role of ecotypic variation within the plant species has been largely overlooked in classifying salt-desert lands. Essential to use of plant indicators is knowledge of whether these dominant species require some particular element or condition found in the soil or whether they are present merely because they can tolerate these conditions. This knowledge is vital to an understanding of the distribution of the flora and to the successful management of the salt-desert ranges.

This study was initiated to obtain information contributing to a better understanding of why some of the desert plants grow where they do, and what role soil, water, and minerals play in plant distribution. Such information should be a useful tool in the hands of persons attempting to classify these lands properly.

REVIEW OF LITERATURE

The plant indicator concept is of long standing. Sampson (42) stated that the plant indicator concept is based on a cause and effect relationship where the effect is taken as a sign of the cause. All plants are a measure of their environment. Any plant species may, to some extent, indicate the nature of its environment; yet only a few key species of a given locality are as a rule, sufficiently restricted by growth conditions to be helpful.

Shantz (43) stated that as a result of rainfall on the land surface of the earth, a plant cover has developed in physiological and ecological balance with the climatic conditions and substratum. He further noted that plant communities are often closely correlated with the developed soil and often quite independent of the parent material from which the soil was originally formed. He also indicated that the great plant communities are relatively independent of such factors as physical composition of the soil, while the smaller or minor communities are often directly affected by such factors.

Mason (36) pointed out that plant distribution is primarily controlled by the distribution of climatic factors. He further emphasized that plant distribution is secondarily controlled by the distribution of edaphic factors. He also recognized that the functions governing the existance and successful reprodution of plant species are limited by definite ranges of intensity of particular climatic, edaphic, and biotic factors. He further observed that in the life history of the organism there are times when it is in some critical phase of its development which has a narrow tolerance range for a particular factor in the environment. The narrower the range of tolerance, the more critical the factor becomes.

Mason (37) concluded that environment determines the pattern of distribution of all plant species. Environment permits the functioning of only those individuals whose tolerances have been preadapted to the special conditions of that environment. Mason also stated that of the various categories of environmental factors, the conditions of any factor or combination of factors may serve to restrict the range of some species of plants. He concluded that the edaphic factor is most likely to occur in sharply defined patterns and often in small areas.

According to Mason (38), functioning of plants is conditioned by the factors of the environment as they operate to control physiological processes. He further stated that the interbreeding population, through physiological functioning of individuals and the mechanism of gene exchange, sets up a self-perpetuating dynamic system so that functioning individuals continually are being produced as old ones die. Out of the mass of preadapted seed, the environment permits the survival of only those which are capable of carrying on all of their vital functions under the conditions prevailing in that environment.

Gleason (25) pointed out that the ordinary process of migration brings the reproductive bodies of a single plant or a species of plant into many places and also the reproductive bodies of many plant species into the same place. Microclimate was believed responsible for determining which may live, depending on the physiological demands of each species.

Billings (10) defines the environment of a plant as the sum of all external forces and substances affecting the growth, structure, and reproduction of that plant. Plant growth and distribution he stated are limited when any factor in the environment falls below the minimum required for the plant or when any factor goes over the maximum tolerated by the plant. A single factor often can limit the growth, reproduction, or distribution of a single plant species. Near the edge of the boundary of a species one environmental factor may compensate for another and the plant will be found growing in habitats that do not seem to be normal.

Billings (9) pointed out that chemical differences in the soil produced a marked change in the vegetation within a fairly uniform climatic. Billings (10) recognized that the fundamental problem of plant ecology is an understanding of the close relationship existing between the vegetation and its environment. He stated that vegetation and soil are subject to the control of climate which plays a leading role in the development and maintenance of both.

In a study of plant distribution, the role of disease or other catastrophe cannot be discounted. Woods (52) found that disease was a conditional response occurring only under suitable environmental conditions but that it was of importance in determining plant distribution.

Billings (5) divides the Intermountain Region into two associations, the Atriplex-Artemisia and the Salvia-Artemisia association. Many vegetational types exist within each of these associations and these vary considerably especially as to their edaphic requirements. He further divides the Atriplex-Artemisia association into two zones on the basis of macro-climate. Each of these zones he points out is a vegetational mosaic consisting of a climax matrix community in which are embedded various edaphic communities. The warmer and drier zone is the shadscale zone the other the sagebrush-grass zone.

Fautin (22) in his study of the biotic communities of the Northern Desert Shrub found shadscale widely distributed in the more xeric parts. He noted that shadscale was well adapted to xeric conditions and that it occurred in areas where the soil mineral content was beyond the tolerance of sagebrush. He noted that greasewood usually grows on soils high in alkali and with a high water table. He emphasized that alkali is not necessary for the growth of greasewood but a high soil moisture content is necessary. The winterfat community was found to occupy sandy, permeable soils where the salt content did not exceed 0.04 to 0.05 percent in the upper two feet.

In studying the vegetation of the Great Basin, Billings (7) found that vegetation zones were caused primarily by the effects of climate and soil on the distribution of the dominant species of the zone. The mosaic of smaller environmental differences within the general environmental limits of the principal dominants may be caused by edaphic factors, topography, or successional stages of the vegetation itself. He indicated that shadscale in Utah occurs in pure stands on the heavy salty soils of the drier valleys, usually with a saline subsoil. He also pointed out that the communities of greasewood, saltbush, and winterfat embedded in the shadscale matrix were all indicators of different combinations of salinity and ground water conditions.

The greasewood association and greasewood-shadscale association in the Carson Desert of Nevada were also found by Billings (6) to be growing on saline clay soils.

Boyko (14) pointed out that the vegetation of an area is a much better index to the climate of that area than is a collection of meteorological data which describes isolated single factors. He also pointed out that plants near the limits of survival react readily to the minutest changes in their environment

Shantz (43) stated that sagebrush in the Northern Desert Shrub type indicates a pervious soil moistened to a depth of several feet and free from alkali. He further noted that shadscale dominates the more level and mature soils of the whole sagebrush desert where the rainfall is less than on sagebrush land. Under the shadscale the soils are of fine texture with harmful amounts of alkali at a depth of one to two feet. Soils under winterfat vary considerably but are often of fine texture with alkali at a depth of one to two feet. Greasewood he said indicates a soil well supplied with water and containing more than 0.5 percent of salt.

Stewart, Cottam, and Hutchings (45) in their study in Western Utah found shadscale on light-textured soils with salt content varying from 0.02 to 0.05 percent depending on depth of sampling. Winterfat also was growing on light-textured soils but with a salt content varying from 0.03 to 0.6 percent. In the same area, sagebrush was growing on the lightest textured soils. The salt content varied from 0.02 percent at six inches to 0.1 percent at 42 inches.

Kearney, Briggs, Shantz, McLane, and Piemeisel (33) in their study in Tooele Valley, Utah noted three characteristics typical of the vegetation of the Great Basin, the great extent of the area occupied continuously by a single type of vegetation, the sharpness of the boundaries between the areas occupied by each type, and the great predominance of one or very few species in each type. They found the sagebrush occurring chiefly on the bench lands, on coarse-textured soils with low salt content. The shadscale was found to occupy a wide belt across the middle of the valley with a high salt content below the depth of one or two feet. They found greasewood to be growing in soil with a fairly high moisture equivalent and a high salt content from the second foot down and often in the surface foot as well.

Shantz and Piemeisel (44) studying the vegetation of Escalante Valley found conditions very similar to those found in Tooele Valley by Kearney et al. (33). Sagebrush was growing on moderately light-textured soils with a low salt content. Plants growing on soils with more than 0.5 percent salt at the three- to four-foot level were sickly and stunted. Winterfat was growing on soils of fine texture with a low salt content in the upper two feet but often with salts up to one percent at greater depths. The shadscale association occupied land that had a high salt content, hardpan, or coarse gravel at 18 to 24 inches. The salt content was usually low in the surface two feet but was as high as 2.5 percent at the three and four foot depth. Greasewood occupied the lower, heavier-textured, more saline soils in the middle of the valley. It was pointed out that while greasewood is not an infallible indicator of a high salt content, the salt content of the first foot usually ranges from 0.03 to 0.41 percent salt, the second foot 0.03 to 0.6 percent, and the third 0.05 to 1.08 percent. Greasewood-shadscale mistures also were found growing in areas with soil conditions intermediate between soil conditions of the pure types.

Weaver and Clements (49) and Clements (16) stated that soils on which sagebrush was growing were free from large amounts of salts and, unless too shallow, were suited for agricultural purposes. According to their analysis, winterfat indicated soils non-saline in the first foot, with saline soils at greater depths. Shadscale also indicated soils non-saline in the first foot with saline soils further down. Greasewood indicated a soil well drained in summer, moist below two feet, and saline throughout.

Marks (35) in a study of vegetation and soil relations in the lower Colorado Desert found a considerable amount of interdependence between the various plant species and soil characteristics.

Working primarily with sagebrush, shadscale, and greasewood, in southwestern Utah, Roberts (41), Fireman and Hayward (23) found that there was a significant difference in pH, soluble salts, and exchangeable sodium in the surface soil collected directly beneath shadscale and greasewood and the surface soil collected in the barren areas between the plants. This condition was not found in the case of sagebrush.

Hayward and Spurr (29) studying the effects of isosmotic concentrations of salts on entry of water into corn roots found that the force with which water was held to the soil particle and also the soluble salt present in a soil were important factors in determining water available to a plant. They further stated that the salt tolerance of a plant may be related to the osmotic pressure that can be maintained by the cell sap of a plant.

Bindschadler (11) in Wyoming found some plants to be an indication of saline soils without a high water table. Shadscale was found on heavy soil. The surface was free of soluble salts but the sub-soil was usually saline and alkali. Greasewood was growing on deep soils, moist in the subsoil and substratum. Many of these soils contained a high total salt content and sufficient sodium to cause dispersion.

According to Beadle (4) soil properties affect both the species composition and the growth form of plants. It was further pointed out that the soil properties which frequently govern plant communities are concentration of sodium chloride, clay pans in the B horizon, or phosphorous content of the soil.

Albrecht (2) pointed out that since calcium, phosphorous, and potassium furnish the major mineral portion of the soil fertility they can greatly influence the ecological array of plants.

The toxicity of chloride and sulfate salts which accumulate in plants was studied by Eaton (21). He found no evidence of an abrupt point at which toxicity effects became pronounced. He further pointed out that the limit of tolerance of a plant appeared to be an intangible concept and that death took place slowly over a range of conditions.

Thorne and Peterson (47) stated that plant injury due to salt concentration in the soil solution varied according to the salts present. They also pointed out that there was often no clear-cut distinction between effects of various salts and of drought on the metabolism and nutrition of plants. Various anions and cations were found to have specific effects on some plants.

Saline and alkali soils were intensively discussed in Agriculture Handbook No. 60 (1). Specific ion effects on various species were pointed out. It was pointed out that saline soils have little if any effect on the absorption of anions by the plants. Phosphorous and nitrogen were found to be less available in calcareous alkali soils. It was further pointed out that analysis of plant parts may serve for diagnosing mineral excesses or deficiencies in a soil.

White (50) studied the ground water supplies of the Escalante Valley of Utah. He estimated the ground water of the area by the transpiration of water from the plants of the area and evaporation from the soils. He concluded that vegetation of an area is sometimes a reflection of the ground water.

Breazeale (15) reporting on the alkali tolerance of plants concluded that the limit of endurance of a plant for alkali salts seems to be determined by the amount of alkali that is required to kill the enzymes of the roots that are concerned with growth. He listed an order of toxicity of alkali salts and pointed out that the order of toxicity depends on the number of units of time that the plant has come in contact with the salt during its period of adaptation.

Further evidence that the soils of an area play an important role in the ecological array of plants was found by Alvim (3). He reports that the distribution of cerrado in Brazil within its phytogeographic regions is controlled by the soil more than any other ecological factor.

Wilde and Leaf (51) studying the relationships between the degree of soil podzolization and the composition of ground cover vegetation in Wisconsin found only restricted overlapping of edaphic and floristic boundaries.

Saline and alkali soils were described and classified by Magistad (34). He pointed out that even though plant growth has been shown to be related to the osmotic pressure of the substrate, the mechanism of the action causing reduced growth is not known. According to his conclusions, this reduction of plant growth may be the result of the precipitation of cell protaplasm with high osmotic pressure or the disturbance of the normal nutrition of the plant. Magistad further observed that the saline alkali soils are usually permeable because of the high salt content present. He also pointed out that plants are unable to absorb the necessary plant food is the pH value is 8.0 or greater.

Kearney and Harter (32) in an early publication on the comparative tolerances of various plants for the salts common in alkali soils pointed out the difference in the way these salts affected some cereal crops. They recognized great differences in tolerance even among plants of the same family. Also the equalizing effects of calcium salts on the toxicity of some of the other salts was emphasized.

Increases in the osmotic pressure of expressed tissue fluids which resulted from the addition of various salts to soils tended to parallel the increases in osmotic pressures of the culture colutions, according to Eaton (21). Also the water requirements tended to be lower for plants growing on saline than for those growing on non-saline soils.

Harris, Gortner, Hoffman, Lawrence, and Valentine (28), working in Tooele Valley, Utah found that the osmotic pressure of expressed tissue fluids from various plant species increased as the osmotic pressure of the soil solution increased. They also showed that the osmotic concentration of woody plants was much higher than that of herbaceous plants.

Harris (27) found physio-chemical properties of the tissue fluids to be of fundamental importance in determining the relationship of the plant organisms to its environment. He further indicated that since external conditions exert influence upon the characteristics of the individual, it must be through the medium of the liquids surrounding the protoplasm.

The possible role of toxic substances produced by one plant in the distribution of other plants has long been a subject of speculation stated Bonner (13). Bonner and Galston (12) found that guayule plants produce substances which reduce or prevent germination of guayule seedlings beneath them. The desert shrub Encelia farinosa was found to produce toxic substances which severely retarded growth of the tomato in the laboratory (26). Artemisia absenthium (26) has been shown to contain in its leaves an inhibiting substance which may severely stunt other species. Bonner (12) concludes that association or non-association of different species may in some cases be the result or specific chemical compounds secreted by one of them.

Hilton (31) studying the germination of seeds of Eurotia lanata under various conditions showed that germination was completely restricted in a sodium chloride solution of three percent. At concentrations of 0.5 to 1.0 percent of salt a higher germination was attained and more healthy seedlings resulted than in distilled water.

Stoddart (46) and Cook and Harris (17) found that the chemical composition of some plants in northern Utah was greatly influenced by the site and soil on which they were growing.

SPECIES STUDIED AND HABITAT DESCRIPTION

Vegetation on the salt-desert ranges of Utah consists primarily of the shadscale and sagebrush association which is a part of the northern desert shrub formation (7). Five vegetation types which are major ones of these ranges were selected for this study. These were sagebrush (Artemisia tridentata), shadscale (Atriplex confertifolia), Nuttall's saltbush (Atriplex nuttallii), winterfat (Eurotia lanata), and greasewood (Sarcobatus vermiculatus). The five species contribute the major portion of winter range forage of Utah. Each of the five has been thought to be associated with particular soil characteristics although they frequently are found growing in close association where there are no apparent differences in soil or topography.

These shrubs have a decided tendency to zone out into pure types (Figures 1 to 3). The line of demarkation between types is usually abrupt. A change from a pure stand of one type to a pure stand of another type may take place in a zone only two to three feet wide (Figure 4). An abrupt transition such as this is known as an alterne (49). Examples are shown in Figures 5 to 10. Occasionally the different types are separated by broad transition zones. A pure stand may grade into a mixture with an adjacent type and then grade out to a pure stand of the other species. Each types studied was found growing adjacent to all other types under study.

Each of the pure types occupied areas ranging in size from a few acres to several hundreds of acres. These areas occupied by pure stands of different species adjacent to one another give the salt-desert a mottled appearance.

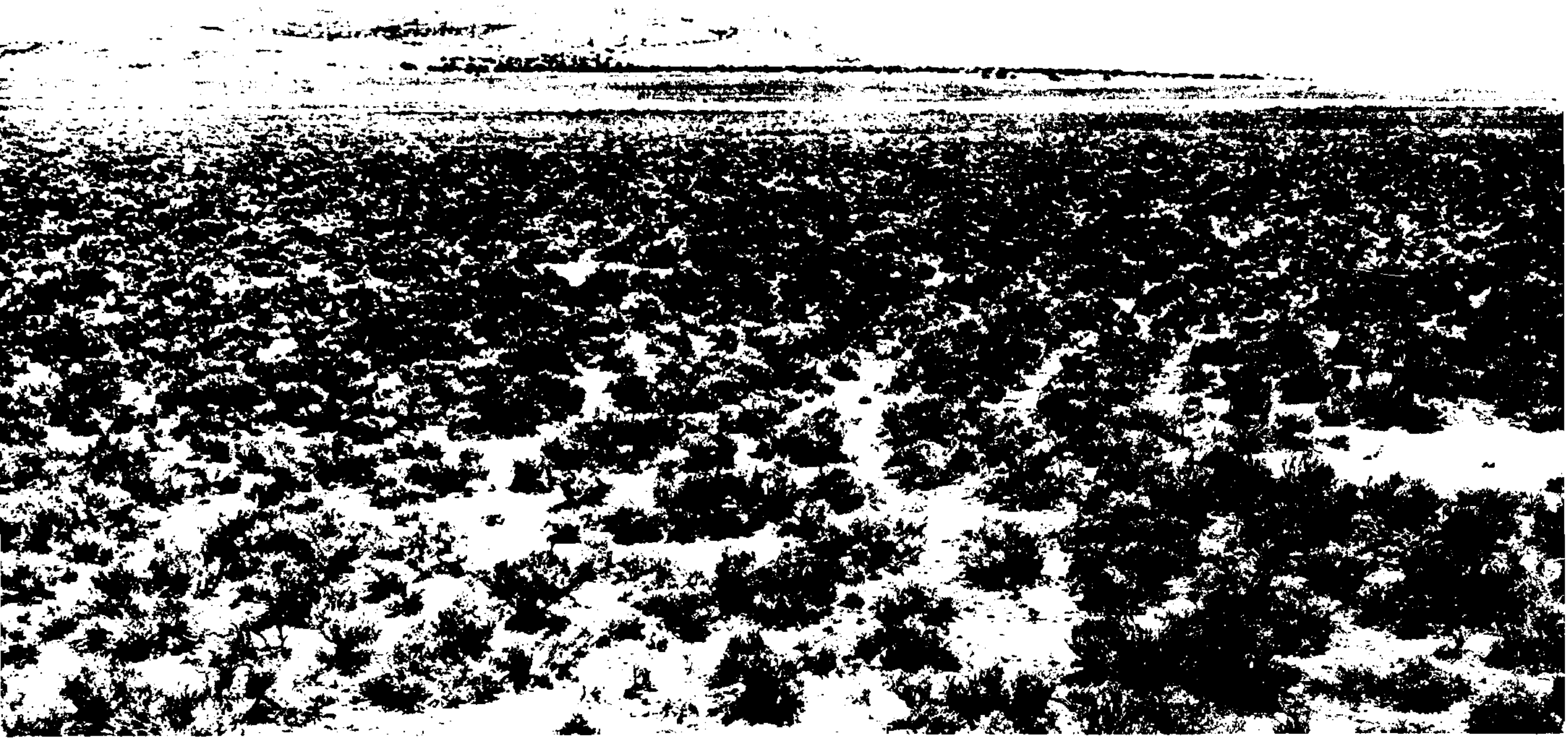

Figure 1. Pure stand of shadscale. An island of winterfat is shown in the background. The foothills are occupied by sagebrush and Juniper.

Figure 2. Pure stand of Nuttall's saltbush. An alterne with sagebrush appears in the background.

Figure 3. Pure stand of winterfat.

Figure 4. An alterne with Nuttall's saltbush in the foreground and shadscale in the background.

Figure 5. An alterne with winterfat in the foreground and sagebrush in the background.

Figure 6. An alterne with shadscale in the foreground and sagebrush in the background.

Figure 7. An alterne with winterfat in the foreground and greasewood in the background.

Figure 8. An alterne with winterfat in the foreground and shadscale in the background.

Figure 9. An alterne with shadscale in the foreground and sagebrush in the background.

Figure 10. An alterne with shadscale in the foreground and greasewood in the background.

Areas selected for study were for the most part confined to three large valleys typical of the salt-deserts of western Utah. Curlew Valley is located in northwestern Utah. It is a broad, flat valley extending from the north end of the Great Salt Lake into southern Idaho. Rush Valley is located in west central Utah. This wide valley extends from Stockton southward to Vernon, Utah. Escalante Valley is a large, flat valley in southwestern Utah which extends from Milford southward to Modena.

Study areas were pure types of each species growing contiguous to another type on the low, flat bottomlands or low terraces. Areas were omitted where a topographic change occurred concomitantly with the change in type. Detailed descriptions of each area studied are given in Appendix Table 1 to 5.

Geographically, the entire salt-desert under study lies within the Great Basin of the Basin and Range Province. Also, all of the areas occupy positions which were covered by the glacial Lake Bonneville. Some of the areas nearer to the Great Salt Lake were undoubtedly submerged by all four high water stages of old Lake Bonneville (50). Thus, the soil-forming processes of these areas have been functional only in recent geologic times. Other areas at greater distance from the Great Salt Lake or which occupy higher topographic positions were probably submerged only by the earlier high water stages. Thus, these areas have been subjected to soil forming processes for a considerably longer period of time.

Soil characteristics vary greatly within the salt-desert. Parent materials for the soils studied were either of sedimentary origin or were alluvial outwash from adjacent mountain ranges. The soils vary in texture from heavy clays to sandy loams and sands. Extreme variations in the amount of alkalinity and salinity are common.

All of the vegetation types under study were growing on immature desert soils which reflected plainly the parent material from which they were being formed. Thus, these soils are classed as azonal. Since they have developed only slightly, a true soil profile could not be recognized, but there was a considerable amount of layering. This layering was primarily geological and related to the deposition of the regolith.

The elevation of the areas studied varied from approximately 4,225 feet above sea level in Curlew Valley, near Kelton, Utah, to slightly over 5,000 feet in Escalante Valley near Lund, Utah. These extremes in elevation were separated by a north-south distance of approximately 350 miles.

All areas were in a semiarid zone. As shown in Table 1, there were relatively small variations in climate between areas. Precipitation varied from 7.04 inches at Kelton (48) to 10.78 inches at Modena. Table 1 shows that long-time average temperature varied from a January low of 22.2 degrees at Kelton and St. John to an average January high of 26.3 degrees at Modena, Utah. July averages varied from 69.9 degrees at St. John to 71.4 degrees at Modena, Utah. Throughout the Great Basin the precipitation is uniformly distributed over the year. According to U. S. climatological records (48) about 60 percent of the precipitation falls as snow and 40 percent as rain. Thunderstorms during the summer months are common. Surface runoff is excessive during periods of high intensity rainfall or rapid snow melt.

Table 1. Summary of climatalogical data from stations located near the study areas 1/

Station	Average annual precipitation (inches)	Average temperature January (degrees F.)	Average temperature July (Degrees F.)
Modena	10.78	26.3	71.4
Kelton	7.04	22.2	72.2
Lund	8.56	---	---
Milford	8.65	25.4	73.4
St. John	9.16	22.2	69.9

1/Data obtained from 1941 Yearbook of Agriculture and other summaries of U. S. Weather Bureau climatalogical data.

METHODS AND PROCEDURES

Soil sampling: Since the edaphic factors were considered of primary importance in the distribution of the vegetation types, methods for properly sampling the soils were of utmost importance.

Soil samples were taken in the field during the summers of 1953 and 1954. The areas studied during the summer of 1953 were confined to northern and central Utah and southern Idaho. In order that critical studies of soil profile characteristics couls be made, trenches 18 inches wide, 7.5 feet deep and 15 to 25 feet long were excavated using a Shawnee Pull-Hoe digger mounted on a Ford tractor (Figure 11).

To ascertain whether soil characteristics near the pheriphery of an area occupied by a pure type were homogeneous with those in the center of the area, a profile was exposed near the edge and another in the center of the area. The trench near the pheriphery of the area was designated as A and the one in the center as B.

In Curlew Valley two profiles were exposed in areas occupied by winterfat, shadscale, Nuttall's saltbush, and greasewood and in two areas occupied by sagebrush. In order that data acquired would be applicable over a large portion of the salt-desert, profiles were also exposed in other locations. Two profiles were exposed in an area occupied by winterfat, located approximately five miles northwest of Strevell, Idaho. In addition, in Rush Valley, two profiles were exposed in areas occupied by sagebrush, shadscale, Nuttall's saltbush, and greasewood.

To determine whether changes in soil occurred concomitantly with changes in vegetation type, trenches were also excavated across

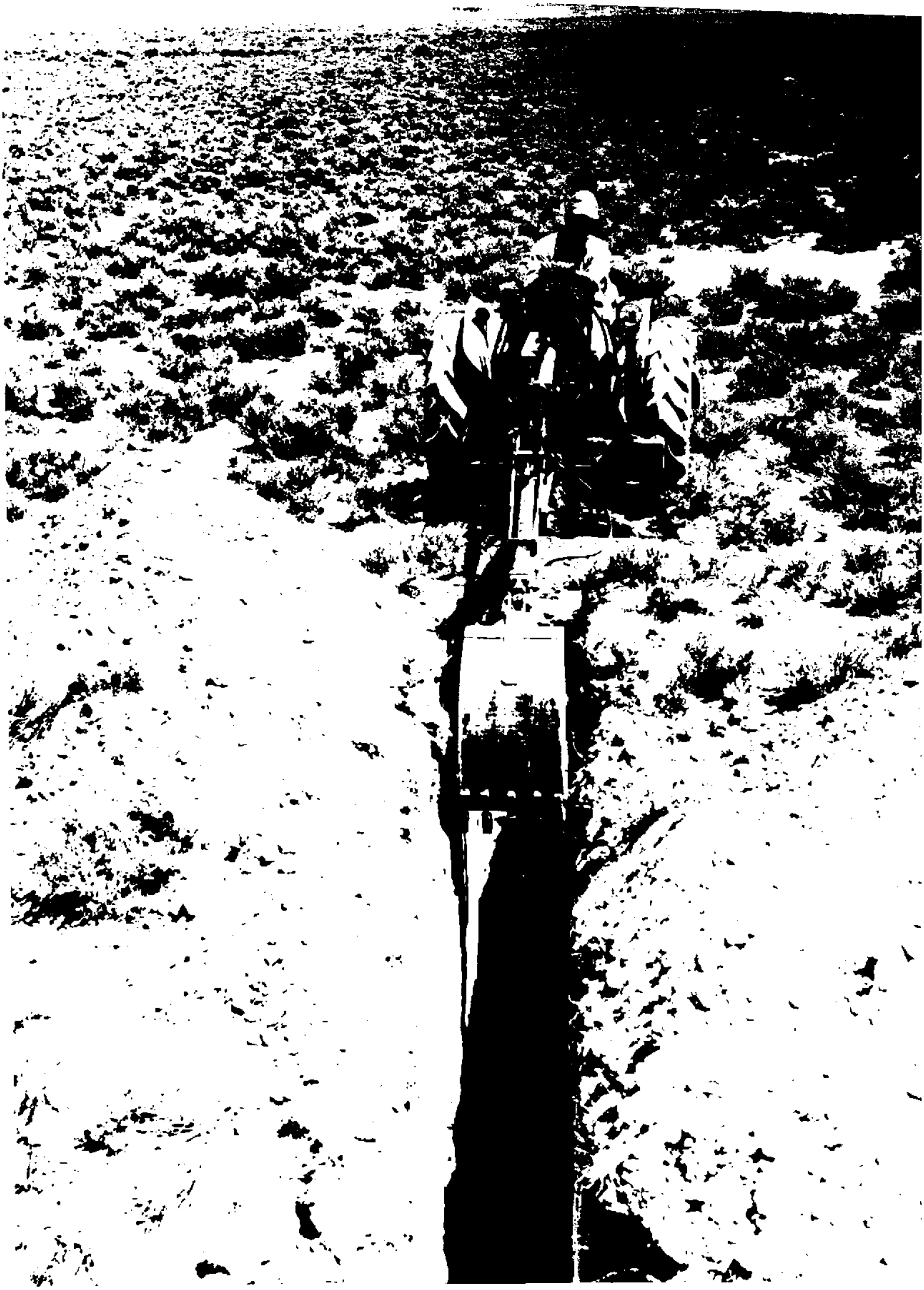

Figure 11. Shawnee Pull-hoe digger used to excavate trenches for soil profile study. A shadscale-sagebrush alterne appears in the background.

alternes between types. These trenches varied in length, depending somewhat on the abruptness of the alterne (Figures 12 and 13).

All exposed soil profiles were studied critically and each layer was described in detail (Figure 14). These descriptions are shown in Tables 2 to 6. While studying the profile characteristics, observations were made as to the depth of root penetration for each species. It was determined that all five species studied regularly rooted to the bottom of these 7.5 foot trenches and it is assumed that conditions encountered anywhere within this depth might influence plant growth.

Soil samples approximately two quarts in size were collected from each of the described layers in each profile. These soil samples were collected in heavy paper bags and placed in storage at room temperature until analyzed.

Soil sampling was continued during the summer of 1954. Soil samples were collected from each type under study in each of the previously described valleys. However, instead of taking samples from the layers of an exposed profile as was done in 1953, soil samples were taken from four predetermined depths, using a Jordan soil auger. Depths sampled were 0 to 6 inches, 6 to 18 inches, 18 to 36 inches and 36 to 60 inches. The change in sampling method made it possible to sample more areas with less expense. This method, however, did not permit complete examination of the profile, or collection of soil samples from each soil profile layer such as was possible during the previous summer.

Similar to the sampling method of 1953, soil samples were collected to represent soil conditions near the periphery of an area (A samples) and the center of the area (B samples). Soil samples for each of the

Figure 12. Trench exposing soil profile across an alterne with Nuttall's saltbush in the foreground and sagebrush in the background.

Figure 13. Trench exposing soil profile across an alterne with Nuttall's saltbush on the right and shadscale on the left.

Figure 14. Examination and description of soil profile in a sagebrush area.

Table 2. Descriptions of exposed soil profiles under sagebrush from three areas on the salt-desert of Utah

	Northern Utah			
	Area 2		Area 14	
	Trench A	Trench B	Trench A	Trench B
Zone I				
Depth	0-7"	0-10"	0-16"	0-20"
Texture 1/	SiL	SCL	L	LiL
Structure	platey	granular to laminar	filaform to angular	filaform to granular
Color	gray-brown	gray-brown	gray-brown	gray-brown
Zone II				
Depth	7-22"	10-27"	16-52"	20-55"
Texture	SCL	L	L	L
Structure	granular	granular	massive to angular	massive to angular
Color	light gray-brown	light gray-brown	light yellowish-brown	light yellowish-brown
Zone III				
Depth	22-32"	27-35"	52-90"	55-58"
Texture	coarse sand and gr.	FSL	L	FSL
Structure	single-grain	single-grain	massive	single-grain
Color	yellowish-brown	yellowish-brown	light yellowish-brown	light yellowish-brown
Zone IV				
Depth	32-60"	35-45"		58-90"
Texture	SCL	gravel & sand		FSL
Structure	granular to angular			single-grain
Color	light gray-brown			light yellowish-brown
Zone V				
Depth		45-72"		
Texture		gravelly loam		
Structure		angular		
Color		light gray-brown		

1/ Si = silt, L = loam, C = clay, S = sand, Li = light, H = heavy, F = fine.

Table 2. (cont.)

Central Utah

Area 31

Trench A	Trench B
0-6" LiCL filaform to granular gray-brown	0-5" HSL laminar to platey gray-brown
6-16" LiCL granular light red- dish-brown	5-11" LiCL granular light red- dish-brown
16-23" C blocky reddish- brown	11-31" C massive light yel- lowish-brown
23-72" LiC angular to blocky light gray-brown	31-72" LiC massive to blocky light yel- lowish-brown

Table 3. Descriptions of exposed soil profiles under winterfat from two areas on the salt-desert of Utah

	Northern Utah		Southern Idaho	
	Area 7		Area 22	
	Trench A	Trench B	Trench A	Trench B
Zone I				
Depth	0-11"	0-14"	0-6"	0-5"
Texture 1/	FSL	L	LiCL	HSL
Structure	platey to granular	platey to granular	filaform to granular	laminar to platey
Color	gray-brown	gray-brown	gray-brown	gray-brown
Zone II				
Depth	11-24"	14-20"	6-16"	5-11"
Texture	FSL	FSL	LiCL	LiCL
Structure	single grain	granular	granular	granular
Color	light gray-brown	light gray-brown	light reddish-brown	light reddish-brown
Zone III				
Depth	24-28"	20-24"	16-23"	11-31"
Texture	L	SL	C	C
Structure	angular	granular to angular	blocky	massive
Color	light yellowish-gray	light yellowish-brown	reddish-brown	light yellowish-brown
Zone IV				
Depth	28-58"	24-50"	23-72"	31-72"
Texture	FSL	FSL	LiC	LiC
Structure	single grain	single grain	angular to blocky	massive to blocky
Color	light gray-brown	light gray-brown	gray-brown	light yellowish-brown
Zone V				
Depth	58-70"	50-84"		
Texture	L	L		
Structure	angular	angular		
Color	light gray-brown	light yellowish-brown		

1/ Si = silt, L = loam, S = sand, C = clay, Li = light, H = heavy, F = fine.

Table 4. Descriptions of exposed soil profiles under shadscale from two areas on the salt-desert of Utah

	Northern Utah		Central Utah	
	Area 4		Area 28	
	Trench A	Trench B	Trench A	Trench B
Zone I				
Depth	0-8"	0-11"	0-7"	0-6"
Texture 1/	SCL	FSL	LiCL	LiCL
Structure	granular to laminar	platey	laminar to platey	filaform to granular
Color	gray-brown	gray-brown	gray-brown	gray-brown
Zone II				
Depth	8-24"	11-20"	7-24"	6-17"
Texture	SCL	FSL	LiC	LiC
Structure	granular	massive to single-grain	angular	granular to angular
Color	light gray-brown	gray-brown	light brownish-gray	light yellowish-brown
Zone III				
Depth	24-38"	20-50"	24-72"	17-30"
Texture	FSL	L	HCL	LiC
Structure	massive to angular	granular to single-grain	blocky	granular to blocky
Color	light gray-brown	light gray-brown	light olive-gray	light gray-brown
Zone IV				
Depth	38-72"	50-84"		30-72"
Texture	FSL	FSL		CL
Structure	massive	massive		angular to blocky
Color	light gray-brown	gray-brown		mottled olive-gray

1/ Si = silt, L = loam, S = sand, C = clay, Li = light, H = heavy, F = fine.

Table 5. Descriptions of exposed soil profiles under Nuttall's saltbush from 2 areas on the salt-desert of Utah

	Northern Utah		Southern Utah	
	Area 10		Area 34	
	Trench A	Trench B	Trench A	Trench B
Zone I				
Depth	0-11"	0-10"	0-10"	0-5"
Texture 1/	L	L	HSiL	LiCL
Structure	platey to granular	platey to granular	laminar to platey	filaform
Color	gray-brown	gray-brown	gray-brown	gray-brown
Zone II				
Depth	11-23"	10-24"	10-35"	5-20"
Texture	L	L	HCL	CL
Structure	granular	granular	granular to massive	massive
Color	light yellowish-brown	light gray-brown	light yellowish-brown	light yellowish-brown
Zone III				
Depth	23-90"	24-90"	35-72"	20-84"
Texture	L	SiL	HCL	C
Structure	granular	angular	massive	granular
Color	light yellowish-brown	light yellowish-brown	yellowish-brown	light olive-gray
Zone IV				
Depth	90-96"			84-90"
Texture	SiL			C
Structure	angular			blocky
Color	light yellowish-brown			light yellowish-gray

1/ Si = silt, L = loam, S = sand, C = clay, Li = light, H = heavy, F = fine.

Table 6. Description of exposed soil profiles under greasewood from 2 areas on the salt-desert of Utah

	Northern Utah		Central Utah	
	Area 20		Area 25	
	Trench A	Trench B	Trench A	Trench B
Zone I				
Depth	0-7"	0-7"	0-8"	0-6"
Texture[1/]	LiSL	L	CL	SCL
Structure	filaform to granular	filaform to granular	platey to granular	laminar to platey
Color	gray-brown	gray-brown	gray-brown	light gray-brown
Zone II				
Depth	7-32"	7-29"	8-31"	6-14"
Texture	SiL	SiL	CL	LiCL
Structure	massive to granular	massive	angular to blocky	granular to angular
Color	light gray-brown	light yellowish-brown	light gray-brown	light yellowish-brown
Zone III				
Depth	32-78"	29-44"	31-60"	14-28"
Texture	SiL	SiL	gravel to cobbles	HL
Structure	blocky to nuciform	angular to blocky	single-grain	angular
Color	gray-brown	gray-brown	gray-brown	light yellowish-brown
Zone IV				
Depth		44-78"		28-60"
Texture		SiL		gravel and cobbles
Structure		blocky to nuciform		single-grain
Color		light grayish-brown		light brownish-gray

[1/] Si = silt, L = loam, S = sand, C = clay, Li= light, H = heavy, F = fine.

four soil depths were drawn from composite samples made up of soil from three borings. To make up the A samples, three borings were made near the periphery of an area and parallel to it. The B samples were obtained in the same manner but were taken from the central portion of the area.

During the two summers, soil samples were collected from ten areas occupied by each of the five types. The ten areas were widely scattered to represent conditions throughout the salt-desert.

Field infiltration studies: In order to understand better the role that soil structure and texture play in distribution of vegetation, water infiltration studies were made in the field during the summer of 1953. Four infiltrometers were established in areas occupied by each of the five vegetation types in Curlew Valley. Areas number 4, 7, 10, 14, and 20 (Appendix Tables 1 to 5) were used for shadscale, winterfat, salt-bush, sagebrush, and greasewood respectively.

The infiltrometers consisted of 9.5-inch diameter steel pipes, approximately two feet long, driven into the ground six inches. The pipes were rapidly filled with water. The water level lowered in the infiltrometer as the water moved into the soil. The distance the water had lowered was measured and recorded at convenient intervals. The pipes were refilled following each reading. Each infiltrometer was operated for a period of approximately 60 hours. By dividing the number of inches the water level in the infiltrometer had dropped by the number of hours since the previous reading, the infiltration rate in inches per hour was obtained.

In an attempt to ascertain further the effects of the water movement in the soil, the flow pattern of the water from each infiltrometer was determined. To accomplish this a trench was dug bisecting the spot where the infiltrometer had been placed. The flow pattern or wetted perimeter was observed on the side of the trench. This wetted perimeter was measured and sketched on graph paper. The dimensions from the four tests on each type were averaged and an average flow pattern was drawn.

Determination of permeability by use of disturbed soil cores: The entry of water into the soil and the rate of movement through the soil can have a profound effect on plant growth. The soil in which a plant's roots are growing serves as a reservoir for storage of water for growth. When this supply is depleted because of evaporation and transpiration, it can only be replenished by water moving through the soil. The only water source for most of the desert plants is snow melt and spring rainfall. Soil texture and structure greatly influence the rapidity with which the water can enter the soil and to a great extent how much water will be retained in the soil.

As a means of ascertaining the rate at which water could pass through the soil at various depths, and to augment field infiltration studies, a laboratory permeability study was run on all soil samples collected. The permeability of the samples was determined by using an apparatus developed by the Bureau of Reclamation at Logan, Utah (Figure 15).

This machine consisted of a water supply bottle, known as a Marriotte bottle, with water feeder lines running to each of 20 brass cylinders containing the soil samples. The apparatus was arranged so that the depth of water standing in each of the cylinders was equal and constant. This depth was determined by the position of the

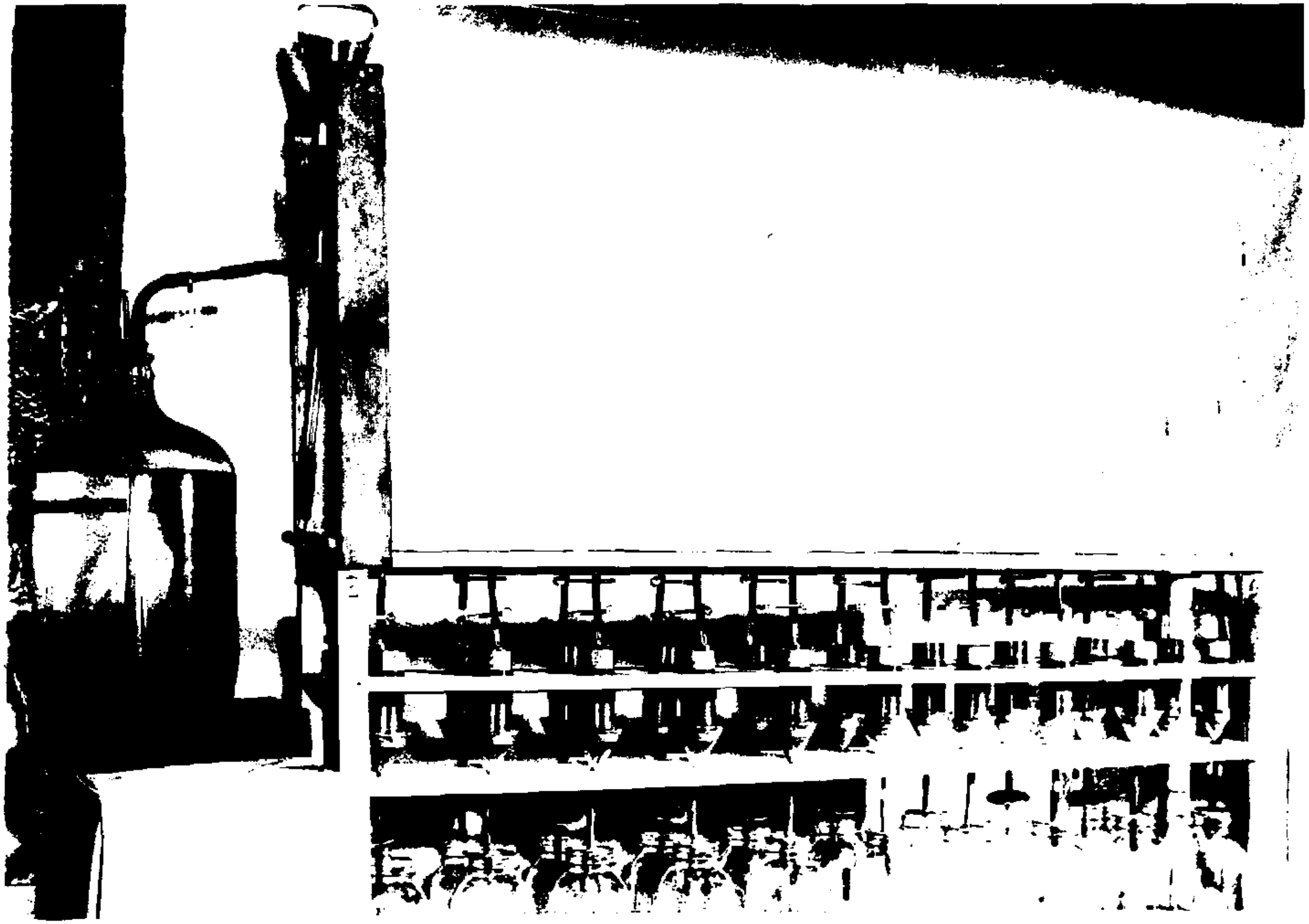

Figure 15. Apparatus for determining permeability rates of disturbed soil cores. Developed by U. S. Bureau of Reclamation, Logan, Utah.

lower end of the standpipe in the supply bottle. Each of the individual feeder lines running to the cylinders was supplied with a pinch-cock. This allowed any one or all of the lines to be closed or opened at any time, thus, allowing samples to be put on or taken off the machine without disturbing the remainder of the samples.

The brass cylinders containing the soil were made of two-inch diameter seamless brass tubing three inches long. A shorter piece of like tubing two inches long was attached to the top of the three-inch cylinder by means of a two-inch rubber band made from a bicycle tire inner tube. The shorter cylinder served as a water reservoir.

In preparing a soil sample for the permeability test it was air dried, pulverized, and put through a 1 mm. soil sieve. The three-inch long brass cylinder, which was to be the soil receptacle, was covered on one end with a piece of light muslin held in place by a rubber band. A thin layer of glass-wool was placed inside the cylinder against the muslin. This was to prevent the soil particles from plugging the muslin and thereby retarding the flow of water through the soil. The cylinder was then filled with the prepared soil. To obtain uniform compaction of the soil in the cylinders, the filled cylinder was dropped ten times from a height of one inch. If the cylinder was not full after compaction more soil was added and leveled off with a putty knife, using care not to further compact the soil.

When the three-inch cylinder was filled with soil, the two-inch cylinder was secured in place. A thin layer of glass-wool was then laid inside the shorter cylinder on top of the soil. This layer of glass wool overlaying the soil acted as a splash board to prevent the water flowing into the reservoir from the feeder line from puddling and further compacting the soil core.

When the cylinders were properly filled with soil they were placed upright in a pan filled to a depth of approximately 2.5 inches with water. This allowed the soil to become completely saturated by upward movement of water through the soil. The upward movement of the water also displaced the soil air thereby preventing air from later moving into a feeder line of the apparatus and causing an air lock. To insure complete wetting, and displacement of air, the samples were soaked over night. After this preliminary soaking period, the samples were allowed to drain for 15 minutes and then they were set in place on the permeability apparatus. The lower end of the brass cylinder, covered with muslin, rested in a glass funnel which was set to drain into a receptacle to catch the percolate. The reservoir was then filled with water and the feeder line inserted so that the lower end of it was submerged in the water. The pinch-cock was then released to allow the water to flow into the cylinder. As pointed out previously, the depth of the water in the reservoir cylinders was regulated by the height of the standpipe in the water supply bottle. The depth of the water in all reservoir cylinders on the machine was equal and constant, thereby, a constant hydrostatic head was maintained on all samples at all times.

The date and hour was recorded as each core was placed on the machine. The amount of percolate that had accumulated in the receptacle was measured in milliliters at the end of one hour. This was recorded and used in the computation of the initial permeability rate of the soil core. For the remainder of the test period the amount of percolate was measured and recorded at convenient intervals. The time lapse, in hours, between measurements of the percolate was also recorded each time the percolate accumulation was read.

The samples were left on the machine for periods ranging from 36 hours to 10 days depending on the rate of permeability and the time required for the soil and leaching water to come into equilibrium. To ascertain when the soil core and the leaching water had reached equilibrium, the Standard Bureau resistance bridge (44) was used. Each day a sample of the leaching water from the supply bottle was placed in the resistance bridge cup and a resistance reading obtained. After the percolate accumulation of a soil core was measured and recorded, a sample of it was placed in the resistance bridge cup and a resistance reading obtained. When the leaching water and the leachate from a soil sample gave similar resistance readings the soil was assumed to have reached equilibrium with the water. The sample was then assumed to have reached or approached its constant permeability rate. The soil core was then removed from the apparatus.

To calculate permeability rate from the data a modification of Darcey's formula (1) for water movement through soil was used. The formula is $P = QL/TAH$, where P equals the permeability rate of the soil in inches per hour, Q equals the millileters of percolate collected between readings, L equals the length of the soil core in inches, T equals the time interval in hours between percolate accumulation readings, A equals the cross-sectional area of the cylinder in square centimeters, and H equals the hydratic head or the length of the soil core plus the water in the reservoir in centimeters. Since cores of the same length and cross sectional area were used throughout the study and the same hydraulic head was maintained, the formula was simplified. The portion of the formula (L/AH) was expressed as a constant (K). The formula than became $P = KQ/T$. The dimensions of the core were, $L = 3$ inches, $A = 18.86$ square centimeters, and H =

11.43 centimeters. When these values were substituted into the formula, K was found to be equal to 0.0138. The final calculation for the determination of the permeability then became P = 0.0138 x Q/T.

Collection and Chemical Analysis of Plant Material: In the process of studying relative tolerances of the plant species, plant samples for chemical analysis were collected from each area. Samples were made up of current-year's growth. In order to be assured of a representative sample, portions of individual plants were clipped at random throughout the sampling area. The samples were air dried, put through a one-millimeter Willey grinding mill, and stored in closed glass jars until analyzed. The plant material was analyzed for the following constituents: sodium, magnesium, chloride, sulfur, potassium, and calcium. All of these elements were present in various amounts in the soil in which these plants were growing. All of these elements have specific effects on plant growth (1) either from the standpoint of deficiency or toxicity.

Sulfur was determined by methods as described by Painter and Frank (39), magnesium and calcium as outlined by Gehrke et. al. (24), chloride was determined by methods as outlined by Hillebrand and Lundell (30), and sodium and potassium by use of the flame photometer as described in Agriculture Handbook 60 (1) under methods 57a and 58a respectively.

Chemical and Physical Analyses of Soil Samples: All soil samples collected during the summer of 1953 and 1954 were subjected to a series of analyses for characteristics which it was thought might influence or determine the plant species produced. The chemical analyses run on the samples were: pH of saturated extract percentage of total soluble salt, saturation extract conductivity, base exchange capacity, amount of exchangeable sodium, exchangeable sodium percentage, lime content, amount of exchangeable potassium, and exchangeable potassium percentage. Analyses also were run to determine the parts per million of calcium, magnesium, sodium, potassium, chloride, sulfate carbonate, and bicarbonate. Soil moisture percentages remaining under 1/3 and 15 atmosphere pressures also were determined for all samples.

Procedures used for these analyses are described in the Agriculture Handbook number 60 (1), chapter 6. Methods used were as follows, for electrical conductivity: method 4a; soluble: method 5; exchangeable cations: method 18; cation-exchange capacity: method 19; exchangeable-cation percentage: method 20a; pH determination: methods 21a and 21b; 1/3 atmosphere percentage: method 30; and 15 atmospheres percentage: method 31. Other determinations used were for calcium and magnesium: method 7; sodium: method 10a; potassium: method 11a; carbonate and bicarbonate: method 12; and chloride: method 13. Sulfate was determined according to method 14a except the sample was centrifuged and the precipitate was caught on ashless filter paper, washed free from soluble salts, then ignited and weighed. Lime was determined by method 23c with the following modifications. One gram of soil was boiled for five minutes with 0.5 normal sulfuric acid. The excess acid was then titrated and 50 millileters of distilled water was added to the solution. Phenolphtaleen was used as an indicator and a special titration light was utilized.

Composition and Density Determinations of Vegetation Cover: To better understand the effects of soil upon composition and density of vegetation, data on these factors were collected during the summer of 1954. Density and composition were determined by a modification of the Parker method (40). A one-hundred-foot steel tape was stretched between uprights in each of the study areas. A plumb was dropped from each foot-mark and a record was made of the conditions contacted at that point. Readings were made as to plant species, erosion pavement, litter, and bare ground. Four such transects were run at random in each area. From these data plant composition and density were calculated. Notes concerning the apparent grazing pressure, vigor and height of the plants, topographic conditions, and contiguous vegetation types were also taken.

RESULTS AND DISCUSSION

Soil analyses data were computed and treated statistically for each soil character individually. Samples were collected from four depths and from two positions (A and B) within ten areas occupied by each of the five species under study.

Each of the A and B samples was a random sample of the variation within its respective portion of the area. The two samples could not be pooled unless the two portions were found to be homogeneous. The Dixon and Massey (19) test for homogeneity of variances was used to test whether A and B samples were homogeneous. If the two samples were homogeneous, they were considered to represent random distribution of variance of the entire population being sampled. A and B samples are compared for homogeneity in Appendix Tables 6 to 10. If the variances were homogeneous, pooling was permitted and the statistical analyses as presented in Tables 8 and 9 were carried out. In a few cases the two samples were found to be heterogeneous and analyses and interpretations were made in accordance with this knowledge.

pH: There appeared to be little difference in pH among soils under the five dominant types or between depths under each type (Table 7). However, an analysis of variance shows significant differences in pH at various depths within the winterfat type (Table 9). This resulted from the small variability from area to area, making even small differences associated with depth significant. In addition, an analysis of variance showed significant difference in pH between soils from various depths when all vegetation types were averaged (Table 8). Also, according to the measure of least significant range 1/, each of these depths differed

1/ This new multiple range test is a technique recently developed by D. B. Duncan (20). This procedure can be used to compare every treatment with every other treatment in an analysis of variance.

Table 7. Mean values for various soil characteristics obtained from four depths in ten different areas of each of five vegetation types of the salt-desert ranges of Utah

Type and depth	pH	Total soluble salts percent	Saturation extract conductivity K x 10^3	Exchangeable Na me./100g.	Base exchange cap. me./100g.	Exchangeable Na percentage
Sagebrush						
0-6 in.	8.1	0.05	1.0	0.5	17.8	3
6-18 in.	8.2	0.13	2.8	1.6	17.8	9
18-36 in.	8.3	0.41	8.3	3.7	16.7	23
36-60 in.	8.2	0.71	15.6	4.7	15.3	32
Mean	8.2	0.32	6.9	2.6	16.9	17
L.E. 1/	—	0.22	4.2	1.2	—	—
Winterfat						
0-6 in.	8.2	0.04	0.9	0.4	16.7	2
6-18 in.	8.3	0.19	4.6	1.8	16.5	12
18-36 in.	8.3	0.52	12.5	3.7	16.4	24
36-60 in.	8.0	0.70	18.9	4.0	15.7	26
Mean	8.2	0.36	9.2	2.5	16.3	16
L.E.	—	0.14	3.4	0.7	—	—
Shadscale						
0-6 in.	8.4	0.09	2.7	1.0	17.0	6
6-18 in.	8.3	0.37	8.1	3.8	19.0	20
18-36 in.	8.3	0.72	17.1	4.7	18.0	26
36-60 in.	8.1	1.12	27.1	5.5	17.4	31
Mean	8.3	0.58	13.8	3.7	17.9	21
L.E.	—	0.28	4.9	1.3	—	—
Nuttall's saltbush						
0-6 in.	8.2	0.18	4.4	1.2	18.5	6
6-18 in.	8.2	0.69	14.4	3.8	18.9	20
18-36 in.	8.3	1.23	26.7	6.2	17.8	35
36-60 in.	8.2	1.47	31.9	5.9	17.2	34
Mean	8.2	0.89	19.3	4.3	18.1	24
L.E.	—	0.28	6.6	1.0	—	—
Greasewood						
0-6 in.	8.2	0.29	6.8	2.2	19.3	11
6-18 in.	8.7	0.82	13.2	6.1	20.5	30
18-36 in.	8.4	1.03	17.7	5.8	18.5	33
36-60 in.	8.2	1.19	23.8	7.2	18.4	31
Mean	8.4	0.83	15.4	4.8	19.2	26
L.E.	—	0.30	4.2	1.8	—	—
Depth means						
0-6 in.	8.2	0.13	3.2	1.0	17.9	6
6-18 in.	8.4	0.44	8.6	3.4	18.5	18
18-36 in.	8.3	0.78	16.4	4.8	17.5	28
36-60 in.	8.1	1.04	23.5	5.0	16.8	31

1/ The limit of error (L.E.) is sometimes expressed as $\pm$ 1/2 the 95 percent confidence interval.

Table 7. (cont.)

Lime percentage	Permeability in./hr.	1/3 atmosphere percentage	15 atmospheres percentage	Exchangeable K me./100g.	Exchangeable K percentage
15	0.66	25.6	10.2	2.8	15
19	0.44	24.9	11.7	3.1	18
25	0.88	32.3	13.3	2.3	14
25	0.75	31.9	11.9	1.8	11
21	0.68	28.7	11.8	2.5	14
—	—	7.1	—	—	—
19	0.80	20.6	8.8	2.6	16
22	0.57	22.8	9.0	2.4	16
23	0.40	25.1	9.1	1.8	12
21	0.33	26.2	10.0	1.5	10
22	0.52	23.7	9.2	2.1	13
—	—	2.6	—	—	—
18	0.31	20.8	9.9	4.1	24
21	0.48	24.4	13.1	3.0	17
24	0.59	26.4	13.6	1.8	11
21	0.69	26.2	13.0	1.6	9
21	0.52	24.4	12.4	2.6	15
—	—	3.5	—	—	—
19	0.38	23.7	10.2	4.6	25
21	0.38	26.7	11.9	2.9	15
22	0.49	29.9	13.1	1.8	10
24	0.45	31.0	12.5	1.4	8
21	0.43	27.8	11.9	2.7	14
—	—	3.7	—	—	—
13	0.25	22.5	10.7	4.0	21
19	0.12	31.6	14.0	3.1	16
19	0.16	30.7	13.0	2.3	12
14	0.31	29.4	11.9	1.4	8
16	0.21	28.5	12.4	2.7	14
—	—	2.9	—	—	—
17	0.48	22.6	10.0	3.6	20
20	0.40	26.1	12.0	2.9	16
23	0.50	28.9	12.4	2.0	12
21	0.51	29.0	11.8	1.5	9

Table 7. (cont.)

Calcium p.p.m.	Magnesium p.p.m.	Sodium p.p.m.	Potassium p.p.m.	Chloride p.p.m.	Sulfate p.p.m.	Carbonate p.p.m.	Bicarbonate p.p.m.
74	14	61	104	70	65	0	432
64	17	298	112	361	103	5	526
196	106	832	114	1,388	1,060	16	602
517	219	1,684	117	2,565	2,665	17	424
213	89	719	112	1,096	973	9	496
—	—	556	—	—	—	—	—
82	22	145	113	148	137	0	495
68	27	556	99	624	273	5	536
146	54	1,236	82	1,433	635	6	513
544	148	1,667	91	1,942	2,237	0	348
210	63	901	96	1,037	820	3	473
—	—	233	—	—	—	—	—
47	12	189	155	190	81	0	538
69	41	995	116	1,118	466	5	680
317	180	1,799	94	2,328	1,522	11	489
1,280	431	2,735	165	3,962	4,704	0	256
428	166	1,429	132	1,900	1,693	4	491
—	—	613	—	—	—	—	—
306	49	347	246	336	1,092	0	482
344	93	1,693	152	1,860	2,019	1	482
561	280	3,269	143	4,124	3,367	20	459
1,198	413	3.551	137	4,950	5,600	2	321
602	208	2,215	170	2,818	3,020	6	436
—	—	918	—	—	—	—	—
63	20	580	158	788	140	0	587
88	47	1,865	118	2,425	1,323	0	697
237	80	2,355	90	2,894	1,412	1	546
1,003	166	2,946	118	3,557	4,244	0	432
348	78	1,936	121	2,416	1,780	0	565
—	—	430	—	—	—	—	—
114	23	264	155	306	303	0	507
127	45	1,081	120	1,128	837	3	584
291	140	1,898	105	2,433	1,599	4	522
908	275	2,517	126	3,395	3,890	12	356

Table 8. Analysis of variance for various soil characteristics obtained from four depths in ten different areas of each of five vegetation types of the salt-desert ranges of Utah

Source	D.F.	pH	Total soluble salts percentage	Saturation extract conductivity K x 10^3	Exchangeable Na me./100g.	Base exchange cap. me./100g.	Exchangeable Na percentage
				Mean Squares			
Type	4	1,369.44	0.543*	195.13*	8.15*	9.78	156.35
Type x area, Error (a)	45	1,638.86	0.185	57.08	2.85	9.38	87.10
Depth	3	1,545.86*	1.576**	792.10**	33.96**	5.38**	1,306.82**
Type x depth	12	882.86	0.040	15.81**	1.01*	0.59	28.06**
Error (b)	135	538.27	0.020	6.72	0.46	1.26	11.65
Between samples	50	717.98	0.021	6.55	0.41	0.92	90.47
Samples x depths	150	480.08	0.006	4.66	0.19	0.51	604.31

* Indicates significance at the 0.05 level.
** Indicates significance at the 0.01 level.

Table 8. (cont.)

Lime percentage	Permeability in./hr.	1/3 atmosphere percentage	15 atmospheres percentage	Exchangeable K me./100g.	Exchangeable K percentage	Calcium p.p.m.
			Mean Squares			
36.90	0.24	45.15**	14.50	0.57	3.40	215,320.22
45.67	0.13	4.10	10.69	0.68	20.90	110,366.64
62.10**	0.03	88.38**	11.68**	8.86**	239.15**	1,401,022.53**
8.72*	0.05	6.15	1.24	0.41**	14.35**	49,726.65
4.34	0.04	6.11	1.23	0.10	2.78	44,686.53
2.02	0.06	4.12	0.70	0.08	2.02	21,164.32
1.52	0.03	2.46	0.37	0.02	0.78	17,037.25

* Indicates significance at the 0.05 level.
** Indicates significance at the 0.01 level.

Table 8. (cont.)

Magnesium p.p.m.	Sodium p.p.m.	Potassium p.p.m.	Chloride p.p.m.	Sulfate p.p.m.	Carbonate p.p.m.	Bicarbonate p.p.m.
			Mean Squares			
319,412.10	33,156,313.6**	60,818.28	49,788,590.9	60,804,931.5	752.94	177,992.83
274,832.34	11,199,680.1	57,056.09	25,318,440.7	29,412,947.5	1,204.17	111,142.63
1,314,801.03**	95,975,848.8**	44,741.42**	181,292,806.8**	249,872,997.6**	2,485.48**	934,333.39**
80,695.10	3,016,556.5*	12,464.76*	6,765,143.9	5,966,741.3	397.56	82,968.49**
89,292.29	1,330,211.8	6,087.51	3,937,548.4	6,893,998.0	710.25	33,785.89
63,630.43	907,118.2	6,314.76	2,965,745.4	4,727,812.4	1,091.63	76,361.14
38,567.56	437,854.0	2,590.22	1,092,261.9	2,768,757.5	701.19	24,304.61

* Indicates significance at the 0.05 level.
** Indicates significance at the 0.01 level.

Table 9. Analysis of variance of soil characteristics of pooled A and B samples collected from four depths in ten different areas of each of five vegetation types of the salt-desert of Utah

Source	D.F.	pH	Total soluble salts percentage	Saturation extract conductivity K x 10^3	Exchangeable Na me./100g.
		Mean Squares			
Sagebrush					
Area	9	309.11**	0.692**	166.65	13.37
Depth	3	309.57	1.840**	868.08**	73.68**
Area x depth	27	62.02	0.204**	85.09**	8.88**
Between samples within areas and depths	40	92.30	0.076	27.14	2.38
Winterfat					
Area	9	155.64	0.40**	132.48**	14.66**
Depth	3	276.18*	1.80**	1,302.55**	57.60**
Area x depth	27	85.80**	0.11**	53.90**	4.22**
Between samples within areas and depths	40	26.05	0.03	17.78	0.83
Shadscale					
Area	9	884.14	1.36**	501.08**	31.31**
Depth	3	694.98	3.99**	2,291.07**	77.35**
Area x depth	27	1,077.17**	0.34**	145.13**	8.00**
Between samples within areas and depths	40	291.41	0.12	38.24	2.50
Nuttall's Saltbush					
Areas	9	552.06	2.57**	1,004.84	28.15**
Depths	3	146.08	6.65**	3,062.48	103.39**
Areas x depths	27	823.95**	0.51**	1,972.57**	6.71**
Between samples within areas and depths	40	412.57	0.12	69.11	1.69
Greasewood					
Areas	9	6,293.34	4.21**	998.78**	55.03**
Depths	3	3,650.48	3.08**	1,029.37**	64.04**
Areas x depths	27	4,502.37**	0.45**	113.16**	13.19**
Between samples within areas and depths	40	1,869.08	0.14	28.42	4.83

* Indicates significance to the 0.05 level.
** Indicates significance to the 0.01 level.

Table 9. (cont.)

Base exchange cap. me./100g.	Exchangeable Na percentage	Lime percentage	Permeability in./hr.	1/3 atmosphere percentage
		Mean Squares		
108.65**	429.24	484.03**	4.01	921.12**
27.29	3,586.58**	508.07**	0.70	314.71
18.09**	253.16**	46.84**	3.70**	231.17**
6.02	83.39	13.25	1.61	79.02
122.41**	783.54**	425.70**	0.43**	180.57**
4.17	2,516.45**	61.93	0.88**	122.97
6.41**	170.90**	36.06**	0.13**	46.18**
1.58	37.10	11.70	0.03	10.81
113.27**	661.34**	618.54**	1.77*	249.38**
15.28	2,330.51**	108.75	0.53	134.07
15.99**	160.90**	66.98**	0.62*	62.39**
3.94	46.06	14.34	0.16	18.99
75.72*	534.70**	167.04	0.67	203.33*
12.03	3,700.56**	90.25	0.05	216.87
24.92*	144.92**	99.72**	0.52**	75.69**
7.40	42.70	24.76	0.14	21.33
49.12	1,916.39	588.28**	0.16	495.43**
18.79	2,056.48	201.00	0.15	341.14*
45.18**	3,557.41**	81.55**	0.26	102.88**
12.05	130.45	13.02	0.92	13.63

* Indicates significance to the 0.05 level.
** Indicates significance to the 0.01 level.

Table 9. (cont.)

15 atmospheres percentage	Exchangeable K me./100g.	Exchangeable K percentage	Calcium p.p.m.	Magnesium p.p.m.
		Mean Squares		
222.17**	9.10**	166.25**	708.69	317,543.54
31.40	7.16**	145.71*	895.12	185,890.88
39.19**	0.10	44.68**	613.74**	177,298.19**
8.90	0.22	8.96	208.02	37,626.45
20.34**	3.38**	259.64**	152,895.20	6,846.74
4.28	6.22*	199.38*	1,015,006.88**	6,845.48
4.05**	1.48**	56.46**	179,448.48**	4,869.08**
1.00	0.24	14.71	30,202.88	1,017.29
213.04**	9.48**	304.44**	782,527.02	447,340.41
56.36*	28.56**	925.22**	6,744,286.18**	732,259.48
18.18**	1.57**	38.46**	844,792.23**	339,159.99**
2.89	0.40	13.62	154,900.95	84,937.00
56.04**	7.90**	165.30**	2,578,620.65*	549,832.02*
31.09	38.93**	1,099.68**	3,411,145.01*	570,726.48
16.32**	1.30**	32.93**	960,833.12**	239,979.64**
5.72	0.22	4.02	363,465.14	97,455.70
22.78	4.28	149.55*	1,295,596.76	52,598.98**
42.48	24.06**	595.35**	3,933,735.91**	80,249.75**
17.65**	2.27**	47.78**	974,701.20**	17,255.94**
4.22	0.72	13.12	147,365.19	3,129.94

* Indicates significance to the 0.05 level.
** Indicates significance to the 0.01 level.

Table 9. (cont.)

Sodium p.p.m.	Potassium p.p.m.	Chloride p.p.m.	Sulfate p.p.m.
	Mean Squares		
1,243,909.99	33,039.41**	12,906,073.70	13,368,837.30
10,363,173.61**	640.82	25,573,769.33*	29,687,815.51*
1,117,193.93**	7,586.18**	6,817,458.62**	8,839,295.59*
487,410.86	1,429.92	1,739,362.48	2,419,279.74
3,455,571.72**	16,318.49*	3,691,185.31**	4,351,159.94
9,262,503.74**	3,496.98	12,921,461.58**	18,726,085.43**
682,170.30**	5,468.14**	992,084.63**	2,775,406.60**
86,113.81	707.29	174,971.59	412,436.75
10,943,447.94**	32,653.89	25,125,678.90**	25,017,931.30
23,778,769.16**	26,957.57	53,120,415.80**	87,991,123.20**
2,947,971.16**	20,910.01**	8,490,105.05**	14,227,170.88**
589,350.58	7,981.85	2,009,366.55	2,392,107.91
18,641,283.60**	157,631.31**	35,583,481.50**	76,932,416.10**
44,378,448.40**	53,110.93**	88,858,364.30**	76,635,403.50**
4,123,316.84**	17,094.19**	11,294,760.81**	15,458,875.92**
1,324,591.35	5,571.58	3,306,003.63	5,798,148.65
21,630,108.30**	45,637.42**	49,285,784.30**	27,394,392.80
20,259,179.84**	15,394.17	27,879,371.43**	60,698,535.40*
1,892,777.74**	5,463.05**	3,653,585.42**	17,306,435.62**
290,883.76	1,916.10	573,459.66	5,270,633.10

* Indicates significance to the 0.05 level.
** Indicates significance to the 0.01 level.

Table 9. (cont.)

Carbonate p.p.m.	Bicarbonate p.p.m.
Mean Squares	
1,792.56	25,513.43
1,351.61	142,409.78
1,816.65**	83,602.32**
774.94	33,698.51
577.81	36,695.92
197.81	144,424.08*
631.61*	47,890.76**
292.81	16,604.52
1,170.45	88,576.34
502.28	619,326.08**
1,493.88*	86,114.00**
669.32	37,003.89
2,262.24	126,141.40
1,806.23	120,029.78
4,985.68**	63,943.80**
2,039.12	27,807.61
217.80	278,786.30
217.80	240,017.62
540.47**	163,724.23**
21.78	71,479.55

* Indicates significance to the 0.05 level.
** Indicates significance to the 0.01 level.

significantly from all others. Mean pH values were 8.2, 8.4, 8.3, and 8.1 for the 0 to 6, 6 to 18, 18 to 36, and 36 to 60 inch depths respectively. Therefore, these desert soils had significantly higher pH values at the 6 to 18 inch depth than at other depths.

There was wide variability in pH among the various areas occupied by sagebrush. This was the only type showing a significant difference between areas (Table 9). Thus, sagebrush soils were shown to be more variable for pH than soils under other types studied.

These data indicate that little variability in pH means existed between soils occupied by the five types studied. The pH of soils did not appear to be a significant factor in determining the distribution pattern of the species studied.

Total soluble salts, percentage: The total soluble salt content of the soil varied widely among the various vegetation types (Table 7) and this difference was significant (Table 8).

Soils under sagebrush averaged only 0.32 percent which was the smallest amount of soluble salts contained under any of the five types. Mean total soluble salt values for the other types were 0.36, 0.58, 0.89, and 0.83 percent for winterfat, shadscale, Nuttall's saltbush, and greasewood respectively (Table 7).

The total soluble salt content increased with depth under each type (Table 7). Under sagebrush the increase was from 0.05 percent in the first six inches to 0.71 percent at the 36 to 60 inch depth. Conversely greasewood average 0.29 percent in the top six inches and 1.19 percent at the 36 to 60 inch depth. Significant differences were found between all depth means.

Using the test for least significant range, it was found that significant differences in total soluble salts also existed between all type means (Tables 7 and 8). Significant increase in soluble salts with increased depth of soil was evident in each vegetation type (Tables 7 and 9).

The content of soluble salts also varied from area to area within each type and this variation was highly significant for all types (Table 9 and Appendix Tables 11 to 15). In addition there was marked variability in the content of soluble salts at the various depths in the different areas within each type. This variability was significant and was not peculiar to any individual type, as shown in Table 9.

These data indicate that sagebrush and winterfat are not generally found on soils with excessive soluble salt content. Greasewood and Nuttall's saltbush usually are indicative of much higher salt content.

It was found in comparing sample A with sample B within each type (Appendix Tables 6 to 10) that A and B variances were homogeneous for all types except sagebrush. In the sagebrush type, the variability in total soluble salts was significantly greater in the center of the areas than near the periphery. This variability within sagebrush is contrary to expectation and no explanation is apparent.

In many cases it was found the five types studied were growing on soil with an equal soluble salt content (Table 7 and Appendix Tables 11 to 15). Figure 16 shows the range of total soluble salts and the amount of overlap between the five types. All types were found to occur on soils with a total soluble salt content between 0.23 and 0.72 percent. Within this range some factor or factors other than total soluble salts act either alone or in combination with soil salt as the limiting factor in determining what vegetation type will occupy the area.

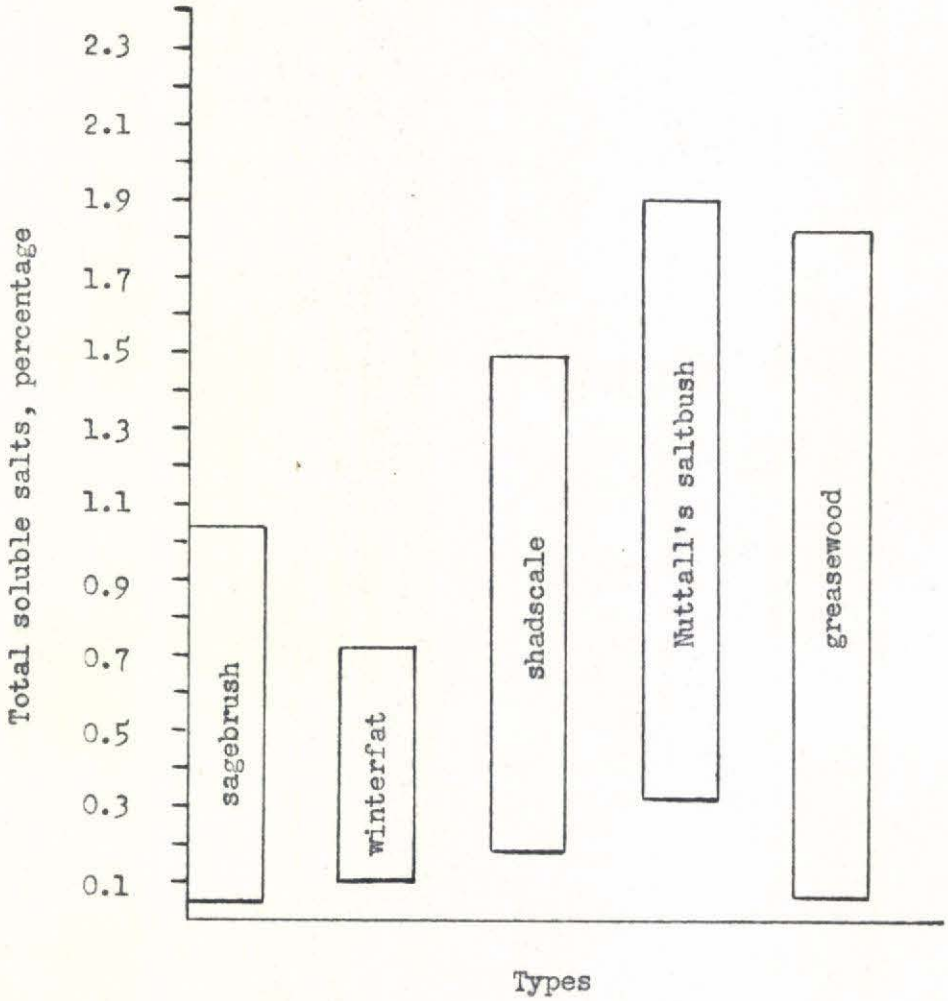

Figure 16. Range of total soluble salt content of soils under five vegetation types on the salt-desert of Utah.

The high variability between areas as shown in Table 9 suggests that each of the five plant species studied has either a broad range of tolerance for soluble salt or that each species is composed of various ecotypes, each with its own tolerance range. Ecotypic variation would seem to be a plausible explanation for the wide variability between areas supporting the same vegetation type. This study, however, was not designed to determine these genetic variations.

<u>Saturation extract conductivity, millimhos per cubic centimeter</u>: Saturation extract conductivity is a measure of soluble salts in the soil. It is believed more meaningful than the total soluble salt percentage as equal quantities of different salts do not give the same saturation extract conductivity.

The saturation percentage of a soil is approximately four times the 15 atmosphere percentage (1). The 15 atmosphere percentage is an approximation of the percent moisture in the soil at the permanent wilting point. The saturation percentage is approximately two times the 1/3 atmosphere percentage (1), which represents the field carrying capacity of a soil. Therefore, the concentration of a soil solution when the soil is at field carrying capacity is approximately twice that expressed in the saturation extract conductivity reading. Likewise, a soil nearing the wilting percentage would have a soil solution approximately four times as concentrated as that expressed in the saturation extract readings. Tables are shown in Agriculture Handbook No. 60 (1) for converting saturation extract conductivity to total soluble salt percentage in the soil.

The saturation extract conductivity of the soil varied greatly among the five vegetation types studied (Table 7). These differences were shown to be significant by analysis of variance (Table 8). The test for least significant range shows differences between all type means to be of sufficient magnitude to be significant. The same is true for all depth means (Table 8).

The soils under sagebrush had the lowest saturation extract conductivity reading with 6.9 millimhos per c.c. Winterfat, shadscale, greasewood, and Nuttall's saltbush followed in order with values of 9.2, 13.8, 15.4, and 19.3 millimhos per c.c. respectively.

Since the saturation extract conductivity values are closely related to total soluble salts in the soil they also could be expected to increase with depth. As shown in Table 7, this was true. The saturation extract conductivity values varied from 1.0 in the surface six inches of soil under sagebrush to 15.6 at the 36 to 60 inch depth. On the other hand, soils under Nuttall's saltbush varied from 4.4 in the 0 to 6 inch depth to 31.9 millimhos per c.c. at the 36 to 60 inch depth.

An increase in saturation extract conductivity with soil depth was evident in all vegetation types (Table 7). This increase was significant (Table 8).

While the saturation extract conductivity values were variable from area to area within each type, the variation between areas was of sufficient magnitude to be significant only in winterfat, shadscale, and greasewood (Table 9 and Appendix Tables 11 to 15). The saturation extract conductivity values at various depths differed significantly even between areas of the same type (Table 9).

When A samples were compared with B samples within each type (Appendix Table 6 to 10) it was found that A and B samples were homogeneous for saturation extract conductivity within all types except sagebrush. In areas occupied by sagebrush the B samples were more variable than the A samples. This indicates greater variability in the center of the sagebrush areas then near their perimeters. No explanation for this variability is apparent.

Data in Table 7 and Appendix Tables 11 to 15 show a considerable overlap between types for saturation extract conductivity tolerance. The range of saturation extract conductivity values for each type are shown in Figure 17. All were growing normally on soils with saturation extract conductivity values between 6.2 and 15.7 millimhos per c.c. Sagebrush and winterfat are shown to have comparable ranges of tolerance for saturation extract conductivity. Shadscale and greasewood have higher ranges. Nuttall's saltbush is shown to be growing on soils with much higher saturation extract conductivity than the other types.

These data indicate that sagebrush and winterfat have a narrower tolerance range for saturation extract conductivity than shadscale, Nuttall's saltbush, and greasewood.

Exchangeable sodium, milliequivalents per 100 grams of soil and exchangeable sodium percentage: Exchangeable sodium can have profound effects on the physical and chemical properties of soil. The effects of a given amount of exchangeable sodium on a soil will vary with such factors as soil texture, surface area of the soil particles, type of clay in the soil, potassium status, and the organic matter content of the soil.

Plant species vary in the amount of sodium they can tolerate. The effects of sodium on plants are not well known (1). A high amount on the exchange complex of the soil may cause deflocculation and puddling which, in turn, decreases soil aeration and

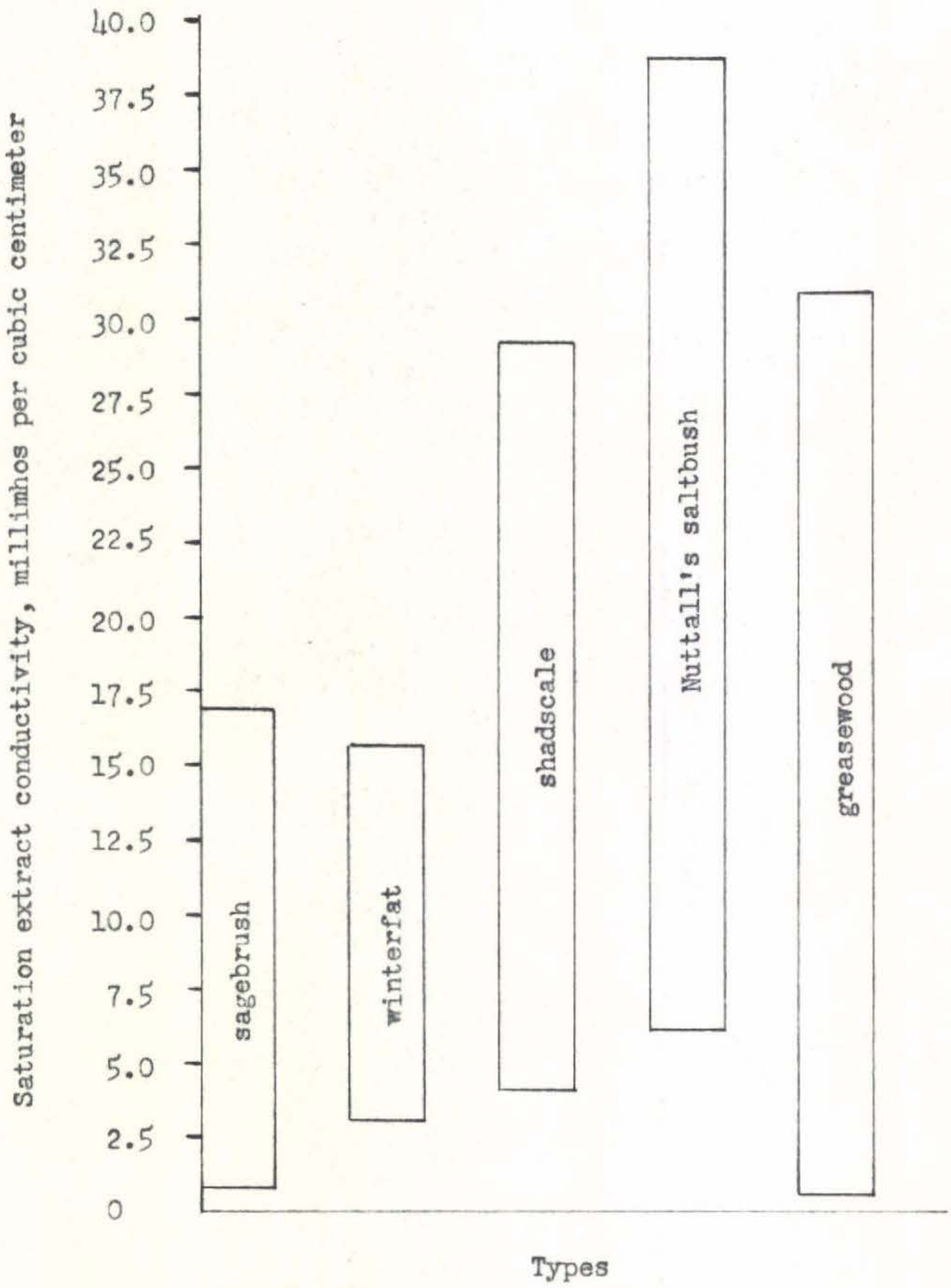

Figure 17. Range of values for saturation extract conductivity of soils under five vegetation types on the salt-desert of Utah.

permeability and may decrease water availability. An exchange complex 40 to 50 percent sodium saturated may cause nutritional deficiencies in some plants (1).

A considerable amount of variability in exchangeable sodium among soils under the different vegetation types is shown in Table 7. These differences in exchangeable sodium are of sufficient magnitude to be significant as shown by averages and limits of error for each type (Tables 7 and 8). There also appeared to be a considerable amount of variability in exchangeable sodium percentage between types (Table 7). This variability, however, was not great enough to show statistical significance (Table 8).

Soils under winterfat had the smallest amount of exchangeable sodium as well as the lowest exchangeable sodium percentage (Table 7). Winterfat soils had 2.5 milliequivalents of exchangeable sodium per 100 grams as compared to greasewood soils which contained 4.8. Soils under winterfat also contained the lowest and greasewood soils the highest mean exchangeable sodium percentages, with 16 and 26 percent respectively.

Both the amount and percentage of exchangeable sodium increased with depth under all vegetation types (Table 7). Under winterfat the exchangeable sodium increased from 0.4 me./100 grams at the surface to 4.0 me./100 grams at the three to five foot depth. Under greasewood the exchangeable sodium increased from 2.2 in the surface six inches of soil to 7.2 me./100 grams at the three to five foot depth. The exchangeable sodium percentage varied from 2 to 26 percent under winterfat to 11 to 31 percent under greasewood.

The test for least significant range indicated that all type means and depth means were sufficiently variable in amount of exchangeable sodium to be significantly different. Depth means for exchangeable sodium percentage also varied sufficiently to be significant.

The increase in exchangeable sodium with depth is to be expected. Sodium salts are highly soluble and the sodium ion also is easily replaced on the soil exchange complex; hence, it leached from the surface soils and accumulated at lower depths.

The amount of exchangeable sodium was variable from area to area within each type and this variation was highly significant for all types except sagebrush (Table 9 and Appendix Tables 11 to 15). The amount of sodium in the soil differed significantly even between depths of each type (Table 9).

The exchangeable sodium percentage of the soils also varied from area to area within each type. This variability was highly significant for all types except sagebrush and greasewood (Table 9 and Appendix Tables 11 to 15). A highly significant variability in exchangeable sodium percentage between depths was shown for all types except greasewood (Table 9).

These data indicate that sagebrush and winterfat are not generally found on soils with a high exchangeable sodium content or a high exchangeable sodium percentage. Greasewood and Nuttall's saltbush were found on the soils with highest sodium values.

The A and B samples within areas of each type are compared in Appendix Tables 6 to 10. These data indicate that the A and B samples of each type are homogeneous and that they represent random distribution of variance of the entire population being sampled.

There was a wide variability between types in amount of exchangeable sodium. Considerable variation also was shown to exist between areas within types. The ranges for exchangeable sodium for each type are shown in Figure 18. A considerable degree of overlap of these ranges is readily apparent. Figure 18 illustrates that all five species may occur in pure stands on soils containing 1.1 to 4.6 milliequivalents of exchangeable sodium per 100 grams of soil. Greasewood is shown to have a range of values that includes the entire range of the other four types. This suggests that while greasewood does not require high concentrations of sodium it is physiologically adapted to tolerate high amounts.

The maximum amount of exchangeable sodium a type can tolerate appears to affect its distribution on the salt-deserts. Plants of a certain species or ecotype are genetically preadapted to tolerate certain maximums in their environment. When these maximums are reached this plant is excluded and other species or ecotypes adapted to tolerate the environment occupy the area. Within the range of exchangeable sodium where the five types are all adapted some other factor or factors play the critical role in the determination of which species will occupy the area.

Base exchange capacity: The base exchange capacity of a soil, or more precisely the cation exchange capacity, refers to the milliequivalents of cations per 100 grams of soil which can be held to the soil particles by surface forces, and can be replaced by other cations (47). The base exchange capacity has a very pronounced effect on the physical and chemical properties of a soil (1). Various clay minerals and organic matter are the surface-active soil constituents that furnish the basis of the exchange complex.

The base exchange capacity of the soils under the five vegetation types studied was similar (Table 7). Analysis of

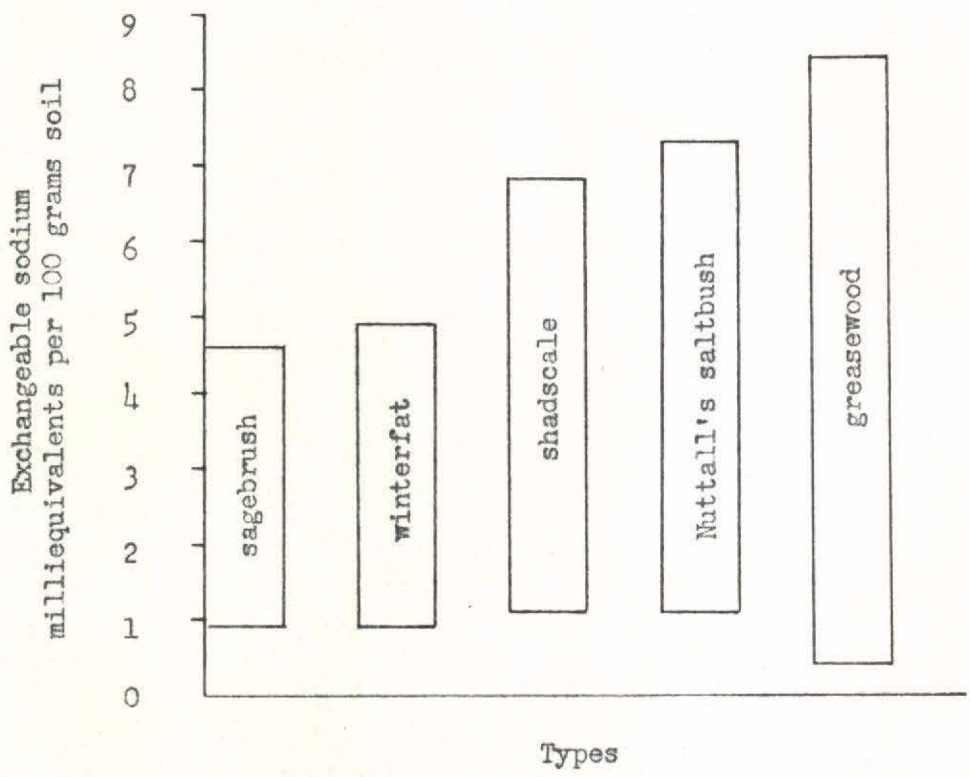

Figure 18. Range of exchangeable sodium content of soils under five vegetation types on the salt-desert of Utah.

variance (Table 8) indicates that significant differences in base exchange capacity do not exist between types.

A significant variation in base exchange capacity is shown to exist between soil depths (Table 8). The test of least significant range shows all depth means for base exchange capacity to vary significantly. The 6 to 18 inch depth was highest except under winterfat and exchange capacity decreased at greater depths for all types except winterfat (Table 7). The significant difference in base exchange capacity between depths is undoubtedly a result of the soil forming processes. The colloidal clay fraction of the soil tends to leach from the surface layer and to accumulate in the subsoil and base exchange capacity tends to correlate with clay accumulation.

The base exchange capacity of the soils was variable from area to area within types (Appendix Tables 11 to 15). This variability between areas was significant in all types except greasewood . (Table 8). A significant area x depth interaction was also shown for all types (Table 8).

The variance between samples A and B for each type (Appendix Tables 6 to 10) was not significant. This was expected since there is no significant difference in base exchange capacity between soils occupied by the five vegetation types studied. Base exchange capacity of soils does not appear to be a critical factor in the distribution pattern of these types.

Exchangeable potassium; milliequivalents per 100 grams soil and exchangeable potassium percentage: Limited amounts of potassium are required for the nutrition of plants. High concentration in the soil solution are rare but toxic effects of potassium on plants have been reported (1).

Little variation in amount of exchangeable potassium was noted between vegetation types (Table 7), and the differences were not significant (Table 8). Also, variability in exchangeable potassium percentage between types was not of sufficient magnitude to be significant (Tables 7 and 8).

Highly significant differences between depth means for both amount of exchangeable potassium and exchangeable potassium percentage are shown in Table 8. Potassium was highest in the surface soil in all types except sagebrush. The potassium content was considerably higher in the 6 to 18 depth and comparatively low in the 0 to 6 inch depth under sagebrush (Table 7).

Variation in amount of potassium between areas occupied by the same type was highly significant except under greasewood (Table 9). Variability between depths is also indicated for all types studied. A significant area x depth interaction (Table 9) indicates inconsistent variability in potassium with depth between areas in all types except sagebrush.

The exchangeable potassium percentage also varied considerably from area to area within types. This variation was significant for all types (Table 9). Also, variation between depths was significant for the five types studied.

When sample A was compared with sample B (Appendix Tables 6 to 10) no significant variability in potassium was found to exist between the periphery and the center of areas occupied by any of the types.

Potassium is apparently not a critical factor in determining desert plant distribution

Lime, percentage: Soils of arid regions are usually calcareous. Because of low precipitation rates and subsequent limited leaching, the lime content of the soil remains at a relatively high level. Lime is very important as it serves as a source of soluble calcium to replace some of the exchangeable sodium. Calcium is important in maintaining favorable structure in the soil.

The lime content of soils under the five vegetation types was remarkably uniform (Tables 7 and 8). However, a highly significant difference in lime content occurred between depths means. Such variation is common because lime is leached from the surface soil and accumulates in the lower depths. A significant type x depth interaction (Table 8) suggests that lime content between depths is not consistant over all types.

Samples A compared with samples B (Appendix Tables 6 to 10) show the variances for lime percentage to be homogeneous for A and B samples within each type.

There were highly significant variations in lime content of soils between areas within all types except Nuttall's saltbush (Table 9). A significant difference between depths occurred under sagebrush only (Tables 7 and 9).

Variations in lime content between soils occupied by the five types appears to be relatively minor and inconsistant. From these data it appears that the lime percentage of the soil plays an insignificant role in determining plant distribution on the salt-deserts of Utah.

Permeability and infiltration rates, inches per hour: The permeability of a soil refers to the readiness with which it transmits or conducts water (1). Permeability may be affected by texture, structure, stability of aggregates, exchangeable sodium, organic matter content, and many other factors. Because of the limited amount of precipitation on the salt-deserts, permeability rate is especially important.

Infiltration refers to the rate of entry of water into the soil. The rate of infiltration is directly related to surface texture, structure, organic matter, litter, and exchangeable sodium. Surface runoff is excessive on soils with low infiltration rates. Where runoff is excessive, water is lost which otherwise would enter the soil and be available for plant growth.

There appeared to be considerable variation in the permeability of soils under the various types studied (Table 7). However, differences among types or depths were not of sufficient magnitude to be significant (Table 8).

Data in Table 9 indicates that differences in permeability rates among areas within some of the types was extremely variable. Significant differences between areas were shown for soil under winterfat and shadscale. A significant difference in soil permeability between depths was noted only for winterfat. Under winterfat soils at lower depths were less permeable than at shallower depths.

When A and B samples were compared (Appendix Tables 6 to 10) they were found to be homogeneous for all types except sagebrush. In the sagebrush type, the variation was much greater near the perimeter of the areas than in the center. Variation within areas would normally be expected to increase as the adjacent types were approached.

Limited data from field infiltrometer studies (Table 10) showed a great amount of variation in infiltration rate of soil within

Table 10. Infiltration rates for soils under five vegetation types on the salt desert of Utah

Type and Area	Rate in./hr. 1/
Sagebrush	
8a	2.0
8b	1.0
13a	1.0
13b	1.4
14a	2.4
14b	1.4
Mean	1.5
Winterfat	
6a	1.8
6b	1.2
7a	1.6
7b	1.6
Mean	1.6
Shadscale	
3a	0.8
3b	0.4
4a	1.3
4b	1.0
Mean	0.9
Saltbush	
9a	1.8
9b	1.1
10a	2.0
10b	4.4
Mean	2.4
Greasewood	
19a	0.4
19b	0.6
20a	1.2
20b	0.9
Mean	0.8

1/ These data do not strictly indicate infiltration rates as the amount of lateral flow was considerable. They do indicate the relative rate of entry of water into the soils under the five vegetation types.

each type. Mean infiltration rates for each type were also divergent. Average flow patterns for each type are shown in Figure 19.

Both the infiltration and permeability rates were low under greasewood (Tables 7 and 10). The permeability and infiltration rates for the other four types were inconsistant. These data indicate that greasewood often is found on soils which take in and conduct water at a slow rate. In the other types these factors are variable and seemed not to be decisive in determining vegetation distribution.

<u>One-third atmosphere percentage</u>: The one-third atmosphere percentage is a laboratory approximation of the percent of water retained in a soil at field capacity. It has a close relationship to texture and organic matter content of the soil. Salt concentrations of the soil solution vary with the amount of water held. The maximum percent water that can be retained by a soil then is of extreme important to plant growth.

Data presented in Tables 7 and 8 show that the 1/3 atmosphere percentage was significantly different between soils occupied by the five vegetation types. A highly significant difference also was shown to exist between depths.

Soils under sagebrush were shown to have the highest 1/3 atmosphere percentage and winterfat the lowest (Table 7) with 28.7 and 23.7 percent averages respectively. The 1/3 atmosphere percentage tended to increase with depth. Sagebrush soils varied from 25.6 percent in the surface six inches to 31.9 percent at the five-foot depth, while winterfat varied from 20.6 percent in the surface soil to 26.2 percent at the lowest depth. The increase in 1/3 atmosphere percentage with depth was apparently due to a textural change in

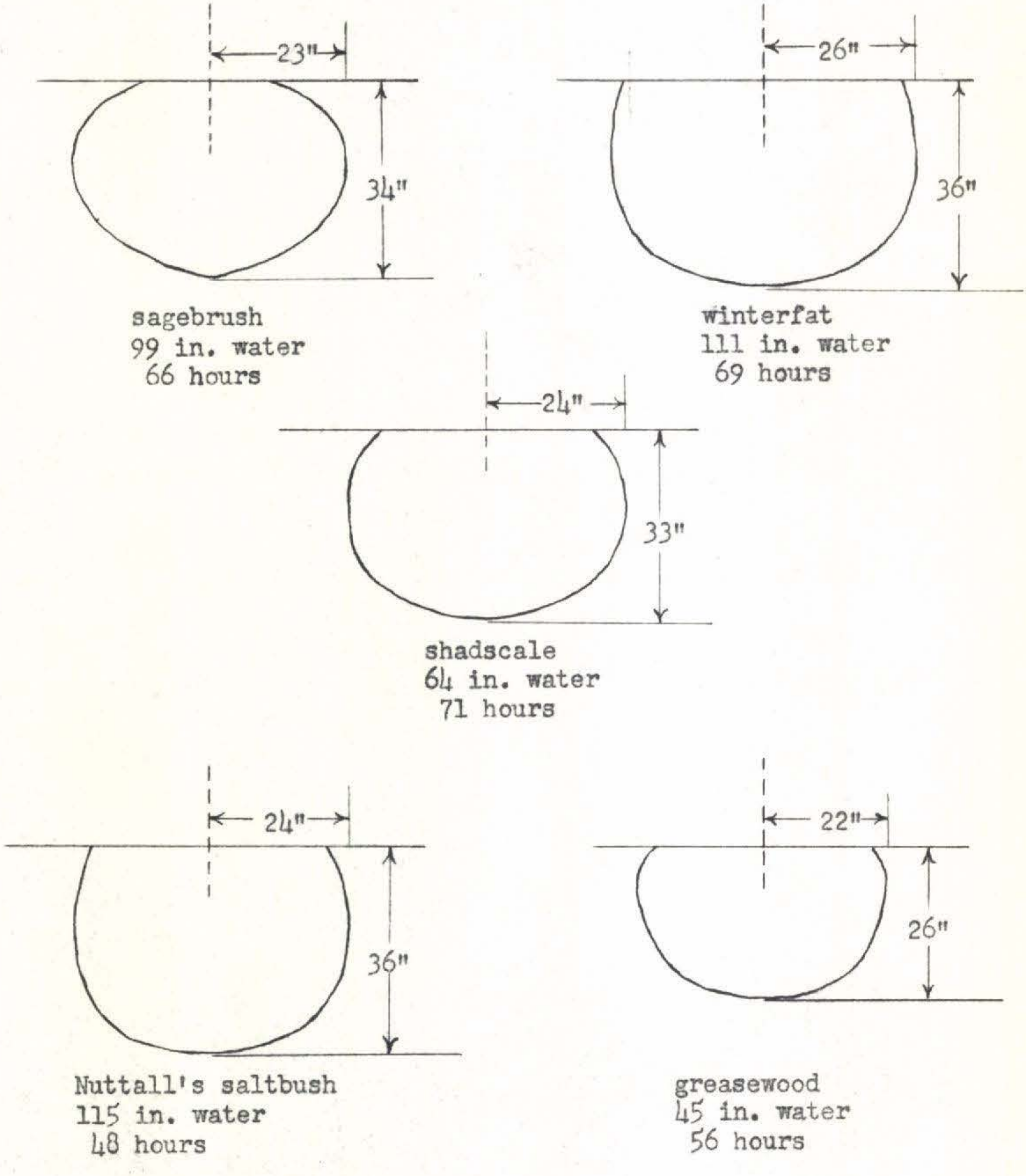

Figure 19. Mean wetted perimeter showing soil-water flow pattern under infiltrometers in five vegetation types on the salt-desert ranges of Utah.

the soil profile.

A significant variation in 1/3 atmosphere percentage between areas within each type was shown (Table 9). An inconsistant variation between area and depth was indicated by a highly significant area x depth interaction for each type. This variation indicated that soils of different areas of the same type did not have similar 1/3 atmosphere percentages at the same depths.

A comparison of the A and B samples (Appendix Tables 6 to 10) shows that they are homogeneous for all types. Thus, A and B samples each represent random variation within the population being sampled.

The mean values for 1/3 atmosphere percentages of all types and areas are shown in Appendix Tables 11 to 15. The range in 1/3 atmosphere percentage for each type is shown in Figure 20. All types studied are shown to occur in pure stands on soils with a 1/3 atmosphere percentage between 20.9 and 26.7 (Figure 20 and Appendix Tables 11 to 15). Sagebrush, shadscale, Nuttall's saltbush, and greasewood were found on soil with a 1/3 atmosphere percentage exceeding 26.7 while sagebrush, winterfat, shadscale, and greasewood were found on soils whose 1/3 atmosphere percent was less than 20.9. Sagebrush, shadscale, and greasewood show wide variation. Winterfat and Nuttall's saltbush have narrower ranges (Figure 20).

Soil texture is closely related to the 1/3 atmosphere percentage. Other things being equal, heavier textured soils have a higher 1/3 atmosphere percentage than lighter textured soils. Soils under winterfat, shadscale, Nuttall's saltbush, greasewood, and sagebrush follow in order for increasing moisture holding capacity. Data presented indicate that the 1/3 atmosphere percentage or field capacity of the soil is an important factor in the distribution of these plants.

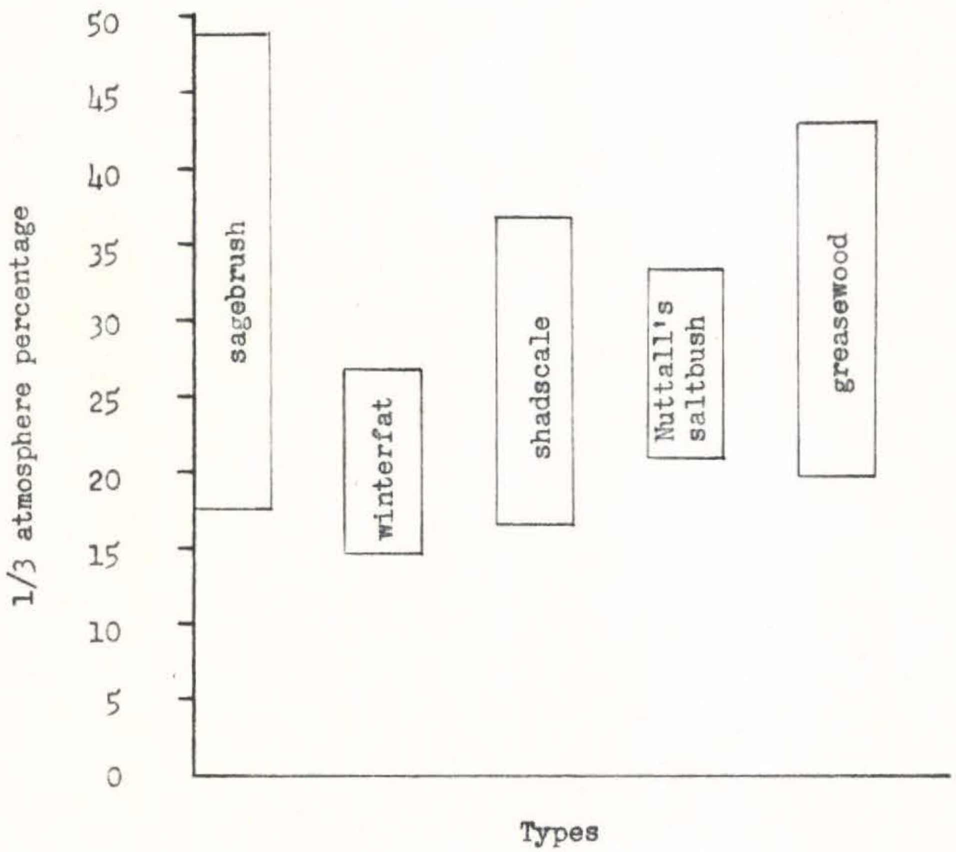

Figure 20. Range of 1/3 atmosphere percentage of soils under five vegetation types on the salt-desert of Utah.

Fifteen atmospheres percentage: The 15 atmosphere percentage value is an approximation of the amount of moisture retained in the soil at the permanent wilting point. The salt concentration of the soil solution increases as the soil moisture decreases. The 15 atmosphere percentage varies with soil texture. Generally speaking the lighter textured soils have the lower 15 atmospheres percentage.

Some variability in 15 atmospheres percentage was shown for soils under the five vegetation types (Table 7). However, this variation was not of sufficient magnitude to be statistically significant (Table 8).

A highly significant difference in 15 atmospheres percentage between areas was shown for all types except greasewood (Table 9). A significant difference in 15 atmospheres percentage between depths was shown only under shadscale. Inconsistant variations between areas and depths were indicated by the highly significant area x depth interaction shown in Table 9.

The A and B samples (Appendix Tables 6 to 10) were homogeneous. Thus, no significant variation in 15 atmospheres percentage existed within areas occupied by each of the vegetation types.

The lack of variation in 15 atmospheres percentage between types indicated that the permanent wilting point of the soil was not a critical factor in determining the districution pattern of the five types studied.

Soluble sodium, parts per million: The adverse affects of sodium on soils have been discussed previously. Soluble sodium in the soil is readily available to react on the soil exchange complex. Sodium may be present in the soil in various salt forms. Sodium chloride is the most common in the salt-deserts of Utah.

Soluble sodium varied greatly between the five vegetation types studied (Table 7). These variations were of sufficient magnitude to be significant (Table 8).

The soils under sagebrush contained the smallest amount of soluble sodium and soils under Nuttall's saltbush the largest, with 719 and 2,215 p.p.m. averages respectively (Table 7). Winterfat, shadscale, and greasewood soils averaged 901, 1,429, and 1,936 p.p.m. respectively.

Soluble sodium in the soil is subject to leaching. Therefore, differences in sodium content would be expected with depth. Analysis of variance (Table 8) shows that such a difference existed between depth means.

A highly significant difference in soluble sodium exists between areas within all types except sagebrush (Table 9). Highly significant differences between depths are also shown within all types. Inconsistant variations between areas and depths within each type were shown by the highly significant depth x area interaction (Table 9). This interaction indicated that the soluble sodium content at a given depth varied among areas even within the same types.

The A and B samples within areas of each type are compared in Appendix Tables 6 to 10. Variances for these samples were homogeneous in all types except sagebrush. The large variance of the A samples of sagebrush indicates that as expected the soluble sodium content of soils in those areas became more variable as the edges of the areas were approached.

The soluble sodium content in each area of each type is shown in Appendix Tables 11 to 15. These tables indicate that considerable variation existed in soluble sodium within areas of each type.

Shadscale, Nuttall's saltbush, and greasewood have wide ranges of tolerance (Figure 21). Sagebrush and winterfat have narrow ranges of tolerance, neither being found on soils with a high sodium content. Within the range of 362 to 1,526 p.p.m. soluble sodium each species was able to occur in pure stands (Figure 21). Within this range other factors must determine distribution of these five species.

Soluble calcium, parts per million: High concentrations of calcium in the soil solution effect various plant species in different ways (47). A specific calcium toxicity for some species has been reported (1). Soluble calcium in the soil is available to replace sodium on the exchange complex. It is also beneficial in maintaining soil structure.

Data presented in Table 7 indicate that relatively little variability exists in soluble calcium content between soils occupied by the five species. Analysis of variance (Table 8) shows these differences to be too small to be significant.

An overall increase in soluble calcium with depth is shown (Table 7). Analysis of variance (Table 8) shows this increase to be highly significant. The test for least significant range also shows all depth means to be significantly different. The soluble calcium average of sagebrush soil varied from 74 p.p.m. in the surface six inches to 517 p.p.m. at the five foot depth. Soils under Nuttall's saltbush varied from an average of 306 in the surface six inches to 1,198 p.p.m. at the five foot depth.

No significant amount of variation was shown to be present from area to area in any type except Nuttall's saltbush (Table 9). Significant differences between soil depths were also shown within each

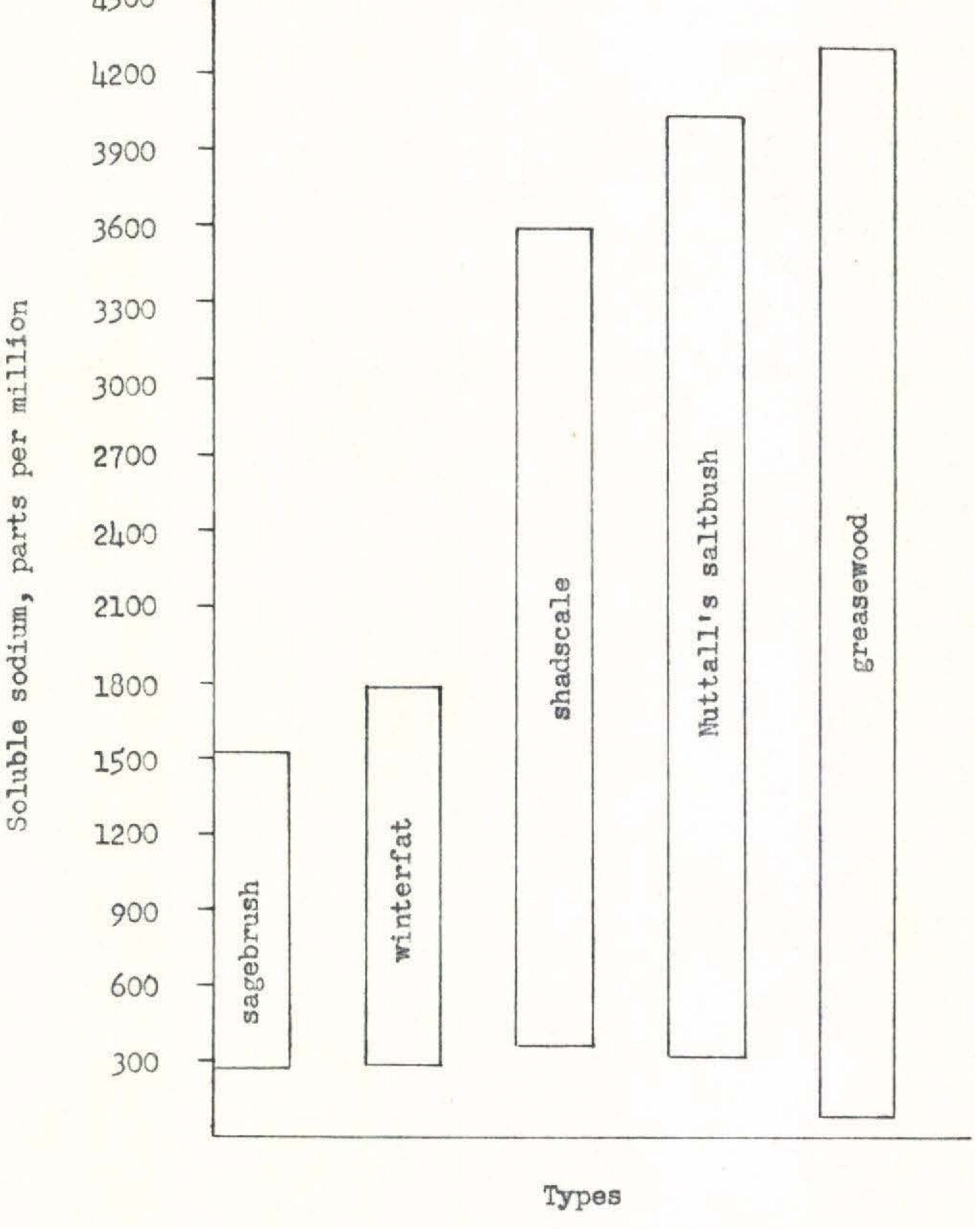

Figure 21. Range of soluble sodium content of soils under five vegetation types on the salt-desert of Utah.

type except sagebrush. Inconsistant variability between areas and depths was indicated by the highly significant area x depth interaction in all types.

When A samples were compared with B samples (Appendix Tables 6 to 10) they were found to be homogeneous in soluble calcium content under all types.

Data presented indicate that soluble calcium is a relatively constant factor in the soils of the salt-desert ranges of Utah and does not appear to be a limiting factor in the distribution of the five species studied. Soils of the salt-desert of Utah are mostly of sedimentary or alluvial origin and are calcareous in nature. Thus, the uniformity in calcium content of the soil between types is a reflection of the parent material.

Soluble magnesium, parts per million: Magnesium salts may be more toxic to plants than isosmotic concentrations of other neutral salts. Relatively high amounts of calcium may do much to alleviate the toxic effects of magnesium (1).

Mean values for soluble magnesium in soils under the five types are shown in Table 7. Magnesium content of the soil varied insignificantly between types (Table 8).

A significant increase in soluble mangesium occurred with increased depth of soil (Table 7 and 8).

Variation in soluble magnesium was insignificant from area to area in all types except Nuttall's saltbush and greasewood (Table 9). Significant differences between depths within areas occurred only under greasewood.

A comparison of A and B samples (Appendix Tables 6 to 10) showed large variation in magnesium between the center and periphery of areas occupied by sagebrush, shadscale, and Nuttall's saltbush. In these types the soils of the center portion of the areas varied significantly more than the soils near the periphery of the areas. No explanation for this variation is apparent.

The soluble magnesium content of the soils is apparently a reflection of the parent materials. Data collected give no indication that the magnesium content of the soil is critical in determining the distribution pattern of the five vegetation types studied.

Soluble potassium, parts per million: Toxic effects of high concentration of potassium in the soil solution have been reported (1). Evidence also has been presented which indicates that potassium toxicity can be reduced by increased calcium in the soil (1).

The soluble potassium content of the soils varied relatively little (Table 7). The analysis of variance presented in Table 8 shows no significant difference between soils occupied by the five types studied. However, a highly significant difference in potassium content between soil depth means was evident. Mean soluble potassium content varied from 96 p.p.m. under winterfat to 170 p.p.m. under Nuttall's saltbush.

The soluble potassium content of soils varied significantly from area to area in all types except shadscale (Table 9). A significant variation in potassium content with depth was found under Nuttall's saltbush only.

The A and B samples for all types are compared in Appendix Tables 6 to 10. These comparisons showed that no significant variation occurred between the center of the areas and the peripheries.

Similar to the other cations, the soluble potassium content of the soil may well be a reflection of the parent materials. These data indicate that potassium is not a limiting factor in the distribution of the five species.

Soluble chloride, parts per million: The uptake of anions from the soil solution is not decreased on saline soils (1). Data have been presented which indicate chloride toxicity to some plants (1 and 21).

The chloride content of the soil varied insignificantly between vegetation types (Tables 7 and 8). A highly significant increase in chlorides with depth was shown for all types (Tables 7 and 8). This increase with depth indicates that chloride salts are subject to leaching.

Variability from area to area was highly significant within all types except sagebrush (Table 9). A significant difference in chloride content also was shown between depths within each type studied.

A comparison of A and B samples (Appendix Table 6 to 10) within areas showed them homogeneous for all types except sagebrush. The B samples of sagebrush had significantly greater variance than the A samples. No explanation is available as to why the center of the areas under sagebrush had a more variable soluble chloride content than soils near the perimeter.

These data indicate that while the chloride content of desert soils is variable it does not vary significantly between soils occupied by the five species studied. The soluble chloride content of soils does not appear to be an important factor in the plant distribution pattern.

Soluble sulfate, parts per million: High concentrations of sulfates in soils have been related to decreased calcium absorption in plants (1). Sulfate is present in the salt-desert soils in various forms.

Values for soluble sulfate content of soils under each of the five types are shown in Table 7. Some variation between types was evident but this variation was not significant (Table 8).

A highly significant variation in sulfate between depths was shown in Table 8. Depth means were all significantly different when tested for least significant range.

Little variation was shown from area to area within types (Table 9). Only Nuttall's saltbush was shown to have a significant variation in sulfate content between areas (Table 9). All depths however, were shown to vary significantly in sulfate content within each type.

The sulfate contents of A and B samples within areas of each type are compared in Appendix Table 6 to 10. These tables showed A and B samples were homogeneous except under greasewood. The B samples in the greasewood type showed significantly more variability than the A samples. This indicated that the interior portions of areas occupied by greasewood were more variable than the peripheries.

Sulfate salts are abundant in salt-desert soils. However, the content did not appear to vary sufficiently between vetetation types to be considered critical in determining plant distribution.

Soluble carbonate, parts per million: A high degree of alkalinity is associated with the carbonate ion and some authors consider this ion to be highly toxic to plants (1). Since the carbonate ion bears such a close relationship to pH it is difficult to determine whether plant responses are due to the carbonate or the hydroxyl ion. Abundant carbonate ions in the soil are associated with high exchangeable sodium (47).

Carbonates were low in all soils studied (Table 7). The analysis of variance shown in Table 8 indicated no significant difference in carbonate content under the five types. A highly significant variation in carbonate content with depth indicated that carbonate content was closely related to soil depth (Table 8).

There was little variation in carbonate shown from area to area within any type (Table 9). Significant area x depth interaction showed that variation between depths within areas was inconsistant in all types.

The A and B samples within areas of each type were compared in Appendix Tables 6 to 10. Only in sagebrush areas were the A and B samples homogeneous. In winterfat, shadscale, and greasewood the B samples were shown to be significantly more variable than the A samples. This denotes greater variation in carbonate content in the centers of the areas than near the perimeters. The reverse was true of Nuttall's saltbush. Variability was expected to increase from the center of an area toward the perimeter.

Since the carbonate content was low and not significantly different between types, the carbonate ion is not considered a limiting factor in the distribution of the five species.

Soluble bicarbonates, parts per million: While the bicarbonate ion is usually present in soil solutions the amount that can remain in solution varies with pH, CO_2 pressure, and soil temperature (47). The bicarbonate ion has specific toxicity for many plants and may affect the intake and metabolism of plant nutrients (1).

The bicarbonate ion varied insignificantly either within or between types (Tables 7 and 8). A highly significant difference, however, was shown between soil depths. Also, a highly significant type x depth interaction (Table 8) indicated that the bicarbonate ion content of soils is not the same at comparable depths for all of the types studied. Variation in bicarbonate content from area to area was insignificant in any type (Table 9).

A comparison of A and B samples within areas of each type (Appendix Tables 6 to 10) showed the two samples homogeneous for all types except shadscale. Shadscale had significantly higher variation in the A samples than the B samples. Greater variation was expected near the perimeter of an area than in the center.

These data showed the bicarbonate ion to be relatively low in soils of the salt-desert. It did not appear to have a significant bearing on the distribution of the five species.

Plant analysis: There was considerable variation in the chemical content of the five species studied (Table 11). Analysis of variance (Table 12) showed highly significant differences between species for each of the components. Only soluble soldium was significantly different between soils occupied by the five plant species (Table 8). The low variability in ionic content of soil and the high variability in ionic content of the plant material suggests that the plant types have differential rates of absorption for the various ions in the soil. The amount of sulfur, calcium, magnesium, sodium, potassium, and chloride in the soil did not appear to affect the chemical content of the shrubs growing upon them. Therefore, the chemical analysis of plant tissue appears to furnish little information for use in deter-

Table 11. Average chemical content of current year's growth of five shrub species on the salt-desert ranges of Utah 1/

Species	Sulfur	Calcium	Magnesium	Sodium	Potassium	Chloride
	Percent	Percent	Percent	Percent	Percent	Percent
Sagebrush	0.24	1.16	0.47	0.09	1.49	0.17
Winterfat	0.22	2.55	0.71	0.08	1.12	0.17
Shadscale	0.36	2.51	0.66	6.03	2.90	4.98
Saltbush	0.42	3.11	1.36	2.35	4.68	2.75
Greasewood	0.37	1.35	0.45	7.02	1.79	1.96

1/ Average of current year's growth collected from 10 areas, for each species during the summer of 1954.

Table 12. Analysis of variance of chemical constituents of five vegetation types found on the salt-desert ranges of Utah

Sources of variation	Degrees of freedom	Mean Square					
		Sulfur	Calcium	Magnesium	Sodium	Potassium	Chloride
Total	49						
Species	4	0.0725**	7.489**	1.367**	106.72**	20.75**	80.55**
Areas	9	0.0100	0.355	0.014	3.68	1.88	0.46
Species x Areas	36	0.0050	0.300	0.015	3.12	0.74	3.77

**Significant to the 0.01 level

mining the distribution pattern of plants. Plant chemistry does not seem to be an accurate index to soil requirements of the plant nor to the nature of the soil upon which the plant grows.

Alterne studies: Data obtained from analyses of soil samples collected from each end of trenches excavated across alternes are presented in Table 13. These data are extremely variable and somewhat inconsistent. Alterne data were too limited to justify statistical analyses, but they tend to point out the extreme variability of soil conditions on the salt-desert.

Analysis of the soil samples collected from each end of a trench across a Nuttall's saltbush-shadscale alterne failed to show significant differences in soil characteristics (Table 13). Since analysis of variance (Table 8) indicated significantly higher values for Nuttall's saltbush than for shadscale for five soil characteristics, total soluble salts, saturation extract conductivity, amount of exchangeable sodium, 1/3 atmosphere moisture percentage, and amount of soluble sodium, similar differences would be expected between the two ends of the alterne trench. However, the reverse actually occurred (Table 13).

Data from a shadscale-sagebrush alterne (Table 13) showed shadscale to have higher values for all significant factors, excepting exchangeable sodium. However, shadscale had significantly higher values for total soluble salts, saturation extract conductivity, exchangeable sodium, 1/3 atmosphere percentage and soluble sodium (Tables 7 and 8).

Analysis of variance (Table 8) showed sagebrush soils had higher values for exchangeable sodium and 1/3 atmosphere percentage than

Table 13. Mean values of chemical analyses for soil samples collected from opposite ends of a trench dug across alternes between various vegetation types of the salt-desert ranges of Utah 1/

Alterne	Alterne No.	pH	Total soluble salts percentage	Saturated extract conductivity $K \times 10^3$	Exchangeable Na me./100g.	Base exchange cap. me./100g.	Exchangeable Na percentage
Nuttall's saltbush Shadscale alterne	11						
Saltbush end		8.2	0.98	18.4	6.8	17.1	41
Shadscale end		8.2	1.17	19.0	9.0	17.4	52
Sagebrush Shadscale alterne	16						
Shadscale end		8.3	1.17	31.0	4.9	17.6	28
Sagebrush end		8.2	1.08	16.7	5.2	17.8	30
Winterfat Sagebrush alterne	18						
Winterfat end		8.5	0.72	12.9	5.8	15.5	37
Sagebrush end		8.6	0.20	5.0	3.0	15.4	20
Nuttall's saltbush Sagebrush alterne	15						
Saltbush end		7.7	0.79	19.5	4.5	17.8	26
Sagebrush end		7.9	0.48	11.3	5.0	18.2	29
Nuttall's saltbush Sagebrush alterne	33						
Sagebrush end		8.0	0.38	5.2	3.0	22.1	9
Saltbush end		8.4	1.07	15.9	8.3	23.1	36

1/ These data represent values for all depths of the soil profile.

Table 13. (cont.)

Lime percentage	1/3 atmosphere percentage	15 atmospheres percentage	Exchangeable K me./100g.	Exchangeable K percentage	Calcium p.p.m.	Magnesium p.p.m.
21	25.0	10.0	3.3	18.7	92	27
23	33.7	13.0	3.3	14.0	88	40
19	47.2	12.8	2.6	16.0	854	250
24	49.0	13.0	3.2	18.0	850	223
20	23.3	7.8	3.0	19.0	602	88
20	22.2	8.1	2.6	17.0	267	64
22	37.0	10.2	3.9	22.0	103	73
20	35.1	10.1	3.3	18.0	65	51
22	32.8	17.7	4.1	18.0	927	248
24	37.3	18.7	4.0	18.0	1,304	722

Table 13. (cont.)

Sodium p.p.m.	Potassium p.p.m.	Chloride p.p.m.	Sulfate p.p.m.	Carbonate p.p.m.	Bicarbonate p.p.m.
1,895	41	2,260	987	0	534
2,421	88	3,000	987	0	593
4,400	154	3,746	5,892	0	485
3,786	184	5,258	3,272	0	11,824
1,564	141	1,291	3,080	44	380
869	95	462	1,712	69	563
2,646	187	4,075	494	0	413
1,658	118	2,468	350	34	566
155	194	108	2,370	0	476
4,790	311	3,236	11,375	0	371

winterfat. The data from a winterfat-sagebrush alterne (Table 13) however, showed that winterfat soils were higher than sagebrush soils in each of the five factors found to be significant between types.

Mean values presented in Table 7 show Nuttall's saltbush to have significantly higher values than sagebrush for total soluble salts, saturation extract conductivity, exchangeable sodium, and soluble sodium. Sagebrush was shown to have significantly higher values than Nuttall's saltbush for 1/3 atmosphere percentage only. Two sagebrush-saltbush alternes were studied on the salt-deserts. Data from each are shown in Table 13. Data from both alternes are variable and are not in complete agreement with data presented in Tables 7 and 8. Data from Nuttall's saltbush-sagebrush alterne number 15 (Table 13) shows Nuttall's saltbush to exceed sagebrush only for total soluble salts and saturation extract conductivity. Nuttall's saltbush-sagebrush alterne number 33 (Table 13) was similar to alterne number 15 for all significant factors except 1/3 atmosphere moisture percentage which in this instance was higher for Nuttall's saltbush.

These data are not in complete agreement with data presented in Tables 7 and 8. However, they tend to show variations as indicated by those two tables. These data furnish evidence that abrupt changes in soil characteristics do not occur concomitantly with changes in vegetation type.

<u>Basal density as affected by soil characteristics</u>: Density of plant cover is a reflection of the environmental characteristics of an area. Major factors of the environment are climatic, edaphic, and biotic. In this study climate was assumed to be comparable over all areas studied. Biotic factors were not measured although

observations were made regarding apparent grazing pressure and plant vigor. In this study the edaphic factors were of primary importance.

Average basal densities for each type studied are shown in Table 14. These varied from 9.7 percent to 5.8 percent for winterfat and greasewood respectively. The purity of each type studied is shown by the low percentage of other species growing in association with each of them (Table 14). Other species contributed only 0.1 percent of the basal density in shadscale, Nuttall's saltbush, and greasewood types and 0.3 percent in sagebrush and winterfat types. The paucity of other species suggests that the five species studied were well adapted to the areas which they dominated. Other species either could not tolerate soil conditions present under the pure types or were unable to become established on areas already occupied by adapted vegetation types or succession was not yet complete.

Significant differences between vegetation types were found in the cases of total soluble salts, saturation extract conductivity, exchangeable sodium, 1/3 atmosphere percentage, and soluble sodium (Table 8). Since these soil characteristics were significantly different between types it was assumed they might also have some effect on basal density of the individual types. Consequently, regression coefficients were calculated for the soil factors which appeared to be most important in influencing distribution of the plants under study. These regression coefficients (Table 15) indicate relatively little correlation between any of these soil characteristics and basal density. In only three cases was basal density found to be significantly correlated to specific soil factors.

Table 14. Basal density and transect analysis of five vegetation types studied on the salt-desert of Utah 1/

Type dominant	Basal Density			Litter	Erosion Pavement	Bare Ground
	Total density	Type dominant	Other species			
	Percent	Percent	Percent	Percent	Percent	Percent
Sagebrush	7.7	7.4	0.3	31.6	11.4	49.3
Winterfat	10.0	9.7	0.3	12.4	2.8	74.1
Shadscale	8.7	8.6	0.1	26.4	8.6	56.1
Saltbush	9.5	9.4	0.1	9.9	0.3	80.3
Greasewood	5.9	5.8	0.1	20.2	6.4	67.6

1/ Values for each type are averages of four one-hundred foot transect lines from each of ten areas within each type. Thus each value is an average of 40 one-hundred foot line transects.

The 1/3 atmosphere percentage of the soil had a significant effect on the basal density of Nuttall's saltbush (Table 15). Within the 1/3 atmosphere percentage range of 20.9 to 33.3 percent an increase of 0.536 percent in basal density accompanied each increase of one percent in 1/3 atmosphere percentage.

Greasewood basal density was shown to be significantly affected by both saturation extract conductivity and exchangeable sodium (Table 15). The regression coefficient for saturation extract conductivity (Table 15) indicates that between the ranges of 0.6 and 30.8 millimhos conductivity there is an increase of 0.079 percent in basal density with each millimho increase in saturation extract conductivity. A regression coefficient of 0.309 for basal density as affected by exchangeable sodium shows an increase of 0.309 percent in basal density of greasewood with each milliequivalent increase in sodium, within the ranges of 0.6 to 7.5 milliequivalent of sodium per 100 grams of soil (Table 15).

Relative position of vegetation types as related to soil characteristics: There was a significant difference between types for five soil characteristics; total soluble salt, saturation extract conductivity, exchangeable sodium, soluble sodium, and 1/3 atmosphere percentage (Table 8), The test for least significant range indicated that all type means for each of these factors were significantly different. The five types studied were ranked according to the relative amount of each of these factors contained in the soils which they occupied (Table 16).

Nuttall's saltbush grew on the most saline-alkali soils (Tables 7 and 16). It appears that Nuttall's saltbush was well adapted to soils of high salt and sodium content, however, the

sped

Table 15. Regression coefficients measuring the relationship of three soil characteristics to basal density of five vegetation types

Type	Saturation Extract Conductivity	Exchangeable Na me./100g.	1/3 atmospheres percentage
	X = millimhos/c.c.	X = me./100 grams soil	X = % moisture
	Y = % basal density	Y = % basal density	Y = basal density
Sagebrush	-0.034	-0.068	-0.017
Winterfat	-0.316	-0.135	-1.660
Shadscale	0.266	0.547	0.123
Nuttall's Saltbush	0.072	0.721	0.536*
Greasewood	0.079*	0.309*	0.070

* Indicates probability at the 0.05 level.

Table 16. Relative position of five vegetation types when ranked according to mean values for characteristics of soils occupied by each 1/

Rank	Total soluble salts, percentage	Saturation extract conductivity, $K \times 10^3$	Exchangeable sodium, me./100g.	Soluble sodium, p.p.m.	1/3 atmosphere percentage
1	Nuttall's saltbush	Nuttall's saltbush	Greasewood	Nuttall's saltbush	Sagebrush
2	Greasewood	Greasewood	Nuttall's saltbush	Greasewood	Greasewood
3	Shadscale	Shadscale	Shadscale	Shadscale	Nuttall's saltbush
4	Winterfat	Winterfat	Sagebrush	Winterfat	Shadscale
5	Sagebrush	Sagebrush	Winterfat	Sagebrush	Winterfat

1/ Number 1 is highest, 5 lowest.

species was not limited in all cases to soils extremely high in these factors (Appendix Tables 11 to 15 and Figures 16, 17, 18, and 21).

Greasewood soils were lower than Nuttall's saltbush soils for all significant factors except exchangeable sodium and 1/3 atmosphere percentage (Table 16). Greasewood generally was found on soils only slightly less saline and alkali than those occupied by the saltbush (Tables 7 and 16). Greasewood soils were also lower in 1/3 atmosphere percentage than were sagebrush soils. While greasewood was shown to occupy soils of realtively high salt and sodium content (Tables 7 and 16) it also was found on soils low for these factors (Appendix Tables 11 to 15 and Figures 16, 17, 18, and 21). These data suggest that greasewood does not require high content of salts and sodium in the soil but that it can tolerate high amounts.

Soils under shadscale contained intermediate amounts of the chemical constituents found to be significant by analysis of variance (Tables 7, 8, and 16). It appeared to be most tolerant of soils with relatively low field moisture capacity. Only winterfat soils had lower values for 1/3 atmosphere percentage (Table 7 and 16). Shadscale however, was not restricted to soils with an intermediate range but was found on soils widely divergent in these respects (Figures 16, 17, 18, 20, and 21 and Appendix Tables 11 to 15).

Winterfat and sagebrush were found on soils relatively low in salinity and alkali (Table 16). Sagebrush was lowest in total soluble salts, saturation extract conductivity, and soluble sodium (Tables 7 and 16). Winterfat soils averaged lowest in exchangeable sodium and 1/3 atmosphere percentage (Table 16). This species however, sometimes was found in some cases on soil with high values for these factors (Appendix Tables 11 to 15 and Figures 18 and 20) indicating a wide range of adaptation.

Soils under sagebrush had the lowest mean values for total soluble salt, saturation extract conductivity, and soluble sodium. In addition these soils had the highest 1/3 atmosphere percentage of the five species studied (Table 16). This species was not restricted in all areas to soils of low soluble salt and sodium content in all areas sampled. In some areas both total salt and sodium content under sagebrush exceeded mean values of those under all the other species (Appendix Tables 11 to 15 and Figures 16 and 17).

CONCLUSION

The distribution pattern of vegetation on the surface of the earth does not result from chance alone. The plant cover of a given area is not a matter of complete randomness with the area being occupied by the first species whose propagules are introduced. The ecological explanation of plant distribution is based primarily upon environmental factors. Such factors may be classified as climatic, edaphic, and biotic. The physiographic position of an area and also fire often play important roles in plant distribution. This study was based on the edaphic factor which was presumed to be the cause of plant zonation on the salt-desert of Utah. Pure types of vegetation are common on the desert and correspond to the consociations of Weaver and Clements (42) which together form the basin sagebrush association.

Soil analyses showed some significant edaphic differences between soils occupied by the various species. However, from the data collected from the various areas within each type it did not appear that any one species was restricted in distribution by a narrow tolerance range for any specific soil factor. Edaphic maximums were not found which abruptly restricted one species while still in the minimum ranges of tolerance for another species. A considerable overlap in the ranges of each soil factor measured was found for all species studied. Within certain ranges for each edaphic factor, all five types appeared to be well adapted. Within this range it would be logical to find mixtures of the various species. Such was not the case. In these instances some other factor or factors which were not measured by this study must have limited plant growth to the single species occupying the area.

Sagebrush was growing on soils with the lowest average values for total soluble salts, saturation extract conductivity, and soluble sodium and had a comparatively low range for these factors. Sagebrush also occurred on the heaviest textured soils of any species studied. Data pertaining to soil texture and salt and sodium content of soils under sagebrush are in disagreement with those of Weaver and Clements (49), Clements (16), Shantz (43), Shantz and Piemeisel (44), Kearney et. al. (33), and Stewart et. al. (45).

The value of sagebrush as an indicator of soil conditions in the northern desert shrub area unquestionably is limited. The wide variability of soil under sagebrush makes any attempt to use it as an index in exact classification of land quite meaningless. The true characteristics of a sagebrush soil can be determined only by chemical analyses.

Winterfat was growing on soils relatively low in amounts of salt and sodium. Also, winterfat soils averaged lightest in texture with lowest field moisture capacity. This species was not, however, restricted to such soils but grew under widely variable edaphic conditions. Other authors, Weaver and Clements (49), Clements (16), Shantz (43), and Shantz and Piemeisel (44) have presented data which show that this species is confined to less saline and alkali soils than was found in this study. The extreme variability of the edaphic conditions under winterfat severely limits its usefulness as an indicator of soil characteristics.

Shadscale was found to occupy soils of intermediate salt and sodium content as compared to the other species studied, but it had a wide range. Shadscale soils were non-saline in the surface six inches but saline-alkali at greater depths. Shadscale soils were also of low water holding capacity suggesting that shadscale is well adapted to relatively light textured soils. However, the edaphic conditions under shadscale also were highly variable. The inconsistent variability of the soils under shadscale severly limits its usefulness as an indicator of soil characteristics. Data on the indicator significance of shadscale by Shantz and Piemeisel (44), Shantz (43), Kearney et. al. (33), Weaver and Clements (49), and Clements (16) do not agree with data presented in this study.

Soils under Nuttall's saltbush were saline in the surface six inches and saline-alkali from six inches to five feet. These soils were of relatively heavy texture, as reflected by high 1/3 atmosphere moisture percentage. Nuttall's saltbush tends to grown on saline or saline-alkali soils. However, its tolerance resulted in wide ranges in adaptibility. Therefore, the use of Nuttall's saltbush as an indicator plant is limited.

Soils under greasewood generally were saline throughout the profile and saline-alkali below the surface six inches. They were of relatively heavy texture as indicated by high 1/3 atmosphere percentage. Shantz and Piemeisel (44) stated that greasewood was not an infallible indicator of salt. Data secured by this study substantiate their work. Greasewood occupies soils with wide and varied amounts of salinity and alkali. Because of this variation in edaphic factors under greasewood, its presence on a site does not indicate that certain soil conditions are or are not present. There may be a relationship between greasewood and subsoil moisture (50); however, this possibility was not measured in this study. Data presented in this study on the indicator significance of greasewood are not in complete agreement with those presented by Bindschadler (11), Shantz (43), Weaver and Clements (49) and Clements (16).

It appears that sagebrush and winterfat may be restricted in their distribution by relatively high amounts of salt and sodium in the soil and this may explain why these species are not found growing in association with shadscale, Nuttal's saltbush, and greasewood in areas of high saline and alkali conditions. However, this does not explain why sagebrush and winterfat are found growing in pure stands in areas of low saline and alkali conditions where all five species appear to be adapted.

The lack of agreement between data gathered in this study and those presented by other authors may result from several causes. Data in this study were collected from much wider geographic locations than were those of the other authors. This could account for some of the wide variability which occurred between areas occupied by the same species. The use of statistics has provided better means of analyzing masses of data than was possible when some of the earlier data were collected. Also new and improved laboratory analytical methods have made possible more precise measurements of soil characteristics than were formerly possible. Some explanations of the indicator significance of plants in the past seem to have been based on visual observations and theory rather than on carefully controlled scientific experiments.

There are several possible explanations for pure stands where mixed stands might be expected. However, this study was not designed to test these possibilities. A considerable amount of work has been done on inhibiting substances produced by certain species which prevent germination and establishment of other species (12, 13, 26). Inhibiting substances could well be functional in the maintenance of pure stands of the various types on the salt-desert of Utah. If such inhibitors exist, they might enable an early-invading species to dominate and hold a local area against other species perhaps better adapted to existing habitat conditions. Additional research will be necessary to furnish information as to the validity of this possibility.

The depth of the water table also may be an important factor in plant distribution on the salt-desert. The effects of water table on plant distribution were kept in mind during this study but the water table was not measured. If the water table is of significant importance in the distributional pattern, the question as to how the young plants became established and survived until their roots made contact with this water table is still unanswered. Additional research along these lines might prove interesting and enlightning.

The role of ecotypic variation within a species has not been investigated for salt-desert shrubs. Such variation seems especially logical as a cause for the wide variability within soils occupied by the same vegetation type. An individual plant is genetically preadapted to tolerate certain maximum or minimum limits in its environment. When these limits are exceeded the plant no longer survives or new plants of similar genetic adaptation fail to become established. However, since the entire species is made up of a variable, interbreeding population, new individuals can be formed which are preadapted to tolerance limits different from those of their parents. Such new individuals may serve as the basis for the establishment of ecotypes within the species with quite different physiological ranges of tolerance than the original species. Thus, through interbreeding and natural selection over a period of time, various ecotypes with different tolerance ranges for various edaphic factors may have developed within the species.

Ecotypic variation within the species was not measured in this study. Evidence points toward the existance of such variation. A transplant study could be employed to isolate ecotypic variation if it does exist in the species studied. Seedlings of each species could be collected from various locations and transplanted into soils occupied by the same species in other locations. This would give evidence as to whether each ecotype was adapted to tolerate all soil on which the species was growing. This could be supplemented with a greenhouse study on germination to determine whether seed of each ecotype would germinate and plants become established on soils from other locations occupied by the species.

If ecotypic variation is a logical explanation for the wide adaptation within each species, then the worth of the species as an indicator is considerably reduced. A species as such, would then give only general and unreliable information about the edaphic conditions in which it was growing. Actually this study may have dealt not with five different species but with an unknown number of ecotypes which were not identifiable morphologically.

The possibility that the vegetation, now present, on the salt-desert is a developmental stage in the succession toward a climax, or that it is a grazing disclimax should not be overlooked. If either of these were the case, the various types would have little meaning as soil indicators. Permanent transects could be established across existing alternes to determine whether the alternes are fixed or whether there is a movement toward one type or the other. If the alternes appeared static, then evidence would favor the idea of the present vegetation being climax. If such were the case, the indicator significance of the various types would be more meaningful.

Data presented and analyzed in this study show many significant soil variations between plant types. However, the variation within types is of such magnitude as to severely limit the usefulness of present indicator concepts. Based on knowledge as revealed in this study it would seem that the present vegetation of the salt-deserts of Utah is not an adequate index for determining soil characteristics or for predicting potential capabilities of the land.

SUMMARY

During the summers of 1953 and 1954 studies were conducted on the salt-desert ranges of Utah to obtain information contributing to a better understanding of why some of the desert plants grow where they do, and what role soils play in plant distribution. Shrub types studied were sagebrush, winterfat, shadscale, Nuttall's saltbush, and greasewood. These types tend to zone out into pure stands separated from other pure stands by alternes or narrow transition zones.

The edaphic factor was considered of primary importance in the distribution of these shrub types. To determine whether changes in soil characteristics occurred concomitantly with changes in vegetation type, intensive soil studies were made in ten areas on the salt-deserts for each of the five species. To ascertain whether significant variation in the soil existed within areas occupied by pure stands, soil samples were taken from near the periphery of each area as well as in the center.

During the summer of 1953, trenches 7.5 feet deep were dug in each of the types to allow a critical study of the soil profile. Soil samples for chemical analysis were collected from each layer of the profile. To ascertain whether abrupt changes in soil characteristics occurred concomitantly with changes in vegetation type, trenches also were dug across alternes.

Soil samples were collected during the summer of 1954 from four predetermined depths, 0 to 6, 6 to 18, 18 to 36, and 36 to 60 inches, by using a soil auger. All samples collected were subjected to extensive chemical and physical analysis.

A significant difference between plant types was found for only five of the edaphic factors studied. Soils under the five plant types differed significantly in total soluble salt, saturation extract conductivity, exchangeable sodium, 1/3 atmosphere percentage, and soluble sodium.

Nuttall's saltbush, greasewood, and shadscale were found on soils with the highest salt content with averages of 0.39, 0.[illegible]3, and 0.53 percent respectively. In addition these species had the highest range in this respect. Sagebrush and winterfat were found on soils with the lowest average salt content with 0.32 and 0.36 percent respectively and also with the lowest range in this respect. As expected, the saturation extract conductivity of the soils varied in a similar manner as the total soluble salts. Soils under greasewood had the highest mean value for exchangeable sodium with 4.8 milliequivalents per 100 grams soil. Nuttall's saltbush, shadscale, sagebrush, and winterfat followed in decreasing amounts with 4.3, 3.7, 2.6, and 2.5 milliequivalents per 100 grams soil respectively. The field moisture capacity is a reflection of soil texture. Sagebrush was growing on soils with a mean 1/3 atmosphere percentage of 2[illegible].7. One-third atmosphere percentages for the other types were 28.5, 27.8, 24.4, and 23.7 for greasewood, Nuttall's saltbush, shadscale, and winterfat respectively. The five types varied significantly from each other in amount of soluble sodium from 719 parts per million for sagebrush to 2,215 parts per million for Nuttall's saltbush.

All five species had a relatively wide range for each of the significant soil factors. Although the means frequently differed significantly, there was a common range for all species for all soil factors studied.

Because the density of vegetation occupying an area was thought to be a measure of the adaptation of that species to the edaphic factors, density studies were made in each study area. However, statistical analysis showed little correlation between the various soil factors and the basal density of the plants occupying the area.

Plant samples of current years growth in each area were subjected to extensive chemical analysis to obtain information as to whether plant chemistry is an index to the nature of the soil on which the plant grows. It was found, however, that plant chemistry was an unreliable index to characteristics of the soil.

Soils under each of the five species studied on the salt-desert were found to be extremely variable. All species had relatively wide ranges of tolerance for the various edaphic factors. The wide tolerance range of each of these species suggests the presence of ecotypic variation. The five species studied were found to be unreliable as indicators of specific soil characteristics but in some cases might be used for imposing limits for certain soil factors.

LITERATURE CITED

1. Agriculture Handbook Number 60

1954, Diagnosis and improvement of saline and alkali soils. U. S. Salinity Laboratory Staff. L. A. Richards, Editor.

2. Albrecht, William A.

1940, Calcium, potassium, phosphorus relations as a possible factor in ecological array of plants. Journal of American Soc. Agron. 32:411-418.

3. Alvim, P. D.

1952, Soil as an ecological factor in the development of vegetation in the central plateaus of Brazil. International Grassland Conf. Abs. Papers 6 (D):1-2, Doc. 5.

4. Beadle, N. C. W.

1953, The edaphic factor in plant ecology with a special note on phosphates. Ecology 34:426-428.

5. Billings, W. D.

1949, The shadscale vegetation zone of Nevada and Eastern California in relation to climate and soils. The Am. Mid. Nat. 42:87-109.

6. Billings, W. D.

1945, The plant associations of the Carson Desert Region, Western Nevada. Butler Univ. Bot. Studies. 7:89-123.

7. Billings, W. D., and Thompson, John H.

1950, Vegetational zonation in the Great Basin of Western North America. Unpublished M.S. Univ. Nevada, Reno, Nevada.

8. Billings, W. D.

1941, Quantitative correlations between vegetational changes and soil development. Ecology, 22:448-456.

9. Billings, W. D.

1950, Vegetation and plant growth as affected by chemically altered rocks in the western Great Basin. Ecology 31:62-74.

10. Billings, W. D.

1952, The environmental complex in relation to plant growth and distribution. The Quart. Rev. of Biol. 27:251-265.

11. Bindschadler, H.

1948, Native vegetation in relation to soil in parts of Wyoming. Wyo. Range Mgt. Issue No. 3. (Mineo.) Laramie.

12. Bonner, J. and Galston, S. W.

1944, Toxic substances from the culture media of guayule which may inhibit growth. Bot. Gaz. 106:185-198.

13. Bonner, James

1950, The role of toxic substances in the interactions of higher plants. Bot. Review 16:51-65.

14. Boyko, H.

1954, Plant ecology problems in increasing the productivity of arid areas. Reprinted from "Biology of Deserts" ed. by J. L. Cloudsley-Thompson. Published by Institute of Biology, London.

15. Breazeale, J. F.

1946, Alkali tolerance of plants considered as a phenomenon of adaptation. Arizona Agr. Expt. Sta. Tech. Bul. 11.

16. Clements, F. E.

1920, Plant indicators. Carnegie Inst. Washington Pub. 353:1-388.

17. Cook, C. Wayne, and Harris, Lorin E.

1950, The nutritive value of range forage as affected by vegetation type, site, and stage of maturity. Utah State Agr. Expt. Sta. Bul. 344.

18. Daubenmire, R. F.

1943, Vegetational zonation in the Rocky Mountains. Bot. Rev. 9:325-393.

19. Dixon, Wilfrid J. and Massey, Frank J. Jr.

1951, Introduction to statistical analysis. New York, McGraw-Hill Book Co., Inc. p. 88.

20. Duncan, David B.

1955, Multiple range and multiple F tests. Biometrics 11:1-42.

21. Eaton, F. M.

1942, Toxicity and accumulation of chloride and sulfate salts in plants. Jour. Agr. Res. 64:357-399.

22. Fautin, Reed W.

1946, Biotic communities of the northern desert shrub. Ecological Monographs 16:251-310.

23. Fireman, Milton, and Hayward, H. E.

1952, Indicator significance of some shrubs in the Escalante Desert, Utah. The Bot. Gaz. 114:143-155.

24. Gehrke, Charles W., Affsprung, Harold E., and Lee, Yung C.

1954, Direct ethylenediamine tetraacetate titration method for magnesium and calcium. Analytical Chemistry 26:1944-1948 .

25. Gleason, H. A.

1939, The individualistic concept of the plant association. Amer. Midl. Nat. 21:92-110.

26. Gray, R., and Bonner, James

1948, An inhibitor of plant growth from the leaves of <u>Encolia farinosa</u>. Am. Jour. Bot. 35:52-57.

27. Harris, J. Arthur

1934, The physico-chemical properties of plant saps in relation to phytogeography. Minneapolis, Univ. of Minn. Press.

28. Harris, J. A., Gortner, R. A., Hoffman, W. F., Lawrence, J. V., and Valentine, A. T.

1924, The osmotic concentration, specific electrical conductivity, and chloride content of the tissue fluids of the indicator plants of Tooele Valley, Utah. Jour. Agr. Res. 27:893- 924.

29. Hayward, H. E., and Spurr, W. B.

1944, Effects of isosmotic concentrations of inorganic and organic substrates on the entry of water into corn roots. Bot. Gaz. 106:131-139.

30. Hillebrand, W. F. and Lundell, G. E. F.

1929, Applied inorganic analysis. John Wiley and Sons, New York. 10th printing 1948.

31. Hilton, J. W.

1941, Effects of certain microecological factors on the germinability and early development of <u>Eurotia lanata</u>. Northwest Science 15:86-92.

32. Kearney, T. H. and Harter, L. L.

1907, The comparative tolerance of various plants for the salts common in alkali soils. U. S. Dept. Agr. Bureau Plant Industry Bul. 113.

33. Kearney, T. H., Briggs, L. J., Shantz, H. L., McLane, J. W., and Piemeisel, R. L.

1914, Indicator significance of vegetation in Tooele Valley, Utah. Jour. Agr. Res. 1:365-417.

34. Magistad, O. C.

1945, Plant growth relations on saline and alkali soils. Bot. Rev. 11:181-230.

35. Marks, John B.

1950, Vegetation and soil relations in the Lower Colorado Desert. Ecology 31:176-193.

36. Mason, Herbert L.

1936, The principles of geographic distribution as applied to floral analysis. Madrono 3:181-190.

37. Mason, Herbert L.

1946, The edaphic factor in narrow endemism I. The nature of environmental influences. Madrono 8:209-226.

38. Mason, Herbert L.

1954, Migration and evolution in plants. Madrono 12:161-168.

39. Painter, E. P. and Frank, K. W.

1936, A comparison between the Benedict-Dennis and Parr bomb methods for the determination of total sulfur in plant and protein. Jour. Biol. Chem. 114:235-239.

40. Parker, K. W.

1950, Report on the 3-step method for measuring condition and trand on forest ranges. Adm. Studies, U. S. For. Ser., and trend on forest ranges. Adm. Studies, U. S. For. Ser. Washington, D. C., 68 pp. processed.

41. Roberts, R. C.

1950, Chemical effects of salt-tolerant shrubs on soils. Transactions Fourth International Congress of Soil Science 1:404-406.

42. Sampson, A. W.

1939, Plant indicators-concept and status. Bot. Rev. 5:155-206.

43. Shantz, H. L.

1938, Plants as soil indicators. U. S. Dept. Agr. Yearbook, Soils and Men. pp. 835-860.

44. Shantz, H. L. and Piemeisel, R. L.

1940, Types of vegetation in Escalente Valley, Utah as indicators of soil conditions. U. S. Dept. Agr. Tech. Bul. ~~173~~. 713

45. Stewart, G., Cottam, W. P. and Hutchings, S. S.

1940, Influence of unrestricted grazing on Northern Salt Desert plant association in western Utah. Jour. Agr. Res. 60:289-316.

46. Stoddart, L. A.

1941, Chemical composition of Symphoricarpos rotundifolius as influenced by soil, site, and date of collection. Jour. Agr. Res. 63:727-739.

47. Thorne, D. W. and Peterson, H. B.

1949, Irrigated soils, their fertility and management. Philadelphia, The Blakiston Co.

48. U. S. Weather Bureau

Climatological data, Utah section 1898-1954.

49. Weaver, John E. and Clements, F. E.

1938, Plant ecology. New York, McGraw Hill Book Co., Inc.

50. White, W. N.

1932, A method of estimating ground water supplies based on discharge by plants and evaporation from soils. Results of investigation in Escalante Valley, Utah. U. S. Geological Survey paper 659-A, Contributions to the Hydrology of the U. S. Vol. 209.

51. Wilde, S. A. and Leaf, A. L.

1955, The relationship between the degree of soil podzolization and the composition of ground cover vegetation. Ecology 36:19-22.

52. Woods, F. W.

1953, Disease as a factor in the evolution of forest composition. Jour. of For. 51:871-873.

APPENDIX

Appendix Table 1. Description of ten areas of pure sagebrush studied on the salt-desert ranges of Utah

Area No.	Location	Adjacent vegetation	Basal density percent	General description of site
2	Curlew Valley	shadscale	5.9	Soil formed from alluvial outwash from Raft River Mountains, a 2-3 % slope, sagebrush 1-2 feet tall.
14	Curlew Valley	Nuttall's saltbush, shadscale	4.6	Alluvial outwash from Wildcat Mountains and volcanic ash sediments, flat, level area, sagebrush 4-6 feet tall.
31	Rush Valley	shadscale	6.2	Soil formed on lake laid sediments, flat area on a low bench, stand vigorous 2-3 feet tall.
37	Curlew Valley	winterfat, shadscale	13.0	Soil formed on lake sediments, vigorous stand 2-4 feet tall on flat level area.
50	Escalante Valley	shadscale	6.5	Small area of sagebrush, plants vigorous to 4 feet tall on soil formed from lake sediment overlaying rock at 3 feet depth.
57	Rush Valley	Nuttall's saltbush	5.8	A rather patchy but pure and vigorous stand, rocky soil developed on lake laid sediments.
62	Rush Valley	Nuttall's saltbush	9.8	A vigorous stand to 4 feet tall, flat, level area, soil developed from lake sediments.
68	Curlew Valley	Nuttall's saltbush	6.5	A vigorous stand with plants to 6 feet tall forming a small island surrounded by Nuttall's saltbush, soil developed on lake laid sediments.

Appendix Table 1. (cont.)

Area No.	Location	Adjacent vegetation	Basal density percent	General description of site
69	Curlew Valley	Sagebrush-greasewood mixture, shadscale	8.5	A thin but vigorous stand of sagebrush to 4 feet tall, on soil formed from lake sediments.
72	Curlew Valley	shadscale, Nuttall's saltbush	7.0	Large area of vigorous plants to 4 feet tall, loose soil developed from lake laid sediments.

Appendix Table 2. Description of ten areas of pure winterfat studied on the salt-desert ranges of Utah

Area No.	Location	Adjacent vegetation	Basal density percent	General description of site
7	Curlew Valley	shadscale, sagebrush	9.8	Large, heavily grazed area of winterfat on broad, flat valley bottom.
22	Southern Idaho	shadscale, sagebrush, greasewood	10.0	Large areas on winterfat infested with hummocks of Opuntia sp.
35	Curlew Valley	shadscale, sagebrush	12.2	Broad valley bottom.
41	Escalante Valley	winterfat-yellowbrush, 1/ sagebrush	11.0	Broad valley bottom, the strip of winterfat extended north and south paralleling the valley.
42	Escalante Valley	winterfat-yellowbrush, shadscale	10.7	Broad, flat valley bottom.
40	Escalante Valley	winterfat-yellowbrush, shadscale, sagebrush	11.0	Extremely vigorous stand. This area was within an enclosure located in a large area of winterfat.

1/ Crysothamnus stenophyllus

Appendix Table 2. (cont.)

Area No.	Location	Adjacent vegetation	Basal density percent	General description of site
44	Escalante Valley	yellowbrush, greasewood-winterfat	10.2	Vigorous stand on broad, flat valley bottom.
45	Escalante Valley	greasewood-winterfat, yellowbrush-winterfat	9.2	A vigorous stand on a 1 to 2 % slope on side of the valley.
55	Rush Valley	shadscale, sagebrush, Nuttall's saltbush	3.2	Typical stand on a 2 % slope with a western exposure, bedrock underlay the area at a depth on 4 feet.
73	Curlew Valley	sagebrush, shadscale	9.5	Heavily grazed stand on slight slope with a northern exposure.

Appendix Table 3. Description of ten areas of pure shadscale studied on the salt-desert ranges of Utah

Area No.	Location	Adjacent vegetation	Basal density percent	General description of site
4	Curlew Valley	winterfat, sagebrush, Nuttall's saltbush	6.5	Vigorous stand to 2 feet high on broad valley bottom.
28	Rush Valley	sagebrush	5.8	Located on a low, flat bench, the stand is relatively vigorous with plants to 18 inches high.
36	Curlew Valley	sagebrush, winterfat	20.5	Typical pure stand on flat valley bottom.
43	Escalante Valley	greasewood-shadscale, winterfat	9.5	A low flat valley bottom area covered by a vigorous stand of shadscale.
47	Escalante Valley	winterfat, greasewood	9.2	Area level, flat valley bottom with typical pure stand, plants vigorous to 18 inches tall.
48	Escalante Valley	greasewood-shadscale, greasewood	6.8	Vigorous growth of shadscale on flat valley bottom.
51	Escalante Valley	sagebrush	9.2	Typical pure stand on flat, low area, soil surface covered with erosion pavement.

Appendix Table 3. (cont.)

Area No.	Location	Adjacent vegetation	Basal density percent	General description of site
58	Rush Valley	Nuttall's saltbush, winterfat	6.5	Extensive, low, flat area covered with shadscale, plants vigorous to 1 foot tall, slight infestation of Halogeton in the area.
63	Escalante Valley	greasewood-shadscale, winterfat	7.0	Vigorous stand to 18 inches tall on low, flat valley bottom.
66	Escalante Valley	greasewood-shadscale greasewood	5.0	Low, flat area with vigorous stand to 18 inches tall.

Appendix Table 4. Description of ten areas of pure Nuttall's saltbush studied on the salt-desert ranges of Utah

Area No.	Location	Adjacent vegetation	Basal density percent	General description of site
10	Curlew Valley	shadscale, winterfat, sagebrush	12.2	Typical pure stand on low flat valley bottom.
34	Rush Valley	greasewood, sagebrush, shadscale	7.4	Vigorous pure stand occupying low flat valley bottom.
38	Curlew Valley	sagebrush	18.0	Island of saltbush surrounded by sagebrush, occupying flat level area.
39	Curlew Valley	shadscale, sagebrush	11.8	Vigorous stand on low flat area.
56	Rush Valley	winterfat, sagebrush, greasewood	8.2	Pure stand on slight slope, the soil was rocky at a depth of 3 feet.
59	Rush Valley	sagebrush, shadscale	6.8	Typical vigorous stand on large flat area, the soil was rocky at 3 to 4 feet.

Appendix Table 4. (cont.)

Area No.	Location	Adjacent vegetation	Basal density percent	General description of site
61	Rush Valley	shadscale, sagebrush, shadscale-sagebrush	9.0	Island of saltbush on low flat area.
64	Escalante Valley	winterfat, sagebrush	4.5	Extensive area occupying a flat, low position.
65	Escalante Valley	greasewood	4.5	Island of pure, vigorously growing saltbush on low, flat area.
67	Curlew Valley	shadscale, sagebrush	11.5	Large flat level area containing a vigorous pure stand of saltbush.

Appendix Table 5. Description of ten areas of pure greasewood studied on the salt-desert ranges of Utah

Area No.	Location	Adjacent vegetation	Basal density percent	General description of site
20	Curlew Valley	shadscale, sagebrush	7.1	Large area of vigorous greasewood with plants to 5 feet tall on low flat area.
25	Rush Valley	shadscale, sagebrush	6.8	Typical vigorous stand on soil which became very rocky at 3 feet.
46	Escalante Valley	winterfat-yellowbrush, winterfat, shadscale	4.0	Vigorous plants to 4 feet tall on low, flat valley bottom.
49	Escalante Valley	greasewood-shadscale, shadscale	4.8	Low valley bottom cut by a gulley, vigorous plants to 4 feet tall.
52	Escalante Valley	shadscale-greasewood, shadscale, winterfat	7.5	Extensive area with soil surface covered with erosion pavement, plant vigorous and to a height of 4 feet.
53	Escalante Valley	greasewood-shadscale, greasewood-sagebrush	6.0	Low, flat area with typical stand of greasewood.

Appendix Table 5. (cont.)

Area No.	Location	Adjacent vegetation	Basal density percent	General description of site
54	Escalante Valley	shadscale, sagebrush	4.5	On broad flat bench, vigorous stand of greasewood to 4 feet tall.
60	Rush Valley	winterfat, sagebrush	5.0	Large area of extremely vigorous plants to 6 feet tall. Soil was very rocky at 3 to 4 feet depth.
70	Curlew Valley	sagebrush, shadscale	5.5	Vigorous but thin stand on low, flat valley bottom.
71	Curlew Valley	saltbush, greasewood-shadscale	7.0	Extensive but thin stand on low, flat valley bottom.

Appendix Table 6. Analysis of variance of soil characteristics of soil for A and B samples from four depths within each of ten sagebrush areas on the salt-deserts of Utah

Source	D.F.	pH	Total soluble salts percentage	Saturation extract conductivity $K \times 10^3$	Exchangeable Na me./100g.	Base exchange cap. me./100g.	Exchangeable Na percentage
				Mean Squares			
"A" Sample							
Area	9	3,256.00**	1.92**	44.16	77.05*	752.33**	1,665.13
Depth	3	3,755.00*	10.31**	3,615.54**	315.58**	219.41	17,220.23**
Area x depth	27	870.74	1.01	224.01	24.71	93.76	750.25
"B" Sample							
Area	9	1,260.67*	6.37**	1,843.01**	102.51*	420.94**	4,414.56**
Depth	3	353.00	8.89**	5,217.91**	439.87**	94.30	18,914.00**
Area x depth	27	502.44	1.48	360.95	43.06	53.51	1,190.48

* Indicates significance at the 0.05 level.
** Indicates significance at the 0.01 level.

Appendix Table 6. (cont.)

Lime percentage	Permeability in./hr.	1/3 atmosphere percentage	15 atmospheres percentage	Exchangeable K me./100g.	Exchangeable K percentage	Calcium p.p.m.
			Mean Squares			
2,547.89**	63.28*	4,393.34**	1,544.14**	45.77**	595.56*	5,025,477.78
2,842.00**	18.03	2,914.19*	303.26	35.16**	621.33	10,355,961.00
271.81	24.64	651.63	237.07	4.66	241.33	3,806,386.00
2,365.11**	2.71	5,957.28**	786.96**	48.80**	1,165.02**	3,989,518.33*
2,284.67**	0.73	917.84	100.53	37.18**	988.90**	1,845,238.33
159.85	1.25	1,195.89	97.51	4.01	149.47	1,301,415.37

* Indicates significance at the 0.05 level.
** Indicates significance at the 0.01 level.

Appendix Table 6. (cont.)

Magnesium p.p.m.	Sodium p.p.m.	Potassium p.p.m.	Chloride p.p.m.	Sulfate p.p.m.	Carbonate p.p.m.	Bicarbonate p.p.m.
			Mean Squares			
485,957.33	16,480,157.80*	135,156.22**	28,765,121.00*	78,749,200.60	21,492.67*	398,074.89
709,971.67	73,699,880.20**	9,306.67	95,877,331.00**	276,235,878.20**	17,483.00	816,321.67*
394,548.89	5,894,126.54	29,197.41	11,033,105.07	50,136,073.80	7,622.07	268,513.33
3,424,674.33**	3,446,410.66	215,449.89**	141,035,020.00**	73,323,231.00*	9,200.69	674,366.69*
1,392,035.33	34,715,468.30**	7,173.67	166,077,360.30*	79,249,900.30*	2,652.23	734,736.23
1,087,127.74	2,352,604.81	38,227.74	41,438,549.40	25,242,987.00	5,430.03	280,384.03

* Indicates significance at the 0.05 level.
** Indicates significance at the 0.01 level.

Appendix Table 7. Analysis of variance of soil characteristics of soil for A and B samples from four depths within each of ten winterfat areas on the salt-deserts of Utah

Source	D.F.	pH	Total soluble salts, percentage	Saturation extract conductivity K x 10^3	Exchangeable Na me./100g.	Base exchange cap. me./100g.	Exchangeable Na percentage
				Mean Squares			
"A" Samples							
Area	9	885.11*	2.73**	1,238.63**	83.06**	699.01**	4,755.13**
Depth	3	96.30	7.85	5,938.71**	241.96**	31.34	10,976.23**
Area x depth	27	358.37	0.58	288.94	19.88	33.40	837.73
"B" Sample							
Area	9	1,000.11*	1.56**	751.47**	68.48**	553.47**	3,381.36**
Depth	3	2,144.67**	10.37**	7,180.53**	349.64**	12.62	14,727.57**
Area x depth	27	351.15	0.36	184.50	18.68	31.97	709.81

* Indicates significance at the 0.05 level.
** Indicates significance at the 0.01 level.

Appendix Table 7. (cont.)

Lime percentage	Permeability in./hr.	1/3 atmosphere percentage	15 atmospheres percentage	Exchangeable K me./100g.	Exchangeable K percentage	Calcium p.p.m.
			Mean Squares			
2,100.11**	1.81*	779.87**	105.68**	17.51**	1,356.56**	710,366.56
435.33	5.48**	788.82**	32.76	41.01**	1,144.67*	6,171,748.66**
165.18	0.62	170.18	19.21	6.60	277.81	632,576.26
2,324.89**	2.77**	1,227.14**	120.06**	20.69**	1,464.69**	1,304,785.11
280.67	3.69**	479.43	14.78	24.06*	896.90*	4,205,648.33*
127.33	0.53	217.38	13.27	6.38	206.18	973,850.37

* Indicates significance at the 0.05 level.
** Indicates significance at the 0.01 level.

Appendix Table 7. (cont.)

Magnesium p.p.m.	Sodium p.p.m.	Potassium p.p.m.	Chloride p.p.m.	Sulfate p.p.m.	Carbonate p.p.m.	Bicarbonate p.p.m.
			Mean Squares			
36,156.22	18,858,795.60**	103,728.22**	20,581,711.70**	31,109,166.90	0.0	220,173.78*
513,472.67**	50,323,336.60**	13,837.67	62,502,222.30**	137,253,907.30**	0.0	1,105,522.67**
19,700.44	3,413,588.33	27,315.26	5,130,457.70	12,249,284.62	0.0	89,410.07
39,574.02	16,667,336.90**	69,788.36*	19,342,976.30**	16,656,249.10	11,556.24**	437,530.11
211,807.57**	42,849,928.20**	30,071.57	67,521,928.90**	59,101,744.20**	3,956.23	640,639.00
21,996.47	3,017,117.51	22,651.03	3,681,938.73	12,630,004.25	3,956.25	290,238.63

* Indicates significance at the 0.05 level.
** Indicates significance at the 0.01 level.

Appendix Table 8. Analysis of variance of soil characteristics of soil for A and B samples from four depths within each of ten shadscale areas on the salt-deserts of Utah

Source	D.F.	pH	Total soluble salts percentage	Saturation extract conductivity K x 10^3	Exchangeable Na me./100g.	Base exchange cap. me./100g.	Exchangeable Na Percentage
				Mean Squares			
"A" Sample							
Area	9	1,425.44	8.82**	2,531.79**	265.34**	701.68**	4,502.11**
Depth	3	2,140.00	23.34**	13,132.06**	526.13**	96.83	13,268.33**
Area x depth	27	1,652.41	1.68	507.80	29.01	86.32	587.22
"B" Sample							
Area	9	12,433.58	7.25**	3,535.62**	89.29*	465.85**	2,657.36**
Depth	3	7,862.90	17.04**	10,006.11**	283.56**	105.89	10,692.23**
Area x depth	27	6,885.51	0.87	563.54	29.35	53.49	748.55

* Indicates significance at the 0.05 level.
** Indicates significance at the 0.01 level.

Appendix Table 8. (cont.)

Lime percentage	Permeability in./hr.	1/3 atmosphere percentage	15 atmospheres percentage	Exchangeable K me./100g.	Exchangeable K percentage	Calcium p.p.m.
3,671.80**	6.07**	1,334.83**	1,149.08	43.50**	1,167.47	5,432,504.00
622.90	3.17	886.23	268.34	167.10**	5,940.90**	39,753,521.00**
316.25	2.25	329.02	840.21	4.84	974.00	5,147,358.22
2,677.33**	7.93*	1,441.18**	1,031.93	58.76**	2,117.80	4,513,402.66
470.00	2.28	534.07	307.26	121.21**	3,484.23	28,306,242.66**
267.78	3.21	186.86	786.10	7.85	1,731.41	2,492,406.37

* Indicates significance at the 0.05 level.
** Indicates significance at the 0.01 level.

Appendix Table 8. (cont.)

Magnesium p.p.m.	Sodium p.p.m.	Potassium p.p.m.	Chloride p.p.m.	Sulfate p.p.m.	Carbonate p.p.m.	Bicarbonate p.p.m.
			Mean Squares			
323,263.89	49,531,985.60**	170,881.11	107,815,697.20**	109,375,060.60	0.0	1,246,688.14*
2,317,013.67**	107,865,170.60**	288,502.33	227,385,820.20**	436,084,118.00**	0.0	3,960,390.00**
379,023.67	12,847,725.66	129,122.14	23,404,926.40	70,031,240.00	0.0	429,030.00
6,012,897.66**	72,539,383.20**	281,787.22**	200,941,038.00**	184,054,806.00**	23,409.04*	214,182.80
5,498,140.66	131,062,467.30**	30,509.67**	307,336,278.20**	445,230,837.00**	10,045.67	2,669,976.90**
2,248,030.48	11,967,605.29	2,590.67	40,864,451.20	57,295,507.50	10,045.67	165,857.84

* Indicates significance at the 0.05 level.
** Indicates significance at the 0.01 level.

Appendix Table 9. Analysis of variance of soil characteristics of soil for A and B samples from four depths within each of ten Nuttall's saltbush areas on the salt-deserts of Utah

Source	D.F.	pH	Total soluble salts percentage	Saturation Extract conductivity K x 10^3	Exchangeable Na me./100g.	Base exchange cap. me./100g.	Exchangeable Na percentage
				Mean Squares			
"A" Sample							
Area	9	11,626.36*	19.11**	7,128.94**	173.14**	364.47**	2,651.16**
Depth	3	4,175.23	28.25**	13,197.08**	578.00**	103.24	19,612.67**
Area x depth	27	4,676.58	2.27	681.64	23.89	47.94	532.67
"B" Sample							
Area	9	693.91	9.04**	3,954.05**	137.61**	519.26**	3,240.11**
Depth	3	424.23	38.85**	18,251.43**	510.57**	54.08	17,666.00**
Area x depth	27	449.62	1.96	844.12	31.71	141.59	704.33

* Indicates significance at the 0.05 level.
** Indicates significance at the 0.01 level.

Appendix Table 9. (cont.)

Lime percentage	Permeability in./hr.	1/3 atmosphere percentage	15 atmospheres percentage	Exchangeable K me./100g.	Exchangeable K percentage	Calcium p.p.m.
			Mean Squares			
739.33*	3.67**	1,250.84**	295.56**	54.87**	951.36**	11,260,335.80**
272.67	0.04	986.68	122.14	185.08**	4,724.90**	12,533,778.90**
322.44	0.95	375.73	71.48	5.40	134.92	2,729,002.99
1,190.02**	4.26	1,090.51**	305.95**	28.93**	778.02**	20,455,397.80**
861.57	1.50	1,203.62*	251.15*	208.76**	639.22*	23,307,105.00**
511.58	3.68	269.64	71.10	5.33	148.92	4,403,374.62

* Indicates significance at the 0.05 level.
** Indicates significance at the 0.01 level.

Appendix Table 9. (cont.)

Magnesium p.p.m.	Sodium p.p.m.	Potassium p.p.m.	Chloride p.p.m.	Sulfate p.p.m.	Carbonate p.p.m.	Bicarbonate p.p.m.
			Mean Squares			
864,742.47**	113,776,064.00**	1,021,521.56**	169,500,944.00**	443,672,705.00**	45,244.89	1,033,897.22**
1,042,547.57**	208,950,468.90**	324,143.00**	333,167,104.90**	261,557,580.60**	36,124.67	316,536.67
132,351.29	12,171,095.22	84,088.00	25,964,890.29	43,489,079.00	39,295.04	293,019.07
5,880,914.68**	94,529,071.10**	704,630.67**	222,195,730.00**	444,773,560.00**	0.0	634,891.36**
5,650,971.56*	250,674,380.20**	232,897.67**	593,012,538.00**	541,193,482.00**	0.0	1,131,273.57**
1,593,769.36	20,002,356.92	34,572.67	68,399,588.00	65,208,950.00	0.0	182,977.66

* Indicates significance at the 0.05 level.
** Indicates significance at the 0.01 level.

Appendix Table 10. Analysis of variance of soil characteristics of soil for A and B samples from four depths within each of ten greasewood areas on the salt-deserts of Utah

Source	D.F.	pH	Total soluble salts percentage	Saturation extract conductivity K x 10^3	Exchangeable Na me./100g.	Base exchange cap. me./100g.	Exchangeable Na percentage
				Mean Squares			
"A" Samples							
Area	9	25,070.69**	25.86**	5,702.10**	378.29**	257.77	13,652.33**
Depth	3	7,072.23	17.78**	5,015.40**	321.24*	91.08	11,474.67**
Area x depth	27	5,420.40	1.50	523.85	83.17	149.85	1,948.18
"B" Sample							
Area	9	61,879.69	20.65**	4,878.07**	248.29**	450.31	7,367.33**
Depth	3	39,036.90	13.32**	5,407.34**	335.22**	113.24	9,729.67**
Area x depth	27	30,511.32	1.39	394.61	18.48	224.03	908.00

* Indicates significance at the 0.05 level.
** Indicates significance at the 0.01 level.

Appendix Table 10. (cont.)

Lime percentage	Permeability in./hr	1/3 atmosphere percentage	15 atmospheres percentage	Exchangeable K me./100g.	Exchangeable K percentage	Calcium p.p.m.
			Mean Squares			
3,480.68**	2.07	2,779.74**	222.02**	22.01**	602.89**	6,467,185.11
1,043.00*	1.59	2,018.92**	265.12*	117.68**	2,909.33**	28,699,883.00**
305.78	1.59	416.26	66.46	6.32	152.67	4,675,213.18
2,585.11*	0.82	2,455.60**	129.65	44.37**	1,312.33**	6,677,670.02
1,049.67	0.76	1,487.83	190.07*	124.97**	3,069.67**	13,542,056.23
437.63	0.52	505.09	63.71	8.18	181.89	4,684,421.80

* Indicates significance at the 0.05 level.
** Indicates significance at the 0.01 level.

Appendix Table 10. (cont.)

Magnesium p.p.m.	Sodium p.p.m.	Potassium p.p.m.	Chloride p.p.m.	Sulfate p.p.m.	Carbonate p.p.m.	Bicarbonate p.p.m.
			Mean Squares			
196,585.11**	129,050,351.00**	178,457.91**	289,133,658.00**	71,514,815.10	0.0	2,511,365.55**
358,325.67**	95,630,218.90**	105,463.57*	129,801,241.50**	412,905,843.00**	0.0	1,066,635.67
48,791.41	7,502,228.00	32,325.25	13,995,512.11	44,791,644.70	0.0	603,539.18
347,925.24**	93,317,986.50**	318,320.80**	214,879,572.00**	261,655,364.00*	4,356.00	2,307,853.77**
475,316.23*	108,011,615.30**	63,764.90**	152,642,434.00**	247,229,425.00	4,356.00	1,554,127.33**
112,267.10	9,071,567.37	7,128.81	17,690,731.22	99,817,945.50	4,393.04	325,385.85

* Indicates significance at the 0.05 level.
** Indicates significance at the 0.01 level.

Appendix Table 11. Mean values of soil constituents of soils collected under sagebrush from ten areas from the salt-deserts of Utah 1/

Area No.	pH	Total soluble salts percentage	Saturation extract conductivity K x 10^3	Exchangeable Na me./100g.	Base exchange cap. me./100g.	Exchangeable Na percentage	Lime percentage	Permeability in./hr.
2	8.2	0.27	8.8	2.7	12.4	28	20	2.49
14	7.9	0.28	6.4	3.3	17.1	20	19	0.64
31	8.2	1.04	16.9	4.1	23.2	17	32	1.15
37	8.5	0.25	6.7	2.4	13.1	20	25	0.60
50	8.3	0.05	0.8	2.0	17.9	12	3	0.37
57	8.2	0.19	5.1	0.9	11.9	9	24	0.73
62	8.0	0.15	3.6	1.1	20.9	6	24	0.19
68	8.2	0.06	2.6	1.2	16.1	8	21	0.30
69	8.0	0.58	10.6	3.7	17.0	23	27	0.30
72	8.3	0.38	7.6	4.6	19.3	23	17	0.06

1/ Values presented are an average of eight values, four depths and two samples in each area.

Appendix Table 11. (cont.)

1/3 atmosphere percentage	15 atmospheres percentage	Exchangeable K me./100g.	Exchangeable K percentage	Calcium p.p.m.	Magnesium p.p.m.	Sodium p.p.m.
19.2	9.0	2.1	16	68	15	750
27.6	9.4	2.6	15	61	12	737
48.9	24.4	3.1	13	932	652	1,159
21.8	6.9	1.8	15	50	10	656
19.0	9.8	1.1	6	32	12	225
17.8	8.8	1.3	10	68	21	532
28.1	17.3	4.6	20	163	33	394
27.1	8.7	3.6	22	43	12	264
44.8	11.9	2.5	14	559	84	1,526
32.6	11.6	2.4	13	150	38	946

Appendix Table 11. (cont.)

Potassium p.p.m.	Chloride p.p.m.	Sulfate p.p.m.	Carbonate p.p.m.	Bicarbonate p.p.m.
70	840	304	26	535
78	823	260	28	480
226	4,197	4,247	0	481
73	739	249	38	388
26	110	64	0	529
60	572	383	2	408
189	152	955	0	521
157	224	152	0	544
147	2,399	1,949	0	534
93	903	1,169	0	539

Appendix Table 12. Mean values of soil constituents of soils collected under winterfat from ten areas from the salt-deserts of Utah 1/

Area No.	pH	Total soluble salts percentage	Saturation extract conductivity $K \times 10^3$	Exchangeable Na me./100g.	Base exchange cap. me./100g.	Exchangeable Na percentage
7	8.4	0.64	15.5	4.9	15.1	33
22	8.2	0.54	12.5	4.2	14.7	30
35	8.3	0.28	6.2	3.0	16.8	17
40	8.3	0.10	3.1	1.0	13.3	7
41	8.0	0.30	8.6	2.3	20.6	11
42	8.3	0.15	4.2	0.9	13.2	7
44	8.2	0.12	5.3	1.6	15.0	10
45	7.9	0.29	7.1	1.3	25.6	5
55	8.2	0.51	15.7	2.5	14.7	17
73	8.2	0.72	13.9	3.3	14.1	24

1/ Values presented are an average of eight values, four depths from two samples in each area.

Appendix Table 12. (cont.)

Lime percentage	Permeability in./hr.	1/3 atmosphere percentage	15 atmospheres percentage	Exchangeable K me./100g.	Exchangeable K percentage	Calcium p.p.m.
22	1.03	23.7	7.9	3.0	20	456
24	0.44	26.7	8.5	1.4	9	224
29	0.32	23.1	10.6	2.4	14	103
12	0.82	14.5	7.0	1.9	14	75
11	0.56	23.1	10.4	1.5	7	301
32	0.53	22.4	8.3	3.0	23	54
26	0.40	20.5	8.9	1.8	12	128
13	0.37	26.4	12.5	1.4	5	385
22	0.31	23.0	9.6	1.6	11	260
24	0.45	23.6	8.2	2.7	19	115

Appendix Table 12. (cont.)

Magnesium p.p.m.	Sodium p.p.m.	Potassium p.p.m.	Chloride p.p.m.	Sulfate p.p.m.	Carbonate p.p.m.	Bicarbonate p.p.m.
71	1,768	117	1,799	2,265	27	447
104	1,705	82	1,695	2,028	0	537
21	869	97	948	676	0	441
26	196	74	212	170	0	401
56	479	52	748	440	0	464
63	298	182	361	319	0	506
92	396	76	517	350	0	462
56	273	51	435	283	0	407
99	1,352	67	1,692	845	0	440
38	1,674	164	1,958	828	0	627

Appendix Table 13. Mean values of soil constituents of soils collected under shadscale from ten areas from the salt-deserts of Utah 1/

Area No.	pH	Total soluble salts percentage	Saturation extract conductivity $K \times 10^3$	Exchangeable Na me./100g.	Base exchange cap. me./100g.	Exchangeable Na percentage
4	8.5	0.60	12.2	4.2	15.9	29
28	8.6	1.12	25.4	6.8	25.2	26
36	8.0	1.49	29.2	5.9	18.7	31
43	8.3	0.18	4.1	1.5	16.2	10
47	8.2	0.26	5.2	1.8	15.8	12
48	8.2	0.36	11.0	5.5	17.4	32
51	8.3	0.40	11.9	4.8	21.4	22
58	8.1	0.55	14.6	2.9	20.6	14
63	8.0	0.35	10.8	1.1	15.6	8
66	8.5	0.45	13.1	2.9	11.8	24

1/ Values presented are an average of eight values, four depths from two samples in each area.

Appendix Table 13. (cont.)

Lime percentage	Permeability in./hr.	1/3 atmosphere percentage	15 atmospheres percentage	Exchangeable K me./100g.	Exchangeable K percentage	Calcium p.p.m.
21	0.93	25.7	8.6	3.3	21	662
26	0.81	36.7	26.7	3.8	15	989
24	0.20	29.3	12.5	2.7	15	573
37	0.24	26.4	12.3	3.4	21	79
22	0.60	20.6	10.7	3.5	22	82
18	0.04	22.5	10.8	3.0	17	122
3	0.10	21.6	9.7	0.8	4	328
20	0.31	24.0	10.6	1.4	7	329
14	0.88	21.1	12.0	3.2	19	336
24	1.08	16.5	10.2	1.1	11	783

Appendix Table 13. (cont.)

Magnesium p.p.m.	Sodium p.p.m.	Potassium p.p.m.	Chloride p.p.m.	Sulfate p.p.m.	Carbonate p.p.m.	Bicarbonate p.p.m.
85	945	108	1,386	1,441	38	525
815	3,588	236	5,222	5,642	0	644
105	3,493	168	5,169	2,162	0	322
80	362	192	529	295	0	566
60	485	154	503	218	0	485
24	1,099	92	1,004	877	0	641
28	1,109	28	1,126	1,257	0	484
83	1,327	50	1,569	1,014	0	404
140	478	140	1,452	194	0	419
241	1,409	157	1,038	3,832	0	419

Appendix Table 14. Mean values of soil constituents for soils collected under Nuttall's saltbush from ten areas from the salt deserts of Utah 1/

Area No.	pH	Total soluble salts percentage	Saturation extract conductivity $K \times 10^3$	Exchangeable Na me./100g.	Base exchange cap. me./100g.	Exchangeable Na percentage
10	8.6	0.75	14.9	5.5	17.1	32
34	8.1	1.90	38.7	5.6	20.1	28
38	7.9	1.37	30.9	5.2	22.0	23
39	8.2	0.32	7.6	3.8	19.2	20
56	8.3	0.56	14.4	2.1	12.7	18
59	8.3	0.32	8.8	2.8	13.8	23
61	8.2	1.45	30.4	7.3	21.0	34
64	8.0	0.23	6.2	1.1	20.4	6
65	8.2	1.22	24.7	5.3	17.9	29
67	8.0	0.79	16.8	4.0	16.8	24

1/ Values presented are an average of eight values, four depths from two samples in each area.

Appendix Table 14. (Cont.)

Lime percentage	Permeability in./ hr.	1/3 atmosphere percentage	15 atmospheres percentage	Exchangeable K me./100g.	Exchangeable K percentage	Calcium p.p.m.
22	0.64	31.7	10.0	2.7	16	485
27	1.11	33.3	16.6	4.4	21	1,964
20	0.22	32.6	12.4	3.0	14	456
17	0.03	33.2	11.6	2.3	12	71
23	0.44	20.9	9.1	1.6	12	167
23	0.42	21.2	9.2	1.4	9	360
20	0.31	28.2	15.1	3.7	17	1,023
12	0.30	25.2	11.4	2.0	10	196
27	0.40	22.2	14.3	2.1	12	911
22	0.38	29.6	9.6	3.7	22	390

Appendix Table 14. (Cont.)

Magnesium p.p.m.	Sodium p.p.m.	Potassium p.p.m.	Chloride p.p.m.	Sulfate p.p.m.	Carbonate p.p.m.	Bicarbonate p.p.m.
106	1,871	109	2,306	1,932	54	512
917	4,862	498	6,968	9,328	0	270
290	3,472	186	5,756	1,922	0	358
35	804	52	903	400	0	553
100	1,442	65	1,736	1,134	0	558
74	945	54	1,028	1,306	5	478
182	4,048	309	3,454	7,178	0	335
81	303	82	493	210	0	453
237	2,926	150	2,926	5,058	0	246
63	1,477	189	2,606	1,729	0	595

Appendix Table 15. Mean values of soil constituents of soils collected under greasewood from 10 areas from the salt-deserts of Utah 1/

Area No.	pH	Total soluble salts percentage	Saturation extract conductivity K x 10^3	Exchangeable Na me./100 g.	Base exchange cap.me./100 g.	Exchangeable Na percentage	Lime percentage
20	7.7	1.76	30.8	6.7	21.2	32	23
25	9.0	1.07	21.1	7.5	16.6	50	12
46	8.2	0.21	6.7	2.6	19.1	13	6
49	8.0	0.06	0.6	0.6	24.3	3	5
52	8.3	0.53	15.4	5.2	15.5	34	9
53	8.7	0.76	16.7	8.4	19.1	43	10
54	8.3	0.08	1.3	1.4	17.5	8	25
60	8.2	0.27	7.0	3.8	19.5	19	25
70	8.1	1.82	29.6	6.7	18.4	36	22
71	8.1	1.76	24.8	4.8	20.5	25	27

1/ Values presented are an average of 8 values, 4 depths from 2 samples in each area.

Appendix Table 15. (Cont.)

Permeability in./ hr.	1/3 atmosphere percentage	15 atmospheres percentage	Exchangeable K me./100g.	Exchangeable K percentage	Calcium p.p.m.
0.24	39.7	13.7	2.1	10	1,077
0.26	27.2	11.1	3.3	18	44
0.44	21.0	9.4	2.0	11	227
0.43	21.5	12.9	1.8	7	83
0.12	19.8	10.4	1.7	9	188
0.01	26.8	13.0	3.2	17	100
0.22	25.0	13.1	2.8	17	43
0.09	27.6	13.9	3.4	18	45
0.14	34.0	11.7	3.3	18	792
0.13	42.8	14.8	3.6	18	878

Appendix Table 15. (Cont.)

Magnesium p.p.m.	Sodium p.p.m.	Potassium p.p.m.	Chloride p.p.m.	Sulfate p.p.m.	Carbonate p.p.m.	Bicarbonate p.p.m.
269	3,834	129	5,680	5,868	0	394
30	1,754	98	1,736	904	16	773
34	465	56	426	708	0	439
9	91	72	41	40	0	408
52	1,590	58	1,565	1,593	0	554
60	2,087	86	1,825	1,572	0	940
26	264	83	154	112	0	629
27	760	114	734	450	0	679
126	4,306	268	5,917	3,446	0	413
148	4,214	247	6,083	3,106	0	423