Station Bulletin 210 October, 1924

Oregon Agricultural College

Experiment Station

Soils Department

A Progress Report of Alkali Land Reclamation Investigations in Eastern Oregon

By

W. W. Johnston and W. L. Powers

CORVALLIS, OREGON

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CONTENTS

SUMMARY

1. Herein is reported the progress of four seasons' field and tank experiments with natural "black alkali" land which is only slowly permeable to water.

2. A method of sluicing deep drainage ditches developed as a result of experiments in this connection has made it possible for farmers, under favorable conditions, to secure drainage cheaply.

3. Leaching alone has been effective in removing the neutral salts but has not been effective in removing the sodium carbonate or in improving the physical condition. Leaching and drainage in connection with chemical treatments have been found necessary in order to remove the neutral salts resulting from the decomposition of sodium carbonate.

4. Seven to ten tons of gypsum per acre have been required to neutralize the sodium carbonate sufficiently to secure a good stand of sweet clover.

5. The application of 500 pounds of sulfur with 20 tons of manure per acre made it possible to secure a fair yield of rye and a good stand of sweet clover. Studies indicate that heavier applications of sulfur alone will be effective. The effect of combinations of sulfur with quicklime, with gypsum and with manure is being investigated.

6. Five tons of aluminum sulfate have been required to soften the soil. Lighter applications have been ineffective.

7. Manure has been effective when in combination with sulfur and gypsum, but not when used alone.

8. Getting uncleared, drained "grease wood land" into pasture and using frequent irrigations has proved to be an economical method of utilizing the hard alkali lands of Malheur county and affords partial reclamation.

9. Tank experiments have verified field results and show the value of heavy gypsum, sulfur, and alum treatments.

A Progress Report of Alkali Land Reclamation Investigations in Eastern Oregon

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INTRODUCTION

It has been estimated that from 12 to 15 percent of the land under irrigation ditches in the United States is limited in production to a greater or less extent by alkali. In Oregon a few projects are practically free from alkali troubles, but most of the projects are somewhat affected and on a few the majority of the lands included are affected to a greater or less degree. There is in Oregon perhaps 75,000 to 100,000 acres of land so affected offering possibilities for reclamation.

Alkali difficulties are generally associated by most irrigation farmers with a water-logged condition of the soil, which results in the accumulation of soluble salts throughout the soil mass at or near the surface as the result of evaporation of water brought up by capillarity from the high water-table. This condition usually exists on soils that are readily permeable to water, and the reclamation of such land is generally accomplished by providing drainage to lower the water-table and by washing out the salts by means of heavy irrigations. This represents our "white alkali" problem or the problem of reclaimed lands that have become affected with soluble chlorids and sulfates of sodium, magnesium, and potassium, and where the land is permeable to water. Such lands are more aptly termed "saline soils."

In addition to these saline soils, we have thousands of acres of so called "black alkali land." The reclamation of this type of soil presents a problem that is much more difficult and very different from that of the white alkali land. These soils are characterized by a high percentage of sodium carbonate and by their poor physical condition, the surface being easily puddled and the entire soil mass partly or nearly impermeable to water. Scofield and Headley,[1] and other investigators[2, 3] have published data showing that this condition is probably due to the substitution of alkaline bases, largely sodium, for some of the earthy bases such as calcium in the finer soil material. This results in a soil of different characteristics, which is less permeable to water, shows a deflocculated condition, and becomes very hard upon drying out. They have shown that this condition may be developed upon leaching the soluble salts from a saline soil, particularly where the replacable calcium content is low as compared to the content of replacable or very slightly soluble sodium and where the soil contains considerable clay. Soluble salts are continually being liberated as soil forming minerals are weathered, but in humid sections the excess of salts is removed in drainage water to the ocean. Irrigation water carrying considerable quantities of sodium salts is objectionable.

True alkalinity is to be distinguished from salinity. The latter condition is one in which neutral salts like sodium sulfate, or sodium chlorid are in solution, and in high concentration this may interfere with the absorption of plant nutrients. True alkalinity obtains where hydrolizable salts give rise to a concentration of OH ions greater than in pure water. Pure water as H_2O or HOH dissociates to a slight extent into hydrogen ions ($H+$) and hydroxyl ions ($OH—$). The hydrogen ions are bitter and give rise to acids and soil acidity. Hydroxyl ions give rise to true alkalinity. Sodium unites with the hydroxyl ion readily to form sodium hydroxide or caustic soda. It may then combine with the finer soil material to form jelly-like compounds causing deflocculation of the soil and consequent impermeability. This gives rise to an excess of OH ions, which are more toxic to plants than hydrogen ions. This puddled alkaline condition interferes with plant nutrition in several ways. It may interfere with root development, germination, bacterial activity, and absorption of plant nutrients. A high concentration of OH ions will cause iron and phosphorus to disappear partly from the soil solution.

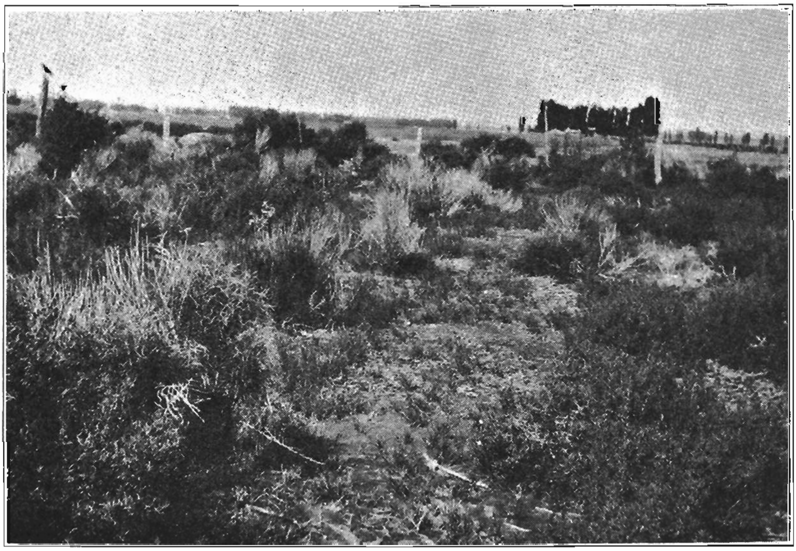

Fig. 1. Native vegetation. Land used for pasture experiment with uncleared land. Note grease wood, salt grass, and small amount of sagebrush.

In order to correct these difficulties in arid soils drainage and leaching are used to remove the soluble salts, while chemical treatment is effective in converting the replacable sodium compound to soluble form and in improving the reaction and tilth so that this soluble material can be leached out. Sulfates and carbon dioxide from the decay of organic matter or excretion by plant roots tend to neutralize the soil. Light, temperature, and humidity are other factors to be considered.

It is certain that we have considerable areas of land that have once been very productive, which have later become saline and finally have turned into black alkali land. In addition to this, we have large areas of so called "grease wood" (*Atriplex nuttellii* S. Wats) land, most of which is unproductive in the virgin state, or has become infertile while still in the virgin state where the total salt content is fairly low, the sodium carbonate content high, and the soil very impermeable to water.

This last type of land is recognized as being very difficult to reclaim, and it is doubtful if reclamation should be undertaken were it not for the fact that thousands of acres of such lands are included in existing projects located under existing ditches and against which lands water-right charges are assessed. The development of a method of reclaiming or utilizing this type of alkali land is one of the important soil problems and is the problem dealt with herein.

Experiments were undertaken in the spring of 1921 by the Soils department of the Experiment Station on a tract of grease wood land near Vale, Oregon. The land was drained, cleared, leveled, diked for flooding, and chemically treated for the purpose of studying this problem.

Fig. 2. Sluicing with the "Purvis sluicer." Two men and teams, a twenty-five dollar machine, and a head of water build cheap drainage ditches. A good fall, a head of water (3 to 4 second feet), and a soil that is loose enough to plow and fine enough to go into suspension with water are the conditions necessary for success with this method.

Tank trials have been conducted in the greenhouse, and numerous laboratory tests and several hundred alkali determinations have been made to check the field work. While the results are still incomplete, it is the purpose of this bulletin to report the findings and the progress made to date.

FIELD TRIALS

The upper Malheur Valley, in which the ten-acre alkali experiment field is located, is of an alluvial formation. The slope of the Valley floor with the river is very good and in the region of the experiment field there is considerable fall across the Valley in the direction of the river. The grease wood lands are found running parallel to the river, including the lower part of the old Valley filling soil. This strip varies from one-eighth of a mile to a mile or more in width, being wider where the Valley is wide. Part of this land is water-logged, but in other localities, particularly in the locality where the experiment field is located, the water-table does not come closer than 6 to 7 feet from the surface. This area is found to contain, near the lower edge, a series of hard-pan dikes, which run parallel to the river and extend from within a foot or two of the surface to a depth of from 8 to 12 feet where they connect with a putty-like clay through which water will seep but slowly. This condition has not held up drainage entirely, but has impeded it to such an extent that the water-table has been high during a certain part of each year as a result of heavy irrigation of the land at higher elevations. Evidently alkaline salts have been brought down with the drainage water and a portion has been left each year, with the result that sodium salts have accumulated and the soil has been changed to its present condition. The land in these grease wood strips is worse in the portion near but not adjacent to the river, having a higher black alkali content, and being more impermeable to water.

The experiment field is located in the latter type of grease wood land and represents the worst type of black alkali land in the Malheur Valley. The soil is heavy loam, and most of the field is underlaid with a streak of hard-pan at from 3 to 4 feet from the surface. Sand is generally encountered at about 8 feet and gravel at 13 feet.

CHEAP DRAINAGE PROVIDED BY SLUICING

It is well known that in any sort of alkali land reclamation drainage is necessary in order to provide an outlet for washing out the natural saline salts in the soil and in the case of soils containing sodium carbonate to remove the neutral salts resulting from the decomposition of this compound by chemical treatment. When the natural drainage is insufficient to take care of the heavy irrigations used in leaching, artificial drainage must be provided. The cost of providing such drainage has an important bearing on the feasibility of reclaiming alkali land.

In an attempt to meet the need for a cheaper method of drainage an experiment was conducted in the spring of 1921 to determine the feasibility of adapting the sluicing method of moving earth to the constructing of deep drainage ditches. This method consists of running a head of water through a shallow ditch and deepening it by stirring the earth in the bottom by some means and washing it out with the water. A ditch was constructed by this means on the field to be used for the alkali experiments. In its construction a number of methods were employed for loosening the earth and keeping it in suspension. A long iron bar, a cultivator, and a shovel were all used, the larger part of the excavation being accomplished by loosening the earth with an ordinary irrigation shovel and allowing the water to carry it out. This was done while the water was running, a head of about four second feet being used. The one-horse cultivator was found to be especially efficient but was rather hard to handle. This tool was operated by attaching it with a long chain to the middle of a pole which extended across the ditch. A horse was hitched to each end of the pole and the machine dragged up and down the ditch. This ditch, which averaged 12 feet in depth, cost 20 cents per foot of ditch and about 11 cents per yard of earth removed.

The Purvis Sluicer

The work of the Station showed a need for some sort of tool which could be operated by horse-power and which would not require a man in the ditch for its operation. Such a tool has been invented by Mr. Percy Purvis of Vale, and is known as the "Purvis sluicer." This machine is cylindrical in shape, and its cutting power is derived from cylinder teeth

Fig. 3. The finished drain. Open ditch twelve feet deep built by sluicing at a cost of seventeen cents per foot of drain. The banks cave in each year as far back as frozen. This earth is sluiced out in the spring. In three years a slope of one to one is secured, and after this but little caving occurs.

which protrude at intervals from the entire exterior area. In operating, the machine is dragged up and down the ditch lengthwise, the same method being employed as that described for the cultivator. The machine is made entirely of iron and can be constructed by any good blacksmith. It costs about $25.00.

Cost of Building Ditches with Water

This method is not applicable to all conditions, but where a deep outlet is available, where the land has a fall of eight feet per mile or more, and the soil is of such nature that it can be readily plowed, the use of this method has provided very cheap drainage. The cost of sluicing a ditch under ideal conditions is well illustrated by referring to one constructed near Vale, Oregon, by Messrs. Russell, Carmen, and Hadley. This drain was built with the Purvis sluicer and is 2,225 feet long, averaging 12 feet in depth, and cost, when all labor charges were considered, $247.00. This amounts to eleven cents per foot of drain or five cents per cubic yard of earth removed. The cost exclusive of labor was less than $50.00. This ditch is estimated by its owners to affect about 100 acres of land. The sluicer has been successfully used on the Ochoco Project and the Grants Pass section, where ditches have been constructed at one-half the cost required by former methods.

ALKALI IN SOILS

In Table I is reported the average alkali content calculated as sodium chlorid, sodium sulfate, and sodium carbonate.

The determinations were made from a 1:2.5 solution with water, and the alkali, reported as sodium carbonate, represents the result of titrating with N/.1 normal hydrochloric acid, using methyl orange as an indicator, and is taken to represent, at least comparatively, the effective alkalinity of the soil.

TABLE I. ALKALI CONTENT, VALE EXPERIMENT FIELD

		Alkali content parts per million		
Depth of sample	Total salts by dessication	Carbonates expressed as sodium carbonate	Chlorides expressed as sodium chlorid	Sulfates expressed as sodium sulfate (by difference)
0' — 1'	7350	1629	639	4082
1' — 2'	7700	1563	705	5432
2' — 3'	5205	1143	513	3549
3' — 5'	4052	850	418	2784
5' — 7'	1463	441	243	779

Note: These figures each represent the average of 14 analyses, each analysis being made from a composite of 3 samples.

It will be seen that the alkali is fairly well distributed through the first three feet of soil, and that while it diminishes at the lower depth, considerable is yet to be found in the sixth and seventh foot.

The area was drained, cleared, and leveled in the spring of 1921, and plots laid out to compare the effect of various treatments of gypsum, sulfur, aluminum sulfate, manure, and certain combinations of these treatments, all combined with drainage and flushing with heavy irrigations to wash out the soluble salts.

Effect of Leaching

During the first three seasons of the experiment all plots were irrigated uniformly. During the first season a little over three and one-half acre feet per acre was used and in the next two seasons a somewhat smaller amount was applied. The soil takes up water very slowly. A four-inch irrigation applied and held on the land will not disappear until forty-eight to fifty-two hours after its application, and considerable of this loss, of course, is due to evaporation. As stated, all plots were uniformly leached whether chemically treated or not, and the effect of leaching, without the aid of other treatment, can be determined by a study of check plots D, E, and I.

Table IIa gives the results of the analysis of samples taken from the various plots in the spring of 1921, when the experiment was started, and

TABLE IIa. ALKALI RECLAMATION TRIALS
Parts per Million of Alkali in Surface foot 1921-1923
(Expressed as salts of sodium)

		Spring 1921—Initial				Fall 1923			
Plot	Treatment	P.P.M. Total salts	P.P.M. Na_2Co_3	P.P.M. NaCl	P.P.M. Na_2So_4	P.P.M. Total salts	P.P.M. Na_2Co_3	P.P.M. NaCl	P.P.M. Na_2So_4
A	Manure 20 T.	7147	1443	378	5326	3450	1006	490	1954
B	Check	4810	444	126	4240	1150	672	175	303
C	Sulfur 500 lbs. Manure 20 T	9918	1554	630	7734	4680	564	129	3987
D	Gypsum 1200 lbs. Manure 20 T	7853	1443	378	6032	2820	1022	824	974
E	Check	7969	2442	378	5149	3800	1022	176	2602
F	Green Manure	10530	2886	756	6888	2370	1839	220	311
G	Sulfur 500	7818	2442	1386	3990	2410	635	1550	225
H	Sulfur 1000	7006	1222	756	5028	2380	1379	499	502
I	Check	5370	1776	882	2722	2140	1622	292	226
J	Gypsum 800 lbs. Increased Fall '22 to 20400 lbs.	6632	1110	252	5270	2450	1450	456	544
K	Gypsum 1600 lbs. Increased Fall '22 to 13600 lbs.	8629	2442	630	5557	2600	490	447	1663
	Gypsum 2400 lbs. Increased Fall '22 to 6800 lbs.	6728	1887	630	4211	1450	954	152	344
	Average	7534	1758	597	5179	2641	1055	450	1036

TABLE IIb. ALKALI RECLAMATION TRIALS
Parts per Million of Alkali — Average Surface 3 Feet
(Expressed as salts of sodium)
(1921-1923)

		Spring 1921 — Initial				Fall 1923			
Plot	Treatment	P.P.M. Total salts	P.P.M. Na_2Co_3	P.P.M. NaCl	P.P.M. Na_2So_4	P.P.M. Total salts	P.P.M. Na_2Co_3	P.P.M. NaCl	P.P.M. Na_2So_4
A	Manure 20 T.	6404	1110	264	5030	2187	698	275	1217
B	Check	5634	592	168	4874	1913	625	342	946
C	Sulfur 500 lbs. Manure 20 T	11484	1517	1134	8833	3993	683	202	3108
D	Gypsum 1200 lbs. Manure 20 T	7668	1591	378	5699	4693	1752	847	2094
E	Check	6700	2072	504	4124	2340	1034	262	1044
F	Green manure	9155	1961	1134	6060	3847	1734	905	1208
G	Sulfur 500	5387	1591	882	2914	2823	1415	979	429
H	Sulfur 1000	5711	705	714	4292	2343	1343	652	348
I	Check	4737	1591	672	2474	3600	1471	346	1783
J	Gypsum 800 lbs. Increased Fall '22 to 20400 lbs.	7791	1147	420	6224	4353	1730	779	1844
K	Gypsum 1600 lbs. Increased Fall '22 to 13600 lbs.	9356	1924	756	6676	4240	894	379	2967
L	Gypsum 2100 lbs. Increased Fall '22 to 6800 lbs.	6036	1517	420	4099	6600	1238	156	5216
	Average	7172	1444	620	5108	3577	1217	511	1849

TABLE III. CHEMICAL COMPOSITION OF SOIL

	April, 1921 sample	September, 1921 sample
K_2O	2.450	2.360
CaO	3.450	3.620
MgO	1.080	1.170
P_2O_5	.242	.237
S	.041	.028
N	.040	.034

Soluble calcium, composite sample, 1921, .0147.
Analysis by Station Chemist, J. S. Jones.

again in the fall of 1923 for the surface foot, and Table IIb gives the average results for the surface three feet. Each sample is a composite from three borings, borings being made from the same location in each

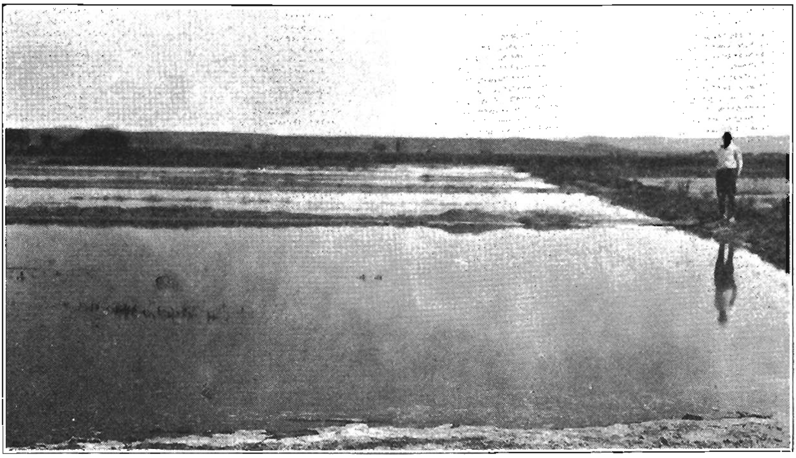

Fig. 4. Flooding to leach sulfur plots. It has been possible to remove the saline salts by leaching after drainage has been provided. The land takes up water slowly but will leach through if held on the land long enough.

plot whenever sampled. It will be noted that plots B, E, and I, which were provided with drainage and heavy irrigation but with no chemical treatment, showed a much lower total alkali content after three years' treatment. The sodium carbonate content, however, has not been consistently reduced and in fact, in one or two cases it appears to have increased. These plots have not shown any improvement in physical condition or in permeability, and while it is now possible to get seed to germinate in the surface soil of these plots, no crops have been produced upon them. The only place where leaching without chemical treatment in addition has been effective is where the land has been uncleared and handled for the purpose of securing pasture, a discussion of which is taken up in a later section.

Effect of Leaching on Plant Nutrients (Table III)

In order to obtain some evidence of the general fertility of this soil and to learn the effect of extensive leaching on fertility, composite samples from the surface foot when the experiment was started, and again after a year's treatment were analyzed by Station Chemist J. S. Jones. Results of analysis are found in Table III. It will be noted that the sulfur and nitrogen content has been reduced somewhat, but that otherwise the leaching has had little effect upon the fertility elements. This soil was found to contain ample amounts of mineral nutrient elements. Leaching has the effect of softening up the hard-pan so that this layer is now but little harder than the rest of the soil, and it has been effective on all plots in removing the neutral salts. Ammonium sulfate applications have not benefited subsequent crops.

The discharge of the drainage ditch has been measured and samples have been taken for analysis. The results of these tests indicate that

Fig. 5. White sweet clover *(Melilotus alba)* on gypsum plot. This plot was treated with gypsum at the rate of 10.2 tons per acre. On an adjoining check plot which received identical treatment with the exception of the gypsum application, no stand was secured.

some 150 tons of alkaline salts have been removed in the drainage water. Not all of this has come from the land in the experiments, but the indications are that a large part of it has come from this source, as but little other land is irrigated in the vicinity, and the flow of water in the drain diminishes markedly when irrigation has ceased on the plots for a few days.

Effect of Calcium Sulfate (Gypsum)

Calcium sulfate (gypsum) has been used in various amounts in the Oregon experiments. When the experiment was started, plots J, K, and L were treated with gypsum at the rates of 400, 800, and 1,200 pounds per acre respectively. The next season these plots were retreated with the same amount, bringing the treatments up to 800, 1,600, and 2,400 pounds per acre. No marked benefits were observed from these treatments. On plot L, which received the heaviest treatment, the soil became somewhat more mellow in the surface inch or two, but the chemical analysis did not indicate that much sodium carbonate had been removed, and the land still remained unproductive. In the fall of 1922 the center one-third of each of these plots was retreated to bring the total amount of gypsum applied to 3.4, 6.8, and 10.2 tons per acre respectively, amounts sufficient theoretically to combine with one-half of the sodium carbonate in the water extract in plot J, enough to combine with all the carbonate in plot K and twice the amount theoretically required to neutralize the sodium carbonate in plot L.

All plots were seeded in the fall of 1922 to rye, and reference to Table IV will show that while the yield of rye hay on plots J, K, and L was very low, it exceeded that of the adjoining check by a large amount. Plot L yielded at the rate of 810 pounds per acre, while plot I, which was untreated, yielded 200 pounds per acre.

In the fall of 1923 all plots were seeded to sweet clover, the crop being irrigated by using corrugations and leaving the water on for several days. The stands obtained on the gypsum plots were decidedly bet-

Fig. 6. Soil structure improved by gypsum treatment. Note the improved soil condition and also the white alkali showing up as a result of the treatment. This can be removed by leaching.

TABLE IV. ALKALI RECLAMATION EXPERIMENTS, YIELD OF RYE HAY 1923

Plot	Treatment	Yield per acre	Sweet clover seeded 8-25-24, results as follows
A	Manure 20 T.	202	No stand
B	Check	0	No stand
C	Sulfur 500 lbs. Manure 20 T.	2020	Fair stand from spring seeding
D	Gypsum 1200 lbs. Manure 20 T.	1700	Fair stand from spring seeding
E	Check	166	No stand
F	Green manure	154	No stand
G	Sulfur 500	350	Slight stand on upper part
H	Sulfur 1000	650	No stand
I	Check	200	No stand
J	Gypsum 800 lbs. Increased Fall '22 to 6800 lbs.	545	Scattering stand
K	Gypsum 1600 lbs. Increased Fall '22 to 13600 lbs.	550	Good stand
L	Gypsum 2400 lbs. Increased Fall '22 to 20400 lbs.	810	Excellent stand—thrifty plants

ter than in any other part of the field, and there was a great deal of variation between these, a fair stand being secured on plot J, a good stand on plot K, and an excellent stand on plot L. The scattering stand on plot J did not live throughout the winter, but plots K and L produced in the summer of 1924 a good crop of sweet clover, the growth being more rank and more uniform in plot K. Its appearance on August 5, 1924, is shown in Fig. 5.

The improvement in the physical condition of the soil, as the result of gypsum treatment, is very apparent. The soil is softer than on the untreated plots, does not run together so badly after irrigation, and absorbs the irrigation water more quickly. The difference is especially

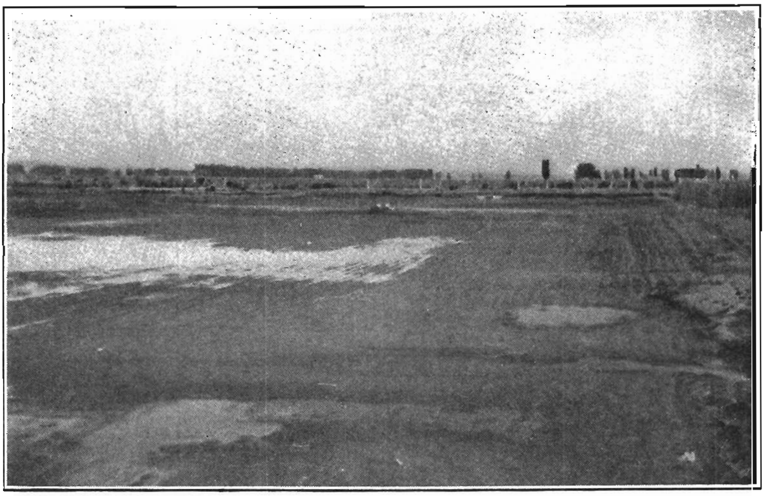

Fig. 7. Grease wood land, Vale, Oregon. Rye failed after drainage and with no chemical treatment.

marked on plot L, which has received 10.2 tons gypsum per acre. On this plot the moisture spread well between corrugations, and the soil did not dry out as quickly as it did where untreated. Reference to Table II shows that the analyses of samples from these plots indicate that the sodium carbonate has been reduced considerably as a result of this treatment, except with the lightest application, plot J.

These results indicate that at least from 7 to 10 tons of gypsum in connection with drainage and leaching will be required to improve this soil to an extent that profitable crops can be grown. Gypsum has been applied on this land in pounds per acre as follows: 400, 800, 1200, 1600, 2000, 2400, 4000, 6800, 13600, 20400. No substantial benefits have been noted in any applications under 6800 pounds, when applied alone.

Plot D was treated in 1921 with twenty tons of manure, combined with 600 pounds of gypsum per acre, and was retreated with the same amount the next spring.

Reference to Table IV will show that this plot yielded rye hay in the fall of 1923 at the rate of 1700 pounds per acre, while the adjoining check yielded but 166 pounds per acre. A fair stand of sweet clover was secured from the spring seeding, while no stand was secured on the adjoining check. Manure alone on plot A, although applied in the same manner and in the same amount, resulted in very little improvement as determined either by the crops raised or by the results of chemical analysis. The yield of rye hay on plot A was 202 pounds per acre, and no growth of sweet clover was secured. It is thought that the benefit from this small amount of gypsum combined with the manure treatment was largely temporary, due probably to the effect of carbon dioxide resulting from the decay of the manure, combined with the flocculating effect of the gypsum on the surface soil. The sweet clover lived into the summer of 1924 but did not grow vigorously, yielding only a small amount of pasture.

Fig. 8. Grease wood land, Vale, Oregon. Received sulfur costing $8 an acre and manure and yielded one ton of rye hay per acre after drainage and flushing.

Effect of Sulfur

In connection with his work on sulfofication, J. G. Lipman[4] suggested that sulfur might be effective in decomposing sodium carbonate in soil. Elemental sulfur when applied to the soil is oxidized by biological activity mainly, and combines with water to form sulfuric acid, an acid which actively combines with basic materials in the soil. Investigators[1, 2] have pointed out that applications of sulfur resulted in the decomposition of sodium carbonate, and also that it probably combines with the complex sodium silicates, which are held to contribute markedly to the impermeable conditions of black alkali soils. When the soil is low in calcium it is very likely that this material, or some similar base, will be needed in addition to the sulfur to effect the proper exchange of bases with the sodium-containing soil substance, and for the return of a flocculated soil condition. When the calcium content is good, however, it is very probable that this end can be obtained by the use of sulfur alone.

Prior to the spring of 1924, sulfur had been used in the Oregon experiments in amounts from 250 to 1000 pounds per acre. While chemical studies have indicated that it has helped to neutralize the alkalinity, the treatments have not resulted in the soil becoming productive when sulfur has been used alone. When in combination with 20 tons of manure, the use of 500 pounds of sulfur per acre resulted in a yield of over one ton of rye hay per acre in the fall of 1923. Sulfur-oxidizing bacteria were probably more active where manure was added. Reference to Table II will show that this plot (plot C) was benefited considerably by the reduction of sodium carbonate.

The preliminary results with sulfur indicated that insufficient amounts had been used, and in order to gain information on this point,

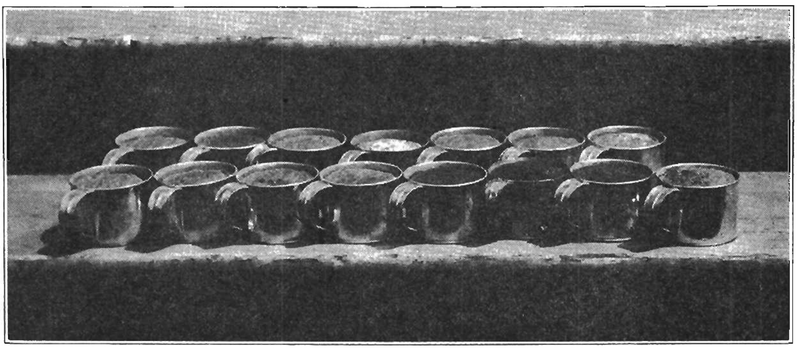

Fig. 9. Samples used for crushing tests. Samples treated with organic matter, gypsum, or aluminum sulfate, crumbled more readily after baking, indicating an improvement in the physical condition.

three of the tanks of alkali soil which are described in another section of this report were treated with heavier sulfur applications. All three tanks had been heavily leached. Tank 1 had received no chemical treatment, while tanks 5 and 6 had been treated with sulfur in October, 1922. The original treatments and new applications, together with the alkali content of No. 1 before the new applications were made and of each of the three six weeks after treating, are given in Table V.

TABLE V. THE EFFECT OF SULFUR TREATMENTS ON THE ALKALI CONTENT OF SOIL IN TANKS

Treatment	Pounds per acre 10-25-22	Pounds per acre 1-4-24	P.P.M. Alkali (expressed as salts of sodium) Total salts	Na_2CO_3	NaCl	Na_2SO_4
1 Ck before treatment	0	....	2050	847	117	1096
Six weeks after treating.						
1. Sulfur	0	1000	2710	429	154	2127
5. Sulfur	1000	3000	3064	195	116	2753
6. Sulfur	500	500	1462	225	132	1105

The time allowed for the oxidation of the sulfur and for the resultant action with the soil constituents was probably too short for the action to be complete. These data, however, indicated that the previous field applications were too light to be effective.

In the spring of 1924, the three one-half-acre sulfur plots were divided lengthwise to make six quarter-acre plots and treatments were increased to give plot G-1 1,000 pounds per acre, plot G-2 2,000 pounds per acre, plot H-2 4,000 pounds per acre, and plot H-1 4,000 pounds of sulfur, with one-fifth of it in the form of gypsum—in other words, 3,000 pounds of sulfur and 5,000 pounds of gypsum. These plots were then fallowed for 12 weeks, irrigating only often enough to keep the soil up to an optimum moisture content, and then were leached by keeping them completely submerged for three weeks. The result of these applications cannot be reported at this time as the plots are yet to be seeded, and samples for chemical analysis are not to be taken until later in the season.

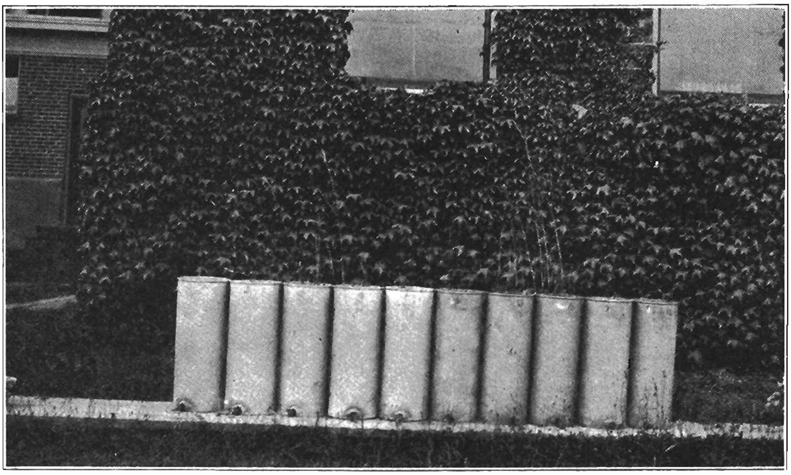

Fig. 10. Soil tanks for leaching experiments. Fourth from the left was treated with sulfur and manure. Nos. 7 and 8 were treated with gypsum.

As Kelley and Thomas[5] have pointed out, soil silicates in black alkali soils are apt to be saturated with sodium, as a result of the readily replaceable calcium having already been substituted in nature by sodium. For this reason, unless the soil is naturally high in calcium, the addition of this or a similar element may be necessary even if the acid formed by sulfur applications is effective in neutralizing all the carbonate, in order to improve the physical condition. When the calcium content is high, as is true of the soil under trial by the Oregon Station, it would seem that sulfur should be effective alone.

In order to study the effect of mixing various elements with sulfur a tank trial was started in the spring of 1924, and while this experiment has not run long enough to warrant any conclusions being drawn, a description of the experiment is thought worth while.

Twelve galvanized iron tanks 18 inches in diameter and 2½ feet in depth were equipped with drains for the purpose of collecting percolating water, and were filled with soil from the Vale experiment field, six being filled with soil that had been leached for three years, but had received no chemical treatment, and six with soil from an adjoining field which was still in grease wood, and which had received no treatment of any sort. These tanks were filled in the field, the soil being transferred in 4-inch layers so as to retain the same state as in nature, and packed so as to take up the same space as it did naturally. The tanks were placed in a trench with the top of the soil even with the surface of the ground, and were treated with (1) sulfur alone, (2) sulfur and gypsum, (3) sulfur and quicklime, and (4) sulfur and manure, the treatments being so applied that the same amount of sulfur was put on each tank. In the case of the sulfur and gypsum, one-fourth of the sulfur was put on in the form of gypsum, and in the case of the quicklime and sulfur mixture enough quicklime was put on to equal the amount of calcium in the sulfur and gypsum mixture. These tanks were left for 12 weeks at an

Fig. 11. Barley on partly reclaimed alkali land. Barley gives a short growth on alkali land. The heads usually fill well. On this field it was possible to secure a stand of sweet clover by irrigating and taking advantage of the shade and protection offered by the barley stubble.

optimum moisture content to allow the sulfur to oxidize and are now being leached. The rate of percolation and the chemical effect of the treatment on the soil and percolates are to be studied and also the effect of the treatment on crop yield.

Effect of Aluminum Sulfate

Scofield and Headley[1, 3] have reported results from the use of aluminum sulfate on the impermeable black alkali soil as a treatment to improve the soil structure and correct the black alkaline condition. Aluminum sulfate has been used in the Vale experiment field in amounts from 500 pounds to 5 tons per acre. Little or no benefit resulted from the 500-1000 pounds or the 1 ton and 2 ton applications, but the application of 5 tons per acre resulted in a decided improvement. On one end of the check plot an area 30 feet square which received this application yielded a vigorous and thick stand of sweet clover, while no stand was secured on the remainder of the plot. The improvement in the physical condition and the rapidity of absorbing moisture were also very marked.

Effect of Manure

Manure alone has not been effective in reducing the black alkaline content as determined by analysis or by the productivity of the land so treated, but it has resulted in an apparent improvement in the tilth and permeability of the soil to which it has been applied. As has already been mentioned the use of manure in combination with gypsum and with

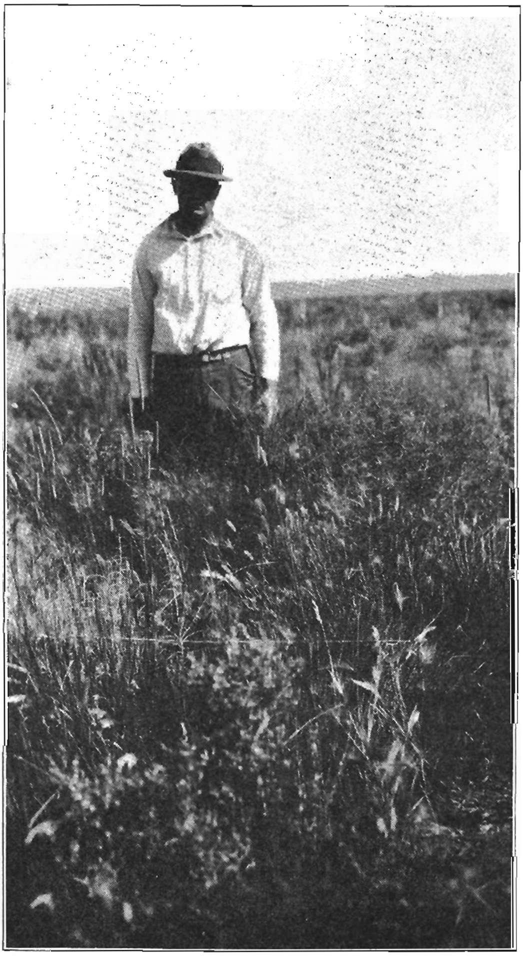

Fig. 12. Pasture on uncleared grease wood land. Native vegetation affords shelter, and a good stand of pasture grasses has been secured on drained and leached uncleared alkali land, where the same methods on cleared and cultivatd land have been unsuccessful.

sulfur has been decidedly beneficial. Manure, upon decaying, produces carbon dioxide and it also aids the oxidation of sulfur. These conditions result in a temporary improvement in alkali soils, particularly in the surface two or three inches, and often make it possible to start crops on land so treated even if the reclamation is not complete and permanent. Many of our crops will withstand considerable amounts of alkali if once established. This is particularly true with sweet clover and to a lesser extent with alfalfa. Treatments of this sort are therefore often profitable even where the application of enough chemical material to afford complete reclamation is not economically possible.

Treatments and Crushing Loads Required to Crumble Sample

In order to get some check on the effect of treatments that were being used in the field on the soil structure, an amount of the surface soil was sent to the laboratory from the Vale experiment field, and the following experiment was conducted. A number of 453-gram samples were treated as shown in Table VI, the amounts being similar to those applied in the field, and were uniformly compacted on a shaker in one-pint cups. Samples were then moistened to saturation and were allowed to sun- and air-dry for a period of two months. By this time the samples had become dry and hard, and the crushing load required to crumble them was determined in the experimental engineering laboratory, the result being recorded in Table VI. It will be noted that the heavier gypsum treatment made the soil crumble more easily. The manure-and-sulfur treatment was also effective.

Field experiments bear out these results in that soils that have been treated with organic matter and also the gypsum plots worked up into good tilth much better than land that had not been so treated.

Effect of Vegetation

When black alkali lands occur in small areas on farms or when such lands are included in districts that have to meet irrigation assessments, it is often important to be able to secure some returns from such lands, even if complete reclamation is not economically possible. It is also thought that the importance of the protection of the land from heat and excessive sunlight has not been given enough attention in attacking the black alkali problem and that the growth of some sort of vegetation on alkali land whether profitable or not, is desirable in that it will help to keep the soil from becoming badly affected.

Light, temperature and humidity may affect toxicity and assimilation,

TABLE VI. EFFECT OF TREATMENTS ON CRUSHING LOAD REQUIRED TO CAUSE BRICKS TO FAIL

Sample	Treatment	Field rate per A.	Lab. Amt. for 1 pound soil	Irrigation	Crushing load
1	Manure	20 T.	9 gr. + .0543	175 c.c. each	112.25
2	Manure + sulfur	20 T. M. 200 lbs. S.	9 gr. + .1628	175 c.c. each	125.00
3	Manure + gypsum	20 T. M. 600 Gyp.	9 gr. + .453	175 c.c. each	117.20
4	Straw	2 T.	.9000	175 c.c. each	99.00
5	Green manure	4 T.	1.8000	175 c.c. each	158.00
6	Sulfur	200	.0543	175 c.c. each	152.50
7	Sulfur	400	.1086	175 c.c. each	122.00
8	Check		.0814	175 c.c. each	139.50
9	Gypsum	300	.1628	175 c.c. each	150.70
10	Gypsum	600	.2442	175 c.c. each	74.00
11	Gypsum	900	.0814	175 c.c. each	64.10
12	Aluminum sulfate	600	.1628	175 c.c. each	124.00
13	Aluminum sulfate	600	.2242	175 c.c. each	117.40
14	Aluminum sulfate	900	....	175 c.c. each	108.30

which are worse with high temperature, strong light, and low relative humidity.

The presence of any vegetation on the surface of the soil affords protection from upward leaching or excessive drying and makes it easier to get a stand of any new crop. It has been observed, moreover, and is well known by farmers who have had experience in farming land of this sort, that it is easier to get a stand and secure a crop from land that has not been plowed deeply, due apparently to the organic matter on or near the surface, and the effect of weathering on the physical condition of the surface soil. It is helpful to keep the surface salts diluted with frequent irrigation; also there is generally some protection afforded by grass and weeds.

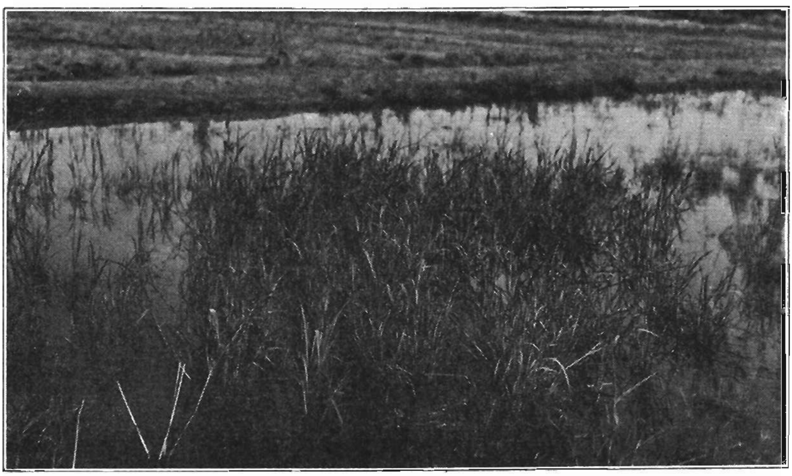

Fig. 13. *Echinochloa crusgalli* (L). Beauv., locally called "water grass."

TAME PASTURE IN UNCLEARED GREASE WOOD LAND

In attempting to study this phase of the problem, an area of uncleared land supporting a growth of grease wood, mixed with a small amount of sage, and some salt grass, was diked in the spring of 1922 and flooded by allowing water to run on at the upper end, spread over the land, and run off the lower end. Flooding was continued during the summer of 1922 and in September this area was seeded to a mixture of bluegrass, redtop, timothy, meadow fescue, alsike clover, and sweet clover. Flooding was then continued for two weeks and was followed with frequent irrigations until the irrigation season closed. An adjoining plot was irrigated and seeded the same, but this had been cleared, plowed, and cultivated. On the uncleared area a good stand of grass and clover was secured, while on the cleared tract no germination was apparent and absolutely no stand was secured. The grass on the uncleared area was best in the shelter of the grease wood clumps, and lived through the winter only when protected by the grease wood and salt grass. During the next summer it continued to grow vigorously and spread out, covering the bare places. During the summer of 1924 this spreading continued so that there is now a fine stand of pasture mixture wherever the water ran over the land. Since this area was not leveled, there were some spots in the check where the water stood too deep for best results. On these areas some wild grasses, such as sedges, and some of the redtop were all that grew. In certain other spots, which were not flooded, no stand was secured. This land has afforded excellent pasture, the carrying capacity being at least half that secured on similar pastures in the vicinity grown on productive land.

This system provides a cheap method of securing some return from black alkali land, and it is believed that the protection provided by the pasture, combined with irrigation, will at least keep the land from becoming any worse and should provide partial reclamation due to the carbon dioxide formed as a result of rotting vegetable matter, shading, and downward leaching from frequent irrigations. This study is not completed. It is planned after the pasture has run for about four years to plow the area and treat it chemically. It is expected that a smaller amount of sulfur or gypsum will be required than on land that has not been given the pasture treatment. In the meantime, it will have brought some income, enough at least to take care of the taxes and annual cost of water, and will have effected partial reclamation.

Handling Hard Alkali Land

All grease wood land is not flat enough to permit the use of this method without first leveling. After land is cleared and leveled, however, the surface should be disturbed as little as possible. Where the black alkali is not too bad it has been found profitable to secure a stand of sweet clover and pasture grasses by seeding in the early fall and giving the land frequent irrigations. Best results have been secured by disturbing the surface soil as little as possible and allowing the salt grass and native vegetation to grow to provide protection. Rye or millet seeded in the salt grass has given better results than when seeded on plowed and carefully cultivated land. The system of seeding grease wood land to pasture mixture and the frequent irrigation required for pasture are safe, of course, only when the soil is well drained naturally or artificial drainage is provided.

On land that has been partly reclaimed by the use of gypsum and that has been leached, the most successful method of securing a stand of sweet clover has been to work up the surface, 2 to 3 inches, into a fine seed bed by use of a disk harrow and clod-crusher. The seed is then broadcasted and planked in. Following this the land is corrugated and then kept moist by irrigating in the corrugations without flooding. Irrigation is continued in this way until the crop is up, without allowing the surface to become dry. This method keeps the remaining alkali diluted and prevents baking. It has been most effective with late summer seeding.

Choice of Crops

During the four seasons that the Oregon experiments have been in progress about twenty types of pasture, grain, and root crops have been tested. On partly reclaimed black alkali land fall rye has proved the easiest to establish and has given fair yields of rye hay.

White sweet clover (*melilotus alba*) has been the most effective in improving the soil condition. This crop stands a great deal of alkali and produces well when once established, but is sensitive to alkali when young and difficulty has been experienced in getting a stand.

On uncleared pasture land blue-grass, meadow fescue, redtop, timothy, and alsike clover have been grown successfully. A native slough grass locally known as "water grass," *Echinochloa crusgalli* (L.) Beauv. (see Fig. 13), has been grown. This grass will germinate and grow in standing water, and a stand was secured by broadcasting before adding heavy irrigations for leaching purposes. The grass is considered by local farmers to have fair value for pasture and as hay for wintering stock.

Latest developments indicate an excellent stand of sweet clover where heavy applications of sulfur or gypsum were fallowed in during the past summer and seeded in early autumn. A combination of sulfur and gypsum gives indications of being more effective than either applied singly. The heaviest sulfur application has caused a little injury, but this will probably be only temporary, due to slight excess of acidity in the surface soil for the time being.

TABLE VII. ALKALI REMOVED IN PERCOLATES — SOIL TANKS — VALE SOIL
(Expressed as salts of sodium)

	Plot	Irrigation	Percolation	Na_2Co_3	NaCl	Na_2So_4	Tl. salts	PH Samples March '24
		c.c.	*c.c.*	*gr.*	*gr.*	*gr.*	*gr.*	
1.	Check	56,111	32,039	107	71	103	281	8.2
2.	Aluminum sulfate 2.5 T.	57,525	30,331	151	85	154	390	8.2
3.	Aluminum sulfate 5 T. Sulfur 1000 lbs.	56,798	25,721	92	68	144	304	7.7
4.	Manure 20 T.	57,525	31,569	85	70	141	286	8.2
5.	Sulfur 1000 lbs.	59,706	20,597	52	45	141	238	7.8
6.	Sulfur 500 lbs.	53,344	15,722	68	65	64	197	8.1
7.	Gypsum 10 T.	57,525	31,709	109	68	224	401	7.8
8.	Gypsum 5 T.	57,525	28,060	76	42	151	269	7.9
9.	Manure 20 T.	57,525	30,454	145	87	112	324	8.7
10.	Check	57,525	31,409	123	82	115	320	8.8

TANK EXPERIMENTS

In the fall of 1922 ten soil tanks, 2 feet in depth and 11 inches in diameter, were filled with alkaline soil shipped from the experiment field at Vale, and were placed in the greenhouse at Corvallis, for the purpose of checking the field work and studying the effects of various treatments, on the amount and composition of the percolates resulting from heavy irrigations.

Effect of Various Treatments on Salts Removed in Percolates

(Table VII)

The tanks were given treatments corresponding to the main applications used in field trials; the irrigation waters and percolates have been measured, and the latter analyzed. The results from the time the experiment was started through 1923 are summarized in Table VII.

In column 1 will be found the treatment given each tank, recorded on the acre basis. Column 2 records the total irrigation applied, and column 3 the total percolate, both expressed in cubic centimeters. In the next four columns are recorded the salts removed, expressed in each case as grams of the material contained in the total percolate. These results were secured by determining the CO_3, Cl, SO_4 and total salts. For purposes of comparison these have been calculated and are reported as salts of sodium.

The amount of sodium carbonate removed does not give a true conception of the value of the various chemical treatments, for their effect is to neutralize the carbonate. Gypsum, for instance, unites to form sodium sulfate and calcium carbonate, and since the latter is not readily soluble, the larger amount of sulfate indicates that considerable of the sodium carbonate had been neutralized, the sodium passing on as sodium sulfate and the CO_3 remaining in the form of calcium carbonate. The rate of percolation was slower for check tanks, yet the total amount of percolate from these is comparable with treated tanks since treatments increased water capacity of the latter.

Effect of Treatments on Crop Production

In March, 1923, after having been leached intermittently for six months, the tanks were seeded to rye and sweet clover. The results are recorded in Table VIII.

It will be noted that rye produced best on the gypsum tanks, the tanks receiving the 5-ton aluminum sulfate treatment being second, and the sulfur and manure tank third. The best stand of sweet clover was secured on the same tanks.

In the fall of 1923 the tanks were subjected to further leaching and then seeded to vetch. No stand was secured on any tanks except the two receiving a gypsum treatment. On tank 8, which had received gypsum at the rate of five tons per acre, the vetch grew to be about two inches high and then grew no further. On tank 7, which had been treated with ten tons of gypsum, the vetch grew very luxuriantly and was fourteen inches high when turned under on February 19.

TABLE VIII. EFFECT OF TREATMENTS ON YIELD OF RYE, AUGUST 3, 1923. ALKALI TANKS

All had 10 rye and 18 sweet clover plants started or set in.

	Treatment	No. rye plants at harvest	Average height	Number of heads	No. plants sweet clover August 3	Average height	Net green weight rye	Net oven dry weight rye	Total irrigation 4/2 8/3 '23
			in.			*in.*	*gm.*	*gm.*	*in.*
1.	X	None			0 (1 salt grass)	0	-------	0.	8½
2.	Aluminum sulfate 2.5 T.	10	24	3	5	5	9.90	5.12	8½
3.	Aluminum sulfate 5 T.	10	27	6	5	5	22.15	11.80	8½
4.	S. 1000 M. 20 T.	9	27	3	5	5½	19.95	10.42	8⅓
5.	S. 1000 lbs.	6	8	1	1 (greasewood)	0	1.35	.95	8½
6.	S. 500	6	6	0	4	9	2.95	1.35	8⅓
7.	Gyp. 10 T.	10	30	7	8	4	37.95	19.05	8⅓
8.	Gyp. 5 T.	10	33	7	5	4⅓	32.80	17.90	8⅓
9.	M. 20 T.	9	7	0	2	9	6.35	3.30	8½
10.	X (Had more shade and moisture)	6	7	1	3 Reseeded 8/3	6	6.60	3.28	8½

The tank experiments have checked the field work and show the effectiveness of heavy gypsum and aluminum sulfate treatments and of sulfur and manure. They also add evidence of the usefulness of small chemical treatments on this type of soil. The chemical effect of heavier sulfur treatments applied to three of these tanks in January, 1924, is included under the discussion of sulfur.

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