Improvement of the Chilcott-Sebree (Solodized-Solonetz) Slick Spot Soils in Southwestern Idaho

September 1964/ARS 41-91
Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE

CONTENTS

IMPROVEMENT OF THE CHILCOTT-SEBREE (SOLODIZED-SOLONETZ) SLICK SPOT SOILS IN SOUTHWESTERN IDAHO [1/]

by

W. W. Rasmussen, G. C. Lewis, and M. A. Fosberg [2/]

INTRODUCTION

Large areas of irrigated farmland in southwestern Idaho and southeastern Oregon contain scattered small areas of nonproductive, salt-affected soil. The peculiar spots are areas of naturally occurring solonetzic soil, containing excessive amounts of adsorbed sodium and soluble salts. Because of the clayey nature of the tilled soils and the persistent wetness and slick condition of the affected soils following rains or irrigations, the soil areas are commonly referred to as "slick spots." In the irrigated croplands the slick spots appear as areas of very sparse and stunted plant growth in otherwise productive lands. The poor plant growth is attributed to the unfavorable physical condition and extremely low rate of water infiltration during irrigations. The low water infiltration capacity results from the deteriorated soil structure caused by the high exchangeable sodium, particularly in the shallow clayey subsoil or B horizons of the soil.

Slick spot soils occur over a wide area, affecting several thousands of acres of irrigated land in the Boise valley in Idaho and adjacent areas in Malheur County, Oregon. Several distinct slick spot or solonetzic soils are recognized. The soils occur in association with several soil series. A number of solonetzic soil complexes have been established.

The soil improvement investigations reported in this paper were conducted on the Chilcott-Sebree (solodized-Solonetz) slick spot soil complex, a principal soil complex representative of relatively large areas of slick-spot-affected soils in this region. Summary descriptions of the Chilcott and Sebree soil series are given in the appendix. The extent of the Chilcott-Sebree soil complex has not been determined. Extensive areas of these soils occur in certain irrigation districts in Canyon and Payette Counties in Idaho. The soils also occur in limited areas in the irrigated sections of Ada, Elmore, and Gem Counties in Idaho and in Malheur County in Oregon. Large

---

1/ Contribution from Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture in cooperation with the Idaho Agricultural Experiment Station.

2/ Research soil scientist, Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture; and associate agricultural chemist and associate agronomist (Soils), University of Idaho.

areas of the soils occur in the rangeland and in land areas being considered for irrigation in these and other areas.[3/]

The Chilcott-Sebree soils are typical of the slick-spot-affected soils in the general area. The Sebree slick spot soil, classified as a solodized-Solonetz, is also described chemically as a saline-sodic (alkali) soil. These soils occur as scattered areas of severely affected saline-sodic soil in close association with less salt-affected or nonsaline soils of the Chilcott and other series. The soils are mapped as a complex. The soils in the complex vary in physical and chemical properties and productivity. Some areas of soil have characteristics transitional between the Chilcott and Sebree soils.

The Chilcott-Sebree soils occur most extensively on the uplands and higher terraces of the irrigated valleys. Certain croplands may contain from 25 percent to more than 50 percent of the unproductive Sebree slick spot soil. The slick spots are resistant to normal soil improvement procedures, and the presence of the spots is considered to be the most serious management problem in the area. The troublesome spots impede farming operations by remaining wet and delaying tillage of the surrounding soils in the spring. They seriously reduce crop yields and greatly reduce land values. Development of practical and economical methods of improving the slick spot soils would greatly benefit the agricultural economy of the area.

This paper reports the results of several soil improvement investigations, conducted over a 7-year period, to determine practical means of improving and reclaiming the slick spot soils.

PREVIOUS STUDIES

The nature and extent of slick spot soils, their properties, and factors responsible for the poor plant growth in these soils have been studied in various experiments for over 50 years. Chemical and physical characteristics of the Sebree soils were studied and described by Peterson (5),[4/] Isaak (2), Bower,[5/] Bushnell,[6/] and Bower and Blair.[7/] A major conclusion from the many chemical analyses made in connection with these studies was that the most

---

3/ Unpublished preliminary soil survey data supplied by M. A. Fosberg, associate agronomist (Soils), University of Idaho, Moscow, Idaho.

4/ Underscored numbers in parentheses refer to Literature Cited, p.34.

5/ Bower, C. A. Some characteristics of Solonetz soils on the Black Canyon and Mountain Home Irrigation Projects in Idaho. U.S. Dept. Agr. Salinity and Rubidoux Laboratory, Riverside, Calif., May 31, 1941. (Mimeo.)

6/ Bushnell, Vernon C. Characteristics of soils of the Black Canyon Project Plots, Payette Division, Boise Project. U.S. Dept. Int., Region 1, Bur. Reclam., December 1949.

7/ Bower, C. A., and Blair, G. Y. A study of "slick spot" soils found on the Black Canyon Irrigation Project, Idaho. U.S. Dept. Agr., Agricultural Research Administration, U.S. Salinity Laboratory, Riverside, Calif., Apr. 1, 1951 (Mimeo.).

specific feature of the slick spot soil profiles was the moderate to high quantities of adsorbed or exchangeable sodium, particularly in the finer textured B horizons.

Recent studies directed toward the characterization and probable genesis of these soils have been made by Sandoval, Fosberg, and Lewis (6), Jordan, Lewis, and Fosberg (3), and Stuart, Fosberg, and Lewis (7). From the results of the characterization studies it was generally concluded that the slick spots evolved through natural soil-forming processes. The slick spots have been classified morphologically as solodized-Solonetz soils.

Studies have been conducted on methods of reclaiming some slick spot soils. The effects of various chemical amendments, manure, and fertilizer in improving the slick spot areas occurring in association with a major irrigated soil in southeastern Oregon were compared in a field study by Bower, Swarner, Marsh, and Tileston (1). The relative infiltration rates and the productivity of the affected soils were increased by the addition of high rates of gypsum, manure, manure and lime, and manure and gypsum over a 3-year period. The permanency of the treatments for maintaining adequate infiltration rates for satisfactory crop production was not evaluated.

The use of different soil treatments, including mixing the horizons of the soil profile and applying manure and chemical additives--gypsum, sulfur, and lime (calcium carbonate)--for improving the Sebree soils in Idaho was investigated in a laboratory and greenhouse study by Bower and Blair.[8] The study indicated that the soils could be improved by mixing the various horizons of the soil profile and by adding adequate gypsum.

Effects of similar treatments on the chemical properties and water intake rates of the soils were studied in a limited small plot study by Pair and Lewis (4). They reported that these soils were effectively reclaimed by the application of 10 or 20 tons of gypsum per acre combined with leaching with 7.5 feet and 15.5 feet, respectively, of water, or by intermixing the various horizons of the soil profile (without gypsum) combined with leaching with a total of 27 feet of water over a 5-year period on small field plots. The treatments were not evaluated under general field conditions.

EXPERIMENTAL AREA

The studies on the Chilcott-Sebree soil series association were performed on sites in Canyon County north of Caldwell, Idaho, within the most recently developed lands of the Payette Division of the Boise Irrigation Project. The irrigated area is referred to locally as the Black Canyon Irrigation District. The irrigated lands in the area are mainly on the higher alluvial terraces or uplands bordering the irrigated river valleys. A large part of the land in this area consists of soils of the Chilcott, Sebree, and related series in complex associations that have developed in alluvial sediments of granitic origin of the Idaho Geologic formation. The soils in the experimental area

---

8/ See footnote 7.

are seriously affected with intensely developed slick spots (fig. 1). These slick spot soils contain excessive amounts of exchangeable sodium but low quantities of soluble salts in the surface and upper subsoils or B_2 horizons. Both high exchangeable sodium and excessive soluble salts occur in the lower B horizons and throughout the lower profile. The Sebree soils are classified as saline-sodic (saline-alkali) soils. The associated Chilcott soils have similar physical characteristics but usually are not saline-sodic.

Figure 1.--A field of alfalfa, near the experimental plot area, severely affected with areas of Sebree slick spot soil. Black Canyon Experimental Tract, near Caldwell, Idaho.

SCOPE OF INVESTIGATIONS

The soil improvement investigations on the Chilcott-Sebree soil complex in southwestern Idaho began in 1957 with experiments on small plots to evaluate the effects of profile mixing (intermixing of soil horizons to simulate deep plowing), subsoiling, and gypsum additions on the physical and chemical properties and productivity of the Sebree soils. The small-plot investigations (experiment No. 1) were considered preliminary to general soil improvement investigations to determine the feasibility of improving and reclaiming the slick spot soils for crop production under irrigation. A larger field plot experiment (experiment No. 2), including actual deep plowing, subsoiling, and gypsum treatments on the Sebree soil and associated

Chilcott soil, was established in the fall of 1959. Several supplemental field tests to determine the feasibility and cost of the deep plowing on operating farm sites were also established in 1959. The investigations described and the results obtained cover the years from 1957 through 1963.

EXPERIMENT NO. 1

Procedures

Experiment No. 1 (the small plot investigations) was begun in the summer of 1957 on the Black Canyon Experimental Tract on a soil site typical of the slick spot soil. The plots were located on separate, individual areas of slick spot soil of the Sebree series selected to be representative of the severe slick spot condition. The original treatments in the study in 1957 included treatments 1 through 7 listed in table 1. Selection of the treatments

TABLE 1.--Summary of treatments in experiment No. 1

Years and treatment No.	Description 1/
1957-62: 2/	
1.	Untreated Check - Vickery (Nonsaline, nonsodic soil).
2.	Untreated Check - Sebree (Slick spot soil).
3.	20 tons/acre gypsum.
4.	Profile mixing to 22-inch depth, plus 20 tons/acre gypsum.
5.	Profile mixing to 60-inch depth, plus 20 tons/acre gypsum.
6.	Subsoiling in 2 directions to 42-inch depth (Shanks spaced 42 inches), plus 20 tons/acre gypsum.
7.	Subsoiling in 2 directions to 42-inch depth and subsequent mixing to 22-inch depth, plus 20 tons/acre gypsum.
1959-62: 3/	
8.	Deep plowing and subsequent profile mixing to 24-inch depth; irrigation by corrugations.
9.	Deep plowing and subsequent profile mixing to 30-inch depth; irrigation by corrugations.
1961-63: 4/	
10.	Profile mixing to 30-inch depth; irrigation by basin flooding.
11.	Profile mixing to 30-inch depth; irrigation by corrugations.

1/ Treatments Nos. 2 through 11 were on Sebree slick spot soil.
2/ Irrigated by basin flooding 1957 to 1960 and by corrugations in 1961 and 1962.
3/ Installed in the fall of 1959.
4/ Installed in April 1961.

to include applications of gypsum was based on the high gypsum requirements indicated by soil tests and on the previous study by Bower and Blair,[9] whose results indicated a serious decline in infiltration rates after mixed soil plots not treated with gypsum were leached. The decision to apply gypsum with the profile mixing treatments was based also on preliminary results from an exploratory farm field plot study[10] which indicated that extremely saline conditions resulted from profile mixing of the slick spot soil. The accumulation of salts on the soil surface retarded germination and delayed emergence of grain under irrigated farm conditions on the mixed profile plots during the first season.

Each treatment was replicated four times in a completely randomized experimental design. The plots subjected to soil horizon intermixing were roughly excavated to size and depth with a small backhoe and finished by hand methods (fig. 2). Subsoiling was done with a large crawler tractor and a heavy-shank, ripper-type subsoiler, (fig. 3). Gypsum was applied to the surface of the plots after the soil horizons were intermixed. The plots were then rototilled to a depth of 4 to 5 inches. Completed plots were 8 feet by 8 feet in area. They were enclosed by a 1- by 6-inch wood frame, faced with asphalt roofing which extended into the soil to the depth of mixing or to a depth below the B_2 horizon at the border of all plots. The frame formed a basin for impounding irrigation water during water applications. The imbedded asphalt material served as a moisture barrier to prevent lateral movement of water from the plot during irrigation and to allow more accurate determination of the water intake rates.

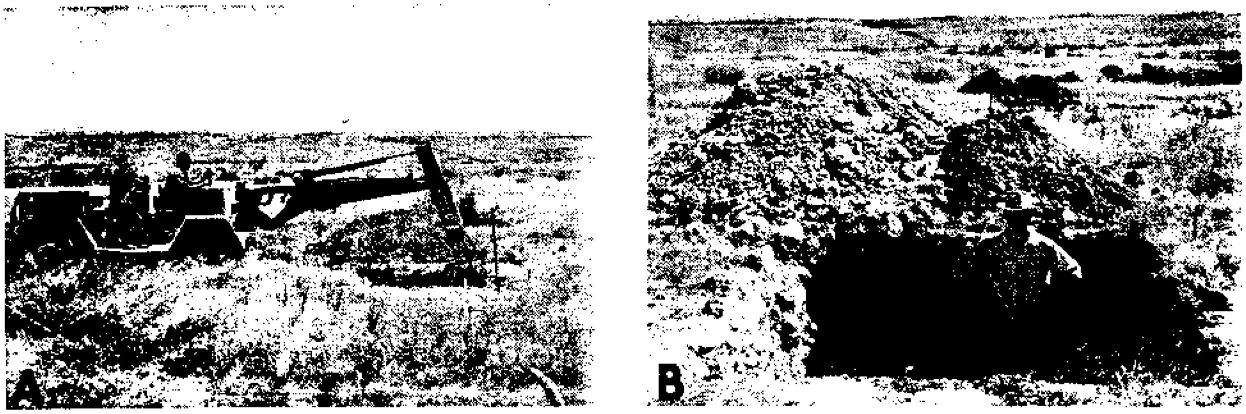

Figure 2.--A, Small backhoe excavating a slick spot area for a profile mixing or simulated deep plowing treatment. B, Deep profile mixing treatment in experiment No. 1.

9/ See footnote 7.

10/ Unpublished data on Sebree (slick spot) soil improvement studies supplied by W. W. Rasmussen, Soil and Water Conservation Research Division, ARS.

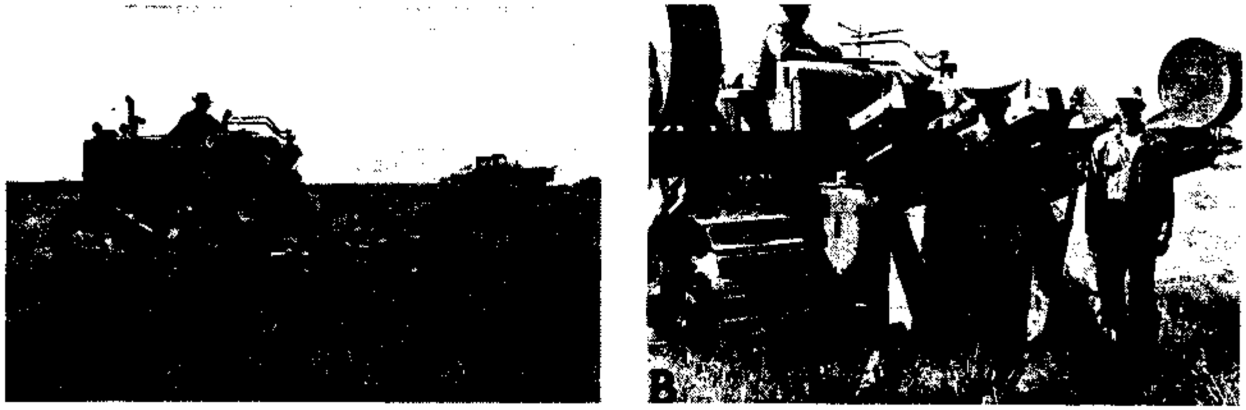

Figure 3.--A, Equipment used in subsoiling treatments in experiment No. 1. B, Closeup view of subsoiling shanks used in subsoiling treatments.

Before the plots were seeded, 10 inches of water were applied to wet the soil profile to field capacity to a depth of 3 feet. Although the irrigation was not intended for leaching, considerable salt was removed from the surface of the mixed plots. The plots were fertilized at a rate equivalent to 60 pounds of N (as ammonium nitrate), 320 pounds of P_2O_5 (as concentrated superphosphate), and 60 pounds of K_2O (as potassium chloride) per acre.

The plots were seeded in August 1957, with a mixture of 6 pounds of Ranger alfalfa, 3 pounds of orchardgrass and 3 pounds of tall wheatgrass, after which they were irrigated at intervals of 7 to 10 days with light (0.5- to 1-inch) water applications, as needed. Germination and subsequent growth of the crop was generally good on all plots. As a result of light irrigations given later in the fall, the soluble salts increased near the soil surface on the mixed profile plots and seriously reduced the plant stands. All plots were reseeded in the spring of 1958 to spring barley interseeded with the alfalfa-grass mixture.

The results of this study during 1958 and 1959 and the results of the exploratory farm field plot study indicated that the soils could be greatly improved by several treatments. Crop yields were substantially increased, and excessive salts and exchangeable sodium were markedly reduced within one cropping year. Infiltration rates remained moderate to high on all mixed-profile, gypsum-treated plots.

In the fall of 1959, when an actual deep plowing soil improvement study was started on an adjacent area, additional profile mixing studies were started as part of experiment No. 1. The supplemental treatments (Nos. 8 and 9) included profile mixing without subsequent gypsum applications. Treatments Nos. 8 and 9 were installed by actual deep plowing and subsequent mixing by hand. In 1961, treatments Nos. 10 and 11 were installed to evaluate profile mixing without gypsum as a means of improving the Sebree soil under controlled basin irrigation and under corrugation irrigation.

The influence of all treatments on soil improvement was evaluated by determining crop response, infiltration rates, and changes in the salinity and sodium status of the soil. Chemical analyses of the soil samples were made using methods described in the U. S. Salinity Laboratory Agriculture Handbook 60 (8). The exchangeable sodium percentage (ESP) of the soils was estimated from the sodium adsorption ratio (SAR) calculated from the soluble cations in the saturation extract. These data were substantiated by direct determination of the exchangeable sodium percentage of a single replication of each treatment. The agreement between the estimated ESP and the ESP determined by the detailed analyses indicated that the estimated ESP values were adequate for this study.

Results

Crop Yields

The effects of the original seven reclamation treatments (see table 1) on barley and on alfalfa hay yields are summarized in table 2. The effects of the supplemental treatments (Nos. 8-11) on yields are summarized in table 3. The results indicate that profile mixing with gypsum, profile mixing only, and gypsum only, greatly increased hay yields as compared with the check plot on the slick spot soil (fig. 4). There were no significant differences in yield resulting from the various methods of profile modification on the slick spot soils. Also, there were no significant differences between yields obtained on the treated slick spot soils and those obtained on the nonsaline-nonsodic soil. Crop yields on the profile mixing plots installed in 1959 and 1961 (treatments Nos. 8-11) cannot be compared directly with the yields from treatments Nos. 3 to 7, since plant growth and yields were probably influenced by the year and age of the alfalfa, climatic conditions, irrigation management, and other factors. However, comparison of the yields on the mixed profile treatments and on the untreated check on the slick spot soils for the same crop year under comparable experimental conditions indicated that the yields of alfalfa hay were increased about fivefold by the mixing of the soil profile alone. The data for the 1961-63 period indicated that yields of alfalfa were essentially the same on the profile mixing without gypsum treatments as on the profile mixing and added gypsum treatments. At the end of the fifth cropping year yields on all the soil improvement treatments were excellent, ranging from about 6.5 to 8 tons per acre. The mixed and subsoiled plots showed some differences in moisture retention and large differences in depth of rooting, but these differences did not affect the yield.

Water Infiltration

The infiltration or intake rates for the various treatments were determined under basin flood irrigation. Water intake rate was considered analogous to infiltration rate, when soils are flooded to a shallow depth during irrigation. The average terminal intake rates by irrigations during the season for the years 1959 to 1962 are summarized in table 4. Terminal intake is defined as the intake rate near the end of the time required for a 4-inch irrigation to be absorbed. Highly significant increases in the intake rate on slick spot soils resulted from all the soil modification treatments. Intake rates on treatments Nos. 3 to 7 remained moderate to high during the 4-year period. Intake rates on the untreated slick spot check plots, treatment No. 1, remained extremely low and essentially unchanged for the 4 years.

TABLE 2.--Yields of barley and alfalfa hay for treatments 1-7, experiment No. 1

Soil and treatment	Basin irrigated				Corrugation irrigated			All air-dried hay
	Barley	Air-dried hay for--			Air-dried hay for--			
	1958	1959	1960	1959-60 average	1961	1962	1961-62 average	1959-62 average
	Pounds per acre	Tons per acre	Tons per acre	Tons per acre	Tons per acre	Tons per acre	Tons per acre	Tons per acre
VICKERY SOIL (Nonsaline-nonsodic)								
1. Untreated check	2,460	6.75	8.90	7.78	7.75	5.84	6.78	7.31
SEBREE SOIL (Slick spot)								
2. Untreated check	1,460	.85	1.83	1.34	1.21	1.24	1.22	1.28
3. Gypsum 20 tons per acre	1,780	6.65	8.45	7.55	8.65	5.02	6.84	7.19
4. Mixed 22 in. plus gypsum 20 tons per acre	2,680	7.42	9.21	8.31	8.88	5.79	7.33	7.83
5. Mixed 60 in. plus gypsum 20 tons per acre	1,730	7.75	9.50	8.62	8.45	6.14	7.29	7.96
6. Subsoiled 42 in. plus gypsum 20 tons per acre	2,210	7.12	7.63	7.37	6.07	5.42	5.75	6.56
7. Subsoiled 42 in., mixed 22 in., plus gypsum 20 tons per acre	1,860	7.06	7.27	7.16	6.52	5.31	5.91	6.54

TABLE 3.--Yields of barley and alfalfa hay for supplemental plots located on Sebree slick spot soil, experiment No. 1

Treatment	Barley for--		Air-dried alfalfa hay for--			
	1960	1961	1961	1962	1963	2-year average
	Lb./acre	Lb./acre	Tons/acre	Tons/acre	Tons/acre	Tons/acre
BASIN IRRIGATED						
10. Mixed 30 in, no gypsum 1/	--	2,250	2/ 5.11	7.55	8.08	3/ 7.81
CORRUGATION IRRIGATED						
8. Mixed 24 in, no gypsum 4/	2,220	--	6.68	7.18	--	6.93
9. Mixed 30 in, no gypsum 4/	2,575	--	6.03	5.33	--	5.68
11. Mixed 30 in, no gypsum 1/	--	--	6.89	6.23	--	6.56

1/ Installed in the spring of 1961.
2/ Yield for 2 cuttings following harvest of barley grain.
3/ 1962-63 average.
4/ Installed in the fall of 1959.

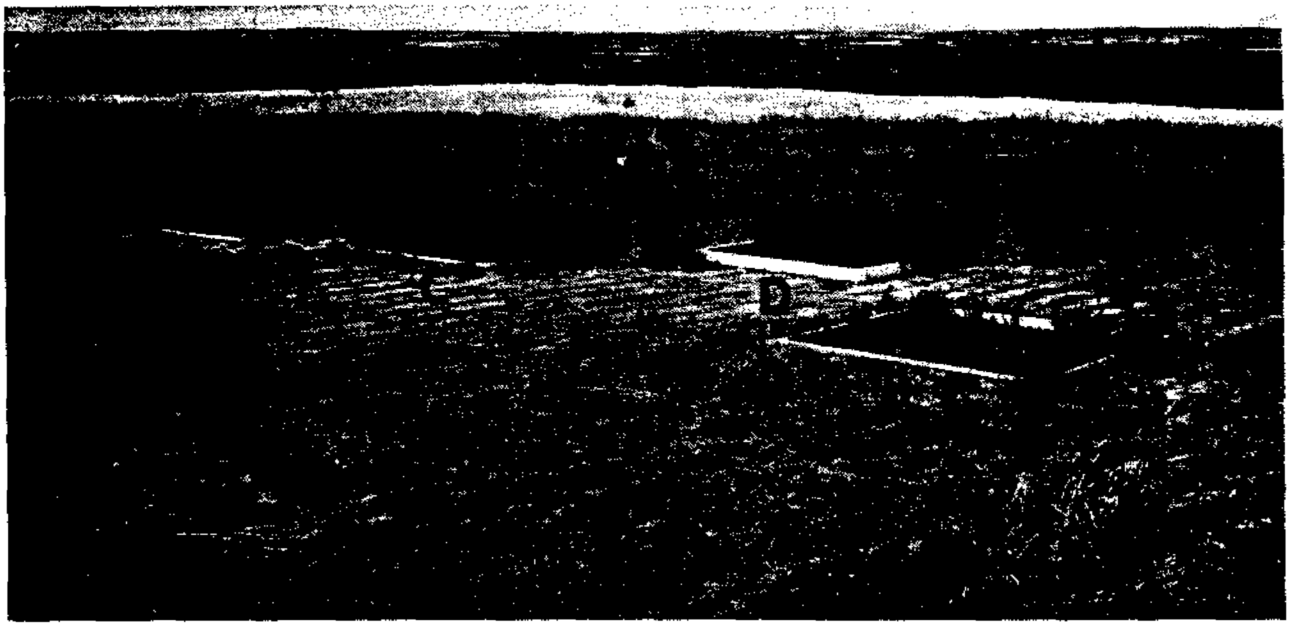

Figure 4.--Relative growth of second cutting of alfalfa hay on representative plots on Sebree slick spot soil, July 1959. Plant growth and yields are extremely limited on the untreated slick spot check plots (A and B). Improved growth and production with 20 tons gypsum per acre (C) and deep mixing plus gypsum (D, plot partially harvested) are evident.

Soil moisture data collected during the study indicated that water penetrated to the full depth of mixing or plowing on all plots within irrigation periods of 10 to 12 hours. Soil moisture was increased to field capacity in the full depth of mixing during most irrigations. The tremendous improvement in infiltration rates resulting from the various treatments and the apparent permanency of the intake rates and depth of penetration indicated that the Sebree soil was effectively reclaimed.

Changes in Soluble Salt and Exchangeable Sodium

Chemical analyses were made on soil samples taken before treatment, after profile mixing, and in the fall of each cropping year. The salinity status of the soil profile as indicated by the electrical conductivity of the saturation extract, before treatment, immediately after mixing, and at yearly intervals for the following three years is presented in appendix table 10. The electrical conductivity data for the soil profile before treatment, immediately after mixing, and three years after treatment are shown graphically in figure 5. The estimated exchangeable sodium percentages at the various dates are given in appendix table 11, and shown graphically in figure 6. These data indicated that soluble salts and exchangeable sodium in the slick spot soils were reduced substantially in the upper 18 inches of the soil profile within one year after treatment. This was substantiated by the increased water intake

TABLE 4.--Terminal water intake rates on basin irrigated plots (average of four replications), experiment No. 1

Soil and treatment	1959 May 19	June 29	July 16	July 30	Aug 28	Average	1960 Apr 22	June 1	July 11	Aug 11	Sept 27	Average
	Inches per hour						Inches per hour					
VICKERY SOIL (Nonsaline-nonsodic)												
1. Untreated check	1.3	1.0	1.3	1.6	1.2	1.3	1.0	1.2	1.2	1.1	1.0	1.1
SEBREE SOIL (Slick spot)												
2. Untreated check	.11	.12	.05	.05	.04	.07	.06	--	.02	.03	.03	.035
3. Gypsum 20 tons/acre	1.1	.75	.82	1.3	.9	1.0	.9	.6	.8	.7	.7	.7
4. Mixed 22 in. plus gypsum 20 tons/acre	1.5	1.2	1.6	1.1	1.3	1.3	1.7	1.2	1.7	1.4	1.4	1.5
5. Mixed 60 in. plus gypsum 20 tons/acre	1.5	1.9	1.8	1.4	2.0	1.7	2.4	2.5	2.2	2.0	1.9	2.2
6. Subsoiled 42 in. plus gypsum 20 tons/acre	.6	.8	1.7	1.3	1.3	1.1	.8	1.1	1.2	1.1	1.2	1.1
7. Subsoiled 42 in., mixed 22 in. plus gypsum 20 tons/acre	1.5	1.4	.95	1.3	.9	1.2	1.8	1.5	1.5	1.4	1.3	1.5
	1961 May 14	June 5	July 15	Aug 10	Aug 30	Average	1962 Apr 23	June 25	July 6	Aug 20	Sept 12	Average
10. Mixed 30 in., no gypsum	2.0	2.4	1.7	1.3	1.4	1.8	2.0	1.2	1.3	1.2	.9	1.3

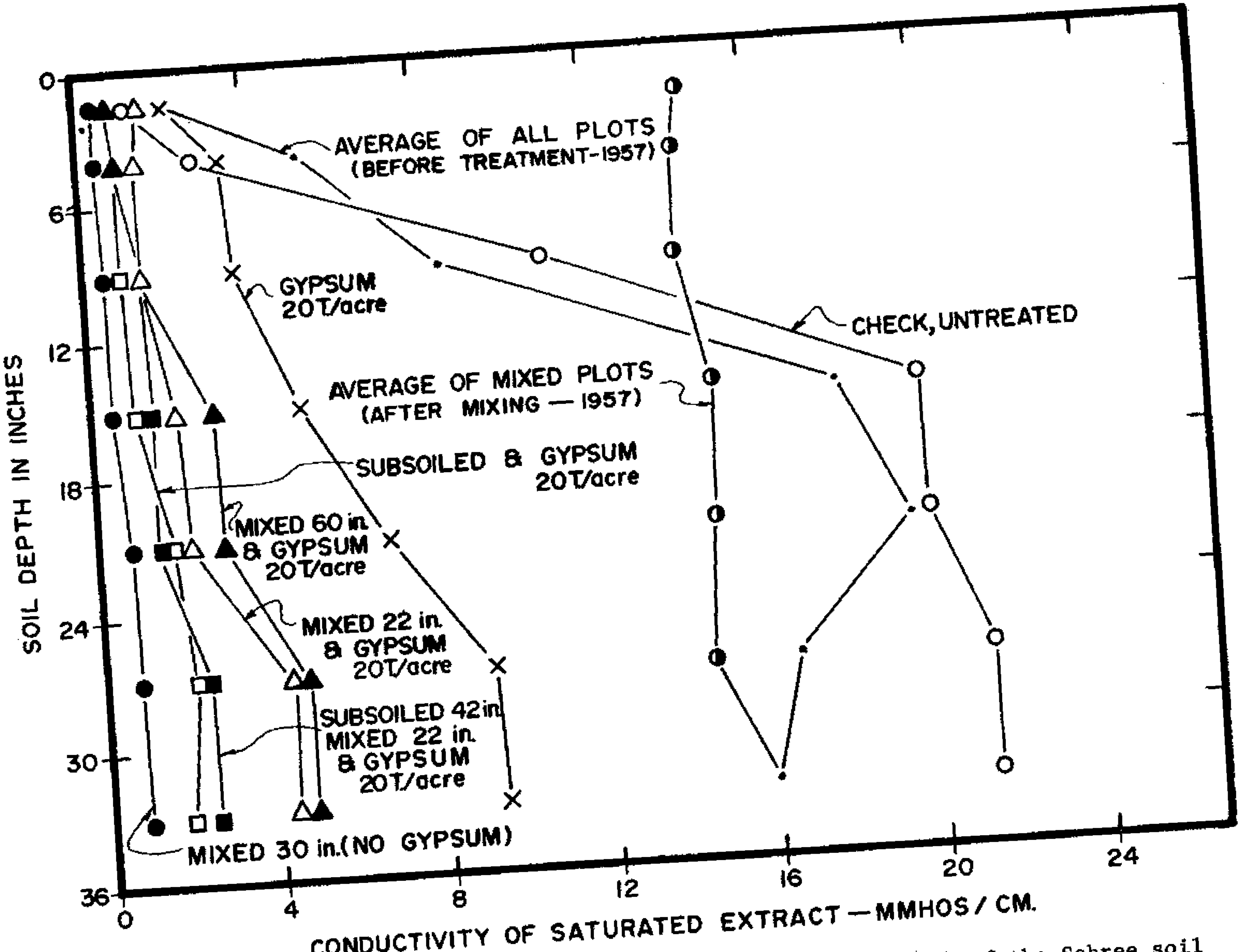

Figure 5.--Electrical conductivity of the saturation extract (EC_e) of the Sebree soil profile before treatment, immediately after mixing, and 3 years after treatment, experiment No. 1.

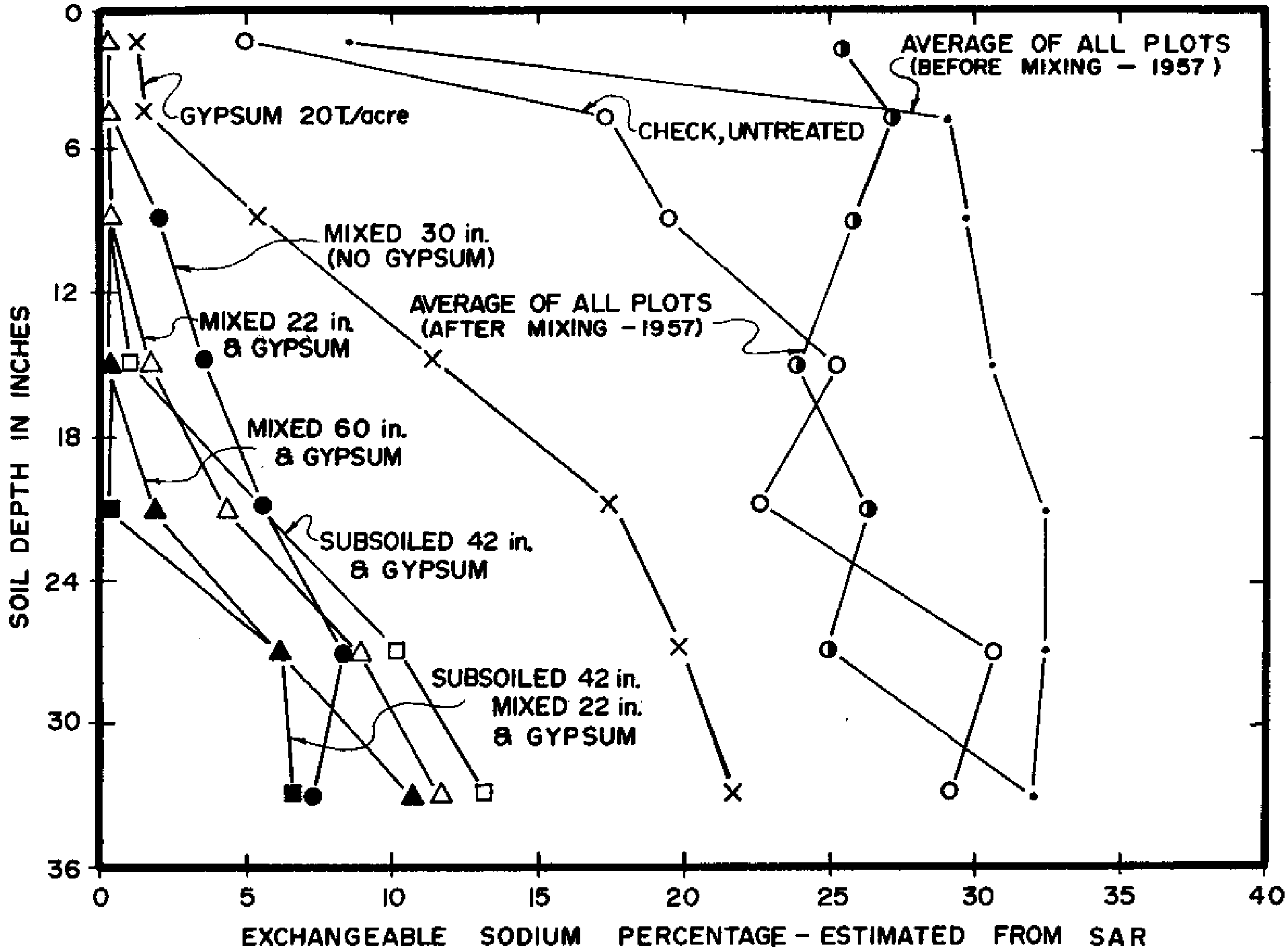

Figure 6.--Exchangeable sodium percentage of the Sebree soil profile before treatment, immediately after mixing, and 3 years after treatment, experiment No. 1.

rates and the greatly increased crop yields. Within three crop years after treatment with only moderate irrigation the excessive exchangeable sodium and soluble salts were reduced to non-critical levels to a depth of 36 inches on most treatments. The exchangeable sodium and soluble salts were substantially reduced throughout the profile on the gypsum-only plots, but both salts and exchangeable sodium remained appreciably higher in the 18- to 36-inch depth than on the other treated plots. The chemical status of the untreated slick spot soil remained essentially unchanged during the entire period of the study.

EXPERIMENT NO. 2

Procedures

A field-scale study was established on the Black Canyon Experimental Tract in the fall of 1959 on an area of Chilcott-Sebree soil complex adjacent to experiment No. 1. Plots were established to evaluate actual deep plowing, subsoiling, and amendment treatments for improving the Chilcott and Sebree slick spot soils under field conditions. A further objective of the large plot study was to gain information on the permanency, cost, and management problems associated with deep plowing treatments. The treatments included in the experiment are listed in table 5.

TABLE 5.--Summary of treatments in experiment No. 2

Soil and treatment No.	Description
CHILCOTT SOIL (Nonsaline-nonsodic)	
1.	Untreated check.
2.	Conventional subsoiling in 2 directions to 28-inch depth (shanks spaced 21 inches).
3.	Deep plowing to 24 inches.
4.	Deep plowing to 30 inches.
SEBREE SOIL (Slick spot)	
5.	Untreated check.
6.	12 tons/acre agricultural gypsum disked into the soil.
7.	Conventional subsoiling in 2 directions to 28-inch depth (shanks spaced 21 inches).
8.	Conventional subsoiling in 2 directions, plus 12 tons/acre gypsum.
9.	Deep plowing to 24 inches.
10.	Deep plowing to 24 inches, plus 12 tons/acre gypsum.
11.	Deep plowing to 30 inches.
12.	Deep plowing to 30 inches, plus 12 tons/acre gypsum.

Treatments were evaluated by yield response, infiltration measurements, and changes in the exchangeable sodium and salinity status of the soil. Plots were installed in a completely randomized design with three replications of all treatments. Main plots treated by deep-plowing and subsoiling were approximately 1 acre in area and contained six to nine Sebree slick spot areas and three to six Chilcott soil areas on which the treatment plots were placed. The subplot areas for treatment with gypsum, for yield determinations, soil moisture and water intake measurements, and collection of soil samples for periodic chemical analyses were 10 feet by 10 feet in size. The selected areas of typical Sebree slick spot soil and Chilcott soil were located by observations of the growing crop during the previous cropping season and by detailed soil profile examination. All the large plots were located on similar slopes and exposure and were spaced to allow for the operation of the large plowing equipment. The plots were plowed to depths of 24 and 30 inches with a 4-foot moldboard plow drawn by a single D-8 Caterpillar tractor,11/ (fig. 7). Deep plowing and subsoiling were done in the fall of 1959. The gypsum treatments were applied in the spring of 1960. The entire plot area was irrigated, prior to planting, by standard corrugations spaced at 24 inches. The experimental area was planted to wheat interseeded with alfalfa in 1960, and cropped to alfalfa for hay production in 1961 and 1962. After the area was planted, the usual field irrigation and cultural practices for the crops were followed.

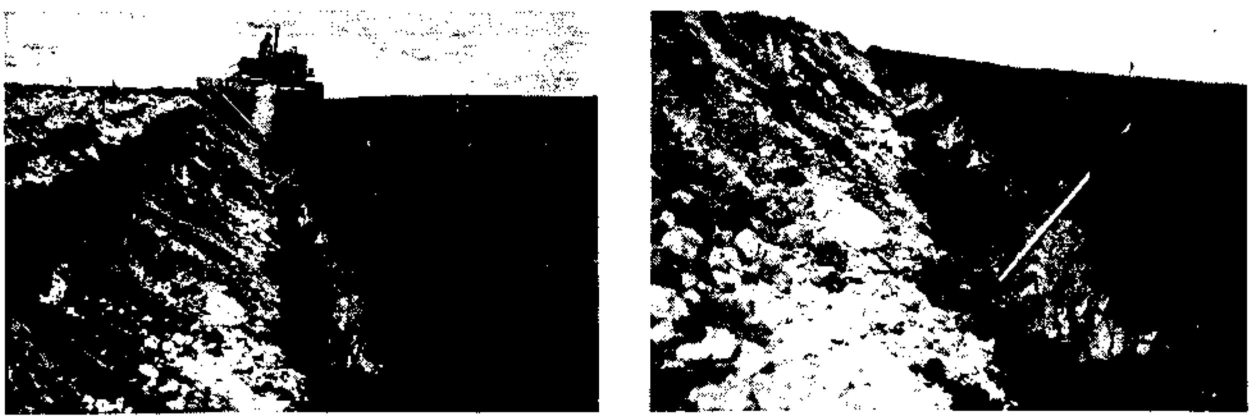

Figure 7.--Deep plowing on experiment No. 2, October 1959.
A, Plowing to a depth of 24 inches with a 4-foot moldboard deep plow. B, Closeup of a furrow plowed to a depth of 30 inches through a slick spot area.

11/ Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture or an endorsement by the Department over other products not mentioned.

Crop Yields

The plots were not planted to wheat until May 3, 1960, a late date for seeding spring wheat in the area. Only moderate yields of wheat were obtained in 1960, probably because of the late seeding. Excellent to good stands of alfalfa were obtained on most plots. The area was cropped to alfalfa cut for hay in 1961 and 1962. The yield of wheat in 1960 and alfalfa yields for 1961 and 1962 are shown in table 6. Statistical analyses of the data (table 7) indicate that highly significant increases in alfalfa yields were obtained for all treatments, except the subsoiling-only treatment, in comparison with the untreated check plots. The yields on the slick spot soil with subsoiling only were essentially the same as on the untreated slick spot soil. The alfalfa yields on the Chilcott soils were significantly increased by deep plowing to 24 inches and 30 inches in comparison to the untreated plots for one year. Subsoiling on the Chilcott soil to a depth of 28 inches apparently increased alfalfa yields in 1962.

Water Infiltration and Soil Moisture

Infiltration and depth of penetration of irrigation water were determined, during 1960 and 1961, by gravimetric soil moisture sampling and observation of water penetration. Intake rates were determined directly by furrow infiltrometer measurements in 1962. Water intake and depth of penetration data are summarized in figure 8. These data indicate that the total intake and depth of penetration in 24 hours were greatly increased by the deep plowing on both the Sebree and the Chilcott soils. This observation was substantiated by the greatly increased crop yields and leaching of the soluble salts on the deep-plowed plots. The total intake and the depth of penetration were also increased considerably by subsoiling the Chilcott soil. Application of gypsum and subsoiling with gypsum increased total intake and penetration in 24 hours on the Sebree soils. Subsoiling alone did not influence the total intake on the Sebree soils after the first year. The apparent increase in total intake on the subsoiling treatment on the Sebree soil indicated in figure 8 resulted primarily from increased water penetration on a single plot during 1961.

The penetration of plant roots on the check and gypsum-treated slick spot soil, and the check Chilcott soil was restricted by the lime-cemented subsoil layers occurring at depths of 15 to 17 inches in both soil profiles. Since plant roots failed to grow into the cemented layers, soil moisture was not extracted from below these depths; this limited the available soil moisture storage capacity. After irrigations, the soil moisture was rapidly depleted from the shallow plant root zones on the shallow-tilled plots. Deep plowing to the 24- and 30-inch depths on both the Sebree and Chilcott soils essentially doubled the depth of water and root penetration, and available soil moisture.

Because of the large differences in the depth of water penetration and the depth of the root development, the soil moisture conditions in the root zone on the various treatments at the time of irrigation differed greatly.

TABLE 6.--Effect of soil treatments on spring wheat and alfalfa hay yields, experiment No. 2

Soil and treatment	Wheat	Alfalfa[1/]					
		2-year average by cuttings			Annual yield		
	1960	1st	2d	3d	1961	1962	2-year average
	Bu./acre	Tons/acre	Tons/acre	Tons/acre	Tons/acre	Tons/acre	Tons/acre
CHILCOTT SOIL (Nonsaline-nonsodic)							
1. Untreated check	17.7	2.08	1.22	1.11	5.06	3.74	4.41
2. Subsoiled 28 in.	27.1	2.12	1.40	1.35	5.03	4.68	4.87
3. Deep plowed 24 in.	37.2	2.52	1.62	1.52	6.40	4.88	5.66
4. Deep plowed 30 in.	30.9	2.67	1.73	1.49	6.62	5.14	5.89
SEBREE SOIL (Slick spot)							
5. Untreated check	11.6	.95	.36	.23	2.06	1.00	1.54
6. Gypsum 12 tons/acre	14.8	1.93	1.29	1.10	5.06	3.57	4.32
7. Subsoiled 28 in.	15.6	.80	.37	.48	2.15	1.14	1.65
8. Subsoiled 28 in. and gypsum 12 tons/acre	26.9	2.46	1.56	1.52	5.47	5.61	5.54
9. Deep plowed 24 in.	27.7	2.21	1.57	1.44	5.69	4.73	5.22
10. Deep plowed 24 in. and gypsum 12 tons/acre	38.4	2.35	1.69	1.42	6.30	4.60	5.46
11. Deep plowed 30 in.	29.3	2.33	1.68	1.43	5.32	5.54	5.44
12. Deep plowed 30 in. and gypsum 12 tons/acre	37.3	2.57	1.77	1.44	6.06	5.49	5.78

1/ Average of three replications of each treatment. Air-dried hay equivalent to approximately 25 percent of the fresh green weight.

TABLE 7.--Comparison of yields of alfalfa hay as influenced by soil treatments

Soil	Treatment	Mean yield per cutting (1961, 1962)	Statistical significance 1/
		Tons/acre	
Chilcott	11. Deep plowed 30 in.	1.973	
Sebree	12. Deep plowed 30 in. and gypsum 12 tons/acre	1.908	
Chilcott	9. Deep plowed 24 in.	1.879	
Sebree	8. Subsoiled 28 in. and gypsum 12 tons/acre	1.846	
Sebree	10. Deep plowed 24 in. and gypsum 12 tons/acre	1.817	
Sebree	4. Deep plowed 30 in.	1.804	
Sebree	3. Deep plowed 24 in.	1.738	
Chilcott	2. Subsoiled 28 in.	1.618	
Chilcott	1. Untreated-check	1.466	
Sebree	6. Gypsum 12 tons/acre	1.415	
Sebree	7. Subsoiled 28 in.	.548	
Sebree	5. Untreated-check	.547	

1/ Duncan's multiple range test. $\alpha = 0.01$
Means connected by same vertical line are not significantly different at the 1 percent significance level.

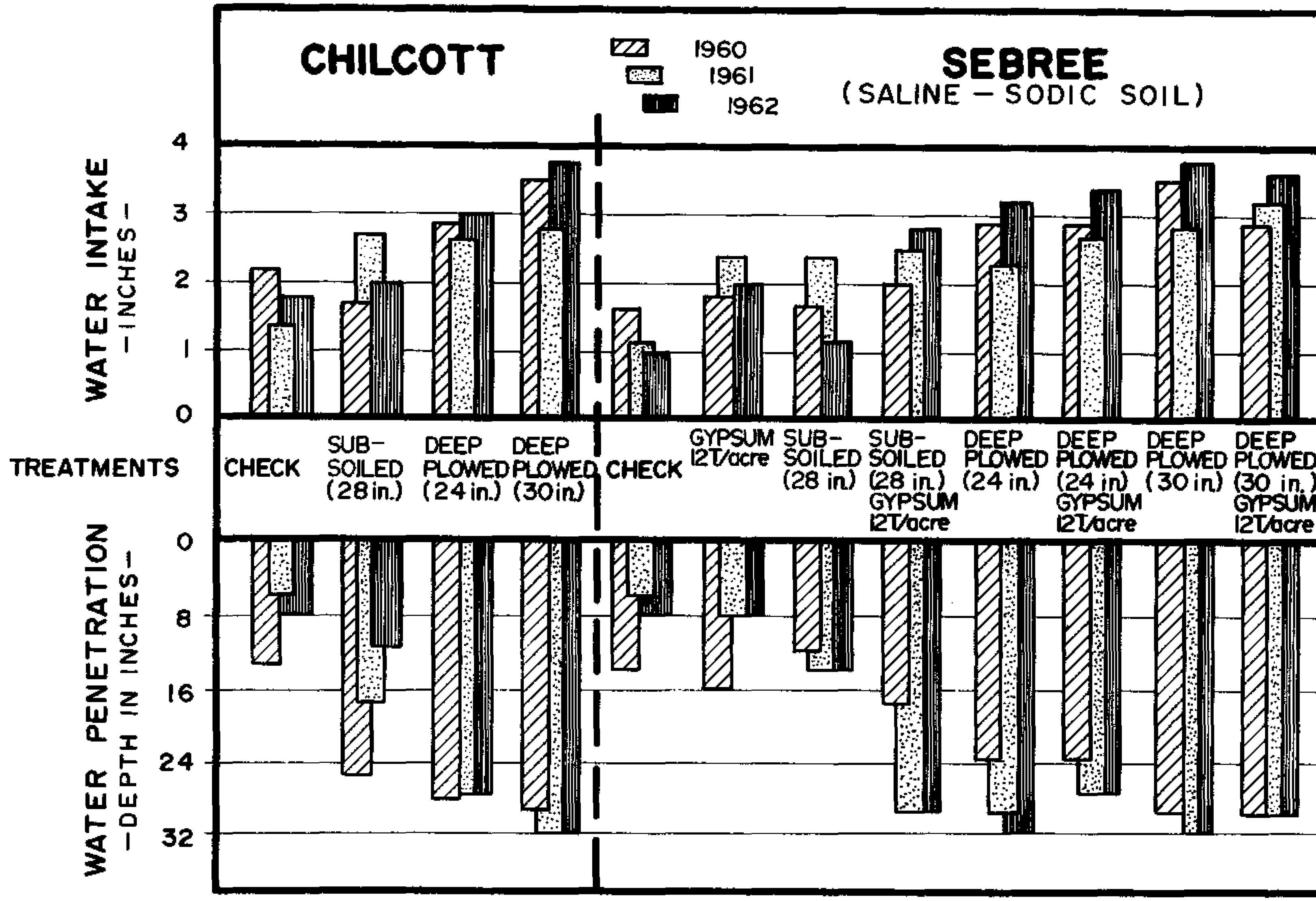

Figure 8.--Average quantity of water absorbed, and depth of water penetration, during 24-hour irrigations using small furrows, experiment No. 2, 1960-62, (values are means for two midseason irrigations each year).

Infiltration measurements were undoubtedly influenced by the wide ranges in soil moisture at the time of irrigation. The initial soil moisture varied from below the permanent wilting percentage on the untreated slick spots to two-thirds or more of field capacity throughout the profile on some deep-plowed plots. The arrangement of subplots, randomly located on the areas of Chilcott or Sebree soil within the large plot areas, did not permit irrigating subplots separately. All subplots in the main treatment plots were irrigated simultaneously. For this reason the determination of the water infiltration was not entirely satisfactory. No absolute comparisons between the total intake on the various treatments at closely controlled moisture levels could be made. However, in view of the large differences in total intake and depth of water penetration among the various treatments on specific plot areas, the results indicate reliable relative comparisons between the treatments.

The average moisture-holding capacity and the moisture retained at the wilting point and at field capacity for the undisturbed Sebree and Chilcott soils were estimated from the moisture retention data reported by Bushnell, and by Bower and Blair.[12] The moisture retained at one-third atmosphere tension (estimated field capacity) on the mixed Sebree soil in this study was determined in 1961. The moisture retention determinations indicated that the soil contained 27 to 30 percent of moisture by weight at the field capacity and 11 to 14 percent by weight at the wilting point. This was in agreement with the values obtained from moisture samples taken at comparable soil moisture levels in the field. Apparently, the profile mixing by deep plowing and the alteration of the soil horizons by deep plowing and subsoiling did not appreciably alter the water-holding characteristics of the soil on a weight basis.

The total water retention and total available water-holding capacity of the soil were greatly increased by the increase in the effective depth of the plant root zone. Deep plowing, subsoiling plus gypsum treatments, and to a more limited extent subsoiling, increased the root zone depth. Mixing the soil textures and breaking up the hardpan and cemented subsoil layers of the soil by the deep plowing treatments resulted in a soil with more desirable soil moisture characteristics.

Changes in Soluble Salt and Exchangeable Sodium

The changes in soluble salt and exchangeable sodium of the Sebree and Chilcott soils were determined periodically during the study. Initial soil samples were taken from all the plots and from the plowed plots in the fall of 1959 after deep plowing. Additional soil samples were collected from all plots in 1960, 1961, and 1962. Detailed chemical analyses, including the determination of pH and electrical conductivity of the saturation extract, were made on all samples. Data on the exchangeable sodium percentage are currently available for the initial sampling and the 1960 and 1961 sampling periods.

12/ See footnotes 6 and 7.

Electrical conductivity of the saturation extract in the Sebree soils after treatment is shown in figure 9. The data are plotted for each year of the study and represent the means for each treatment. Although the soil samples were taken by horizon depth, they were grouped into 0- to 8-, 8- to 16-, and 16- to 30-inch depths or to the depth of tillage for comparison purposes.

The deep plowing treatments, with and without gypsum, were the most effective in reducing the amount of salt throughout the soil profile. Plowing to 30 inches initially increased the salt in the 0- to 8- and 8- to 16-inch depths but this salt was subsequently reduced by leaching to a low level by the third year of the experiment. Adding 12 tons of gypsum per acre, and subsoiling to 28 inches plus 12 tons of gypsum improved the top 16 inches of soil, but was less effective lower in the profile. Subsoiling alone did not reduce the salt content of the profile below that of the check plot.

The effect of mixing the soil horizons in reducing the exchangeable sodium percentage of the Sebree soils, shown graphically in figure 10, was similar to its effect in reducing the salt content. Deep plowing, with and without gypsum, was the most effective treatment in reducing the exchangeable sodium throughout the profile, and especially in the lower horizons. Subsoiling plus gypsum reduced the sodium as much as deep plowing in the top 16 inches of the profile, but was less effective below 16 inches. Subsoiling alone did not reduce the exchangeable sodium level below that of the check plot during the study.

Deep plowing alone was effective in reducing the salt content of the lower part of the profile in the Chilcott soils, as shown in figure 11. Subsoiling had no beneficial effect over the check plot in reducing the salt.

Deep plowing the Chilcott soil reduced the exchangeable sodium content at depths below 8 inches in the profile. Subsoiling did not reduce the exchangeable sodium content below that of the check during the 3 years of the study.

The changes in the exchangeable sodium percentage and the salt content in the lower profile appeared to be quite variable on some plots. The variations apparently occurred from variable leaching resulting from irrigation by small corrugations and may not be significant under the conditions of the study.

The use of gypsum in addition to deep plowing appeared to increase crop yields for the first crop year on some plots. Although the increases were not significant, the apparent increased growth may have resulted from slightly improved initial soil conditions and may have improved alfalfa stands on the gypsum-treated plots. There were no marked differences in effects on plant growth or in total yields between the effective soil treatments at the end of the third cropping year.

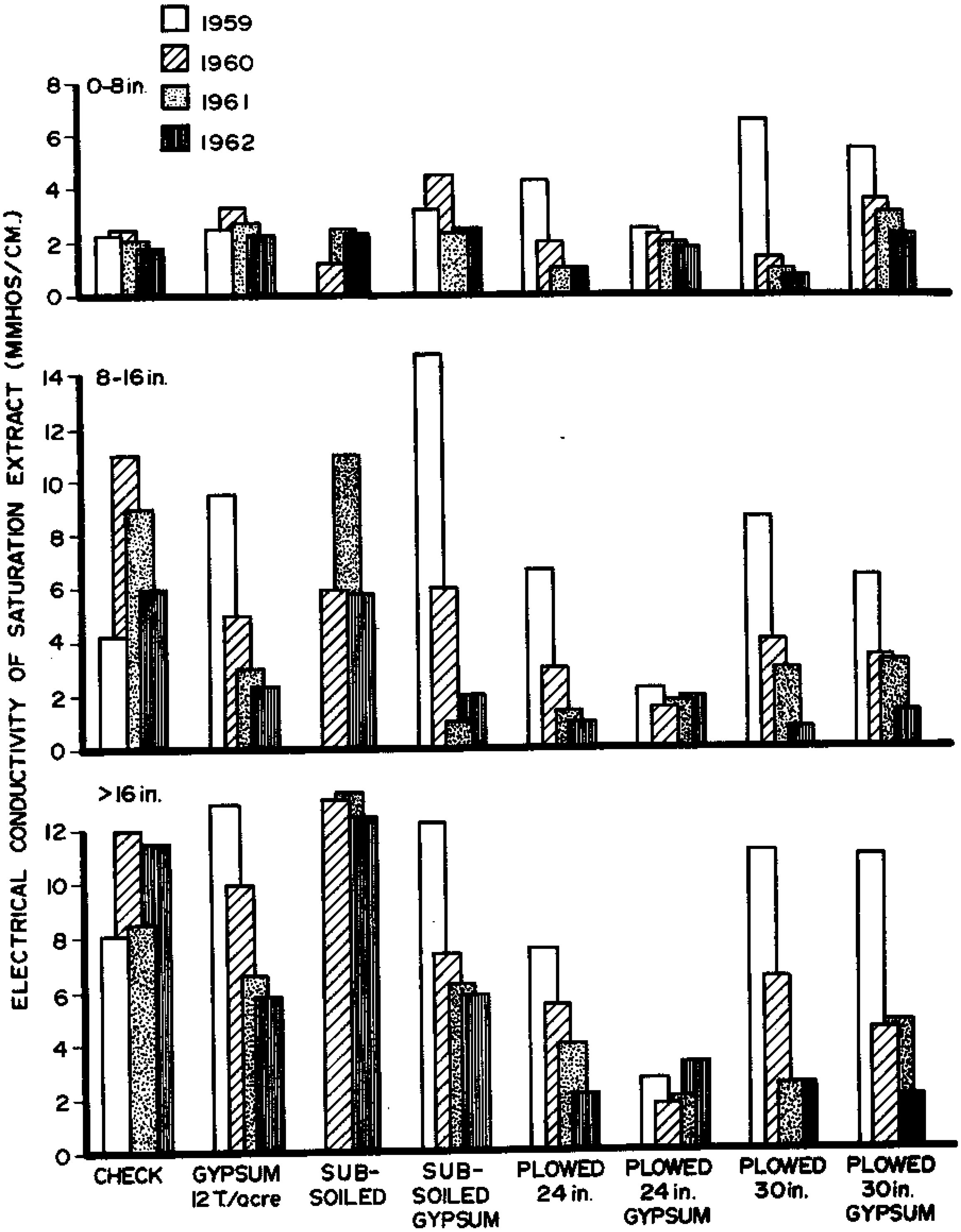

Figure 9.--Electrical conductivity of the saturation extracts for the 0- to 8-, 8- to 16-, and greater than 16-inch depths of the Sebree soil, experiment No. 2.

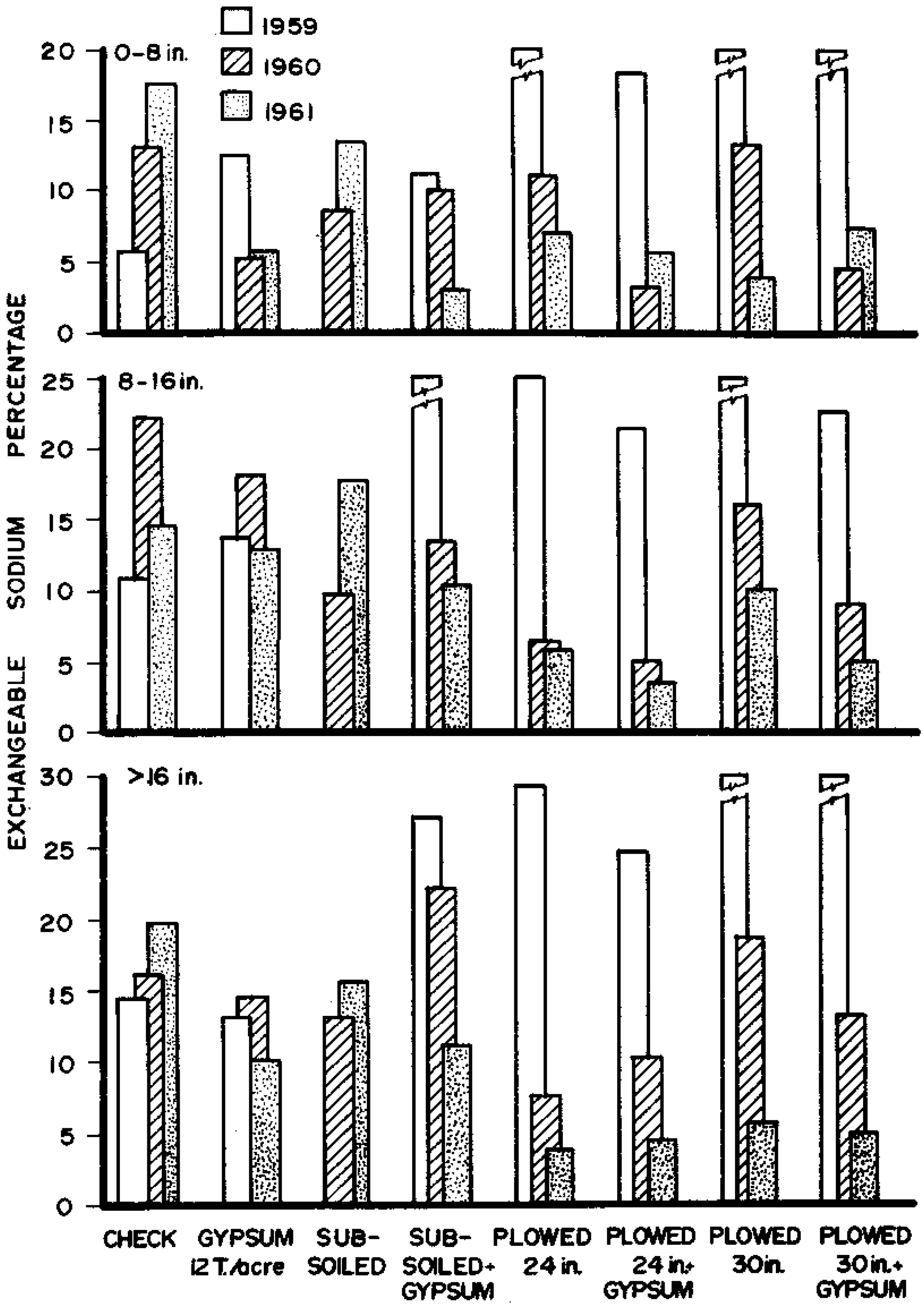

Figure 10.--Exchangeable sodium percentage for the 0- to 8-, 8- to 16-, and greater than 16-inch depths of the Sebree soil after each of 3 years of treatment, experiment No. 2.

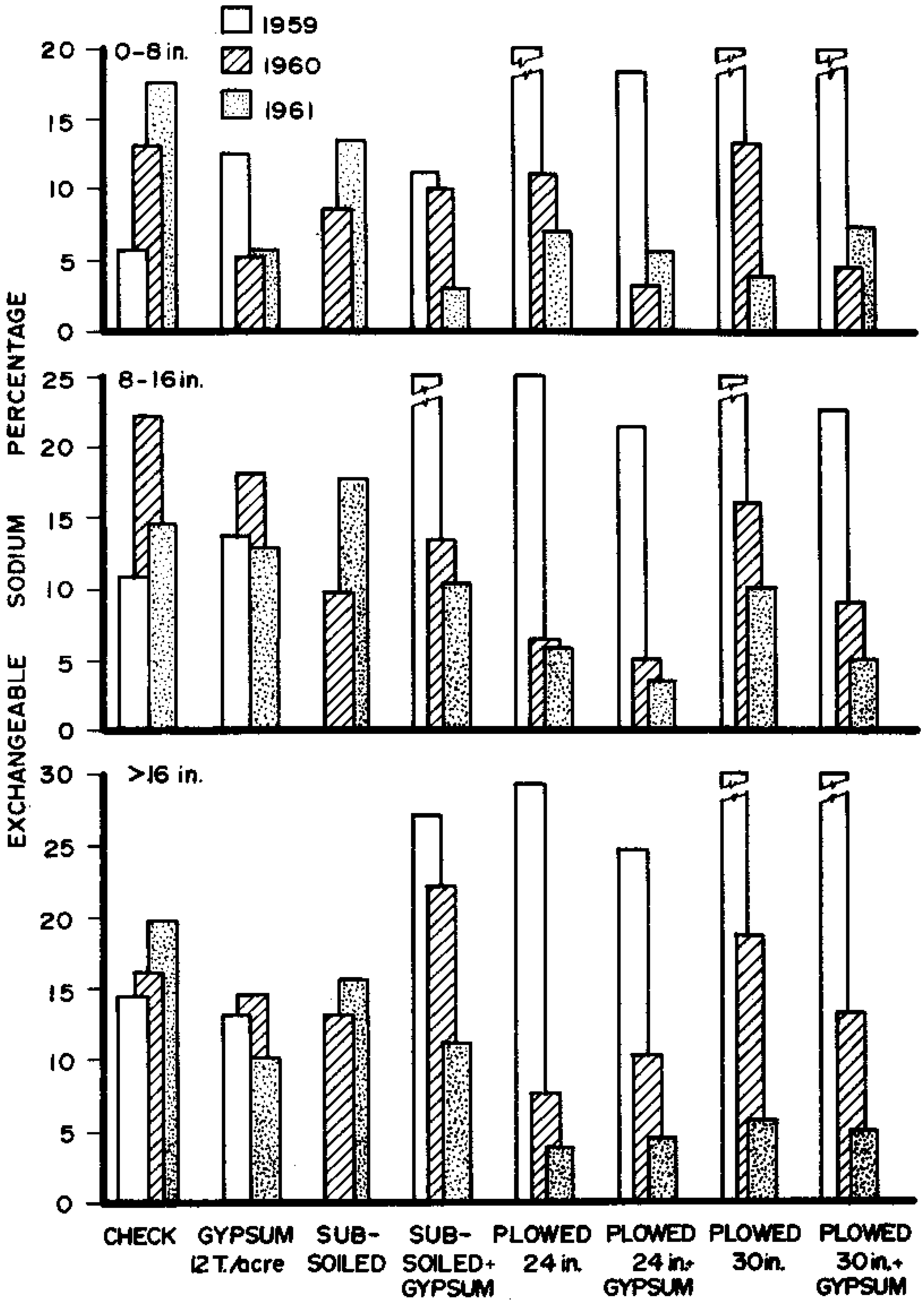

Figure 10.--Exchangeable sodium percentage for the 0- to 8-, 8- to 16-, and greater than 16-inch depths of the Sebree soil after each of 3 years of treatment, experiment No. 2.

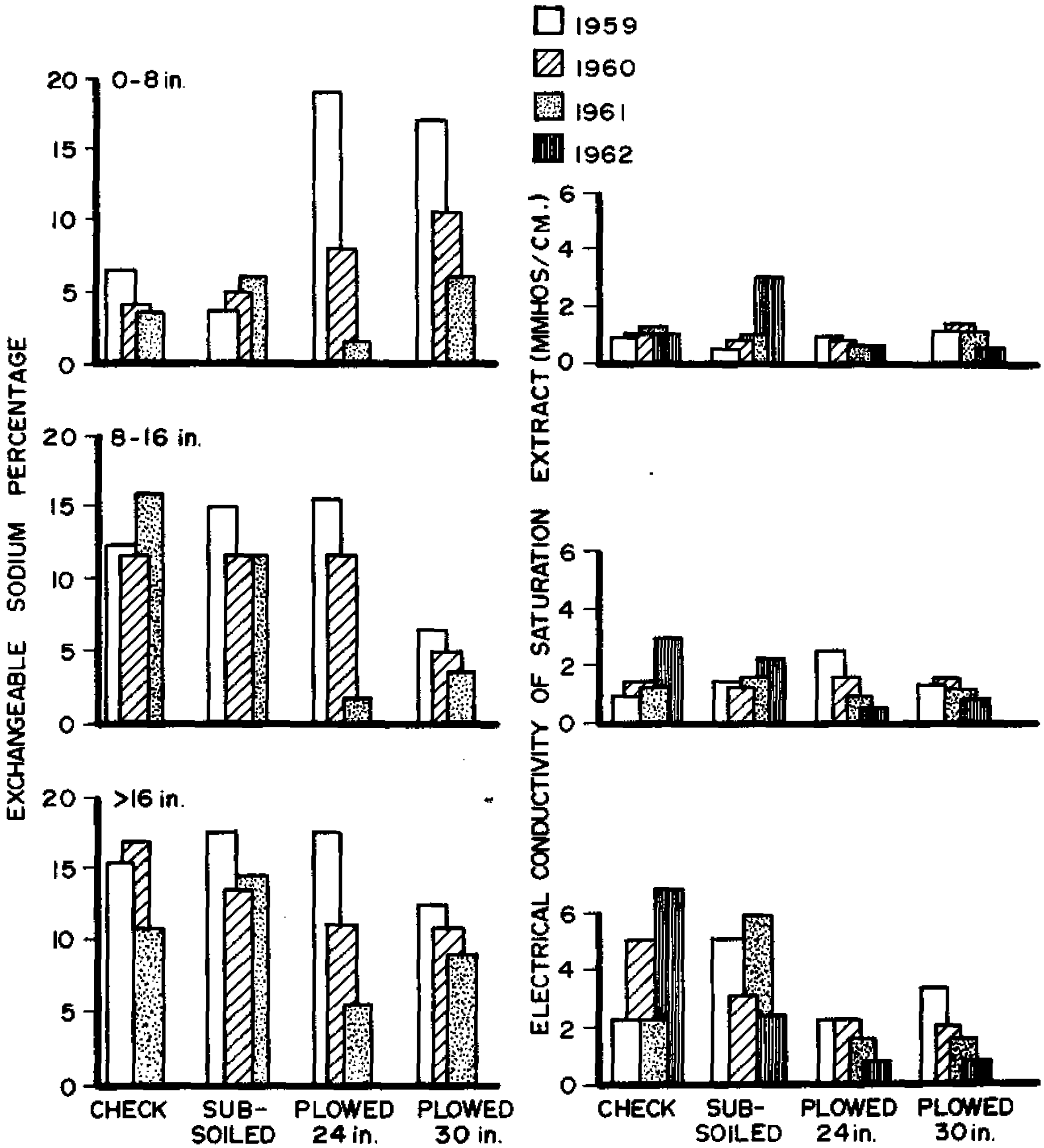

Figure 11.--Exchangeable sodium percentage (after each of 3 years of treatment) and mean electrical conductivity of the saturation extract (after each of 4 years of treatment) for the 0- to 8-, 8- to 16-, and greater than 16-inch depths of the Chilcott soil, experiment No. 2.

Results

Yield data for the study, presented in table 8, show that the yields of corn on the deep-plowed Sebree soil were greatly increased in comparison to the yields on untreated or subsoiled slick spot soil. During the 3 years there were no appreciable differences between the yield of corn on the deep-plowed Sebree plots and on the deep-plowed or untreated Chilcott plots. In 1960, the first season after the deep plowing, high salt concentrations occurred in small areas on the surface of some of the deep-plowed Sebree soil plots. The stands of corn were reduced on these plots but the final yields were essentially the same as on the deep-plowed Chilcott soils.

TABLE 8.--Average yield of ear corn, supplemental deep plowing and subsoiling test, Black Canyon Experimental Tract, 1960-62

Treatment	Year 1/		
	1960	1961	1962
	Bu./acre	Bu./acre	Bu./acre
UNTREATED CHECK			
Chilcott soil	83.5	154.3	101.0
Sebree soil	7.0	4.3	5.4
SUBSOILED - 28 in. depth (Shanks operated on 21-inch spacing)			
Chilcott soil	90.0	150.5	103.3
Sebree slick spot soil	12.4	3.6	0
DEEP PLOWED - 24 in.			
Chilcott soil	91.0	147.5	2/ 104.6
Sebree slick spot soil	87.5	145.6	103.8
DEEP PLOWED - 30 in.			
Chilcott soil	90.0	143.0	101.4
Sebree slick spot soil	85.0	145.1	107.5

1/ Average yield from three replications of each treatment, equivalent to No. 2 shelled corn at 15.5 percent moisture.

2/ Yields from one replication only in 1962.

Observations of soil moisture on the plots during the test period indicated that infiltration rates and depth of water and root penetration on the slick spot areas were greatly increased by deep plowing.

Chemical analyses of soil samples collected from selected slick spot areas in 1961 and 1962 indicated that the chemical condition of the soils had been greatly improved by deep plowing. The available data showed that the excess soluble salts and exchangeable sodium were reduced to low, noncritical levels to approximately the 24-inch depth on the deep-plowed slick spots under ordinary furrow irrigation within two cropping years. The chemical status of the subsoiled and untreated slick spots remained essentially unchanged during the period of the study.

FIELD TEST 2 - OPERATING FARM SITES

Procedures

Investigations on three operating farm sites consisted of deep plowing without gypsum to depths varying from 24 to 30 inches on 2- to 5-acre areas on field sites seriously affected by slick spots of the Sebree series. Parts of the fields were left unplowed for comparison. The areas were cropped to common crops during the 3 years the study was in progress. Conventional cultural and irrigation practices were followed.

To observe changes in the chemical status soil samples were collected from selected slick spot areas before deep plowing and at the end of the second cropping year.

Results

The effects of the deep-plowing treatments on pH, soluble salt, and exchangeable sodium content of the slick spot soils on the farm sites are shown in table 9.

The influence of the deep-plowing treatments on soil conditions and crop yields by farms is summarized in the following discussion.

Farm Site A

Sugar beets were grown on a deep-plowed test area (farm site A) in 1960 and 1961. The yield of sugar beets was increased from approximately 6 tons per acre on the unplowed slick spot area to 25 to 30 tons per acre on the deep-plowed slick spot area. In 1960, the first season after deep plowing, germination and stand of beets were reduced on a few areas where high concentrations of soluble salts developed. Some yellowing and a slight reduction in early growth of beets occurred on plants growing along deep plow furrow marks--apparently where the greatest amount of subsoil had been brought to the surface. The most marked yellowing occurred on the deep-plowed slick spot areas showing some accumulation of soluble salts. The effect was attributed to redistribution near the surface of higher concentrations of salts naturally present in the subsoils of the slick spot soils as well as in the subsoils of the normal soils. The yellowing and dwarfing effects disappeared by midseason of the first year. Final growth and development appeared to be normal. Yellowing was not apparent in the sugar beets the second year. The plot area, planted to wheat in 1962, produced an average of 80 bushels per acre. Plant growth appeared to be normal over the entire deep-plowed area.

TABLE 9.--Chemical properties of Sebree slick spot soil as influenced by deep plowing treatments, supplemental deep plowing tests, Black Canyon Area, 1959-61

Farm site	Treatment	Soil depth	pH, saturation extract		Conductivity, saturation extract		Estimated exchangeable sodium[1/]	
			Before plowing	After 2 years	Before plowing	After 2 years	Before plowing	After 2 years
		Inches			Mmhos/cm.	Mmhos/cm.	Percent	Percent
A	Deep plowed, 24 to 30 inches	0- 3	7.5	7.2	1.6	3.6	6.5	4.8
		3-10	7.4	7.3	2.4	2.1	7.3	6.7
		10-16	7.5	7.5	4.9	2.0	17.5	6.6
		16-19	7.5	7.7	19.2	1.7	25.5	8.1
		19-24	7.9	7.8	21.1	1.9	27.0	10.4
		24-32	8.0	7.9	19.2	1.6	26.4	12.4
B	Deep plowed, 24 inches	0- 3	7.1	7.7	6.1	1.3	8.3	6.0
		3- 9	7.4	7.7	6.6	1.4	15.4	6.6
		9-12	7.3	7.6	10.6	1.5	20.1	9.0
		12-16	7.7	7.6	--	1.1	30.5	7.0
		16-20	7.9	7.7	8.8	1.6	34.0	6.1
		20-24	8.3	7.6	8.3	1.9	36.5	4.2
C	Deep plowed, 24 to 30 inches	0- 3	7.3	7.5	3.0	3.0	2.6	8.0
		3- 8	7.4	7.5	3.0	3.5	10.4	8.0
		8-11	7.7	7.5	2.4	3.6	24.0	9.2
		11-15	7.6	7.6	11.1	3.1	18.0	9.2
		15-20	7.8	7.6	8.9	2.4	32.5	11.6
		20-30	7.9	7.6	13.7	5.7	38.0	--

1/ Estimated exchangeable sodium percent calculated from sodium adsorption ratio.

Field observations of soil moisture and depth of water penetration before and after irrigations in 1960 and 1961 indicated that intake rates and depth of water penetration on the slick spot areas were greatly improved by deep plowing.

Farm Site B

Farm site B was located on a site estimated to contain more than 50 percent of slick spot soil (fig. 12). Part of the area was deep plowed to an average depth of 24 inches in October 1959. Adjacent areas were left unplowed for comparison. The entire area was planted to mixed barley and wheat interseeded with red clover and alfalfa in the spring of 1960. The site was not irrigated prior to seeding and was irrigated only three times during the first season. A good stand of grain and an excellent stand of red clover and alfalfa were obtained on the area.

The first-year yield of mixed grain on the deep-plowed slick spot areas averaged 60 bushels per acre in comparison to less than 20 bushels per acre on the unplowed slick spot areas. The considerable regrowth of red clover and alfalfa following grain harvest was not sampled for yield but was estimated at 1.5 tons per acre. In 1961, the second year after deep plowing, the mixed crop of red clover and alfalfa was cut for hay. The growth of the second cutting of red clover and alfalfa on the field in 1961 is shown in figure 13. The total annual yield of hay on the deep-plowed slick spot areas was 6.5 tons per acre in comparison to less than 2 tons per acre on the unplowed slick spot areas.

Figure 12.--Deep plowing an old stand of alfalfa growing on a field severely affected with areas of Sebree slick spot soil. (The slick spot areas are indicated by the sparse growth of alfalfa.) Farm site B, Black Canyon area, October 1959.

Figure 13.--Excellent stand of red clover growing on the Sebree slick spot soil shown in figure 12, after deep plowing treatment to a depth of 24 inches. Farm site B, Black Canyon area, July 1961.

Yields were not determined in 1962, but field observations indicated excellent yields of hay on the entire deep-plowed area. There were no apparent differences in height of plant growth or in yield of deep-plowed slick spot soil and deep-plowed normal soil.

Field observations of the soil moisture immediately before and after irrigations indicated that the intake rates and depth of water penetration on slick spot areas were greatly increased by deep plowing.

Farm Site C

The test area on farm site C was deep plowed in the spring and planted to russet potatoes in 1960. Potato yields on the deep-plowed slick spot areas for the first year after deep plowing ranged from 300 cwt. to 370 cwt. per acre. Potatoes grown on adjacent areas of unplowed slick spots yielded less than 50 cwt. per acre and the potatoes were of extremely low quality. There were relatively few areas on the deep-plowed area where sufficiently high accumulations of soluble salts developed to reduce the stand and yield of potatoes. The quality and yield of potatoes on the Chilcott or nonsaline soils were apparently improved by the deep plowing in comparison to the quality and yield on unplowed Chilcott soil. The quality of the potatoes grown on the deep-plowed area the first year after plowing was relatively low but this was not attributed to deep plowing. Potatoes grown in the general area were damaged by extremely high temperatures in 1960. Potatoes grown on large areas of unplowed portions of the field were not harvested because of the poor quality and low yields. Satisfactory yields of moderately good quality potatoes were produced on a similar area of an adjacent field, deep plowed in the fall of 1961 and planted to potatoes in 1962.

Sugar beets were grown on the area in 1961. Yields were generally good on the deep-plowed area except on a few areas where the germination and final stand of beets were reduced by the accumulation of soluble salts on the surface. Salt accumulations had occurred in the upper portions of the potato rows or beds of some deep-plowed slick spot areas in 1960. Apparently the excessive salts resulting from the mixing of the soil profile by deep plowing were not adequately leached from the soil surface layers by the irrigation of potatoes using deep furrows.

Sugar beet growth was somewhat variable but the yields were generally good on deep-plowed slick spots and were apparently not seriously affected by soluble salts. Yields on the deep-plowed slick spot areas averaged from 25 to 30 tons per acre in comparison with 4 to 6 tons per acre on the unplowed slick spot area.

Spring wheat was grown on the test area in 1962. Wheat on the deep-plowed portion of the field yielded approximately 80 bushels per acre and plant growth was relatively uniform over the area. Plant growth on the unplowed area was characteristically extremely variable, and yields on individual unplowed slick spot areas were estimated to be less than 20 bushels per acre.

Available yield data and observation of soil moisture conditions indicated that deep plowing greatly improved the Sebree slick spot areas. There were indications that crop yields and water penetration were substantially improved by deep plowing the Chilcott soil and nonsaline soils with strongly developed, clayey B_2 horizons and shallow lime-cemented subsoils. At the end of three cropping years, all the soils on the deep-plowed areas appeared to be of extremely favorable texture and good tilth.

SUMMARY AND CONCLUSIONS

The soil improvement investigations on the Chilcott-Sebree soils showed that the Sebree slick spot soils can be greatly improved by the application of gypsum, subsoiling in combination with gypsum, profile mixing to simulate deep plowing, and actual deep plowing to depths of 24 and 30 inches alone and in combination with gypsum. These treatments increased infiltration rates and crop yields severalfold. Excessive exchangeable sodium and soluble salts initially present in the slick spot soils were reduced to safe levels in the plant root zone within two to three cropping years under normal irrigation practices.

Gypsum at rates of 12 and 20 tons per acre greatly increased the infiltration rates but did not increase the depth of water penetration on the slick spot areas. Subsoiling without gypsum did not improve the slick spot soils.

The Chilcott (nonsaline-nonsodic) soils were also improved by deep plowing. Crop yields, intake rates, and depth of water and root penetration were greatly increased by this treatment.

Other associated (nonsaline) soils were apparently not adversely affected by deep plowing.

The physical condition of both the Chilcott and Sebree soils was extensively modified by deep plowing. The texture of the horizons and the inherent poor profile characteristics of the soils were completely altered by disruption of the hardpan and cemented subsoil layers and by thorough mixing of the soil horizons. Mixing the calcareous silt loam soil material from the deeper soil horizons with the clayey B horizons resulted in a more uniform soil throughout the mixed layers. Intake rates and depth of water penetration appeared to be permanently increased within the active root zone and the effective available water-holding capacity more than doubled by plowing or mixing to a depth of 30 inches.

With improved water infiltration rates and increased water penetration resulting from deep plowing, soluble salts were leached from the active root zone of the soil in two to three cropping years by application of adequate irrigation water using conventional furrow and corrugation methods.

The calcareous subsoil and naturally occurring gypsum brought up by deep plowing improved the physical condition of the soil and apparently provided the necessary soluble calcium to replace excessive adsorbed sodium within the root zone of the saline-sodic slick spot soils. When ordinary irrigation and cropping procedures similar to general farm practices were used the excessive exchangeable sodium was reduced to low, safe levels in the plant root zone on the deep plowing treatments, without added gypsum, within two to three cropping years. The physical condition of the soil appeared to be greatly improved by the deep plowing treatments. Four years after the deep plowing treatment, the mixed soil appeared to be of favorable texture and good tilth.

The sustained excellent crop yields and the apparent permanency of the improved chemical and physical condition of the soil indicate that the slick spot soils can be permanently improved by a single adequate deep plowing treatment.

It was concluded from these investigations that the Sebree slick spot soils can be effectively and most economically reclaimed by deep plowing alone, without the addition of gypsum. For deep plowing to be effective, the soils must be plowed to such depths and in such a manner to mix sufficient amounts of the calcareous subsoil and naturally occurring gypsum throughout the profile to provide the necessary calcium to replace the excessive sodium in the root zone. For permanent reclamation the excess sodium must be replaced by the calcium, and the sodium and soluble salts must be removed by leaching. The calcareous subsoil horizons of the Sebree slick spot soil usually contain sufficient soil lime and gypsum to completely reclaim the saline-sodic soils, when mixed by deep plowing to a depth of 30 inches.

Deep plowing the Chilcott and Sebree slick spot soils for general soil improvement and for reclaiming the nonproductive saline-sodic soil areas appears to be a feasible and economical practice. The affected soils can be plowed to adequate depths with a 4-foot moldboard plow at costs varying from $35 to $45 per acre. The increased yields resulting from the deep plowing should repay the cost of plowing in 1 or 2 years. While deep plowing is beneficial it should be supplemented with effective irrigation and with good fertility and soil management practices. The deep-plowed soils must be fertilized, after plowing, with nitrogen and phosphate adequate to meet the needs of the crop grown; moderate applications of zinc fertilizers may also be necessary. Fertilizer requirements and the need for special fertilizers (such as zinc) were not studied in the present investigations.

It should be noted that the terms "slick spots" and "slick spot soil" are general terms frequently applied to many soil areas and soils which may have adverse physical and chemical properties resulting from high salt concentrations or excessive sodium or sometimes from high clay content in the soil profile. The conclusions reported in this article specifically apply to the results obtained on the solodized-Solonetz Sebree slick spot soil and the associated calcareous Chilcott silt loam soil. These soils usually have thin, medium-textured silt loam surface horizons and shallow silty clay loam to clay loam subsoils underlain with silt loam, loam, or fine sandy loam, highly calcareous subhorizons beginning at about 17 inches below the surface. The slick spot soils may contain natural gypsum equivalent to 1 to several tons of gypsum per acre in the subsoils and lower soil horizons. The effect of deep plowing "slick spot" or salt-affected soils of differing chemical and physical properties may not be beneficial. Soil improvement and deep plowing investigations on other naturally occurring solonetzic slick spot soils are being carried out at the present time.

ACKNOWLEDGMENT

The authors wish to express their appreciation to E. N. Poulson, regional soil scientist, and L. R. Swarner, irrigation engineer, Region 1, Bureau of Reclamation, U.S. Department of the Interior; and to W. J. Leighty, assistant State soil scientist, Soil Conservation Service, for their interest and assistance in various phases of the research work.

LITERATURE CITED

(1) Bowers, C. A., Swarner, L. R., Marsh, A. W., and Tileston, F. M.
1951. The improvement of an alkali soil by treatment with manure and chemical amendments. Oreg. Agr. Expt. Sta. Tech. Bul. 22.

(2) Isaak, Philip.
1934. The nature of slick spot soil in southern Idaho. Soil Sci. 37: 157-165.

(3) Jordan, J. V., Lewis, G. C., and Fosberg, M. A.
1958. Tracing moisture in slick spot soils with radio sulfur: Part I. Amer. Geophys. Union Trans. 39: 446-450.

(4) Pair, C. H., and Lewis, G. C.
1960. Chemical and intake rate changes with various treatments on Sebree-Chilcott soil series association (slick spots). Soil Sci. 90: 306-311.

(5) Peterson, F. P.
1919. The "slick spots" of middle western Idaho with suggestions for their elimination. Idaho Agr. Expt. Sta. Bul. 114.

(6) Sandoval, F. M., Fosberg, M. A., and Lewis, G. C.
1959. A characterization of the Sebree-Chilcott soil series association (slick spots) in Idaho. Soil Sci. Soc. Amer. Proc. 23: 317-321.

(7) Stuart, D. M., Fosberg, M. A., and Lewis, G. C.
1961. Caliche in southwestern Idaho. Soil Sci. Soc. Amer. Proc. 25: 132-135.

(8) U.S. Salinity Laboratory Staff.
1954. Diagnosis and improvement of saline and alkaline soils. U.S. Dept. Agr. Handb. 60. 160 pp.

Chemical Status of Soils

The numerous chemical and physical data collected during the course of the several studies reported herein are briefly summarized in tables and figures in the text of the report. Detailed data on the chemical status of the soils on the treatment plots included in experiment No. 1 are given in appendix tables 10 and 11.

TABLE 10.--Average salinity status of the profile of the Sebree slick spot soil as indicated by the electrical conductivity ($EC_e x10^{-3}$) before and after treatment and at various sampling dates

Soil and treatment	Soil depth[1]	Electrical conductivity of saturation extract[2]				
		Before treatment	After mixing	Fall 1958	Fall 1959	Fall 1960
	Inches	Mmhos/cm.	Mmhos/cm.	Mmhos/cm.	Mmhos/cm.	Mmhos/cm.
Sebree soil, untreated	0- 3	2.0	(3/)	2.9	2.2	1.1
	3- 6	4.3	(3/)	3.5	2.2	2.6
	6-12	4.3	(3/)	9.1	9.4	10.7
	12-18	20.4	(3/)	15.3	15.7	19.9
	18-24	22.5	(3/)	18.8	17.6	19.9
	24-30	16.6	(3/)	16.3	16.7	21.3
	30-36	16.6	(3/)	16.3	16.7	21.3
Sebree soil, gypsum only[4]	0- 3	2.7	(3/)	2.3	1.2	2.3
	3- 6	4.3	(3/)	3.2	1.2	3.4
	6-12	8.7	(3/)	3.2	1.0	3.5
	12-18	8.7	(3/)	3.4	3.6	5.0
	18-24	15.6	(3/)	6.6	6.0	7.0
	24-30	14.6	(3/)	6.5	7.8	9.4
	30-36	14.6	(3/)	6.5	7.8	9.4
Sebree soil, shallow mixed, gypsum[4]	0- 3	3.0	15.8	2.7	1.5	1.4
	3- 6	10.0	15.8	2.7	1.5	1.4
	6-12	10.0	15.8	2.9	1.6	1.2
	12-18	20.5	16.6	6.3	3.2	2.1
	18-24	20.5	16.6	6.3	3.2	2.1
	24-30	16.3	16.0	11.9	7.4	4.4
	30-36	17.0	16.5	11.9	7.4	4.4

See footnotes at end of table.

Table 10.--Continued.

	Inches	Mmhos/cm.	Mmhos/cm.	Mmhos/cm.	Mmhos/cm.	Mmhos/cm.
Sebree soil, deep mixed and gypsum 4/	0- 3	2.8	12.2	2.8	1.5	0.9
	3- 6	5.1	12.2	3.8	2.5	0.9
	6-12	5.1	12.2	4.4	2.7	1.2
	12-18	20.9	12.6	9.8	4.9	2.9
	18-24	20.9	12.6	9.8	4.9	2.9
	24-36	15.6	12.5	11.1	8.6	4.6
	36-48	11.3	13.6	11.8	10.1	6.4
	48-60	16.0	13.5	13.2	9.5	8.6
Sebree soil, deep subsoiling and gypsum 4/	0- 3	3.1	(3/)	1.4	1.9	1.0
	3- 6	3.1	(3/)	1.4	1.9	1.0
	6-12	7.9	(3/)	2.3	1.9	0.7
	12-18	19.4	(3/)	2.3	3.2	1.0
	18-24	19.4	(3/)	--	3.2	1.8
	24-30	20.0	(3/)	--	5.6	2.2
	30-36	20.0	(3/)	--	5.6	1.9
Sebree soil, deep subsoiling, shallow mixed 4/	0- 3	1.5	14.4	2.1	1.3	1.1
	3- 6	3.8	14.4	3.1	1.3	1.1
	6-12	9.1	14.4	3.1	1.6	1.3
	12-18	18.3	12.9	6.0	2.5	1.4
	18-24	18.3	12.9	6.0	2.5	1.4
	24-30	16.3	--	6.8	4.6	2.4
	30-36	12.0	--	5.3	4.1	2.3
	36-42	12.0	--	5.3	4.1	2.3
				Fall 1961	Fall 1962	
Sebree soil, mixed 30-inch depth 5/	0- 3	1.9	15.6	0.9	0.4	
	3- 6	5.4	14.4	0.9	0.4	
	6-12	13.1	14.4	1.1	0.5	
	12-18	17.0	17.5	1.3	0.5	
	18-24	19.5	16.7	1.6	0.7	
	24-30	16.7	15.1	1.4	0.8	
	30-36	15.9	18.8	1.4	0.6	

1/ Average approximate soil depth for comparison purposes; original samples collected by soil horizons.
2/ Conductivity values are average of four replications.
3/ Not mixed.
4/ Treatment in fall of 1957.
5/ Treatment in April of 1961.

TABLE 11.--Average estimated exchangeable sodium percentage of the Sebree (slick spot) soil profile before and after treatment and at various sampling dates

Soil and treatment	Soil depth[1/]	Estimated exchangeable sodium percentage[2/]				
		Before treatment	After mixing	Fall 1958	Fall 1959	Fall 1960
	Inches	Percent	Percent	Percent	Percent	Percent
Sebree soil, untreated	0- 3	8.5	(3/)	9.3	14.0	5.0
	3- 6	25.0	(3/)	18.0	14.0	15.5
	6-12	28.0	(3/)	24.8	23.0	22.2
	12-18	29.2	(3/)	28.5	27.9	27.3
	18-24	29.2	(3/)	28.5	27.9	27.3
	24-30	32.5	(3/)	28.5	28.8	30.0
	30-36	31.5	(3/)	28.5	28.5	30.4
Sebree soil, gypsum only[4/]	0- 3	10.6	(3/)	0.1	2.2	1.1
	3- 6	31.0	(3/)	0.1	2.2	1.5
	6-12	31.0	(3/)	8.0	2.2	5.3
	12-18	30.2	(3/)	11.2	9.8	11.5
	18-24	31.0	(3/)	10.2	14.6	17.5
	24-30	32.5	(3/)	10.2	20.1	20.0
	30-36	31.0	(3/)	--	20.2	21.8
Sebree soil, shallow mixed and gypsum[4/]	0- 3	5.3	27.2	0.0	0.0	0.1
	3- 6	29.0	27.2	0.0	0.1	0.1
	6-12	31.0	26.2	0.1	0.1	0.2
	12-18	33.0	26.0	13.0	1.8	1.8
	18-24	33.2	26.0	13.0	1.8	4.5
	24-30	29.0	--	14.9	18.0	9.0
	30-36	20.2	--	14.9	17.1	12.0
Sebree soil, deep mixed and gypsum[4/]	0- 3	8.4	26.5	0.2	0.1	0.2
	3- 6	26.5	26.5	0.2	0.1	0.2
	6-12	26.5	26.5	4.5	0.1	0.2
	12-18	24.8	26.0	20.0	5.6	0.2
	18-24	34.8	26.0	20.0	7.5	2.0
	24-30	33.0	23.7	23.6	18.8	6.2
	30-36	30.2	23.7	23.6	18.8	11.0

See footnotes at end of table.

Table 11.--Continued.

	Inches	Percent	Percent	Percent	Percent	Percent
Sebree soil, deep subsoiling and gypsum4/	0- 3	--	(3/)	0.1	0.1	0.1
	3- 6	34.8	(3/)	0.1	0.1	0.1
	6-12	34.8	(3/)	0.1	0.4	0.4
	12-18	34.8	(3/)	4.5	6.6	0.7
	18-24	34.8	(3/)	8.8	9.0	5.2
	24-30	37.5	(3/)	--	39.5	10.2
	30-36	48.0	(3/)	--	29.2	13.1
Sebree soil, deep subsoiling, shallow mixed, and gypsum4/	0- 3	8.9	28.1	0.1	0.1	0.1
	3- 6	32.8	28.1	0.1	0.1	0.1
	6-12	32.8	28.1	5.0	0.1	0.2
	12-18	33.0	28.1	13.9	5.9	0.2
	18-24	34.0	26.1	13.9	6.0	0.1
	24-30	37.2	26.1	23.2	10.8	5.4
	30-36	--	--	21.4	6.0	7.5
				Fall 1961	Fall 1962	
Sebree soil, mixed 30-in. depth5/	0- 3	7.8	20.0	3.0	0.3	
	3- 6	24.0	23.0	5.0	0.2	
	6-12	23.0	23.0	8.3	2.0	
	12-18	28.0	17.0	12.0	3.5	
	18-24	31.0	28.0	16.0	5.7	
	24-30	29.0	26.0	14.0	8.8	
	30-36	27.0	41.0	14.0	7.5	

1/ Average approximate soil depth for comparison purposes; original samples collected by soil horizons.

2/ Estimated ESP values are averages of four replications; estimated ESP calculated from SAR of saturation extract.

3/ Not mixed.

4/ Treatment in fall of 1957.

5/ Treatment in April of 1961.

Summary Descriptions of Soil Series

Chilcott Soil Series

The Chilcott series consist of soils, in uplands and high terraces, having an indurated or strongly cemented silica-lime hardpan at a depth ranging from 18 to 40 inches. The soils are associated, in complexes, with the Sebree, Vickery, and other series. The surface soils are light colored and mostly silt loams and loams. The subsoils, beginning at about 8 inches, are clayey and range from heavy silty clay loam or silty clay to heavy clay loam. The subsoils grade into nonconsolidated, high lime materials at an average depth of 18 inches in the Black Canyon area. This lime layer is slightly or moderately saline in places. The hardpan lies on sandy or gravelly sediments of granitic origin.

Sebree Soil Series

The Sebree soils occur as spots (slick spots), in uplands, associated in a complex with the Chilcott and related soil series. The plow layer is a mixture of a very thin (1 inch) surface soil of silt loam or loam and part of the underlying silty clay loam or clay loam subsoil. The subsoil grades into an unconsolidated lime layer at an average depth of 15 inches on the Black Canyon plots. The lime layer lies over an indurated or strongly cemented hardpan at depths ranging from 20 to 40 inches. The entire soil, except the very thin surface layer, is usually high in total salts and has a high percentage of exchangeable sodium.