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Alkali Reclamation Investigations

By

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Summary and Conclusions

Alkali reclamation investigations on the Helms experimental tract during a period of 7 years have resulted in the following observations:

1. Soil drainage was a limiting factor in economical alkali land reclamation. Impervious soils or subsoils hindered or prevented adequate drainage, thus causing slow and uncertain reclamation.
2. Laboratory measurement of factors influencing relative permeability was a dependable guide in estimating the economy of reclamation of alkali lands.
3. The character of native vegetative cover served as a means of quickly classifying alkali land for reclamation purposes.
4. Moderately alkaline irrigation waters were successfully used in alkali land reclamation.
5. Frequent flooding with surface run-off in general gave the best results on poor types of alkali land. Frequent sprinkling was an aid in crop establishment and growth.
6. Chemical treatments often produced noticeable improvement in soil condition but at excessive cost for general crop production. Such treatments may be of value in special cases.
7. Ground surface coverings, such as well-rotted manure or Adco-treated straw, served as temporary buffers against the action of alkali until crops had been started.
8. Ground shading, either with artificial or natural cover, aided materially in starting the first crop.
9. Mixed seedings of perennial legumes and grasses were found desirable as original plantings on the poorer types of soil.
10. Silver poplar, Weeping willow, Siberian elm, and Russian olive were found especially suitable as shade trees on alkali land.
11. The following recommendations are offered for economical reclamation of impervious or semi-impervious alkali land:
    a. Disturb the ground surface as little as possible.
    b. Utilize the native vegetative cover for ground shading.
    c. Use mixed seedings of perennial legumes and grasses for the first planting.
    d. Delay intensive farming and restrict land use to pasturing until improvement in soil condition warrants the expense of leveling and cultivation.

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By

ROBERT S. SNYDER, MARK R. KULP, G. ORIEN BAKER*,
and JAMES C. MARR†

Introduction

THE alkali reclamation investigations included in this work were carried on cooperatively by the Departments of Agricultural Chemistry, Agricultural Engineering, and Agronomy of the Idaho Agricultural Experiment Station and the Division of Irrigation, United States Department of Agriculture. They were conducted during the 7-year period, 1925-1932, on the southerly 55 acres of the Helms farm, 1½ miles west of Caldwell, Idaho, in section 20, township 4 north, range 3 west *(Fig. 1)*.

The soils are representative of some 35,000 acres of contiguous bottom land on the lower reaches of the Boise River and are, for the most part, water-logged, alkaline, and worthless except for scant pasture. Furthermore, the characteristics of these soils are similar to alkali soils found elsewhere in western Idaho and in other western states. They aggregate an important potential agricultural area.

The characteristics of the soils found in the Helms tract represent practically all conditions likely to be encountered in alkali land reclamation. Thus, the results of the investigation present an unusual opportunity to distinguish between alkali lands that may be economically drained and reclaimed and those that may not.

A great variety of remedial measures were employed, including chemical and cultural treatments and various methods of irrigation and drainage. The results of these various treatments should contribute to the available information regarding the proper methods of handling alkali lands.

Description of the Area

Soils

The Soil Survey of the Boise area (1901) made by the United States Bureau of Soils classified the soil of the Helms tract as Caldwell loam. This soil has developed from stream-laid or alluvial material of recent formation and as a result is rather variable in

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The authors acknowledge with gratitude assistance from the following:

The late Harry P. Magnuson, Acting Head of the Department of Agricultural Chemistry, who planned much of the experimental work and assembled many of the data resulting from it; Arthur M. Sowder, former Extension Forester; G. Raymond McDole, former Soil Technologist; Hobart Beresford, Agricultural Engineer; and M. R. Lewis, former Irrigationist, all of whom collaborated in various phases of the investigation.

Figure 1.—Aerial view of the Helms alkali tract.—1932. Letters show relative location of Series A to I.

character, ranging from a light colored, deflocculated, relatively impervious, strongly alkaline, unproductive type to a friable, dark colored soil, fairly productive. At the time of the classification (1901), the soil of this series contained from 1,000 to 2,000 parts per million (ppm) of alkali salts.

This survey indicated that during alternate periods, extending back perhaps hundreds of years, these lands had been subjected to processes of alkali accumulation and diminution, with the result that much of the soil had suffered all the possible deteriorating effects caused by alkali. As might be expected of such river bottom deposits, there appear frequent and marked changes in soil and subsoil texture varying from sand and gravel bars to lenses of clay and fine sediment. The effect of alkali on the coarser soil materials has been slight, while with the deep, fine-textured soils an adverse chemical and physical condition has occurred. These variations were present in a marked degree on the Helms tract, about half of the area being a strongly alkaline, hard, impervious soil to a depth of from 5 to 7 feet, while the remaining portion, although distinctly alkaline, was more friable and less impervious.

As determined in 1925, the best soil was fairly porous, the pH close to 9.0, and the surface foot contained from 100 to 200 ppm normal carbonate, from 150 to 300 ppm sulphates and a negligible quantity of chlorides. The worst soils were deflocculated to a degree that made them practically impervious, had a pH of 10.0 or higher, and contained in the surface foot 700 to 4800 ppm of normal carbonate, from 600 to 4,000 ppm of sulfates, and usually a moderate amount of chlorides. Beneath these poorest soils at depths of from 3 to 7 feet, several strata occurred which, in some cases, were even more deflocculated and impervious than the surface soil. Below these strata the material changed to sand or gravel, the upper few inches of which were either partially cemented or heavily impregnated with colloidal matter. Beneath the best soils these dense layers were either absent or of a semi-permeable nature and coarse sand or gravel occurred from 3 to 6 feet below the ground surface and extended well below the ground water table.

Vegetation

Before starting the investigation the native vegetative growth was carefully mapped to ascertain if, as has been suggested*, various growths indicate different soil conditions which affect reclamation. As illustrated in Figure 2 the growth was quite variable since it included patches of rabbitbrush, greasewood, salt grass, and areas supporting no vegetation. An exceptional opportunity was thus afforded to observe a possible relationship between the surface appearance of alkali land and the feasibility of its reclamation.

During 1924, a year prior to the reclamation investigations, a deep open drain *(1, Fig. 2)* was constructed for a distance of 3,000

* Partial Report of Work of the Agricultural Experiment Stations of the University of California for the Years 1895-96; 1896-97, pages 53 to 75. (Being a part of the report of the Regents of the University. Published March 1898.)

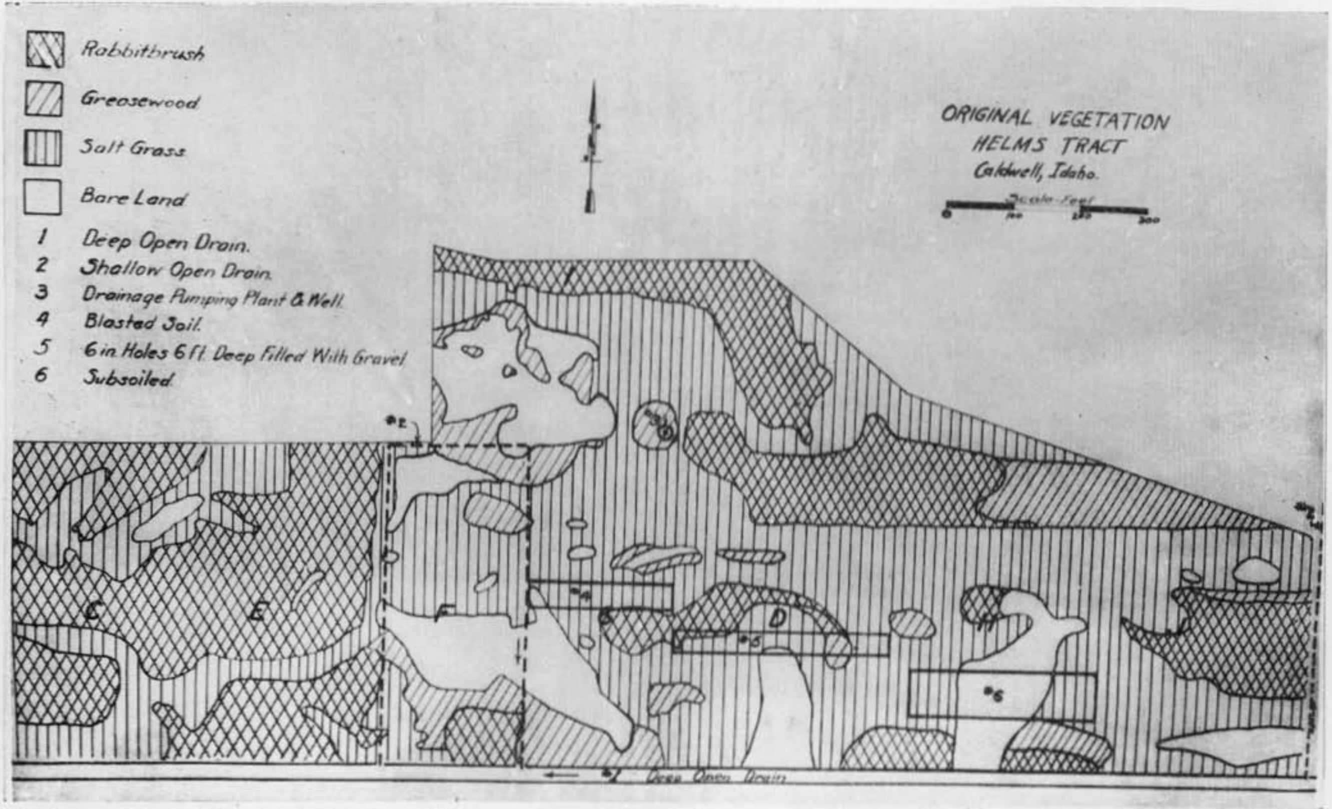

Figure 2.—Original native vegetative cover on series C to I, Helms tract. There was no original vegetative cover on series A and B when the experiment was started.

feet along the south side of the 55-acre tract. Subsequently the following additional drainage works or operations were added in areas where a perched water table occurred: return-flow wells or open pits *(5, Fig. 2)*, a pumped well *(3, Fig. 2)*, closely-spaced shallow open drains *(2, Fig. 2)*, blasting *(4, Fig. 2)*, and subsoiling *(6, Fig. 2)*.

Originally the water table throughout the experimental tract was at or very close to the ground surface most of the time. After the deep open drain was excavated the general water table was lowered to approximately the level of the water in the drain. This constituted satisfactory drainage in areas having sufficiently permeable soil or subsoil to permit free vertical percolation of water applied to the ground surface. Elsewhere poor drainage occurred for long periods following irrigation or heavy rainfall and was caused by the nearly impervious strata located at various levels in the soil profile above the general water table. These perched water table spots were irregular and included both large and small areas, thus complicating somewhat the arrangement of soil treatments to eliminate their detrimental influence. Obviously improvement in permeability of the nearly impervious strata must precede drainage. This may result slowly through the action of growing plants under favorable conditions *(See page 32)*.

The water for irrigation was obtained from several sources. None of it was ideally suited for the purpose. It contained, on an average, 147 ppm total carbonate, 130 ppm sulfates, and 60 ppm chlorides. The sodium-potassium content usually exceeded the calcium-magnesium.

Procedure

Experiments were planned and plats laid out to show the effects of drainage, irrigation, leveling, subsoiling, blasting, chemical treatments, manures, straw, and ground shading upon the establishment of various crops and upon the permeability of the soil in this area. A summary of the results is shown in Table 1.

Drainage

The deep open drain *(Figs. 2 and 3)* which had been completed before the alkali investigations were started was favorably located and of ample depth and capacity to drain the experimental tract. It was approximately 10 feet deep, had a fall of 7.5 feet per mile, and throughout most of its length penetrated the generally underlying sand and gravel stratum. The average water level held well within the sand and gravel substratum and was measured by means of recording gauges in a series of open pits across series A and B. The pits were sunk well into the loose gravel or sand. While the deep open drain provided satisfactory drainage for the more porous types of soil, it did not take care of those places where the soil was less permeable and where a perched water table occurred. It remained to be discovered whether there was a means by which drainage of these areas might be perfected.

Table 1.—Summary of investigations conducted on Helms tract, showing irrigation methods, chemical and other treatments, and crops grown.

Series	Plat Number	Irrigation Method	Chemical treatment*	Miscellaneous treatments	Crops
					Barley, all plats, 1929 and 1930
A	1	Border	Check	Return flow wells and pits	Alfalfa, sweet clover
	2	"	Gypsum, 1 T./A.	" " " " "	" " "
	3	"	" 2 T./A.	" " " " "	" " "
	4	"	" 4 T./A.	" " " " "	" " "
	5	"	" 8 T./A.	" " " " "	" " "
	6	"	Check	" " " " "	" " "
	7	"	Sulfur, 372 lbs./A.	" " " " "	" " "
	8	"	" 744 lbs./A.	" " " " "	" " "
	9	"	" 1488 lbs./A.	" " " " "	" " "
	10	"	" 2976 lbs./A.	" " " " "	" " "
	11	"	Check	" " " " "	" " "
					Barley, alfalfa, all plats '29, '30
B	1	Border	None	Straw after seeding	Meadow fescue
	2	"	"	Alfalfa chaff, N ½ after seeding	Meadow fescue
	3	"	"	" " " " " "	Western rye grass
	4	"	"	Straw, N ½ after seeding	Bromus inermis
	5	"	"	" " " " "	Sorghum ('26), Millet ('27)
	6	"	"	" " " " "	Rape ('26), Rye ('27)
	7	"	"	" " " " "	Sunflower ('27), Z. Alkali Grass ('28)
	8	"	"	" " " " "	Tall meadow oat grass
	9	"	"	" " " " "	Italian rye grass
	10	"	"	" " " " "	Hubam sweet clover
C		Border	None	Rough leveled, uncleared pasture	Alfalfa and sweet clover
D		Border	None	Return flow wells and pits—Plat 5 Infiltration tests—Plats 13, 14 Green manure p'owed under on rest	Alfalfa and sweet clover
E		Border	None	Carefully leveled and watered, releveled. Cleared pasture.	Alfalfa and sweet clover

* T./A.=tons per acre; lbs./A.=pounds per acre.

Table 1 continued

Series	Plat Number	Irrigation Method	Chemical treatment*	Miscellaneous treatments	Crops
F				Shallow drain around F. and G.	
	1-W	Border	Check	W-½ Straw (1926)	Sweet clover, alfalfa
	1-E	"	"	E-½ " "	" " "
	2-W	"	3.2 T. Sulfur/A.	W-½ " "	" " "
	2-E	"	" " " "	E-½ " "	" " "
	3-W	"	6.4 " " "	W-½ " "	" " "
	3-E	"	" " " "	E-½ " "	" " "
	4-W	"	17.2 T. Gypsum/A.		" " "
	4-E	"	" " " "		" " "
	5-W	"	Check	W-½ " "	" " "
	5-E	"	"	E-½ " "	" " "
	6-W	"	H_2SO_4, 15.2 T./A.	W-½ " "	" " "
	6-E	"	" 11.4 "	E-½ " "	" " "
	7-W	"	$CaCl_2$ 6.3 T./A.		" " "
	7-E	"	Black Sulfur, 3.9 T./A.	E-½ " "	" " "
	8-W	"	None	Straw and Adco (1926)	" " "
	8-E	"	"	Straw (1926), Infiltration (1930)	" " "
	9-W	"	Check	W-½ Straw (1926)	" " "
	9-E	"	"	E-½ " "	" " "
	10-W	"	Sulfur, 3.2 T./A.	W-½ " "	" " "
	10-E	"	" " "	E-½ " "	" " "
	11-W	"	" 6.4 "	W-½ " "	" " "
	11-E	"	" " "	E-½ " "	" " "
	12-W	"	Gypsum, 17.2 T./A.	W-½ " "	" " "
	12-E	"	" " "	E-½ " "	" " "
	13-W	"	" " "	W-½ " "	" " "
	13-E	"	" " "	E-½ " "	" " "
	14-W	"	Check	W-½ " "	" " "
	14-E	"	"	E-½ " "	" " "
G				Shallow drain around F. and G.	
	1	Border	Check		
	2	"	"		Sweet clover, alfalfa
	3	Cont. ponded (1926-27)		Planted to tules (1927)	" " "
	4	Border		Straw plowed under	" " "
	5	"		Manure plowed under	" " "
	6	"	Check		" " "
	7	"		Blasted on 10 ft. centers (3 to 5 ft. deep)	" " "
	8	"		" " " " " " "	
	9	"		W-½ straw '27 ; N-½ manure '27	" " " bluegrass
	10	"		" " " " " "	" " " "
	11	"		" " " " " " "	" " " "
	12	Cont. ponded		Planted to tule (1926-1927-1929)	" " " "
	13	Border	Straw and Adco	Kept wet continuously	" " " "
	14	"	Straw only	" " "	" " " "

* T./A.=tons per acre; lbs./A.=pounds per acre.

Table 1 continued

Series	Plat Number	Irrigation Method	Chemical treatment*	Miscellaneous treatments	Crops
H	1	Border	None	N-½ subsoiled ('26)	Sweet clover, alfalfa, timothy and alsike
	2	"		" " "	Sweet clover and alfalfa
	3	"		" " " manured after planting ('26, '27)	" " " "
	4	"		N-½ subsoiled ('26) manured after planting ('26, '27)	" " " "
	5	"		N-½ straw after planting ('26)	" " " "
	6	"		N-½ manured before planting ('26)	" " " "
	7	Corrugated		N-15 ft. strip manured ('26)	" " " "
	8	Furrowed		" " " " ('26, '27)	" " " "
I		Wild Flooding	None	Uncleared pasture	Timothy, alsike and sweet clover
J	Control	Border	None	Various methods of planting and back-filling with sand, gravel, soil.	Forest and shade trees
	Alkali	"			" " " "
	Lawn	"		Fine, well-rotted manure, small portion burlap-shaded to start seed. Sand and straw coverings tried.	White clover and bluegrass
	Garden	"		Planted on rabbit brush soil	Assortment of vegetables
	Misc.	"			Small plat of tobacco

* T./A.=tons per acre; lbs./A.=pounds per acre.

During 1926 a trench 2.5 feet deep *(Figs. 2 and 3)* was excavated along the north, east, and west sides of series F and connected with the deep drain. Thus, one of the larger areas embracing the impervious type of soil containing a perched water table was completely surrounded by open drains. The shallow drains were kept in operation for 6 years. During the first 3 years, series F was copiously irrigated and water was allowed to stand over the plat surface until it evaporated or percolated into the soil. During the last 3 years, water was applied only at such times as inspection showed the perched water table to have disappeared and was allowed to stand on the plat surface not longer than 30 minutes.

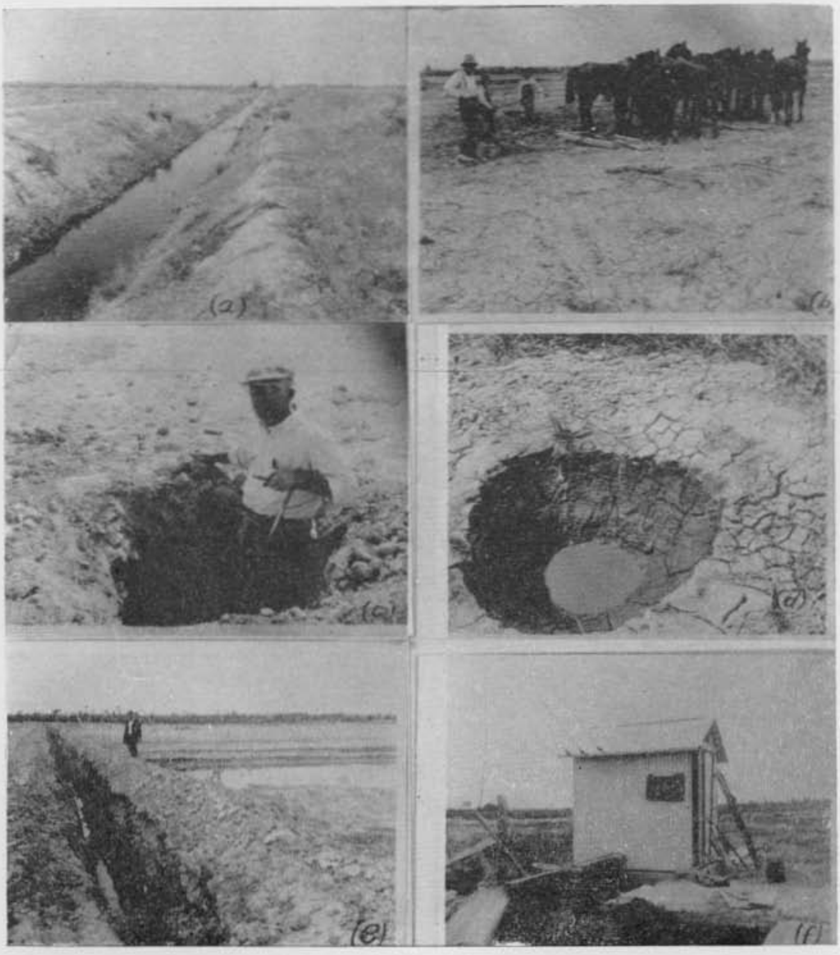

Figure 3.—Drainage works, Helms tract. (a) Deep open drain; (b) Subsoiling; (c) Land blasting; (d) Return-flow wells; (e) Shallow drain; (f) Pumping from drainage well.

Shallow-placed tile drains were not tried because it appeared that the high colloidal content of the soils dealt with would tend to seal the tile and therefore the closed drains would be less effective than open ditches. This was demonstrated by the difficulty experienced in keeping casings of observation wells open in order to procure accurate ground water elevations.

Plats 7 and 8, series G, consisting of impervious soil, were thoroughly blasted with a view toward establishing better vertical drainage through the soil *(Figs. 2 and 3)*. The blast holes were 10 feet apart and from 3 to 5 feet deep. The entire surface and subsoil were thoroughly crumbled. Irrigation water was applied to plat 7 soon after blasting, and the soil immediately settled into an impervious mass. Plat 8 was kept dry for 2 months to effect, if possible, stabilization of the soil colloids, but the same result followed when it was finally irrigated.

The north halves of plats 1, 2, 3, and 4, series H, were subsoiled during June 1926. The operation was difficult to perform efficiently to the desirable depth with equipment and power available *(Fig. 3)*, but the ground was fairly well broken to a depth of from 12 to 18 inches. Intensive cultivation and different methods of leveling, as shown in Table 1, were also tried.

Return-flow wells *(Table 1 and Fig. 3)* or holes sunk for drainage outflow into the sand and gravel substratum, left open or backfilled with porous material, were tried in several of the poorly drained areas. These channels of escape for the perched water were soon closed by the jelly-like constituents of this soil.

To remove all doubt as to the effectiveness of underdrainage in overcoming the perched water table condition, the general water table was further lowered by pumping from a large well. The well for this purpose *(Fig. 3)* was completed on July 9, 1929, and thereafter was pumped fairly continuously throughout each season until the fall of 1932. The water level in the well during the pumping was about 28.5 feet below the ground surface. The lowering effect on the general water table is illustrated in Figure 6. Infiltration tests on the impervious soils were made to study the effect of this lowering upon the perched water table.

Irrigation

The irrigation supply came from three sources but all of it originated principally as seepage and waste water from higher irrigated lands and was of the same general character. Prior to July 1929, Indian Creek water was generally used. During the growing season this stream was fed entirely by return flow caused by irrigation. After drainage-well pumping started in July 1929, water from Indian Creek and the well water, in approximately equal parts, constituted the main irrigation supply. The third source was Riverside canal, which has its heading in the lower reaches of the Boise River. Though of slightly better quality, this water was seldom used, owing to inadequate facilities for getting it to the tract.

Five irrigation methods were employed, i. e., furrow, corrugation, border, wild flooding, and ponding *(Table 1)*. The water was applied to some plats continuously, to others intermittently, with run-off in some cases and with none in others.

Chemical Treatments

Except for a series of infiltration tests with water containing chemicals conducted on plats 13 and 14, series G, the chemical experiments were restricted to series A and F.

Series A was exclusively devoted to experiments in the use of gypsum and sulfur. Plats 1, 6, and 11 were left untreated. Gypsum and sulfur were applied to the remaining 8 plats on April 20, 1925, as set forth in Table I. During that year the entire area was planted to barley and irrigated to suit the requirements of the crop. During 1926 and 1927 sweet clover was planted. In 1929 this part of the tract was returned to the owner who planted it to barley that year. In 1930 alfalfa was planted and has been continued as the crop since then. The soils of this series were principally of the more porous type although there were hard, impervious spots.

Series F was exclusively devoted to experiments in the use of chemicals. Plats 1, 5, 9, 14 and the east half of 8 were left untreated. Calcium chloride, gypsum, sulfur, sulfuric acid, and Adco-treated straw were applied to the remaining 10 plats and to the west half of plat 8 principally during 1926 as shown in Table 1. All the plats in this series were alternately cultivated and irrigated until February 1928, when they were seeded to sweet clover. Thereafter, until 1932, when the experiments were terminated, the entire area of Series F was reseeded each year to sweet clover and alfalfa and irrigated as required. The soil of this area was principally of the hard, impervious type.

Chemically Treated Waters

As an extreme test of the possible effect of chemically treated waters on the permeability of strongly alkaline impervious soils circular spots of land 18 inches in diameter were isolated by galvanized iron open-end cylinders imbedded into the soil and kept inundated with 2 and 5 per cent solutions of sulfuric acid, or saturated solutions of gypsum and iron sulfate. Similarly several tests were made with untreated irrigation water. A galvanized iron tank of the same size was imbedded in the soil and kept filled with water to serve as an evaporimeter. These experiments were conducted on plats 13 and 14, series D, and on plat 8-E, series F *(Fig. 9)*, where the soil was known to be of the hard impervious type.

Manure, Adco-treated Straw, and Straw Applications

Manure was applied to a number of plats but in largest amounts to the north half of plats 9, 10, and 11, and to all of plat 5, series G, to the north half of plats 3, 4, and 6, series H *(Table 1)*. The best results were secured when a 3 or 4 inch layer of well-rotted manure was spread over the ground surface, followed by irrigation and heavy seeding of perennial grasses and legumes. On plat 5, series G, large quantities of manure were plowed into the soil. By using well-rotted manure as a surface covering a minimum amount was required in order to start a crop on the hard impervious soil. It was necessary to plow manure under in large amounts and several times before useful growth could be established on plat 5.

Adco in the amounts of 1.4 and 0.7 tons per acre was scattered by hand over a 6-inch depth of straw on plat 8-W, series F and plat 13, series G, respectively. These two plats were then periodically irrigated in order to maintain a moist condition of the covering and to reduce the straw to manure.

Straw was used on numerous plats and portions of plats both before and after seeding. The purpose of the straw covering was to keep the ground surface moist, thereby lowering the alkali concentration so that the seed would readily germinate and the young plants become established. Large quantities of straw were turned under on plat 4, series G. It was hoped that the incorporation of sufficient coarse material with the soil would produce a better aerated, more friable condition.

Ground Shading

Burlap was supported horizontally over several hard, impervious spots at the east end of the tract to afford shade for the ground surface. These small areas were then seeded to bluegrass and kept moist with the result that satisfactory germination and growth were secured. Practical application was made of this principle in series I, where the original vegetation was preserved to provide shading for starting legumes and pasture grasses.

Field Crops

An early endeavor, principally on series B, was made to determine which crops made the best growth and had the greatest beneficial effect on alkali soils. Here, or elsewhere on the experimental tract, 18 different crops were tried *(Table 1)*. Each year the stand and condition of the crops were mapped, the harvest weighed or measured, and soil samples taken and analyzed.

Forest and Shade Trees*

In April 1928-1929, identical groups of forest and shade trees each consisting of 13 different species of deciduous (Siberian elm, White elm, Black locust, Honey locust, Russian olive, European mountain ash, White ash, Norway maple, Silver maple, Box elder, English oak, Silver poplar, Weeping willow) and 7 conifers (Norway spruce, Western yellow pine, Austrian pine, Jack pine, Scotch pine, Douglas fir, and American arbor vitae) *(Table 1)* were planted in two plats. The plats were located in the west portion of series J *(Fig. 1)*. One was representative of the hard, impervious soil and was termed the alkali plat. The other, the control plat, was more porous and only moderately alkaline. The soil analyses for the two plats are given in Table 2.

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* All the trees used were donated by courtesy of the School of Forestry, University of Idaho, and the Washington Nursery Company of Toppenish, Washington. The stock was healthy and was handled with extreme care while being planted.

Table 2.—Analysis of the soils of the alkali and control plats for forest and shade trees, series J, 1928-1929.

Alkali Plat (hard impervious soil)

Sample	Depth	Normal Carbonates, CO_3 1st yr.	Normal Carbonates, CO_3 2nd yr.	Total Carbonates, CO_3 1st yr.	Total Carbonates, CO_3 2nd yr.	Chlorides, Cl 1st yr.	Chlorides, Cl 2nd yr.	Sulfates, SO_4 1st yr.	Sulfates, SO_4 2nd yr.
Number	*Feet*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*
X-1	1	785	704	1454	963	251	114	447	229
	2	778	829	1404	1001	328	84	571	134
	3	538	625	959	748	220	81	282	171
Total	3 ft.	2101	2158	3817	2712	799	279	1300	534
X-2	1	624	474	1196	731	71	67	133	129
	2	628	647	1099	874	196	67	318	105
	3	582	576	1061	743	149	47	210	88
Total	3 ft.	1834	1697	3356	2348	416	181	661	322
X-3	1	1353	1277	2361	1483	767	138	705	208
	2	1315	1310	2306	1366	490	182	420	263
	3	911	853	1053	1051	234	146	193	126
	3 ft.	3579	3440	5720	3900	1491	466	1318	597
X-3	4	568	698	678	867	258	165	205	162
	5	0	470	96	754	370	317	3942	541
	6	0	248	15	474	415	265	5344	518
Total	3 ft.	568	1416	789	2095	1043	747	9491	1221
Total	6 ft.	4147	4856	6509	5995	2534	1213	10809	1818
X-4	1	1064	800	1358	1095	361	72	451	128
	2	1075	928	1328	1238	244	91	336	160
	3	794	806	893	1106	134	106	108	137
Total	3 ft.	2933	2534	3579	3439	739	269	895	425
X-4	4	596	608	637	858	209	120	256	151
	5	59	406	471	723	200	177	3101	340
	6	0	372	15	627	229	246	6544	931
Total	3 ft.	655	1386	1123	2208	638	543	9901	1422
Total	6 ft.	3588	3920	4702	5647	1377	812	10796	1847
X-5	1	1404	193	1676	505	513	36	1210	142
	2	1132	998	1712	1248	737	127	1561	138
	3	1095	896	1501	1222	504	109	22	196
Total	3 ft.	3631	2087	4889	2975	1754	272	2797	476
X-6	1	1568	1048	1894	1238	869	70	1176	149
	2	1188	983	1812	1229	991	108	1378	144
	3	987	1130	1321	1343	558	54	852	89
Total	3 ft.	3743	3161	5027	3810	2418	232	3406	382
X-7	1	525	——	764	——	241	——	451	——
	2	184	——	527	——	853	——	2055	——
	3	61	——	329	——	661	——	1128	——
Total	3 ft.	770	——	1620	——	1755	——	3634	——
X-8	1	322	——	634	——	346	——	640	——
	2	99	——	291	——	935	——	2140	——
	3	63	——	321	——	446	——	313	——
Total	3 ft.	484	——	1246	——	1727	——	3093	——

Control Plat (More porous. Only moderately alkaline)

Sample	Depth	Normal Carbonates, CO_3 1st yr.	Normal Carbonates, CO_3 2nd yr.	Total Carbonates, CO_3 1st yr.	Total Carbonates, CO_3 2nd yr.	Chlorides, Cl 1st yr.	Chlorides, Cl 2nd yr.	Sulfates, SO_4 1st yr.	Sulfates, SO_4 2nd yr.
X-9	1	419	——	1129	——	198	——	212	——
	2	33	——	269	——	1748	——	18	——
	3	0	——	162	——	808	——	342	——
Total	3 ft.	452	——	1560	——	2754	——	572	——
X-10	1	127	——	497	——	126	——	396	——
	2	0	——	169	——	380	——	718	——
	3	0	——	122	——	127	——	1390	——
Total	3 ft.	127	——	788	——	633	——	2504	——
X-10	4	0	——	141	——	116	——	2959	——
X-11	1	342	——	821	——	77	——	——	——
	2	0	——	175	——	407	——	735	——
	3	0	——	155	——	148	——	368	——
Total	3 ft.	342	——	1151	——	632	——	1103	——
X-12	1	71	——	372	——	101	——	281	——
	2	0	——	165	——	211	——	61	——
	3	0	——	213	——	125	——	261	——
Total	3 ft.	71	——	750	——	437	——	603	——

In 1928, two methods of planting were employed on the alkali plat, i. e., the roots of three of the groups of 20 trees each (the middle 3 groups) were planted directly in the alkali soil while the roots of the three groups of 20 trees each on the east side of the plat were surrounded with sand during the planting. In 1929 a third method was used in adding three additional groups of the same trees to the west side of the plat. In this planting, holes 8 inches in diameter were drilled until loose sand or gravel was encountered; the holes were backfilled with sand and the roots surrounded with sand. This addition increased the original planting to 12 groups of 20 trees each.

In the control plat, the trees were planted without special precaution to protect the tree roots from the action of alkali.

By the end of the first growing season 105 trees had failed to survive and were replaced. By the end of the second season it was necessary to replace 95 more trees. By the end of the third year it was necessary to replace an additional 102 trees. In all, 542 trees were planted. During this period every care was taken to prevent loss of trees and to encourage growth. The plats were fenced to exclude livestock. Shade was provided, particularly for the conifers. Water was carefully applied when moisture was needed. The required amount of cultivation was performed by hand. The trees were scientifically pruned each year.

Results

Drainage

Measurements of water levels in a series of open pits placed at several points over the experimental tract indicated that the average water level was held within the sand and gravel sub-stratum *(Fig. 4)*. Continuous records procured by means of recording gauges revealed that the water level rose almost to the ground surface following irrigation but receded to its former level in about

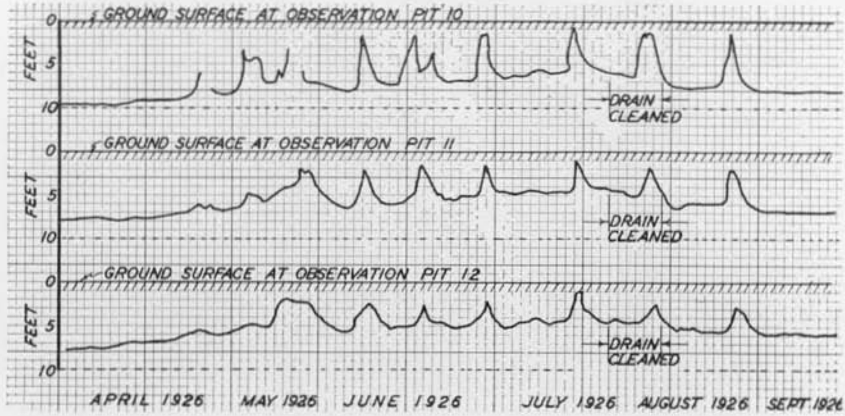

Figure 4.—Continuous graph of water level across series A and B.

24 hours. This constituted satisfactory drainage in those areas where the soil was of the more porous type.

Alfalfa and other crops could be grown successfully on this type of soil. They could not be grown, however, on spots where the soil was impervious. Here, investigation showed, a perched water table occurred. This perched water was not taken care of by the deep open drain.

Most of series F was of the hard, impervious type of soil and was surrounded by open drains. Following heavy irrigation, 10 to 40 gallons per minute of strongly alkaline water flowed for short periods in the shallow ditches. The amount of ground water thus disposed of was insufficient to diminish the perched water in this series. Neither continuous ponding of the hard, impervious soil for a 3-year period nor permitting just sufficient irrigation water on the soil to maintain the perched water table for 3 years appeared to have any effect in improving the drainage of the soil.

When irrigation was just sufficient to maintain the perched water table, the soil absorbed only about 6 inches of water a season and none of the water reached the shallow ditches. It is evident that trenching has little or no value in improving the drainage of hard, impervious soils.

When return-flow wells were sunk into the sand and gravel sub-stratum in an attempt to lower the perched water level and were either left open or backfilled with porous material, it was found that these channels of escape for the perched water were soon closed by the gelatinous constituents of the soils of this area and were useless.

To determine whether increased effectiveness of underdrainage would overcome the perched water condition the general water table was further lowered by pumping from a large well *(Fig. 5)*. The effect on the perched water table and the downward movement of the water through the least pervious soils is best shown by the results of an infiltration test. Plat 12, series G, located within an average of 250 feet of the pumped well, was ponded with water and the elevation of the water surface noted daily from July 1 to September 30, 1929. Measurement was made of loss due to evaporation. As illustrated in Figure 6, loss of water from the flooded plat during this period was little more than may be accounted for by evaporation, and there was no perceptible difference with the pump running or idle. The more perfect underdrainage thus established failed to effect a better vertical drainage of the hard, impervious soils. Many other observations during the 4 years of pumping support this conclusion.

It was thought that breaking up the subsoil might permit better vertical drainage. Blasting was tried. The entire surface and subsoils of plats 7 and 8, series G, were thoroughly intermixed and crumbled. Immediately following application of irrigation water, regardless of time applied, the soil again settled into an impervious mass and a perched water table again appeared.

Subsoiling had the same effect as blasting. Ever since the north halves of plats 1, 2, 3, and 4, series H, were subsoiled it has been impossible to detect any difference in the north and south sides of these plats attributable to subsoiling.

Intensive cultivation also failed to improve structure. Furthermore, the leveling of series H, G, and F to prepare them for irrigation appeared to have retarded their reclamation. Under comparable soil conditions in series I, where the ground surface was disturbed as little as possible in preparing for irrigation and seeding, a better crop stand was procured than was obtained in the plats

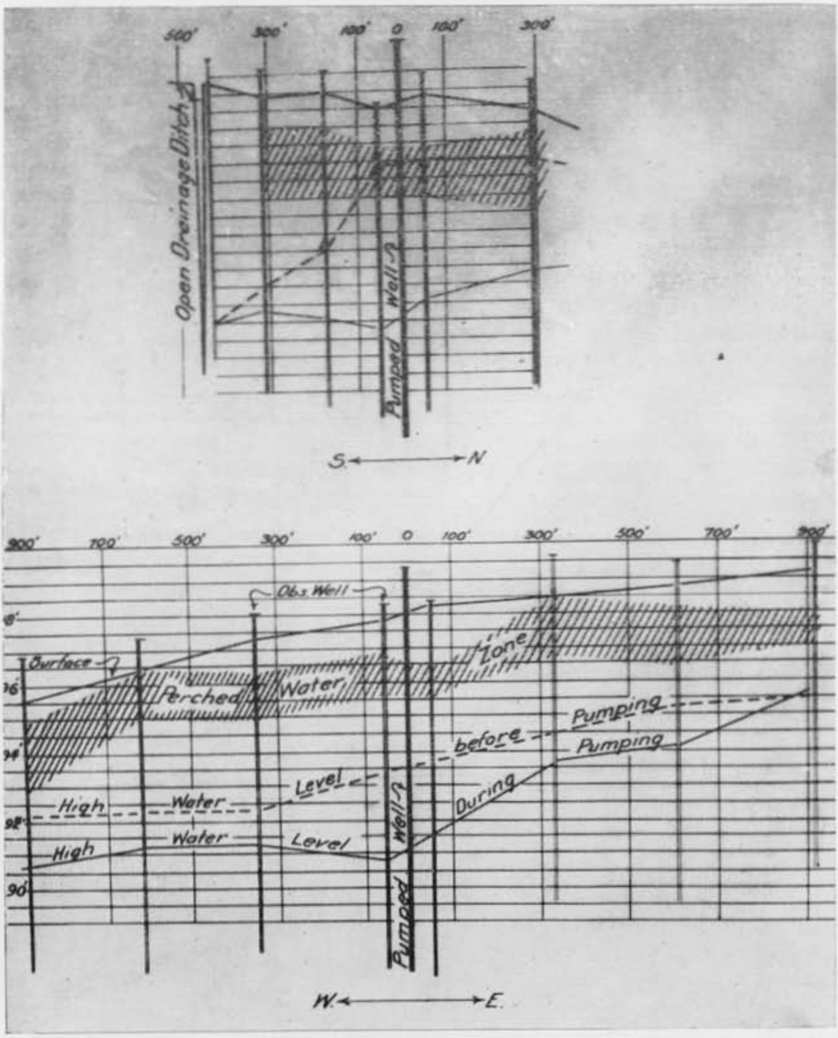

Figure 5.—Effect of drainage-well pumping on permanent water table.

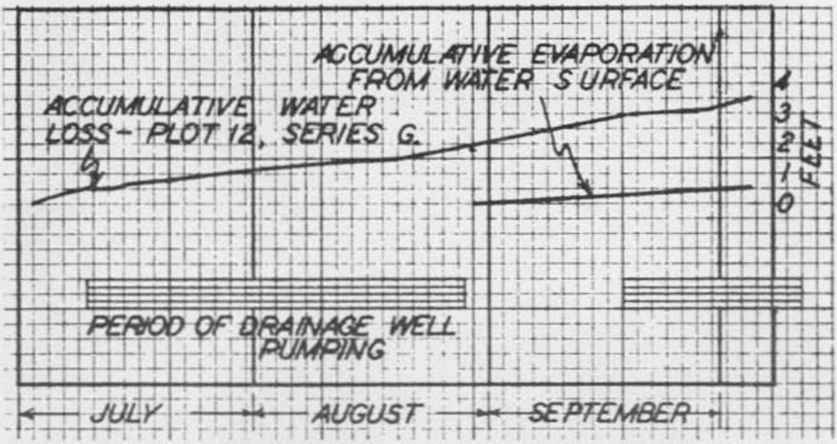

Figure 6.—Evaporation and percolation losses from plat 12, series G, when continuously ponded. July 1 to September 30, 1929.

which were leveled, seeded, and irrigated. In view of the failure to effect greater permeability of the impervious soil by blasting, subsoiling, intensive cultivation, or leveling and the lack of evidence that these operations facilitated the downward movement of alkali salts in the soil column, and because of their retarding effect on crop production, it is concluded that only shallow cultivation is warranted in dealing with strongly alkaline, impervious soils of this nature. For economical improvement of these soils they should be disturbed as little as possible (usually low contour levees made with the plow will serve) and the native vegetation left in place.

Though successful drainage of impervious alkali soils still may be considered possible through correction of physical and chemical defects of these soils, the outcome of drainage experiments discourages hope that favorable, as well as economical, drainage conditions may be effected to begin with or much in advance of actual reclamation of such soils.

Irrigation

Since in some respects the water used for irrigation and leaching was of questionable quality as to salt content, its chemical analysis and effect on alkali land reclamation was studied. Other irrigation experiments were tried to determine the most effective method of applying the water. The average salt content of the three waters used as determined from numerous analyses is shown in Table 3.

The most objectionable feature of these waters is the somewhat higher sodium content compared with that of calcium and magnesium. Scofield* states, "When the sum of the milligram equivalent

* *Hardness of Irrigation Water* by C. S. Scofield, Weekly Report, Bureau of Plant Industry, U. S. Dept. of Agriculture, June 25 and July 2, 1932, Pages 90-91.

Table 3.—Average salt content of waters used for irrigation on the Helms tract, 1926-1932.

Source	CO_3	Cl	SO_4	Ca	Mg	Na
	ppm	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*
Indian Creek	161	81	141	51	11	86
Pumped drainage well	190	65	186	35	10	87
Riverside Canal	135	47	83	33	7	57

of the sodium and potassium contained by an irrigation water exceeds that of calcium and magnesium, as is the case with these waters, its use is reported to make soils gelatinous and impervious." Thus the use of such water for leaching alkali land might be expected to prevent or retard the removal of the harmful salts. The question arises as to whether this condition was sufficiently pronounced in any of these irrigation waters to affect or prevent reclamation.

Irrigation waters of a similar character have been used in Idaho without noticeable harm to the soils *(Table 4)*.

Table 4.—Salt content of waters used for irrigation on other projects.

Source	CO_3	Cl	SO_4	Ca	Mg	Na
	ppm	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*
Payette River	84	77	98	29	6	83
Boise River (Caldwell)	120	63	56	19	4	47
Boise River (Parma)	114	94	115	47	7	97

Experiences on the Helms tract agree with that in other areas in Idaho. Plats 3 and 12, series G, were continuously flooded for several seasons and closely observed for possible effects. Originally the soil of plat 3 was distinctly less pervious to water than the best soils of the Helms tract; nevertheless it was sufficiently porous to permit a large amount of water to pass through it during a period of months. The soil of plat 12 was virtually impervious. Results of these tests, as well as the effect of irrigation elsewhere on the tract, show that the water did not prevent improvement of either permeable or semi-permeable soils. Even the impervious soil improved slightly.

Plat 3 was continuously flooded during 4 months of 1926 and 6 months of 1927. During the two periods 10.75 and 19.28 feet depth of water, respectively, either evaporated or percolated into the soil. If an allowance of 0.25 inch daily for evaporation is made and the difference in length of record is taken into account, an increase in soil permeability approximating 80 per cent is indicated for the second year. The soil analysis of this plat *(Table 5)* clearly indicates that a corresponding reduction in the salt content of the soil occurred. Leaching of the salts from this soil continued at least until experiments were terminated in 1932.

Since continuous flooding was the first and only treatment on plat 3 (except that alfalfa and sweet clover were planted and periodic irrigation practiced following the season of 1927) it seems reasonable to assume that improvement of this rather impervious soil was due to use of the water in question. It appears, also, that the more porous and less alkaline soils of this tract were benefited rather than harmed by these waters since they improved steadily and in some instances were fully reclaimed when the treatment consisted solely of seeding to crops and irrigating in the usual manner.

Table 5.—Soil analysis of plat 3, series G, showing salt content (1926-1932).

Depth	Normal Carbonates, CO_3		Total Carbonates*, CO_3		Chlorides, Cl		Sulfates, SO_4	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
feet	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*
0-1	2700	755	2700	1221	957	125	1605	378
1-2	2065	691	2096	1145	612	66	1035	99
2-3	854	539	995	895	200	65	403	71
3-4	574	547	746	852	140	33	646	87
4-5	27	0	381	100	77	100	2617	3820
0-5	6220	2532	6918	4213	1986	389	6306	4455

* Total carbonates refer to the sum of the normal carbonates plus the bicarbonates, determined separately.

Plat 12 was kept continuously flooded with water during the same periods as plat 3 in 1926 and 1927 and, in addition, for 3 months in 1929. At other times, up to and including the growing season of 1932, it was seeded to alfalfa and sweet clover and periodically irrigated, as was plat 3. During the three periods of flooding, 3.84, 5.53 and 3.35 feet depth of water, respectively, either evaporated from or percolated into the soil. Allowing, as before, 0.25 inch daily for evaporation and correcting the differences in length of records, the soil permeability is shown to have been 29 per cent higher in 1927 and 8 per cent higher in 1929 than it was in 1926. Analyses of the soil of this plat *(Table 6)* indicate moderate improvement of the soil. Other areas where the soil was highly deflocculated and impervious to begin with reacted similarly under the influence of periodic irrigation and efforts to establish crop growth, even including those which received heavy applications of gypsum, sulfur and sulfuric acid which should have compensated somewhat for the poor quality of water. On the other hand, results procured from tank experiments using chemically-treated water, cited hereafter, indicate that had the general plan of mixing the irrigation supply with large amounts of sulfuric acid, sulfur, gypsum or iron sulfate been adopted more effective leaching would have occurred. It appears doubtful, however, that an appreciably higher rate of leaching would have taken place in these impervious soils had it been possible to use water of ordinary good quality.

Table 6.—Soil analysis of plat 12, series G, showing salt content (1926-1932).

Depth	Normal Carbonates, CO_3		Total Carbonates, CO_3		Chlorides, Cl		Sulfates, SO_4	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
feet	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*
0-1	688	146	818	499	169	50	446	235
1-2	943	654	1060	942	68	65	116	96
2-3	578	309	754	648	34	32	123	202
3-4	481	218	644	613	16	46	76	215
0-4	2690	1327	3276	2702	287	193	761	748

Table 7.—Effect of irrigation method on reduction of salt content in impervious soils (1926-1932).

Series	Plat	Irrigation method	Depth	Normal Carbonates, CO_3		Total Carbonates, CO_3		Chlorides, Cl		Sulfates, SO_4	
				Initial	Final	Initial	Final	Initial	Final	Initial	Final
	Number		*Feet*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*
H	8	Deep furrow	0-1	651	117	816	399	105	50	166	101
			0-3	1521	1089	2264	2009	194	132	370	329
H	7	Corrugations	0-1	325	178	572	450	84	34	98	92
			0-3	815	493	1653	1370	205	105	365	220
I	5	Flooding and Surface run-off	0-1	119	0	294	288	51	18	129	53
			0-3	1759	848	2492	1442	85	131	558	167
I	4	Flooding and Surface run-off	0-1	568	127	846	450	17	90	54	234
			0-3	1046	127	1830	859	91	313	208	721
G	12	Continuous Ponding	0-1	688	146	818	499	169	50	446	235
			0-3	2209	1109	2632	2089	271	147	685	533

Where the soil was fairly porous, irrigation, regardless of method, caused satisfactory movement of the alkali salts downward through the soil column and afforded proper soil moisture conditions for seed germination and crop growth. With the impervious soils, however, some specific method of applying the water appeared to give best results. Generally the leaching effect was the same for all methods *(Table 7)*, but variation appeared in the vegetative cover that resulted *(Fig. 7)*. Plat 12, series G, the whole of which consisted of hard impervious soil, was planted to tules and continuously flooded with water throughout the growing season with the result that the tules made good growth. Tule swamps lying within badly alkaline areas quickly respond to reclamation when drained. This fact coupled with the demonstration that tule can be

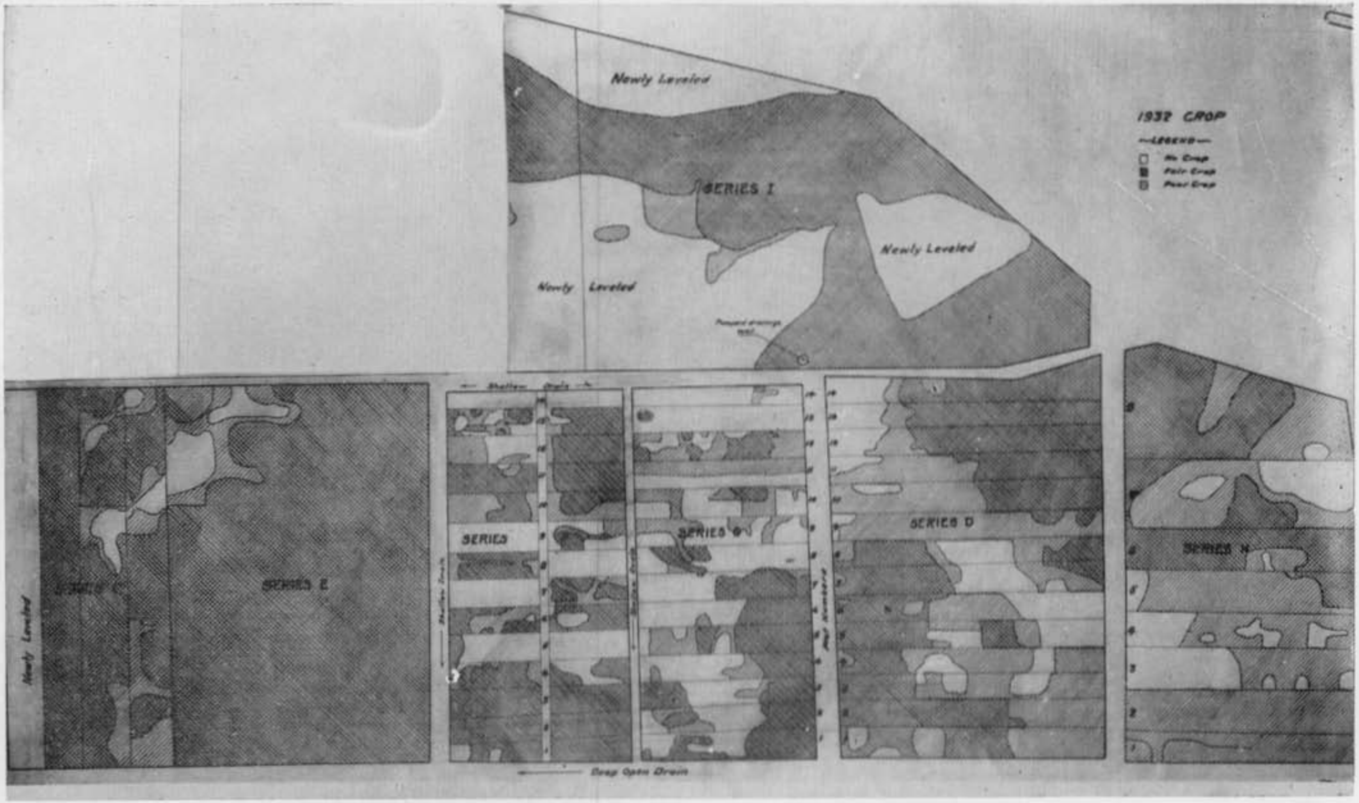

Figure 7.—Vegetative cover map of series C to I at end of investigation, 1932. Helms tract. (See Table 1 for crops grown.)

made to grow on strongly alkaline impervious soil gives promise that such soils may be reclaimed if kept under water for long periods and planted to crops which flourish in standing water. In this case flooding apparently ameliorates the effect of alkali on such plants. On series I, much of which consisted of impervious soils, a fair stand of pasture grasses was procured by copiously and frequently flood-irrigating the area, and by permitting much of the water applied to run off the plats. In this case the resulting vegetative cover was superior considering the adverse nature of the soil. Some of this improvement may be accounted for by the fact that neither the original ground surface nor the native vegetation was disturbed, which suggests that when strongly alkaline, impervious soil is dealt with land leveling and other operations required in order to prepare ground surfaces for border and furrow irrigation might best be delayed until such soil is markedly improved. Sprinkling the ground surface frequently with water so that the top soil was kept moist at all times was an aid in establishing useful crop growth on impervious, alkali soil.

Chemical Treatments

Application of certain chemicals to properly irrigated and adequately drained alkali soils is supposed to produce a more porous condition, convert the alkali into less harmful and more soluble salts which may be removed through irrigation and drainage, and prevent further deterioration of the soil. Calcium chloride, gypsum, sulfur, and sulfuric acid were used on the Helms tract with these purposes in view.

Series A was devoted to experiments involving the use of gypsum and sulfur and series F to treatments with calcium chloride, gypsum, sulfur, and sulfuric acid. Calcium chloride, gypsum, sulfuric acid, and iron sulfate were also used in infiltration experiments for the purpose of ascertaining their effect on the permeability of the soil.

Calcium chloride. The west half of plat 7, series F, was treated with calcium chloride. It consisted entirely of an impervious, strongly alkaline type of soil comparable with adjacent plats. No particular benefit was observed from the use of this chemical. Each year the plat was seeded to sweet clover and alfalfa and regularly watered during the growing season. Every effort to establish a useful crop growth failed *(Fig. 7)*. Some reduction in salt content occurred over the 7-year period *(Table 8)* but apparently it was not sufficient to permit good crop growth or cause beneficial leaching. Soil analyses, including pH determinations, to a depth of 6 feet indicate that this soil has not undergone a change greater than has occurred in similar soil on the check plats in the same series.

Gypsum. In Table 9 are tabulated soil analyses for the plats upon which gypsum was applied and for those used as checks. The plats of series A which were used for a part of this experiment comprise the better soils of the Helms tract. They were seeded principally to alfalfa and sweet clover and irrigated by the border method in accordance with crop needs. At present (1939) they are almost completely covered with a very satisfactory stand of alfalfa. It can be noted in Figure 8 that a marked improvement in crop occurred. A large reduction in salt content was observed in all plats, both treated and untreated, to a depth of 3 feet. Apparently, proper irrigation and adequate drainage are more important in the recovery of permeable soils of this type than the use of gypsum.

Far less benefit was obtained in series F, in which the original soil was principally of the impervious type. A general reduction in salt content occurred in all plats but was greater in the gypsum treated soils. This was indicated also by the better vegetative

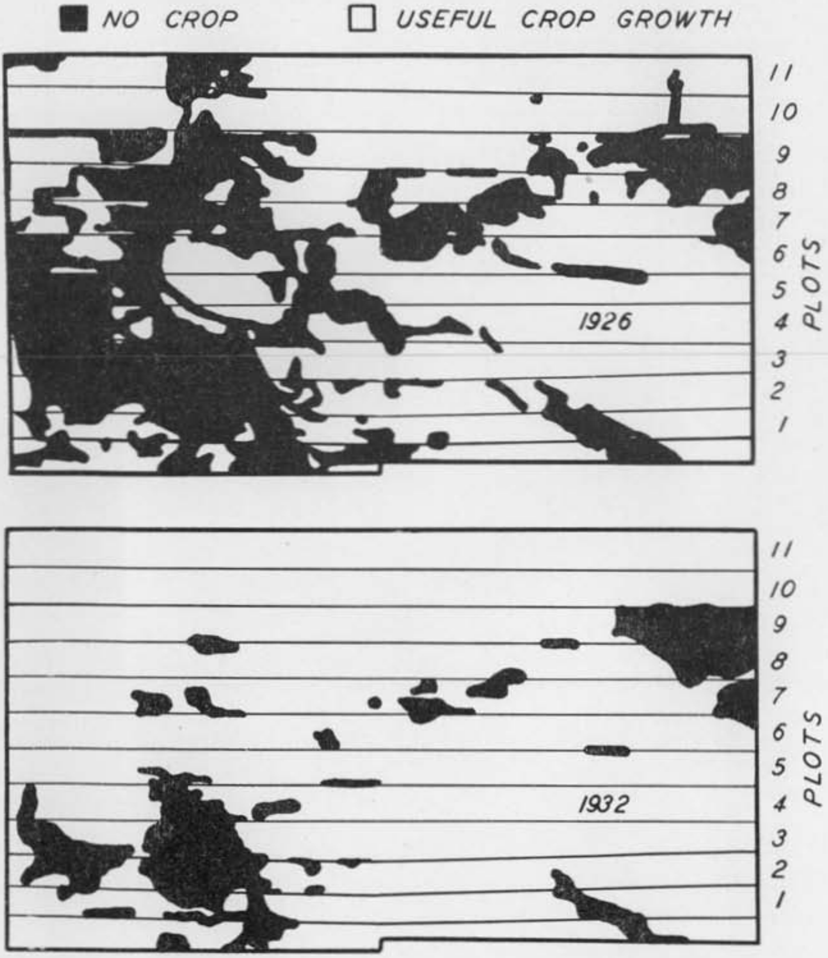

Figure 8.—Improvement of vegetative cover on series A from 1926-1932. Sweet clover was used as an index crop in 1926; alfalfa in 1932.

Table 8.—Effect of miscellaneous chemical treatments on salt content of soil at beginning and end of investigation, 1926-1932.

Series	Plat	Treatment	Depth	Normal Carbonates, CO_3		Total Carbonates, CO_3		Chlorides, Cl		Sulfates, SO_4		Calcium, Ca		Sodium, Na	
				Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
		Sulfuric Acid													
	Number		*Feet*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*
F	5	None	0-1	3000	1601	3000	2157	900	555	1572	1208	—	4	—	2691
			0-3	6545	3806	6825	5048	3324	790	3173	1615	—	8	—	5250
			0-6	7316	5243	8232	7107	4516	3955	11265	2834	—	16	—	7776
F	6	11.4 T.	0-1	2340	598	2340	801	2410	237	1440	811	—	4	—	1212
			0-3	5058	2523	5382	3079	6104	560	3844	1685	—	12	—	3653
			0-6	5529	3947	6284	4942	7780	661	10722	3008	—	16	—	5932
		Calcium Chloride													
F	7-W	6.3 T.	0-1	2580	791	2580	982	2975	69	1787	61	—	8	—	826
			0-3	5845	2806	5957	3208	7767	416	4005	689	—	15	—	2532
			0-6	6289	4299	6832	5161	9841	599	11954	1985	—	27	—	5207
		Adco and Straw													
F	8-W	0.8 T.	0-1	1680	200	1680	520	850	94	762	172	—	—	—	—
		Adco 6"	0-3	3770	1076	4071	2175	1884	250	1645	486	—	—	—	—
		depth of straw	0-6	4232	1219	4939	3284	2694	441	9756	11354	—	—	—	—
F	9	None	0-1	1400	59	1400	631	762	185	813	437	—	—	—	—
			0-3	2205	637	2529	1871	1113	306	1400	678	—	—	—	—
			0-6	2636	812	3465	2718	1261	456	4128	2425	—	—	—	—

Table 9.—Effect of gypsum applications on salt content of soil at beginning and end of investigation, 1925-1932.

Series	Plat	Sample	Treatment	Depth	Normal Carbonates, CO_3 Initial	Normal Carbonates, CO_3 Final	Total Carbonates, CO_3 Initial	Total Carbonates, CO_3 Final	Chlorides, Cl Initial	Chlorides, Cl Final	Sulfates, SO_4 Initial	Sulfates, SO_4 Final	Calcium, Ca Initial	Calcium, Ca Final	Sodium, Na Initial	Sodium, Na Final
	Number	*Number*	*T./A.*	*Feet*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*
A	2-E	24	None	0-1	680	0	800	223	0	18	380	82	16	25	740	204
				0-3	750	0	1290	662	48	53	800	262	73	29	1243	736
A	3-E	25	1	0-1	100	0	380	159	18	36	300	120	16	20	406	157
				0-3	160	0	800	454	70	83	680	363	80	57	833	405
A	4-E	26	2	0-1	190	0	590	216	18	0	350	81	18	24	597	241
				0-3	380	0	1280	583	124	34	640	355	52	28	1262	657
				0-6	—	0	—	1091	—	97	—	801	—	39	—	1558
A	5-E	27	4	0-1	160	0	320	201	0	19	140	105	0	25	312	172
				0-3	260	0	720	562	40	92	420	378	16	93	751	564
A	6-E	28	8	0-1	450	156	610	534	55	71	230	253	25	24	604	590
				0-3	653	224	1410	1477	220	144	530	655	33	52	1453	1463
A	7-E	29	None	0-1	600	370	860	685	144	123	560	307	2	12	997	800
				0-3	1900	1027	2330	1989	268	227	970	510	0	27	2601	2165
F	4		17.2	0-1	2320	222	2320	545	472	54	814	45	—	8	—	574
				0-3	3290	1186	3555	2103	1253	160	1890	49	—	20	—	2544
				0-6	5977	2473	6532	3951	1560	294	10066	769	—	35	—	4902
F	5		None	0-1	3000	1601	3000	2157	900	555	1572	1208	—	4	—	2691
				0-3	6545	3806	6825	4948	3327	790	3173	1615	—	8	—	5250
				0-6	7316	5243	8232	7107	4506	3955	11265	2834	—	16	—	7776
F	12		17.2	0-1	3420	750	3420	1181	873	388	1463	369	—	0	—	1863
				0-3	6730	1665	7059	3069	1457	617	2582	1339	—	0	—	4091
				0-6	7740	2828	8179	4877	1752	778	5508	2425	—	0	—	7246
F	13		34.4	0-1	4860	435	4860	900	303	123	4000	808	—	8	—	1261
				0-3	9050	1614	9220	2690	3603	225	5269	1046	—	15	—	2946
				0-6	10175	2758	10869	4304	5616	623	12146	2674	—	29	—	5423
F	14		None	0-1	1230	937	1230	1220	260	191	392	490	—	8	—	1359
				0-3	3240	2324	3445	3293	389	366	720	726	—	8	—	3316
				0-6	4890	3136	5665	4714	880	516	2324	1812	—	8	—	5538

cover on the treated plats. According to both the degree to which the salt content was lowered and the condition of vegetative cover noted in 1932, the treated plats generally responded better than the checks. However, in 1932 there still remained excessive amounts of alkali salts along with the adverse physical condition in these soils and their recovery was far from assured. Conditions of crop during 1926 and 1932 are illustrated in Figures 2 and 8. At present (1939) there is little difference in improvement of the gypsum-treated and check plats, the former having reverted markedly to their previous alkali condition. Little reason for recommending gypsum as an economical treatment for alkali land can be found in the results so far procured. Areas in which the soils were of the more pervious type improved satisfactorily regardless of whether gypsum was used or not. Areas in which the soils were of the impervious type improved somewhat more rapidly at first with gypsum treatment than when cultivated and irrigated only, but after 14 years time this difference is small, and the total amount of improvement that has occurred is far from impressive.

Sulfur. Results obtained from the sulfur-treated plats were much the same as those from the gypsum treatments. There was as much improvement shown on the check plats in series A (soil of the more porous type) as on the sulfur-treated plats. Table 10 and Figures 7 and 8 illustrate these facts. It is more difficult to compare results procured in series F, where the soil is principally of the impervious type. The treatments as a whole were beneficial, although, as compared to the effects of gypsum and other chemical treatments, the difference is less well defined. Variable results were obtained which were probably due to variable conditions in the original soil.

The results obtained indicate that: (1) Sulfur treatments were slightly more successful than were the gypsum treatments; and (2) Black sulfur (25 per cent crude sulfur) was somewhat more effective than the other two grades of sulfur employed. At present (1939) the variation in condition of sulfur-treated plats in series F and their check plats appears less than in 1932 and reclamation is far from complete. Apparently, many years will be required for the reclamation of these strongly alkaline, impervious soils.

It is concluded that nothing was gained through the application of sulfur to the better types of soil of the Helms tract, while the slight benefit obtained from such treatments on the impervious types was not sufficient to justify the expense, unless special purposes were involved.

Sulfuric acid. During the summer of 1926 crude sulfuric acid was applied to plats 6-W and 6-E, series F, at the rate of 15.2 and 11.4 tons per acre, respectively, by adding it to the water during the first irrigation. The treatment was accompanied by violent effervescence, and the surface soil which originally was hard and impervious was flocculated and became permeable. During the first 3 years a marked improvement of the soil structure was noted.

Table 10.—Effect of sulfur applications on salt content of soil at beginning and end of investigation, 1925-1932.

Series	Plat	Sample	Treatment	Depth	Normal Carbonates, CO_3 Initial	Normal Carbonates, CO_3 Final	Total Carbonates, CO_3 Initial	Total Carbonates, CO_3 Final	Chlorides, Cl Initial	Chlorides, Cl Final	Sulfates, SO_4 Initial	Sulfates, SO_4 Final	Calcium, Ca Initial	Calcium, Ca Final	Sodium, Na Initial	Sodium, Na Final
	Number	*Number*	*T./A.*	*Feet*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*
A	7	29	None	0-1	600	370	860	685	144	123	560	307	2	12	997	800
				0-3	1900	1027	2330	1989	268	227	970	510	0	27	2601	2165
A	8	30	0.186	0-1	230	0	410	198	0	18	70	51	0	32	348	185
				0-3	450	0	910	506	0	85	240	185	0	66	812	546
A	9	31	0.372	0-1	260	0	460	200	0	36	130	122	0	28	399	189
				0-3	500	0	1010	581	37	36	360	300	0	40	955	674
A	10	32	0.744	0-1	330	0	410	172	0	18	90	88	4	32	353	165
				0-3	740	0	1160	465	0	70	300	243	0	67	1028	515
A	11	33	1.988	0-1	200	0	340	156	0	18	70	62	8	16	400	142
				0-3	320	0	660	472	47	68	430	232	46	71	796	499
F	1		None	0-1	785	160	921	326	94	72	167	114	—	4	—	591
				0-3	1599	221	1918	589	137	174	904	346	—	484	—	1736
				0-6	1987	377	2784	1483	153	333	3667	862	—	573	—	3439
F	2		3.2	0-1	645	0	811	193	34	38	78	294	—	29	—	248
				0-3	1026	0	1348	655	161	56	432	529	—	38	—	907
				0-6	1460	0	2112	1282	192	192	8968	1607	—	54	—	2875
F	3		6.4	0-1	1100	127	1100	358	278	18	660	1929	—	12	—	1209
				0-3	2652	1149	2728	1942	603	109	1230	2949	—	12	—	3039
				0-6	3852	2300	4154	3834	801	194	4928	3934	—	25	—	5008
F	9		None	0-1	1400	59	1400	631	762	185	813	437	—	0	—	906
				0-3	2205	637	2529	1871	1113	306	1400	678	—	0	—	2083
				0-6	2636	812	3465	2718	1261	456	4128	2425	—	82	—	4464
F	10		3.2	0-1	1450	121	1510	413	387	27	736	565	—	8	—	1555
				0-3	2832	962	3110	1881	553	250	1060	1686	—	8	—	3221
				0-6	3450	1286	4497	3115	632	450	6210	2253	—	15	—	8903
F	11		6.4	0-1	1267	90	1267	351	188	237	594	335	—	4	—	1759
				0-3	2717	733	3101	1760	273	411	841	1059	—	11	—	3434
				0-6	3154	1055	4014	3066	303	560	7288	1541	—	19	—	5654

There was a definite reduction in pH and salt content, and considerable hope was entertained that these soils might be reclaimed. Fair stands of alfalfa and sweet clover were procured over a large portion of the two plats. Several years afterwards, however, the difference in appearance of these and adjoining plats became less striking. The soil gradually became more compact until, at the present time (1939), much of the original effect of the treatment has been lost and these plats show only slight improvement over adjoining check plats. Possibly, if further additions of sulfuric acid had been made until the carbonate was neutralized down to the sand and gravel layer, these soils might have been fully reclaimed. The cost of such treatment, however, would preclude the economical reclamation of this soil. The condition of vegetative cover in 1926 and 1932 is illustrated in Figures 2 and 7. The reduction in salt content is shown in Table 8.

Since these plats are not yet restored to a state of useful production (1939) and since the treatment involves considerable expense, results fail to show that the use of sulfuric acid is an economical method for reclaiming such impervious types of alkali land.

Chemically Treated Waters

As previously stated, these experiments were conducted in open-end cylinders, 18 inches in diameter, imbedded in the soil on spots known to be of the impervious alkaline type. They were kept filled with various solutions of sulfuric acid, gypsum, and iron sulfate. They were compared with cylinders kept filled with untreated irrigation water. The cylinders were placed on plats 13 and 14, series G, and plat 8-E, series F. The rate of percolation is shown in Figure 9. Measurement of the amount of percolation during several

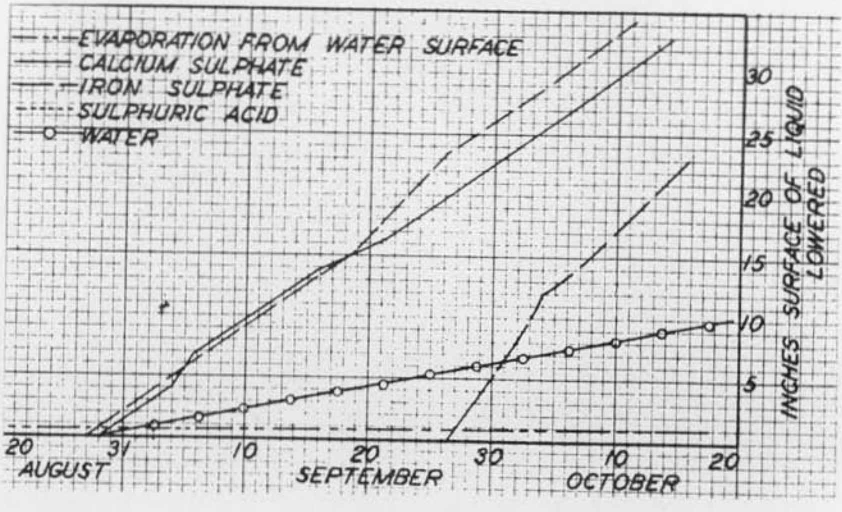

Figure 9.—Influence of chemical treatments on rate of percolation.

months of 1929 and 1930 gave strong supporting evidence that these chemically treated waters greatly increased the permeability of the soil.

After these experiments had been conducted during one irrigation season, they were repeated a second season, irrigation water alone being used. Little diminution of soil permeability occurred. It was considered, therefore, that the improvement brought about by these treatments might be permanent. To make such beneficial effects lasting, however, satisfactory underdrainage must be maintained.

Miscellaneous Treatments

Any method of shading the ground and thus retaining moisture at the surface either by artificial means or by vegetative cover was found to facilitate the starting of useful vegetation. No growth could be procured on impervious soils unless some such method were used.

Manure. When a 3- or 4-inch layer of well-rotted manure was spread over the ground surface, followed by irrigation and heavy seeding of perennial grasses and legumes, a fair stand could be obtained. The advantage gained by using well-rotted manure as a surface covering is that a minimum amount is required in order to start a crop on very poor alkali land. Useful growth was also established by plowing manure under, but not until the manure had been applied several times in large amounts.

Adco-treated straw. A result similar to that which followed the use of a fairly heavy, well-rotted manure surface covering was procured on plat 8-W, series F *(Fig. 7)*. The stands obtained, however, were not as uniformly good as those secured with manure. It appears that manure might better be used for this purpose. The results from plat 13, series G, where the Adco-treated straw was kept saturated with water, were not as satisfactory as from plat 8-W, series F, where a moderately moist condition of covering was maintained.

Straw. The purpose of the straw covering was to keep the ground surface moist so that seed germination would take place. It was hoped that the alkali concentration would be less and therefore not so toxic to young plants. Such results were prevented by accumulation of alkali salts between the layer of straw and the ground surface. When the straw covering was of sufficient thickness to prevent high evaporation, which accounted for the accumulation of alkali salts, it smothered growth that started beneath it.

The purpose in plowing straw under on plat 4, series G, was to mix sufficient coarse material with the soil to obtain a better aerated, more friable condition. The improvement which resulted was no better than that which occurred on the check plats and was less than that on plat 5 which received manure.

Burlap. The use of burlap, supported horizontally, to afford shade for the ground surface when starting growth, was very successful. Small areas of impervious soils, seeded to bluegrass and kept moist, produced satisfactory seed germination and plant growth.

Practical use was made of this finding in series I by allowing the original vegetation to remain undisturbed while legumes and pasture grasses were being started. It was found that the shade afforded by the original vegetation aided materially in establishing the more useful growth.

Field crops. Because of inconclusive data in regard to the various crops grown on series B as to their tolerance for alkali and their ability to produce satisfactory yields, it is felt that these experiments need not be discussed in detail except for the following general conclusions:

All the crops employed made a satisfactory showing when planted on the fairly porous, moderately alkaline soil. In contrast to this, none of them was easy to start, or when started continued to grow in the impervious soil, unless aided by extraordinary methods.

An advantage was gained by planting deep-rooting, heavy-foliating perennials since they continued to grow from year to year in the areas where the soil was favorable and gradually encroached upon the barren, alkali spots. This fact is well illustrated in Figure 8. Nearly one-third of the total area of the 11 plats in series A failed to produce a crop in 1926. During the 6 years following, there was gradual encroachment upon these barren spots, until by 1932 only small areas remained upon which no crop was growing. Several factors may have contributed to this reduction. The carbon dioxide generated in the soil by the plant roots may have acted as a neutralizing agent. The root systems may have increased soil aeration and drainage, particularily on the edges of these barren spots, so that they were incorporated into the more porous soils. The shade afforded by the growing plants may have kept the ground more moist in their immediate vicinity so that the alkali was not so concentrated at the soil surface and thus aided in establishment of seed germination and plant growth.

Whatever the reason, it is evident that there occurred a gradual increase in area which would support plant growth, and it is reasoned from these observations that a study of native vegetative cover and use of whatever crops can be grown upon such areas will gradually bring about a reclamation of these types of soil.

Sufficient headway was made in growing several plantings of tule on plat 12, series G, to warrant the belief that it is possible to establish such a crop upon the most unfavorable types of alkali soils. It seems likely that such areas might be eventually reclaimed provided they are first underdrained and crops which will thrive in standing water are grown upon them. Then later, as the soils gradually become more pervious, other crops might be established.

While experimental plans did not include the planting of vegetables, they were grown most of the time from 1925 to 1932 by the caretaker of the experimental tract for his own use. They were grown on a portion of the tract which consisted of fairly impervious, alkali soil. Squash, pumpkins and cucumbers generally rotted before maturity. Peppers matured but were too bitter to use. Tomatoes, sweet corn, and popcorn were the usable garden products produced.

Forest and Shade Trees

The conifers as a group and as individuals proved a failure on both alkali and control plats. Some species of the deciduous trees on the alkali plat survived fairly well but with little growth and have since died as a result of neglect. With few exceptions the deciduous trees on the control plat survived well and made fair to excellent growth. Of the 13 species of deciduous shade trees planted, Silver poplar, Weeping willow, Russian olive and Siberian elm have made the best showing.

Much the same conclusions can be drawn concerning forest and shade trees in relation to these soils as were obtained with various crops. Certain species can be grown with excellent results upon the more pervious soils but none can be successfully produced upon the impervious, more alkaline types encountered in this experiment. As with the crops, it was possible to maintain life with little growth in certain species over a period of years by use of extraordinary systems of treatments, but the expense involved and time expended were rather discouraging and seems to have been hardly worthwhile.

Discussion

In studying the reclamation of soils, similar to those involved in the experiments here reported, emphasis should be placed at the very outset upon the kinds of vegetation present. Apparently, plant growth and nature of vegetation are determined to a considerable extent by the character of surface and subsoils. When the soil has been classified and methods of reclamation established, the native vegetative cover of contiguous areas should furnish an excellent indication for the reclamability of these lands. This is particularly true of those areas which must undergo a gradual process of reclamation and which can best be recovered as pasture lands before they may be considered as valuable for other agricultural purposes.

Soil drainage is undoubtedly the most important factor to be considered in economical alkali-land reclamation. Where the soil is porous or semi-permeable and natural underground drainage can be secured, the recovery of such areas is only a question of time, dependent upon the kind and amount of salts present and the degree of percolation. When, however, the soils have become highly deflocculated owing to the nature and concentration of the alkali salts present, the impervious condition of the soil overcomes the value of drainage as far as economical reclamation is concerned. Irrigation waters will not penetrate such soils to any great depth and no economical artificial method of improving the vertical drainage has been developed, at least up to the time when this report was written, to overcome this difficulty.

The best method of reclamation for such alkali lands, at least from the standpoint of economical recovery, seems to lie in the practice of irrigation with as little disturbance of the surface soil as possible. The native vegetation should be left untouched so that it will serve as a cover or shade for the protection and establishment of crops. Perennial legumes and grasses appear to be best suited to these soils. When the crops have become established on the more permeable areas they will gradually encroach upon the impervious spots and, through the additions of organic matter and because of increased carbon dioxide activity, will gradually overcome the impervious nature of these areas and bring about their recovery.

Chemical treatments with gypsum, sulfur, and sulfuric acid caused varying degrees of flocculation in these soils and might, in time, have brought about reclamation. However, the cost of the chemicals needed to neutralize the large amount of alkaline salts present made such recovery uneconomical and their use is not recommended unless for special purposes.

Where more rapid recovery of small areas or spots of impervious soil is desired, it has been found that such methods as the use of artificial shading, covering the soil with Adco-treated straw or well-rotted manure, and continuous flooding or sprinkling with water to keep down the salt concentration will all help in establishing seed germination and early crop growth. Chemical treatments might be used on small areas where the cost is not a consideration or where the alkaline salt concentration is not too great. Ponding, or continuous flooding along with attempts to establish such crops as will thrive in standing water might eventually render impervious soil sufficiently permeable to permit successful production of other crops and the use of ordinary irrigation methods.

Deciduous trees can be grown successfully on alkali soils of the more pervious types. They cannot be established with any degree of success on the more alkaline impervious soils. Here, as with crops, unusual and tedious methods must be used in order to establish even a minimum of growth.

The irrigation waters used in these investigations were somewhat alkaline with moderate amounts of sodium carbonate, chloride, and sulfate present. They held a slight excess of sodium-potassium balance over the calcium-magnesium content. This was to be expected since the sources of supply originated principally in the seepage and waste waters from the higher irrigated lands. Results of experiments failed to show that this water was unfit for use. In general, it appears that all types of soils on the Helms tract, even the more impervious, were benefited rather than harmed by these waters. Irrigation waters of a similar character have been used on other tracts in Idaho without noticeable harm to the soil.

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