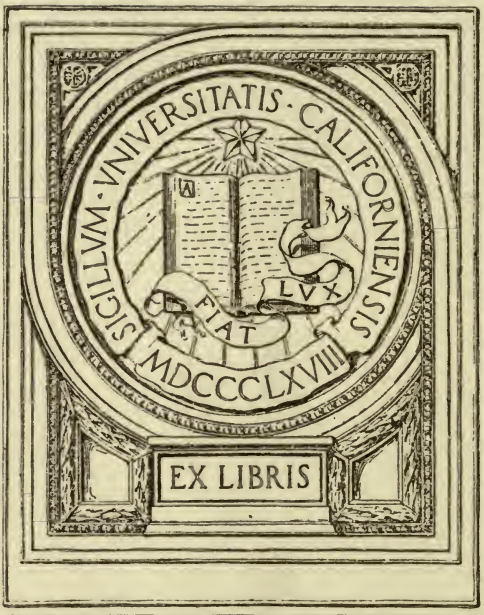
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SOIL ALKALI

Frontispiece

WHEAT RAISED ON RECLAIMED ALKALI LAND

WILEY AGRICULTURAL SERIES

SOIL ALKALI

ITS ORIGIN, NATURE, AND TREATMENT

BY

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To

DR. JOHN ANDREAS WIDTSOE

PIONEER-INVESTIGATOR OF ARID AGRICULTURE, TEACHER AND FRIEND, THIS BOOK IS AFFECTIONATELY DEDICATED

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PREFACE

THE study of soil alkali is by no means simple, nor have all the problems relating to it been solved. The many different salts involved, each with its own properties; the various types of soils in which these salts occur, all with different textures and composition; the complex relations between the soluble salts of the soil and the plants growing on it; and the several economic factors involved in the reclamation of alkali land: these and numerous other considerations make the problems connected with soil alkali as difficult to solve as any found in agricultural science.

The excuse for writing a book on a problem that is so far from solution is found in the great demand that exists for one volume containing the important information concerning alkali. At present, the literature of the subject is very much scattered and is largely unavailable to the average student of soils.

There are hundreds of millions of acres of land in the world that are at present not used for agriculture but which might become productive if the alkali could be eliminated. The need for more land to supply food for the world's increasing population is making a very insistent demand that some of these alkali lands be made available. The response to this demand will depend on a better understanding of the nature of alkali and methods of reclaiming land impregnated with it. This accounts for the new interest that is being shown in the study of soil alkali.

The present volume is intended as a text and reference work for students of soils and others interested in arid agriculture. It should find wide use by county agricultural agents and the better trained farmers in regions where the alkali problem is encountered.

References are given in connection with each chapter. The figures in parenthesis in the body of the text indicate the number of the reference at the end of the chapter. No attempt has been made to cite all the literature, but most of the important papers are included. Foreign titles have usually been translated into English in order to make them clearer to the general reader. Where the original article is likely to be unavailable an attempt has been made to refer to an abstract in some available publication such as the Experiment Station Record.

The author wishes to acknowledge his indebtedness to all who have contributed either directly or indirectly to the work. He has drawn freely from all available sources, but he is particularly indebted to Dr. E. W. Hilgard and his associates in California and to the workers in the Bureau of Soils, U. S. Department of Agriculture. These two sources of information have proved to be veritable "gold mines."

The following who have read part or all of the manuscript have given many valuable suggestions: Doctors J. E. Greaves, E. G. Peterson, F. L. West, Willard Gardner, and G. R. Hill, Jr., and Professors George Stewart, O. W. Israelsen, D. W. Pittman, M. D. Thomas, Mrs. B. C. Pittman, and Mr. K. B. Sauls.

The author also wishes to express his appreciation to the several assistants and co-workers who have helped in his experiments with alkali during a number of years. Without the faithful and efficient services of these men the

experimental work which led up to this book could not have been done. Mr. N. I. Butt deserves special mention for his help in reviewing literature and preparing the material of this book for publication.

F. S. HARRIS

LOGAN, UTAH
November 1, 1919

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SOIL ALKALI

SOIL ALKALI

CHAPTER I

INTRODUCTORY

WHENEVER the word "alkali" is mentioned there immediately arises in the minds of some people a vision of desolation. They may picture to themselves a barren tract of land devoid of vegetation and covered with a blanket of white salt mixed with earth; or they may fancy that they see worthless wastes of what had been fertile fields. They imagine beautiful trees being reduced to stumps and fence posts and remnants of farm buildings gradually being eaten away by a slowly advancing white cover, which will eventually reduce the entire landscape to a gray barrenness. Probably each of these pictures has a prototype in some local section. Alkali does prevent the cultivation of vast areas of land, and it has caused the abandonment of many fertile fields; but to give up all effort when alkali makes its appearance would be like abandoning a farm just because some crop became infested with a pest.

The successful pursuit of agriculture calls for the constant overcoming of difficulties. New problems arise each season, but success demands that these be solved. The difference between civilization and savagery consists largely in meeting difficulties and being masters of nature instead of merely victims of circumstance.

The welfare of the entire people is dependent on the prosperity of agriculture, and in turn agriculture rests on the productivity of the soil. Human well-being is therefore closely tied up with the land. Whatever affects agriculture is important not only to the tillers of the soil but to all who consume the products of the farm. In order that an ample food-supply may be assured at a low price, the people generally are interested in having available as large a producing area as possible.

Most of the more desirable lands of the world have been settled. This means that an extension of the area of production will often necessitate the use of land that has some unfavorable condition. There are in the world vast tracts that are not susceptible of cultivation without special treatment. In the arid parts of the earth, which comprise about one-half of the total land, two great conditions are withholding from cultivation millions of acres of land. They are drouth and alkali. The successful overcoming of drouth and alkali means the addition of countless acres to the productive part of the earth. It is with alkali and its conquest that the present volume deals.

It has been estimated that about 13 per cent of the irrigated land of the United States contains sufficient alkali to be harmful. This means that there are over nine million acres of land under present canal systems that are affected with alkali. There are many more million acres of alkali land in the United States that do not lie under irrigation systems. Similar figures might also be given for other countries of this continent and for all of the other continents. The alkali problem is one of no mean importance to farmers, nor to any who are interested in the world's food-supply.

In a strictly chemical sense the word "alkali" refers

to a substance having a basic reaction. As applied to the soil, however, this restricted meaning does not hold, and alkali refers to any soluble salts that make the soil solution sufficiently concentrated to injure plants. This includes the chlorides, sulphates, carbonates, and nitrates of sodium, potassium, and magnesium, and the chloride and nitrate of calcium. The sulphate and carbonate of calcium are not sufficiently soluble to be injurious to crops. Most of the alkalies are in reality neutral salts. It may be somewhat unfortunate to use for general substances a word that also has a restricted technical meaning, but the word has become so well established in agricultural literature that it would now be very difficult to change it.

Aside from their practical importance, the soluble salts of the soil are of great scientific interest. They offer fruitful fields for investigation to the geologist, the chemist, the plant physiologist, the bacteriologist, the mycologist, the agronomist, and the engineer. The complexity of the soil makes the problems connected with alkali very difficult to solve. There are so many interacting factors that no simple statement of the problem can be made and no simple solution arrived at. A complete understanding of the problem will call for careful researches by investigators in different branches of science and a careful coördination of the findings. The importance of the subject justifies giving it the most careful consideration.

CHAPTER II

GEOGRAPHICAL DISTRIBUTION

Soils containing injurious quantities of alkali are found on every continent. These soils, however, do not occur in all parts of the continents, the distribution being confined to areas where conditions favorable to their formation prevail. The most important of these conditions is aridity. Another important factor is the nature of the rock from which the soils were formed. Because these conditions are local, alkali soils are likely to be found over large areas, but all the soils of these areas are not necessarily highly charged with soluble salts. Part of the soils in a region having a climate favorable to alkali formation may be derived from rocks that are low in soluble salts and may have been so deposited that they have good natural drainage. Soils of this kind do not contain alkali even though most of the soils of the region are impregnated. Likewise, soils high in soluble salts may be found over limited areas in regions where most of the soils are free. This condition is sometimes found in climates that are not entirely arid, or where a soil having poor drainage was derived from rock that was high in soluble salts. Thus, the alkali problem has local as well as general aspects. A general alkali condition may prevail over an extensive region, the smaller areas of which may be exceedingly variable.

North America.— More than half of the North-American continent is arid or semi-arid. Throughout this vast area alkali soils are found. There are many large tracts

in which the soluble salt content of the soil is not at present sufficient to interfere with crop growth, but there is sufficient of the salts present if concentrated by unwise methods of irrigation, by drouth, or by other means to bring the soil to the danger point, especially should drainage be poor.

The 100th meridian may be taken roughly as the line separating the humid from the arid part of the continent. This line is not absolute; it varies somewhat with latitude, altitude, and several other factors. There are a number of places west of this line where the rainfall is high. This is particularly true along the northwest coast and along some of the mountain ranges.

Canada. — In western Canada, especially in the provinces of Saskatchewan, Alberta, and British Columbia, there are several rather large tracts where the soluble-salt content of the soil is sufficiently high to render crop production difficult. In southeastern Alberta the soil of one of these regions originated from the glaciation of shale that was high in soluble salts, particularly the sulphates. Therefore, sulphates are the predominating salt of the region. The soil is heavy and impervious; consequently, there has been very little movement of salts from its original place in the soils.

Under irrigation these salts may be either leached downward or brought to the surface. When appearing as a white inflorescence they are very conspicuous and would lead the casual observer to believe the condition to be much worse than it really is. A large quantity of gypsum is present in these soils and, when dissolved and brought to the surface, it, together with sodium sulphate, forms a conspicuous white soil covering. Fortunately, the percentage of the more harmful chlorides and carbonates is very low.

The composition of an alkali soil in Alberta as determined by Shutt (16) is given in the following table.

TABLE I. SOLUBLE SALTS IN ALKALI SOIL OF ALBERTA, CANADA (PER CENT)

Depth (feet)	Growth	Na_2SO_4	$MgSO_4$	$CaSO_4$	Total Soluble-saline Content
0.0–0.5					
0.5–1.5	Good	.178	.087	.163	.440
1.5–3.0		.877	.132	.447	1.572
3.0–5.0		.973	.563	2.926	4.640
3.0–5.0	Poor	.123	....	.....	.180
		.701	.247	.491	1.480
		.719	.309	.588	1.680
		.799	.062	.192	1.060
3.0–5.0	No	1.741	.900	.648	3.260
		1.001	.323	.364	1.700
		.701	.222	.220	1.164
		.579	.084	.192	.900

United States. — In sixteen or seventeen of the western states of the Union, alkali is found to be one of the chief agricultural problems. The problem is much more acute in some regions than others. The San Joaquin, Sacramento, and Imperial Valleys of California; the Great Basin, comprising a large part of Utah and Nevada; the Colorado River drainage basin, comprising parts of Wyoming, Utah, Colorado, Arizona, and California; the Rio Grande River drainage area, including parts of New Mexico and Texas; parts of the Columbia River drainage basin; and rather extensive sections in the Great Plains east of the Rocky Mountains include the most important parts of the United States affected with alkali. In practically all the western states certain areas affected by alkali have been described in publications of the state

experiment stations or in the United States Bureau of Soils. (See Table II.) These publications show that the composition of the alkali salts as well as the methods of reclamation vary greatly.

TABLE II. COMPOSITION OF ALKALI FROM DIFFERENT PARTS OF THE UNITED STATES EXPRESSED IN PERCENTAGE OF DIFFERENT SALTS

Salts	Percentage of Different Salts in the Alkali						
	Colorado[1]	California[2]	Washington[3]	Montana[4]		Arizona[5]	
				Crust	Surface, 10 in.	Crust	0–72 in.
KCl	1.64	.....	5.61	.....	.....	4.00	22.10
K_2SO_4	.....	3.95	.....	1.60	21.41	.....	.....
K_2CO_3	.....	.....	9.73	.....	.....	.....	.....
Na_2SO_4	.....	25.28	.....	85.57	35.12	.....	.....
$NaNO_3$	33.07	19.78	.....	.....	.....	.....	.....
Na_2CO_3	.....	32.58	13.86	.....	7.28	.....	.....
$NaCl$	6.61	14.75	.....	0.55	.....	81.15	13.77
Na_3HPO_4	.....	2.25	.....	.....	.....	.....	.....
$MgSO_4$	.....	.....	.....	8.90	4.06	.....	6.88
$MgCl_2$	12.71	.....	.....	.....	.....	7.71	3.98
$CaCl_2$	17.29	.....	.....	.....	.....	0.25	.....
$NaHCO_3$	.....	.....	36.72	0.67	22.06	0.28	21.02
$CaSO_4$	21.48	.....	1.87	2.71	10.07	6.61	32.25
$Ca(HCO_3)_2$	.....	.....	16.48	.....	.....	.....	.....
$Mg(HCO_3)_2$	.....	.....	15.73	.....	.....	.....	.....
$(NH_4)_2CO_3$	.....	1.41	.....	.....	.....	.....	.....

Mexico. — The greater part of the high plateau of Mexico has an arid climate. This, like all similar regions, has had but comparatively little of the soluble salts contained in the country rock removed. In this section there are many large valleys having no outlets. During

[1] Colorado Exp. Sta., Bul. 155, p. 10.
[2] Hilgard "Soils," p. 442.
[3] U. S. D. A. Bur. Soils, Bul. 35, p. 79.
[4] U. S. D. A. Bur. Soils, Bul. 35, p. 103.
[5] U. S. D. A. Bur. Soils, Bul. 35, p. 109.

the rainy season the lower parts of these valleys are flooded by the waters of swollen streams; during the dry season this water is practically all evaporated, leaving its soluble material behind. This results in great level bodies of land charged in varying degrees with soluble salts. The composition of these saline deposits depends on the composition of the country rock through which the streams flow. Very little work up to the present time has been done to reclaim the alkali soils of Mexico.

South America.— No important published material is available on the alkali condition of the soils of South America. It is known, however, that the arid sections of that continent do not differ essentially from those of other arid sections of the world. Practically the entire western part of the continent is arid and throughout this section areas subject to alkali troubles are found. It includes most of the Pacific slope west of the Andes and the greater part of the western plains of Brazil and Argentina east of these mountains.

The deposits of sodium nitrate in Chile are a conspicuous example of the retention of soluble salts that would be leached out in a humid climate.

Africa.— The distribution of alkali soils in Africa is not the same as in North and South America. It is found over practically the entire northern portion of the continent and also in the southwestern part. The central, and particularly the west-central, portion is practically free. Throughout the Union of South Africa up into Rhodesia alkali soils are found but have not received as much attention as some of the sections of North Africa, particularly in Egypt. The soils of the Sahara as well as many of those of Algeria, Morocco, and Tunis are so contaminated with soluble salts that it was necessary for

the agriculture of these countries to be adjusted to this condition. It is probable that the alkali problem is being given more consideration in Egypt than elsewhere.

Egypt.— The greater part of Egypt is a barren desert, being one of the most desolate parts of the earth. The annual precipitation at Alexandria averages 8.26 inches; at Port Said, 3.49 inches; and at Cairo it is only 1.06 inches, which is not enough to support vegetation of any kind. The country is traversed from south to north by the Nile River along which is a narrow, highly cultivated, and thickly populated strip of river-formed land. In the southern part of the country the river flows through sandstone and occupies a shallow valley, but farther north a deep gorge is cut down from the surrounding limestone plateau. On both sides of the river are alluvial plains composed of fine silt which for the most part has been carried by the Nile from the disintegrated volcanic material of the Abyssinian highlands. Thus the soil of the lower Nile Valley bears no relation to the country rock of the immediate vicinity.

In the delta portion of the valley, the land is very flat and there is but little opportunity for drainage. Much land that was cultivated anciently has since been abandoned on account of the accumulation of alkali. The area thus abandoned has been estimated to be more than one and a half million acres. Most of this land is on the fringe that borders the sea and is influenced by sea water. The higher lands are practically free from alkali.

Formerly all the land was watered by the basin system of irrigation. With this method, the land is flooded to a depth of from three to five feet at the season when the Nile is high. After standing at this depth for about six weeks and allowing the sediment to settle, the water is drained

back into the Nile, and the crops are planted in the mud without plowing. By this system only one crop is grown each year, but the accumulation of alkali is prevented by washing part of it to lower depths in the soil, by depositing a fresh layer of salt-free silt on the surface, and by carrying away with the water that is drained off any soluble material that may have accumulated on the surface at the time of flooding.

In order to raise more than one crop a year and thereby get greater profit from the land, the basin system of irrigation is being largely supplanted by the perennial system, by means of which water is applied throughout the year. This brings about almost continuous evaporation from the surface and a consequent accumulation of soluble salts. Of the 6,250,000 acres of irrigable land in Egypt, only about 1,730,000 acres are irrigated by the old system of basin irrigation. This means that the alkali problem will continue to be more acute in Egypt until suitable means of coping with it are worked out. Already some rather ingenious methods (23, 25) of drainage are in operation.

The following analysis reported by Means (14) of an alkali soil from Kom-el-Akhdar is typical of the alkali land of lower Egypt:

TABLE III. CHEMICAL ANALYSIS OF ALKALI SOIL FROM KOM-EL-AKHDAR, EGYPT (Surface foot)

Ions	Per cent	Conventional Combinations	Per cent
Calcium (Ca)	3.07	Calcium Sulphate ($CaSO_4$)	10.43
Magnesium (Mg)	2.00	Magnesium Sulphate ($MgSO_4$)	9.90
Sodium (Na)	28.83	Potassium Chloride (KCl)	3.62
Potassium (K)	1.90	Sodium Chloride (NaCl)	60.88
Sulphuric Acid (SO_4)	24.56	Sodium Bicarbonate ($NaHCO_3$)	1.41
Chlorine (Cl)	38.62	Sodium Sulphate (Na_2SO_4)	13.76
Bicarbonate Acid (HCO_3)	1.02	Per cent Soluble	8.2

Europe.— Of all the continents, Europe is the most free from alkali, although it has several alkali sections. Probably the most conspicuous of these is found in Hungary. The "Szik" lands of the plains contain some soluble salts and lower down in the valley of the Theiss genuine alkali lands are found with a high content of both white and black alkali. From these lands carbonate of soda has long been obtained commercially. In the lower valley of the Po in Italy (2) and in many other sections of Europe bordering the Mediterranean local alkali areas are found.

Asia. — The main alkali regions of Asia are found in the central and southwestern portions of the continent. Arabia, Mesopotamia, Persia, Afghanistan, Baluchistan, Turkestan, and Northern India are all more or less affected with alkali salts. In some of these countries agriculture has continued in spite of the excess of soluble salts because special methods have been devised as a result of experience extending back to prehistoric times.

Modern investigations of alkali have been more complete in India than in other parts of Asia; consequently, more attention will be given to that country in the present discussion.

India. — The alkali, or *reh*, lands of India were first investigated by the "Reh Commission" about 1876. This commission was appointed to discover the cause of deterioration of some of the lands that had previously been fertile. Since that time the various experiment stations in India have made more extensive investigations. They have shown that "usar" lands (12) exist largely not only in the northwestern provinces and Oudh, but also in the Punjab, especially on lands bordering the Chenab River, likewise to a slight extent in the Bombay Presidency.

The Reh Commission brought out the fact that under the ancient systems of agriculture in India there was very little increase in the amount of soluble salts at the surface, but with the construction of large modern canals and the application of unnecessarily large quantities of irrigation water the increase in alkali was very rapid.

Leather (12) has pointed out that not all the lands called by the natives "usar" owe their infertility to alkali. Some simply have very hard clay soils which are difficult to bring into a good state of tilth. The true "reh" lands, however, are like the alkali lands of other parts of the world.

Australia. — The greater part of Australia may be considered as arid although the rainfall of the eastern part of the continent is high. During the last generation large irrigation works have been constructed and vast tracts of land containing a rather high content of soluble salts have been brought under cultivation. In such sections alkali is one of the serious problems. Alkali conditions in Australia are somewhat similar to those of the western part of the United States.

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CHAPTER III

THE ORIGIN OF ALKALI

THE presence of alkali incrustations over the surface of the soil was observed long before scientists were able to account for the origin of these salts. This led to quite a number of theories regarding the source of the alkali. Several of the early theories have been found untenable in the light of later investigation. Many of the formerly obscure facts are now definitely known and there is a much clearer idea of the source of the soluble salts of the soil; but even today considerable difference of opinion exists regarding the origin of some of these salts. More data must be gathered before it will be possible to state definitely why certain deposits of alkali occupy their present position and maintain their present composition. It is definitely known that there are a number of distinct conditions promoting the accumulations of alkali in various sections.

TABLE IV. AVERAGE COMPOSITION OF IGNEOUS ROCKS, SHALE, AND SANDSTONE (PER CENT)

	Igneous Rocks	Shale	Sandstone
Quartz	12.0	22.3	66.8
Feldspar	59.5	30.0	11.5
Hornblende and pyroxene	16.8	....	....
Mica	3.8	....	....
Clay	....	25.0	6.6
Limonite	....	5.6	1.8
Carbonates	....	5.7	11.1
Other minerals	7.9	11.4	2.2

Composition of Soil-forming Materials. — There seems to be no doubt that the soluble salts of the soils have come from the same materials as the soils. The exact chemical reactions that have brought about these changes and the methods of concentrating the soluble constituents are, however, not so well known. The materials composing the soil have been derived largely from the rocks and minerals which constitute the crust of the earth, together with a greater or lesser quantity of organic matter coming from the dead bodies of plants.

TABLE V. AVERAGE COMPOSITION OF THE LITHOSPHERE

	Igneous (95 per cent)	Shale (4 per cent)	Sandstone (0.75 per cent)	Limestone (0.25 per cent)	Weighted Average
SiO_2	59.83	58.10	78.33	5.19	59.77
Al_2O_3	14.98	15.40	4.77	.81	14.89
Fe_2O_3	2.65	4.02	1.07	.54	2.69
FeO	3.46	2.45	.30	.....	3.39
MgO	3.81	2.44	1.16	7.89	3.74
CaO	4.84	3.11	5.50	42.57	4.86
Na_2O	3.36	1.30	.45	.05	3.25
K_2O	2.99	3.24	1.31	.33	2.98
H_2O	1.89	5.00	1.63	.77	2.02
TiO_2	.78	.65	.25	.06	.77
ZrO_2	.02	.....	.....	.....	.02
CO_2	.48	2.63	5.03	41.54	.70
P_2O_5	29	.17	.08	.04	.28
S	.11	.....	.....	.09	.10
SO_3	.....	.64	.07	.05	.03
Cl	.06	.....	.....	.02	.06
F	.10	.....	.....	.....	.09
BaO	.10	.05	.05	.....	.09
SrO	.04	.....	.....	.....	.04
MnO	.10	.....	.....	.05	.09
NiO	.025	.....	.....	.....	.025
Cr_2O_3	.05	.....	.....	.....	.05
V_2O_3	.025	.....	.....	.....	.025
Li_2O	.01	.....	.....	.....	.01
C	.....	.80	.....	.....	.03
	100.000	100.00	100.00	100.00	100.000

Compilations made by Clarke (6) show the earth's crust to be made up largely of the important minerals shown in Table IV (page 16).

On the basis of the composition and relative amount of the different rocks he computes the average composition of the earth's crust as shown in Table V (page 17).

Clarke (6) gives the composition of the ocean waters as follows:

TABLE VI. COMPOSITION OF OCEAN WATER

Salts	Per cent	Elements	Per cent
Sodium Chloride ($NaCl$)	77.76	Oxygen	85.79
Magnesium Chloride ($MgCl_2$)	10.88	Hydrogen	10.67
Magnesium Sulphate ($MgSO_4$)	4.74	Chlorine	2.07
Calcium Sulphate ($CaSO_4$)	3.60	Sodium	1.14
Potassium Sulphate (K_2SO_4)	2.46	Magnesium	.14
Magnesium Bromide ($MgBr_2$)	.22	Calcium	.05
Calcium Carbonate ($CaCO_3$)	.34	Potassium	.04
		Sulphur	.09
		Bromine	.008
		Carbon	.002
	100.00		100.00

He reports a maximum salinity of 37.37 grams of salts to a kilogram of water, or 3.737 per cent with an average of about 3.5 per cent.

These figures give a general idea of the materials from which soils are made and the substances which have been leached from them.

In order to determine soluble matter that might be washed from rocks and minerals of various kinds, Whitney and Means (23) compiled the material contained in Table VII from the writings of G. P. Merrill.

This table gives an idea of the material that is usually washed from rocks and minerals of different kinds in the

TABLE VII. AMOUNT OF SOLUBLE MATTER REMOVED IN THE DECOMPOSITION OF ROCKS AND THE FORMATION OF SOILS

Kind of Rock	Locality	Rock Removed by Solution from Each Acre-foot of Soil Formed	
		Per cent	Tons
Granite	District of Columbia	13	261
Gneiss	Virginia	45	1,431
Syenite	Arkansas	56	2,227
Phenolite	Bohemia	10	195
Diabase	Massachusetts	15	309
Diabase	Venezuela	40	1,166
Basalt	Bohemia	44	1,376
Basalt	France	60	2,625
Diorite	Virginia	38	1,072
Soapstone	Maryland	52	1,895
Soapstone	Virginia	78	6,204
Limestone	Arkansas	98	85,760

formation of soils. Dissolved material may be washed to the sea or into lakes, or it may simply be transferred to lower lying soil and there often concentrated so highly that it becomes injurious to plant growth. Some of these dissolved materials, such as limestone, are not sufficiently soluble to be troublesome even in the highest possible concentrations.

TABLE VIII. PERCENTAGE OF ALKALIES IN VARIOUS SOIL-FORMING MINERALS

Feldspars	Per cent of Alkalies	Micas	Per cent of Alkalies
Orthoclase	17	Muscovite	12
Microline	17	Biotite	10
Albite	12	Phlogopite	9
Olioclase	9	Nepheline	24
Andesite	8	Leucite	21.5
Labradorite	4	Sodalite	26
Bytownite	3.5	Haüyne	17
Anorthite	2		

The same authors (23) give a list of alkali-bearing minerals occurring in primary rocks as the ultimate source of soil alkali.

"Some of these alkali-bearing minerals are very generally present in the primary rocks from which the soils have all ultimately been derived, but they are of course usually mixed with other minerals, so that the total percentage of alkalies in the rock is not so great as would appear from these minerals."

As to the method of separating these soluble substances and transferring them to the surface, Cameron suggested a hypothesis which is quoted by Dorsey (7) as follows:

"The major part of the complex crystalline masses or of rocks forming the earth's crust contain chlorine and sulphur. F. W. Clarke gives as an average 0.07 per cent chlorine and 0.108 per cent sulphur. As a result of the hydrolyzing action of water and other decomposing agencies probably all the chlorine and very much of the sulphur is converted into hydrochloric acid and sulphuric acid, which in turn form the corresponding salts of the alkalies and alkaline earths. The aggregate amount which is thus being constantly formed in the subsoils and underlying strata of any one area must be very large. As evaporation proceeds at or in the surface soil, there is a rise of the water in the underlying layers through the capillary spaces toward the surface, bringing with it the hydrochloric and sulphuric acids or their salts.

"The sulphuric acid moves up more slowly than does the hydrochloric acid; partly, perhaps, because the rock masses and the soils have a greater absorbing action on sulphuric than on hydrochloric acid, tending to withdraw it from solution; partly, perhaps, because reducing conditions may exist on some layers tending to the formation

of metallic sulphides; and, partly, undoubtedly, to the formation of the slightly soluble calcium sulphate. This last, however, is gradually brought toward the surface, and is often found in enormous masses at moderate depths in the soils of arid regions. Undoubtedly the calcium carbonate so generally found in large masses at moderate depths in the soil of arid regions originates in a similar manner.

"Hydrochloric acid is transported through soils and most absorbing media with comparative ease. Moreover the chlorides of the alkalies and alkaline earths are readily soluble. Chlorides should be expected, therefore, to accumulate in preponderant masses at the surface, which under arid and semi-arid conditions they generally do.

"The preponderance of sodium chloride above other chlorides is readily explicable. It is well known that when solutions of chlorides are poured through columns of soil or similar substances, offering a large surface of contact to the solution, there is a well-marked selective absorption, the soil tending to withdraw the base from the solution to a decidedly greater extent than the acid, with the result that the leaching generally contains free acid. So far as the experience we have goes, it would seem that, in general, soils absorb potassium most readily, then magnesium, calcium, and sodium in the order named. Supposing the hydrochloric acid when found in the lower layers to be neutralized with a mixture of these bases, as it rises in the capillary movement, there is always a tendency, owing to the selective absorption of the soil, toward a lagging behind of the potassium, a lesser lagging of the magnesium and calcium (these bases probably tending also to form the much less soluble sulphates and carbonates) and a much less lagging of the sodium. In consequence, sodium

is the predominating base in the readily soluble salts at the surface."

This hypothesis does not explain the method of accumulation of alkali at certain places in the soil; it merely attempts to show why certain salts are present at the surface in larger quantities than others.

Salts from Ancient Seas. — The observation that alkali is found in large quantities in one section, whereas it may be almost entirely lacking in another section of similar climatic conditions early led to an attempt to trace the salt to the rock from which the soil was formed. Traphagen (21), at the suggestion of W. H. Weed of the U. S. Geological Survey, made a comparison of the composition of the alkali near Billings, Montana, with the soluble salts in the Fort Benton shales from which the soils were in part derived. As a result of this study he was led to the conclusion that in this case the soluble salts in the soil resulted from a transference of the salts to the soil while the shale was being disintegrated. This theory was afterward supported by the work of Whitney and Means (23) in the same region. Cameron (4) also mentions shale and similar deposits as a source of alkalies.

It seems, however, to have been left for Stewart, Peterson, and Greaves (17, 16, 19, 18) to explain clearly the intimate relation existing between present alkali accumulations and the presence of large quantities of alkali salts in country rocks from which these soils were formed. They made extensive examinations of the geological formations in Utah, Colorado, Arizona, Wyoming, Idaho, and Nevada, and analyzed the soil-forming country rock of these areas.

These examinations and analyses revealed the fact that in these sections wherever alkali is present in very large

quantities it apparently originated from materials deposited from concentrated solutions in some ancient sea. The deposits in the areas studied were made during Cretaceous and Tertiary times which seemed to have been influenced by arid climatic conditions. This area including the eastern part of Utah, the western half of Colorado, and the southwestern part of Wyoming was covered with water during upper Cretaceous times leaving the Uintah anticline as an island.

A description of the method of formation of these shales and sandstones that are so high in soluble salts is given as follows (17):

"**Jurassic Beds.** — The Jurassic beds contain highly colored red, yellow, gray, green, or blue shale and sandstone ranging from fine grain to coarse grits. In the upper members of the deposit are often found thin lenses of limestone and an accumulation of gypsum. The accumulation and position of the gypsum beds would seem to indicate that they had resulted from precipitation from the water of isolated brackish lakes.

"At the end of Jurassic times the inland sea, in which the Jurassic deposit accumulated, disappeared and the area was subjected to erosion. This probably took place during lower Cretaceous times. Later the section was again covered with an inland sea and deposits were laid down unconformably on top of the Jurassic.

"These belong to the Dakota beds, the lower part of which were composed of conglomerates and coarse sandstones, above which are carbonaceous shales and some low-grade coal, overlain by more sandstone and highly colored shales. Above the shale are found thick beds of light-colored sandstone, shales, and dark-brown sandstones.

"At about the end of the Dakota period there seems to

have been some shifting and readjusting of the land as the Dakota beds are found to be quite thick in the northern section where the Mancos are thin; while in the southern section the Mancos are found to be exceedingly thick in places where the Dakota is comparatively thin.

"Where they are not capped with the sandstone the beds do not form abrupt ledges, but weather off into rather rounded symmetrical clay hills — at least they appear

FIG. 1. — SALT-BEARING SHALE FORMATION. THIS TYPE OF SOIL-FORMING MATERIAL IS A COMMON SOURCE OF ALKALI.

to be clay hills. This disintegration of the shales gives rise to a very sticky, plastic clay which forms numerous cracks when dry, but becomes a continuous coat of plastic clay when wet. The material is so close grained that when rain falls upon it, it seals up all the pores and cracks so that water does not seem to penetrate it. These hills are very sparsely covered with vegetation and it is not an unusual thing to see an area of more than an acre which does not contain a single plant.

"On these rounded clay hills one seldom has to dig more than a foot before the shale is found in place. However, the material covered is not uniform, especially on top of the clay knolls. The usual condition is that on the surface is from one to two inches of earthy clay, under which is

from one to six inches of what appears to be a gray ashy material. On close examination this proves to be crystals of salt together with flocculent clay. Immediately under this is found the shale in place. Samples of the clay and gray ashy material, and the shale in place were taken separately, and the analyses show the nitrate contents of each.

"The dark-colored shales show numerous crystals of gypsum in the cracks and bedding planes. Where the shale is dry and considerably weathered the gypsum appears like white flour. In the seams of the shale, but a foot or more under the surface in the same place, the crystals are still firm and solid.

"At Emery, Utah, the gypsum crystals were not only taken out of the bedding plane of the thick layers, but numerous cross fractures were found which were also filled with gypsum crystals. Many of these cross fractures were as much as a half inch thick and pieces of gypsum this thickness and a foot long were removed from the shales.

"**Montana.**— Overlying the Mancos is the Montana Mesa Verde formations which are essentially sandstones, shales, and grits, light gray to dark brown in color. Carbonaceous shales with thick beds of workable coal occur near their base, while sandstone occurs in the upper part. 'Transition marked by increase of sandstone upward and appearance of brackish and fresh water arise instead of marine conditions.'

"The upper layers of sandstone are often found in thick lenses and in many places contain high percentages of gypsum. The vegetation accumulated in these shallow seas resulted in the formation of coal. The sea seems to have increased sufficiently after the formation of the coal

so the area was covered with thick layers of sand and shale, but the sea does not seem to have continued without interruption. Arid conditions seem to have again prevailed and the sea was reduced so that isolated portions became brackish and from these isolated waters gypsum and other salts were precipitated.

"At the end of the Montana series the sea seems to have again entirely disappeared and the area was subject to erosion.

"In the beginning of Tertiary times the section was

FIG. 2. — MANCOS SHALE HILL. SOIL FROM THIS FORMATION IS HIGH IN ALKALI.

again covered with inland seas over much the same area as that occupied by the upper Cretaceous. The lower portion of these Tertiary deposits consisted of yellow and reddish-yellow sandy clays with regularly bedded sandstones, with some conglomerates near the base, over which were deposited thin beds of light-colored sandstones associated over much of the area, especially in Utah, with rhyolitic ash beds and fresh-water deposits. In some places the ashes show distinct stratification as though they

had fallen into the inland sea and had been worked over by the water.

"The upper part of the Tertiary is composed of shaly sandstone and arenaceous shale, and in some sections thick beds of subbituminous coals. The shale and much of the sandstone are gypsiferous and in many places contain high percentages of sodium salts.

"Near the close of the period the high evaporation seems to have so reduced the sea that parts of it became isolated lakes and from these brackish deposits were precipitated the salts and gypsum in question.

"The Green River formation is composed essentially of light-colored thinly laminated beds, characterized by light-colored thin bedded shales. In appearance these shales of the Green River formation are much like those of the Mancos, especially some of the light-colored and thinner beds.

"The Green River shales weather into a series of 'bad lands, and it is not an unusual thing to have a large area entirely devoid of plants."

Arms of the Ocean. — Many soils have been formed by deltas of streams deposited in the ocean. These sometimes enclose portions of the ocean which may be shut off from the main body of water. The inclosed salt water gradually evaporates and leaves deposits of soluble salts or an alkali condition in the soil. This may be either a surface accumulation that is comparatively easy to remove, or the salts may extend to considerable depth and be very difficult to handle. The type depends on the way in which the soil was laid down and the nature of the area of inclosed sea water. Subsequent deposits of soil may leave the alkali at considerable depths. The alkali land of the lower Nile Valley as well as the small alkali tract along

the coast of Southern California derived their soluble salts from ocean water, which was inclosed in arms shut off from the main body of the ocean.

Evaporation of Saline Lakes.— In arid countries numerous lakes without an outlet to the sea are found. All the water running into them is evaporated leaving the dissolved material to be gradually concentrated until the waters become saturated. Around the bodies of these lakes the soil is likely to be high in soluble salts. Arms of the lake may be shut off in the manner already described. These become centers of local salt accumulation. The lands for some distance surrounding these saline lakes are likely to be somewhat impregnated with alkali, but as the water is approached the concentration is generally increased. There is usually a fringe near the lake that is entirely unproductive. This is surrounded by a zone in which only alkali-resistant plants grow, and still farther away the less-resistant plants are found. The Great Salt Lake in Utah is an example of this kind.

Formation of Soluble Carbonates.— On account of their soluble action on the organic matter of the soil and the hard crust which they form on the soil, the soluble carbonates are, of all the soluble salts, most to be dreaded. Fortunately, they are not so widespread in their occurrence as are the chlorides and sulphates. The comparatively insoluble carbonates of calcium and magnesium are very abundant but, being only slightly soluble, they are seldom if ever harmful to plants.

The exact method of soluble-carbonate formation is not well known. Cameron (3), from studies of greasewood and the creosote bush, held that these plants are instrumental in converting the neutral salts into carbonates. Aladjem (1), from laboratory experiments with soil kept

in a water-logged condition and to which nitrates were added, concluded that sodium carbonate is readily formed from the nitrates in a water-logged soil.

Treitz (22) concluded from his studies of alkali soils of Hungary that the soluble salts found in them are derived from the ash constituents of the plants produced on the soil and that the first and most necessary condition for the formation of sodium compounds, particularly the carbonates, is a calcareous subsoil, carbonates of the alkali being formed by the action of calcium carbonate on the humates, sulphates, and chlorides of the alkalies.

From a study of water extracts of typical alkali soils and of soils to which various salts were added, Cedroits (5) concluded that sodium carbonate is not formed in the soil by direct reaction between sodium chloride and calcium carbonate, but that the sodium of the chloride replaces other bases — potassium, calcium, and magnesium — in humates and silicates, and the latter give up soda to the soil solution when the excess of soluble sodium salts is removed.

Kelley (13) and Breazeale (2) have concluded that sodium nitrate reacts with calcium carbonate in the formation of small quantities of sodium carbonate. In discussing this reaction Breazeale has the following to say: "In the reaction between sodium nitrate (or sodium chloride or sodium sulphate) and calcium carbonate, resulting in the formation of sodium carbonate, the presence of relatively small amounts of calcium nitrate or calcium chloride in the reaction impedes and may prevent the formation of sodium carbonate. The presence of a saturated solution of calcium sulphate in this reaction does not entirely stop the formation of sodium carbonate. Sodium nitrate, sodium chloride, and sodium sulphate in

the presence of carbon dioxide react with calcium carbonate, with the formation of sodium bicarbonate. The presence of relatively small amounts of calcium nitrate or calcium chloride in this reaction impedes and finally prevents the formation of sodium bicarbonate. The presence of calcium sulphate has no effect in preventing the formation of sodium bicarbonate when sodium sulphate, or a mixture containing sodium sulphate, reacts with calcium carbonate. Sodium nitrate, sodium chloride, and sodium sulphate react with calcium carbonate in the soil with the formation of sodium carbonate (black alkali)."

Nitrate Formation. — In alkali areas in many parts of several western states, certain brown-colored spots are found to contain large quantities of nitrates. Headden (10, 11) and Sackett and Isham (15) believe that these nitrates are formed within the soil by the action of non-symbiotic nitrogen-fixing bacteria. Stewart and Greaves and Stewart and Peterson (17, 16, 18) are convinced, however, that large quantities of nitrates seep into the soil with the other salts from the country rock and that local nitrogen fixation is a minor matter in the accumulation of sodium nitrate in alkali soils.

Localization mentioned by Headden is claimed by him to preclude the theory of transportation and concentration in some cases. He states that certain of the spots are in the center of the valley the soil of which is so deep as to preclude the theory of transportation. He also says the ground water about and beneath the spots is not high in nitrates, which again apparently contradicts Stewart and Peterson's theory.

Concentration by Irrigation Water. — Whatever the original source of alkali in the soil, one fact has been well demonstrated. The condition may be greatly aggravated

by the improper use of irrigation water. The author (8) and many other workers have shown that the soluble salts are carried through the soil very readily by irrigation water. In some soils, like those in parts of the large interior valleys of California, the original salt content, though high, was not sufficiently high to prohibit the growth of crops. After irrigation the salts are leached from the higher land and carried to the lower, here to be concentrated at the surface until the amount becomes too great for ordinary crops to grow successfully. This condition is found to an extent in practically every large irrigated section of the world. Methods of preventing accumulation in this way will be more fully discussed in a later chapter.

Considerable salt may also be added directly to the land by the use of irrigation water carrying large quantities of soluble salts. This method of contamination is discussed rather fully in Chapter XV.

Relation of Origin to Methods of Treatment. — An understanding of the origin of the alkali in a given area is essential to an intelligent treatment of the condition. This is as true in handling a soil as in treating a human disease. A physician who would give a remedy for a headache without seeking the cause of the trouble might entirely fail in curing. He might in any case give some simple treatment that would be harmless, but a really intelligent treatment would be founded on a knowledge of the cause of the trouble. Likewise in handling alkali land the source of the salt should be known.

In one region an irrigation canal passed through a shale hill that was very high in soluble salts. Large quantities were dissolved and taken directly into the stream. Seepage was also excessive and much alkali was carried to the

lower land by the seepage water. The land was finally drained, but the alkali content of the soil was not reduced since the quantity added was greater than that lost by drainage. Lining the canal through the alkali-charged shale corrected the entire matter. Soil experts and drainage engineers, before deciding on the methods of reclaiming any alkali tract, should discover all probable sources of the alkali in the area under consideration and select their methods of reclamation accordingly.

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CHAPTER IV

NATURE OF ALKALI INJURY TO THE PLANT

MANY of the general effects of excessive quantities of soluble salts in the soil are well known, but there still remain to be worked out a number of important problems, the solution of which will throw a great deal of light on the exact nature of alkali injury. Every farmer in alkali regions recognizes by the appearance of the soil and the limitations in crop growth the presence of alkali, but the actual underlying causes of the abnormal conditions are in part a mystery to even the most profound students of the subject.

Prevention of Water Absorption. — Doubtless one of the very important injuries caused by alkali results from checked absorption of water by plants. It matters not how desirable other conditions are — how much plant-food is available, how deep the soil, or how favorable the temperature — if the plant cannot secure water it can make no growth. Roots absorb water from the soil by the process of osmosis. Because the cell-sap of root-hairs contains a stronger solution than the soil, water passes through the cell-wall and plasma membrane into the cell where it assists in the vital processes of the plant. Since carbohydrates are constantly being elaborated in the leaves, the cell-sap farthest from the roots is more concentrated than that which has recently been diluted in the roots by the entrance of water from the soil. The transpi-

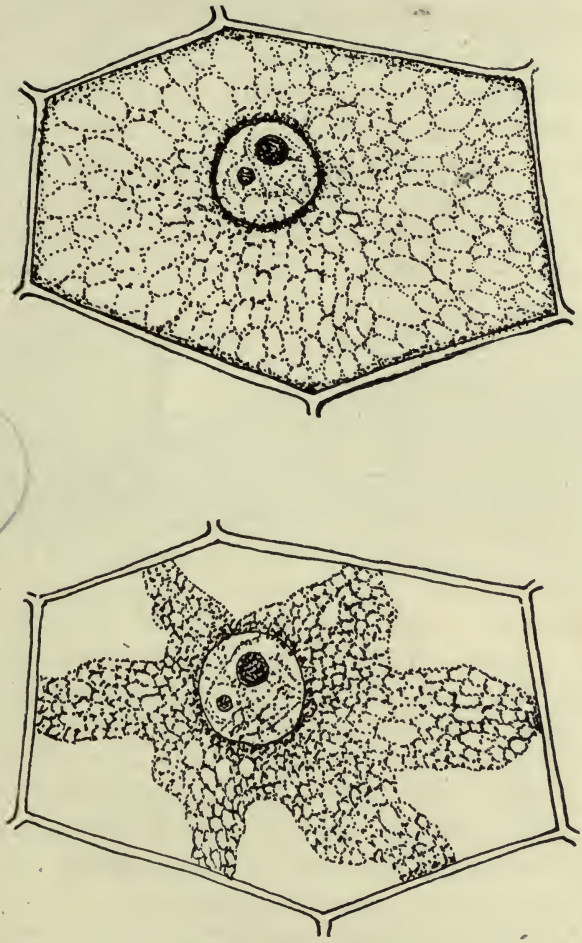

FIG. 3. — UPPER, NORMAL PLANT CELL. LOWER, CELL THAT HAS BEEN PLASMOLYZED.

ration of water from the leaves also tends to concentrate the cell-sap in the leaves. This continuous diluting in the roots and concentration in the leaves causes a movement of water from root cells upward toward the leaf

cells. This movement is necessary to the normal functioning of plants. An ordinary plant, such as wheat, absorbs and transpires several times its own weight of water each day. Should this movement be reduced, the growth of the plant is retarded. If it is entirely shut off the plant dies, as pointed out by Pfeffer (12).

The exact action that takes place when a plant cell comes in contact with a solution more concentrated than its own content was long ago pointed out by deVries (15) and Pfeffer (11). Water passes out of the cell and the plasma membrane draws away from the cell-wall leaving the cell in a plasmolyzed condition. The rapidity of plasmolysis depends on the relative concentration of the solution inside and outside of the cell. So well known is this phenomenon that the method is used constantly in determining the concentration of the cell-sap under various conditions.

The above conception helps to explain the observed action of plants. The soil solution of land high in alkali is stronger than the cell-sap; therefore, no plant growth takes place. In other land where there is less alkali, the concentration may be just strong enough to reduce the rate of water absorption but not enough to shut it off entirely. Under this condition the crop yield would be reduced. Thus, every gradation from a normal crop to no crop at all may be found in a single field.

Under some conditions, such as after irrigation or heavy rains, alkali may be so diffused throughout the soil that the concentration at any point is not sufficient to prevent the crop from beginning a good growth. As the season advances, the salt may accumulate at the surface of the soil until irrigation water is applied. It may then be washed down to the roots in a concentrated form causing

the death of the plant. The farmer says his crop has been burned since it has that appearance. As a matter of fact water may have been drawn out of the plant through the roots. This, taken with the loss by transpiration, desiccates the plant to the point at which it dies.

Effects on Germination. — Before a seed can germinate it must absorb water. Ordinarily when a seed is planted in a moist soil it absorbs moisture and swells. At once

FIG. 4. — AN ORCHARD PLANTED ON LAND THAT CAME FROM A FORMATION HIGH IN SOLUBLE SALTS. THE SALTS HAD KILLED MOST OF THE TREES BY THE SECOND YEAR.

the enzymes contained in the seed convert part of the starch into sugar which increases the strength of the solution in the seed. This in turn hastens absorption and the seed soon contains sufficient moisture with which to carry on rapid cell division and growth. Within a few days a root is sent out, then a shoot for the top, and a new plant is growing.

When a seed is placed in a strong salt solution or a soil that has a large amount of alkali, it does not absorb moisture; consequently, it lies dormant the same as it would in dry soil or in dry air. The coating on the seed protects it from absorbing most of the salts. It may not be injured, and as pointed out by Slosson (13) it will germinate when removed from the alkali soil to conditions favoring ger-

mination. Under similar conditions, a plant would not only be hindered from growing, but would actually be killed.

A salt solution not sufficiently strong to prevent entirely the germination of seeds may greatly delay it. The author has shown (3) that seeds which normally germinate in six days may be delayed as long as twenty-one days under conditions in every way similar except in the salt content of the soil. This delayed germination may be very serious in regions where the normal length of the growing season is greater than that required for maturity of the crop even if growth after germination were satisfactory.

Effect on Structure of the Plant. — Vegetation growing on alkali soil has a characteristic appearance similar to that found growing under desert conditions. It generally lacks that bright green appearance of vigorous and healthy growth. This condition is observed even in water-logged land where there is an ample supply of moisture. A similar moisture supply without alkali would result in a succulent growth.

Harter (4) examined the structure of plants to determine the effect of soluble salts in the soil. He found that culture in a soil containing considerable quantities of sodium chloride together with other salts produced measurable changes in the leaf structure of wheat, oats, and barley. The most notable modification produced was the conspicuous bloom or waxy deposit that formed on the surface of the leaves. This development of bloom was accompanied by an easily measured increase in the thickness of the cuticle and outer walls of the epidermal cells and by a marked decrease in their size.

In regard to transpiration of the plants, it was found that when the alkali salts are present in sufficient con-

centration to cause the modifications of structure noted, transpiration is much reduced. On the other hand, the same salts when present in amounts too small to produce any measurable influence upon structure have a decidedly stimulating effect upon transpiration.

FIG. 5. — THE LOWER PART OF AN ORCHARD BEING KILLED BY ALKALI BROUGHT TO THE SURFACE BY A RISING WATER TABLE.

Similar modifications in structure have been pointed out by Kearney (7) who shows that thickness of leaves and stems with zerophytic tendencies characterizes plants growing in a saline soil.

Injury at the Surface of the Soil. — Orchards and vineyards in many cases have been planted in soils containing a rather high salt content, but not high enough to prevent growth. A root system may become thoroughly established in an untoxic lower layer of soil which is slightly

alkaline and yet there may be a gradual accumulation of salt at the surface of the soil. This condition has the effect of corroding the plant and it often destroys the bark so thoroughly that the passage of elaborated food from leaves to roots is prevented. This injury is rather limited in the total damage done and may be overcome without great expense.

Formerly it was thought that the principal injury to vegetation by alkali resulted from a corroding action. This is probably not the case, with the possible exception of the carbonates. The carbonates, in addition to any direct action on the plant itself, make the soil hard and a poor medium for the plant.

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CHAPTER V

TOXIC LIMITS OF ALKALI

NUMEROUS attempts have been made to determine the approximate quantity of the different alkali salts, both singly and in various combinations, which may be withstood successfully by crops. Some experimenters have confined their work almost entirely to field observations. Others have worked with natural alkali soils from the fields or soils made alkaline by the addition of salts in definite quantities and sown to crops under laboratory conditions. Still others have used different solutions containing salts as the medium for determining the toxicity of salts to plants. Each method has both advantages and disadvantages.

The field work has often been done by sampling soils showing injury to plants and also adjoining soils where the effects of the alkali could not be detected. These observations are usually taken after the crop has made considerable growth, when the extent of injury may be estimated by the appearance of the plants. Such determinations may not take into consideration conditions prevailing during the earlier stages of growth. The vigor and delicacy of the plant at the time the alkali comes in contact with it appear to have much to do with its tolerance. Alfalfa, sugar-beets, and a number of other plants do not withstand alkali well in their seedling stages, but are among the most tolerant during later stages of growth. Most plants do better under alkali conditions as maturity

approaches. Since the conditions under which plants grow at different times is modified by rainfall, movement of ground water, evaporation, and other factors, an analysis of the soils at a particular period of growth is not so definite for indicating toxicity as might be wished. Because of the difficulty in fixing definite toxic limits under field conditions, these observations will not be considered in the present discussion but will be reserved for Chapter XIV dealing with crops for alkali land.

Toxicity in Solution. — Some of the first attempts to establish the toxic limits of alkali were made in solution cultures because the solution was easy to make up, easy to analyze subsequently where it was desired to learn the final concentration of the water, and because such complicating factors as absorption of the salts, moisture content of the soil, and nature of the soil were eliminated. Some of the experiments were carried on in cultural media, such as Knop's solution, in an attempt to duplicate soil conditions as nearly as possible, whereas others were made in water containing only alkali salts.

Nutrient Solutions. — Some of the nutrient-solution cultures were carried to later stages of growth than those with the toxic salts alone. Since, however, the strength of the nutrient solution, its composition, and other factors modify the results almost as much in some cases as the alkali salts the advantages of the culture media over the simple solutions are not so apparent. Plants are usually at their most critical life period in the seedling stages where they are still depending on the seed for their nutrition. The results of LeClerc and Breazeale (17) show the tolerance of wheat seedlings for sodium chloride in culture solutions to be about 3000 parts per million, which is not essentially different from certain other results

where the solution containing the alkali salts was tap water. Tottingham (29) did not find the introduction of potassium chloride or sodium chloride into Knop's solution to have any marked effect on wheat plants, although the sodium chloride depressed the dry weight and length of roots of buckwheat.

Alkali Solutions. — Alkali solutions have been used in a number of different ways to determine toxicity. Some experimenters have germinated the seed in the alkali solutions; others have used the alkali solutions in which to immerse the roots of the seedlings after they have germinated under normal conditions. Since conditions differ so widely under the two methods and because the time allowed for the alkali to become effective differs considerably, the two methods will be treated separately.

Seed Germination. — Experiments with wheat in Wyoming (4, 27) show that salts hinder the absorption of water by the seed so that germination is retarded and that the kind of neutral salt is of less importance than the osmotic pressure of the solution. The work of Kearney and Cameron (14) on antagonism and of the author (10) apparently disprove the latter statement, however. From the Wyoming experiments which included salt solutions from 1000 to 90,000 parts per million in strength, it was found that inhibition was not retarded in as rapid proportion as the osmotic pressure of the solution was increased. Inhibition was apparently not influenced by the vitality of the seed nor did the salts affect the vitality of the seed when removed before sprouting. The weaker solutions up to 4000 parts per million of sodium sulphate, sodium chloride, magnesium sulphate, or sodium carbonate had a beneficial effect on the germination of the seed and the growth of the plants.

Miss Magowan (19) states that alkali experiments are not reliable when they are continued only a week because the relative toxicity of the salts may change later. She found that although magnesium chloride was at first the most toxic of the chlorides, followed by sodium chloride, potassium chloride, and calcium chloride, this relationship did not hold throughout the experiment.

Working with wheat seedlings in solutions of 0.01 normal, or 585 parts per million, sodium chloride, 850 parts per million sodium nitrate, 746 parts per million potassium chloride, and 1011 parts per million potassium nitrate, Micheels (21) found chlorine more harmful than nitrate ions, and sodium more harmful than potassium ions. He ascribed the variation to physiological and not chemical differences, as did also Slosson and Buffum (27) working with wheat, rye, and beans in the common alkali salt solutions. Sodium carbonate was the only salt found causing other than physiological injury.

Wyoming experiments (27) show the highest concentration of salts not retarding germination of wheat and rye to be as follows:

	$MgSO_4$	Na_2SO_4	NaCl	Na_2CO_3
Wheat	10,000	7000	4000	4000
Rye	10,000	7000	4000	1000

The vitality and time to germinate were effected deleteriously as the strength increased above the minimum. Rye was as a general rule more tolerant of the higher concentrations of these salts than was wheat.

Sigmund (26) found 5000 parts per million of sodium chloride or of sodium carbonate retarded the germination of cereal seeds in solutions of these salts. Vetch and rape seeds were killed in 5000 parts per million solutions

of sodium carbonate, but neither they nor wheat were injured in 5000 parts per million of sodium bicarbonate. According to this author the highest strength of sodium chloride endurable by the cereals was 5000 parts per million, by legumes 3000 parts per million, and by rape 1000 parts per million. Jarius, as quoted by Kearney and Cameron (14), reports a stimulating effect on seeds of wheat, rye, rape, maize, beans, and vetch in a solution containing 4000 parts per million of sodium chloride. Storp, as quoted from Kearney and Cameron (14), found this salt to stimulate germination in solutions as strong as 100 parts per million. In his work with solutions of sodium chloride in concentrations ranging from 1250 to 50,000 parts per million, Coupin (6) found the toxic limits for wheat to be 18,000 parts per million, of lupine 22,000 parts per million, of maize 14,000 parts per million, of peas 12,000 parts per million, and of vetch 11,000 parts per million. In this author's experiment the endurance of the plant as a whole to the solution was taken to indicate the limit, whereas with some of the others the death of the root or some other part is sometimes taken to indicate the injury to the plant. He found the toxic limits for seashore plants to be several times that for the crop plants mentioned above. Nessler, who is quoted by Hicks (12), states that hemp seed was injured in germinating by 2500 parts per million of sodium chloride, clover by 5000 parts per million, and wheat by 10,000 parts per million. Rape seed was found to resist sodium chloride, potassium chloride, calcium nitrate, sodium nitrate, and potassium sulphate in concentrations as high as 5000 parts per million, but the vitality of wheat, rye, maize, beans, and peas was seriously injured when using solutions as strong as this (12). Sodium chloride had a stimulating effect.

Seedling Transference into Alkaline Solutions.— This practice has been preferred to germinating and growing the plants in the alkaline solutions by some investigators. Certain experiments have indicated that plants may gradually become accustomed to salts as they grow older so that the injurious strength of solution at one period may not be so at another. By dipping the seedlings into the alkali solutions at a definite period after germinating, it has been hoped that a better standard for comparing toxicity would be fixed. For such work many standard conditions have been suggested but few of these standards have been accepted by other workers, so there is a wide difference in the conditions under which the toxicity of the plants have been determined.

In the experiments of Kearney (13) and his co-workers the roots of the seedlings were placed in the alkali solutions for twenty-four hours and the death of the root tip was taken to indicate the toxic limit for the plant. As a result of this work, corn showed the toxic effect of magnesium less than other salts, but with lupines, alfalfa, wheat, sorghum, oats, cotton, and beets the magnesium compounds were considerably more toxic than other salts. The sodium chloride and sodium sulphate did not differ greatly in toxicity to the different plants in several cases, and the sodium carbonate was several times more toxic than these two salts in most cases. Corn, which is considered rather sensitive to alkali, endured more sodium carbonate than the other crops, whereas sorghum, cotton, and beets, which are usually resistant in soils, were affected most by this salt in solution. The limits for wheat were 650 parts per million of sodium carbonate, 2610 parts per million of sodium chloride, and 2830 parts per million of sodium sulphate. Comparing the two series with lupines

it is seen that the variations are wide. In another experiment with lupine, where growth was prevented by the salts contained in the solutions, the magnesium salts were not so toxic as the carbonates of sodium, and the magnesium sulphate was the least toxic of all salts. This shows that very wide differences might be expected according to the method employed.

True (30), using the above method for obtaining the toxic limit of lupine in sodium chloride solutions found it to be 3625 parts per million, which again shows the possible error. Coupin (5) allowed the plants to remain in the solutions until the whole plant showed the salts to be causing injury. His limits for lupine using sodium chloride, magnesium chloride, and magnesium sulphate were 12,000, 8000, and 10,000 parts per million for the respective solutions, which is about the same as the above results where growth was prevented.

The resistance here is several times that found by Harter where the first injury was the point of indication rather than the death of the plant. Allowing the roots to remain in the salt solution twenty-one days and then weighing, the author (10) found wheat seedlings to produce about one-half as much as the check in the solutions containing 5000 parts per million of sodium carbonate, or in those containing over 10,000 parts per million of sodium chloride or sodium sulphate. Haselhoff (9) concluded that growth might be inhibited with a 5000-parts-per-million solution of sodium chloride and injury would result in the presence of 500 parts per million.

Hansteen (8) states that 5000 parts per million of salts other than calcium are injurious when used singly, but when combined with lime the injury is greatly diminished. Others have found the same antagonistic effects of dif-

ferent salts. This subject is reserved for Chapter VIII and will not be discussed here.

A series of experiments was made by Marchal (20) to discover the effect of salts on the bacterial activities of the nodules of pea roots. He found alkaline nitrates in concentrations of 100 parts per million checked the tubercle production in water cultures. Ammonium salts were injurious in concentrations of 500 parts per million. Potassium salts at 5000 parts per million and sodium salts at 3333 parts per million tended to retard symbiosis, but calcium and magnesium salts favored it.

Soil Results. — Soil studies of alkali have been found to show less variation for like treatment than solution studies. Some of the other disadvantages of solution studies of the effect of alkali on the higher plants are that the seed in germination tests and the root system are placed in an unnatural environment, the air circulation being eliminated and the normal resistance of the soil being changed. Studies of plants in solutions compared with similar soil cultures have shown that physiological disturbances are more likely to occur in solutions than in soils; the root-hairs are less numerous and the roots grow longer and thinner in the solution than in the soil. Individuals show much more variation due to unfavorable causes in the solutions than in the soils even where the soil consists of sand containing practically no nourishment.

In Sand. — The physical conditions under which the plants grow seem to have some influence on their natural development. The author (10) found that whereas wheat seedlings produced about a half normal crop of dry matter in a sand containing 1000 parts per million of sodium chloride in solution cultures, more than half a normal crop was obtained when the concentration was over 10,000

parts per million of this salt. For sodium carbonate the relationship between sand and solution cultures was about 1000 and 5000 parts per million, respectively, and for sodium sulphate it was about 5000 to over 10,000 parts per million, respectively, for half-normal crops of dry matter. Le Clerc and Breazeale (17) found wheat seedlings more tolerant for sodium chloride in sand than in solution. Breazeale (2) states that the reverse relation-

FIG. 6. — EXPERIMENTS TO DETERMINE THE TOXICITY OF VARIOUS ALKALI SALTS.

ship for nutrient solutions holds, 300 parts per million of nutrient solution being the best concentration for wheat seedlings, while 2500 parts per million was best for them in sand. Others have found the latter relationship to hold for sand. The size of pure quartz sand particles apparently had no effect on the toxicity of alkali in tests made by Harris and Pittman (11), but the quantity of moisture in the soil had considerable influence.

The differences which may be expected in alkali experiments with differing moisture contents are shown in tests

made by the author (10). The toxic limits of wheat for salts in a sand were as follows: sodium chloride with 12 per cent moisture 2900 parts per millon, with 18 per cent 5700 parts per million; sodium carbonate with 12 per cent 2700 parts per million, with 21 per cent 3300 parts per million; sodium sulphate with 12 per cent 8000 parts per million, with 24 per cent 16,000 parts per million. When the salts were added dry to the soil rather than in solution as in the above experiments, the limits of tolerance were higher, but the quantity of moisture added to the soils would influence the permissible quantity even more in such experiments than where the solutions were added because the quantity dissolved would be more dependent on the water present.

In the work of Buffum and Slosson (4) sand was used as the medium for growing seed in a nutrient solution, an attempt being made to duplicate soil conditions as nearly as possible. Their work was with wheat and alfalfa in sand containing solutions with osmotic pressure equivalent to 2.03, 3.80, and 7.10 atmospheres which corresponds to 5000, 10,000, and 20,000 parts per million of sodium sulphate, or 2700, 5100, and 9700 parts per million of sodium chloride. The conclusions were that the lower concentrations of the salts were stimulating to the plants but that the higher ones were harmful. Solutions of sodium sulphate, potassium sulphate, sodium chloride, and potassium chloride were all about equally harmful to those plants at the same osmotic pressures when based on germination and several other observations of the growing plants.

A series of germination experiments in a sand by Stewart (28) showed that 10,000 parts per million of sodium sulphate was generally fatal to seeds of barley, rye, wheat, oats, peas, alfalfa, and red and white clovers. The re-

sistance of the plants was about in the order given, barley being most tolerant. About 5000 parts per million of sodium carbonate or sodium chloride was fatal to the germination of these plants, and, excepting that peas were the most resistant to sodium carbonate and alfalfa was weakest for those salts, the order of toxicity was about as given above.

Oats and mustard were found more resistant than flax for sodium chloride and sodium sulphate in pots of sand containing 315 to 1889 parts per million of these salts. Some influence of sodium sulphate was perceptible at the higher concentrations and the sodium chloride caused injury to the oats and mustard in the larger quantities. Wheat, oats, and peas failed to grow in soils containing 390 parts per million of chlorides but survived in the presence of 10,000 parts per million of total salts. Wheat and oats could withstand 20,000 parts per million of total salts where the chlorine content was less than 1250 parts per million.

Claudel and Crochetelle (12) found that sodium nitrate in concentrations of 2000 parts per million prevented the germination of buckwheat and beans, injured or checked the germination of beet seed, and badly injured those of clover. However, it had very little effect on wheat and barley seed. Buckwheat was considerably, and clover slightly, affected by 1000 parts per million. Barley was the only crop able to withstand 5000 parts per million of this salt.

From the above discussion of the effects of alkali in sand on plants, it is seen that where allowance is made for the difference in the method of arriving at the toxic limits, the results are fairly uniform when compared with those of solution determinations. The two salts, sodium carbonate and sodium chloride, are nearly the same in toxicity,

while sodium sulphate is considerably less harmful than the former two salts.

In Loam Soil. — From a practical point of view loam soil is a much more desirable medium for studying the effect of alkali on plants than is either sand or a solution. Absorption, antagonism, and physical conditions must all eventually be taken into consideration before the real toxic effect of the salts under normal conditions can be arrived at correctly.

The use of loam, or other soil containing organic matter and having high absorptive properties, complicates the determination of the toxicity of salts. Harris and Pittman (11) found that of two soils containing equal quantities of alkali and equivalent moisture contents, wheat on the soil with highest organic matter was injured less than where the organic matter was about as it is in ordinary loam. The organic matter appeared to remove sodium carbonate from the soil solution so that this salt appeared less toxic than has usually been ascribed to it from solution or sand cultures or field extraction experiments. Wheat plants tolerated more alkali in a loam than in either a sand or clay and more in a coarse loam than a finer one with the same percentage of moisture, although with equivalent moisture contents the coarser loam was less tolerant than the finer. The toxicity of the salts decreased with increasing percentages of soil moisture up to the maximum moisture content producing good crops. Changing the moisture relationship of the soil influenced the toxicity of sodium chloride and sodium sulphate more than did changing the organic matter, but the organic matter had the greater influence for sodium carbonate. High organic matter and moisture content offered the most favorable conditions for alkali toleration.

The work of Haselhoff (9) on heavy loam and clay soils led him to conclude that because these soils absorb chlorine from the solutions of chlorides and thereby gradually destroy the physical condition of the soil, the injurious influence of chloride solutions on soil productiveness and crop yield takes place gradually.

Le Clerc and Breazeale (17) found the greater tolerance of wheat seedlings to sodium chloride in clay as compared

FIG. 7. — GROWTH OF WHEAT WITH VARIOUS CONCENTRATIONS OF DIFFERENT SALTS.

to sand and solution cultures to be due to the lime which the clay contained. Shutt (25) found that calcium oxide was very effective and calcium carbonate less so in correcting the toxicity of soil containing 50,000 parts per million of magnesium sulphate. Even when calcium oxide was used, germination was still retarded but a larger percentage of the plants grew and the growth was more healthy. This antagonistic action of calcium and other salts will be taken up in greater detail in Chapter VIII.

In the work done on the germination and growth of plants in Wyoming by Buffum (2), alkali soils were leached of their alkali and then made up to the required percent-

age by the addition of the pure salts in one part of the experiment and in the other the soil was leached of a portion of its alkali sufficient to obtain the required alkali content. The alkali was two-thirds sodium sulphate and one-third magnesium sulphate and in concentrations from 10,000 to 50,000 parts per million. The test showed that in a soil containing 25 per cent moisture, rye germinated almost normally with 22,500 parts per million of these salts; barley nearly perfect with 10,000 but less than half normal with 22,500 parts per million in the natural alkali soil; wheat about two-thirds normal with 10,000 parts per million; alfalfa perfect with 10,000 parts per million but producing hardly a sprout in 22,500 parts per million; while turnips and oats produced less than one-half normal germination in soil containing 10,000 parts per million. The time taken for the seeds to germinate was increased in proportion to the salt present even for the lower quantities of alkali.

Table IX summarizes the work of Guthrie and Helms (7) in a rich garden loam soil mixed with nearly an equal quantity of light sand.

TABLE IX. CONCENTRATIONS OF SALTS AFFECTING THE GROWTH OF VARIOUS CROPS

	Sodium Chloride			Sodium Carbonate		
	Wheat	Barley	Rye	Wheat	Barley	Rye
Germination affected	500	1000	1000	3000	2500	2500
Germination prevented	2000	2500	4000	5000	6000	5000
Growth affected	500	1000	1500	1000	1500	2500
Growth prevented	2000	2000	2000	4000	4000	4000

From the figures it is seen that the resistance of seed to alkali during germination is not always the same as the

resistance during later growth, and the relation between germination and subsequent growth differs for these two salts.

With the following quantities of alkali added to loam soil the author (10) found the plants indicated in the table to produce about half-normal crops of dry matter.

TABLE X. QUANTITIES OF VARIOUS SALTS ADDED TO THE SOIL WHICH REDUCED THE YIELD OF CROPS TO ABOUT HALF NORMAL

Crop	Sodium Chloride	Sodium Carbonate	Sodium Sulphate
Barley	5000	10,000	Above 10,000
Oats	4000	8,000	" 10,000
Wheat	3000	9,000	" 10,000
Alfalfa	3000	6,000	" 10,000
Sugar-beets	3000	6,000	" 10,000
Corn	3000	4,000	" 10,000
Field peas	3000	4,000	" 9,000

It will be noted that the figures by the author are considerably above those of Guthrie and Helms, but that the carbonates when added to the soil in each case were less harmful than the sodium chloride. In the sand soil the sodium chloride and sodium carbonate were noted to be nearly equally toxic and for the field results presented in Chapter XIV the sodium carbonate shows nearly the reverse relationship to this. The low toxicity of the salts as compared with those for field determinations are probably due partly to absorption of some of the salts and to the even distribution and favorable moisture content possible in controlled experiments compared with field conditions. Of the salts used in the experiments of the author with wheat seedlings, the order of toxicity for salts added from highest to lowest was as follows: sodium chloride, calcium chloride, potassium chloride, sodium nitrate, magnesium chloride, potassium nitrate, magnesium

nitrate, sodium carbonate, potassium carbonate, sodium sulphate, potassium sulphate, and magnesium sulphate. This order does not hold when the concentration is determined by an analysis of the soil. The anions were found to affect the toxicity more than the cation, the chloride being the most toxic anion and sodium the most toxic cation.

Bancroft (1), in his work with beans growing in large pots to which alkali was added from below after the plants were growing until they wilted and died, found the following quantities of salts just killed the plants: magnesium chloride, 2640 parts per million; sodium carbonate, 2710 parts per million; sodium nitrate, 3700 parts per million; sodium chloride, 5660 parts per million; magnesium sulphate, 5820 parts per million; sodium sulphate, 6810 parts per million; and sodium bicarbonate, 12,300 parts per million.

In germination tests on sugar-beet seed by Headden (Colo. Sta. Bul. 46) it was found that while 1000 parts per million of sodium carbonate permitted the seed to germinate freely, 5000 parts per million was injurious. The limit for sodium sulphate was about 8000 and for a mixture of the two about the same as the sodium carbonate.

From the foregoing discussion of the various experiments with alkali under different conditions and from the results given in Chapter XIV on crops for alkali land, it is seen that the limits vary so widely because of the different methods of arriving at these limits, that unless the conditions can be duplicated, considerable error might result from estimates secured by different experimenters. The estimates under field conditions would be expected to range through a wider limit because of the complicated changes within the soils and because of differences in de-

termining the salts in the soils. With laboratory experiments, the same allowances must be made because of the various complicating factors such as moisture content, organic matter, antagonism of the salts, absorption, and differences in tolerance of the plants at different times.

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CHAPTER VI

NATIVE VEGETATION AS AN INDICATOR OF ALKALI

It is highly desirable that the prospective landowner should, by studying the trees, shrubs, and grasses, be able to say that the soil is deep, well-drained, fertile, free from injurious properties, and capable of producing profitable crops. Upon many soils the native plants tend to group themselves to the exclusion of nearly all other species. Generally when such grouping occurs, there is some peculiarity of the soil which is made evident by such grouping. The luxuriant growth of one species of plant to the exclusion, or the near exclusion, of other species affords an excellent index to the nature of the soil.

How Plants Indicate the Soil. — Certain plants in arid regions are seldom found except when the soil contains alkali salts. Davy investigating in California (1) states that "there are at least 197 species natives of California, which are restricted to alkali soils." Some of these plants seem to thrive only when some particular salt is present in certain strengths, resenting even small quantities of other salts. Other plants do well in the presence of any of the alkali salts so long as moisture or soil conditions are right. In each portion of the arid region may be found some plants which indicate extremely large quantities of salts when found alone. They indicate that so much alkali is present in the soil that the land is worthless for agri-

cultural plants without reclamation methods first being applied.

These characteristic plants are generally recognized by the farmers of the district in which they occur, but the exact qualities of the soil and the possibilities of its reclamation are not so often known. The kind of plant also varies considerably even within relatively short distances be-

FIG. 8. — ALKALI CRUSTS AT THE SURFACE PREVENTING THE GROWTH OF PRACTICALLY ALL VEGETATION.

cause of difference in soil or drainage. Changes in climate or altitude also influence the type of plant that indicates a particular type of soil.

A number of studies of the characteristic plants of alkali lands have been made together with the kind and amounts of alkali present in soils on which they grew. From these studies fairly intelligent conclusions may be drawn as to the kind and quantity of alkali in the soil without making a chemical analysis.

In using native vegetation to indicate the alkalinity of a soil, however, it is essential that judgment should not be

passed when only a few scattered or stunted plants are found. Generally when such scattered alkali-indicating individuals are found the soil contains some alkali, but the quantity is not clearly indicated. It is only when the plants produce a vigorous growth and occupy the land to the exclusion of non-resistant — if not all other species of plants — that they may be taken to indicate the kind and quantity of alkali characteristic of their species.

FIG. 9. — ALKALI LAND WHICH IS INDICATED BY THE GROWTH OF SHADSCALE.

It should be kept in mind also that under certain conditions alkali-indicating plants may grow well where alkali may not be present in quantities injurious to general crops and that non-resistant plants may be growing well on land so strongly impregnated with alkali that farming would be practically impossible without reclamation. Such conditions as a shallow hardpan, a dry sandy layer of soil, or other conditions which cause the plants to suffer for want of water, as they do when in the presence of excessive quantities of alkali, may allow the presence of the alkali-resistant plants in abundance to the exclusion of

others. On the other hand, shallow-rooted plants which cannot endure alkali may grow luxuriantly on land which contains alkali below the depth to which its roots feed but so near to the surface that when farming is attempted the land may soon be ruined. The latter condition is represented by the Bear River Valley, Utah, where sage brush, rabbit brush, and salt grass are growing on land practically free from alkali in the upper foot or so, but the soil to a depth of six feet contains from 6000 to 30,000 parts per million of salts, mostly sodium chloride. This salt is quickly concentrated near the surface when irrigation is practiced, making farming impossible.

Alkali-indicating Plants. — Some of the characteristic plants of the western part of the United States which should, when present as a luxuriant growth upon the land, be regarded as indicating distinctly alkali soil, or soil which should be looked upon with suspicion until chemical analyses of it have been made, are given below.

Well-defined alkali-indicating plants

Inkweed, or saltwort (*Suaeda* spp.)
Tussock grass, or purple top (*Sporobolus airoides*). Torr.
Bushy samphire, or Kern greasewood (Allenrolfea occidentalis) (S. Wats.). O. Ktze.
Dwarf samphire (*Salicornia* spp.)
Greasewood (*Sarcobatus vermiculatus*)
Alkali-heath (*Frankenia grandifolia campenstris*). A. Gray
Spike weed (*Hemizonia pungens*)
Little rabbit brush (bushy goldenrod) (*Isocoma veneta*) H. R. K. (A. Gray)
Arrow or irrigation weed (*Pluchea servicea*) (Nutt.). Coville. (Sometimes *Pluchea borealis*)
Salt-bush or shadscale (*Atriplex confertifolia*, etc.)
Kochia or white sage (*Kochia vestita*)
Salt-grass (*Distichlis spicata*). Greene
Cressa (*Cressa cretica truxillensis*). Choisy
Rabbit brush (rayless or false goldenrod) (*Chrysothamnus* spp.)

Alkali-indicating plants not commonly forming the major portion of alkali-land vegetation

Inhabiting moist saline lands:

Arrow grass (*Triglochin maritima* and *T. palustris*) L. (Across continent)
Alkali meadow grass (*Puccinellia airoides*. Nutt.) (Entire west. N. Mex.-Mont.)
Marsh grass (*Spartina gracilis*. Trin.) (Oregon to Texas)
Trailing buttercup (*Halerpestes cymbalaria*. Pursh.) (Rocky Mts., n. seacoast)
Shooting star or American cowslip (*Dodecatheon salinum*. Nels.) (Western Wyoming, Utah, Idaho)
Glaux (*Glaux maritima*. L.) (Subsaline soil west of Mississippi)
Aster (*Aster angustus*. T. and G.) (Colorado and Utah to Minnesota)
Aster (*Aster pauciflorus*. Nutt.) (New Mexico, Arizona, Utah)
Crepis (*Crepis glauca*. T. and G.) (West of Missouri to Nevada)
Plowman's wort (*Pluchea camphorata*) (Coast of Florida to Texas)
Mousetail (*Myosurus apetalus*. Gay) (Western North America)
Valeria (*Valeriana furfurescens*. Nels.) (Colorado and Wyoming)
Pyrrocoma uniflora. Greene. (Montana to Colorado and Utah)
Rush (*Scirpus nevadensis*. Wats.) (Wyoming, California)
Tuber bubrush (*Scirpus paludosus*)

Inhabiting soil not moist at the surface:

Bud-brush (*Artemisia spinescens*. Eat.) (Colorado to Montana and west)
Aster (*Aster zylorhiza*. Nutt.) (Southcentral Wyoming. Naked, clayey, saline)
Pyrrocoma lanceolata. Greene (Saskatchewan. Northern Colorado and west to Nevada)
Flaveria angustifolia. Pers. (Eastern Colorado and New Mexico to western Texas)
Pepper grass (*Lepidium montanum*. Nutt.) (Montana to New Mexico and westward)
Wild barley (*Hordeum nodosum*. L.) (Arizona to Alaska)
Wild rye (*Elymus salinus*. Jones) (Wyoming and Utah. Saline situations)
Goosefoot or pigweed (*Chenopodium rubrum*. L.) (Across continent northward)
Goosefoot or pigweed (*Chenopodium soccosum*. Nels.) (Southern Wyoming)
Monolepsis spp. (Colorado and westward. Saline soils)

Botanically, probably half of the alkali-loving plants belong to the *Chenopodiaceae*, or goosefoot family, which

includes beets, mangles, samphire, saltwort, salt-bush, and greasewood. Some of the smaller families such as *Frankeniaceae*, *Plumbaginaceae*, *Rhizophoraceae*, and *Tamaricaceae* are noted for the alkali resistance of most of the species. Some other families, notably *Gramineae*, *Cruciferae*, and *Compositae*, contribute some of the more important plants found to do well on alkali lands.

Discussion of Plants. — "*Inkweed, or saltwort,* is a perennial shrub with a small, fleshy, stem-like leaf. Each winter the plant dies down close to the ground leaving behind a dark-colored bush" (5). It is found on some of the worst alkali lands of California (1), in one instance being found on soil containing 38,000 parts per million of total salt in the top foot of soil, and it has been found growing luxuriantly with as high as 32,000 parts per million of total salts in the top foot of soil. Where growing luxuriantly, the soil has been found to contain 837 parts per million of sodium carbonate, and 3313 parts per million of sodium sulphate in the upper three feet of soil. It thus indicated a soil with a high content of black alkali. Where found in abundance the soil is generally of a heavy, sandy-loam or a clay-loam texture occurring on low-lying lands and reclaimable only at great expense. Because of the presence of black alkali the soil is puddled so badly that rainwater generally evaporates from it before it will penetrate. When found on the higher lands, the soil is generally underlain with a hardpan near the surface.

Tussock grass (*Sporobolus airoides*) sometimes forms a coarse, matty or tree-like growth, the trunks of which are often from 18 to 20 inches high. It forms feathery purple panicles in late summer and is relished by stock better than most any other native alkali-resistant plant. Ani-

mals eat only the grass part of the plant leaving the trunk-like stems behind. It is a good alkali indicator for the arid Southwest, but is not common north of the 40th parallel, or about the center of Utah and Nevada. It has been found growing in a soil with an alkali content of 31,190 parts per million in the upper four feet, although it makes its best growth with about 3000 parts per million

FIG. 10. — GREASEWOOD AND SHADSCALE. THESE PLANTS INDICATE ALKALI IN THE SOIL.

of total salts. Of the separate salts in soil on which the plants were growing vigorously, the following amounts were found:

Sodium carbonate	1437 parts per million
Sodium chloride	387 parts per million
Sodium sulphate	1227 parts per million

It has been found growing with over 10,000 parts per million of sodium chloride and 20,000 parts per million of sodium sulphate. The range of tolerance is great; hence, scattered individuals should not be taken to indicate excessive quantities of alkali, although when thick and

vigorous, especially when occurring along with other alkali indicators, it may be safe to call the land unsuitable for farming. It may occur on dry prairie soils where very small quantities of alkali are present.

Kern greasewood or bushy samphire (*Allenrolfea occidentalis*) is a shrubby evergreen bush 1 to 4 feet in height with numerous cylindrical, fleshy, practically leafless alternating branches, and with a large taproot. It is nearly always found on the low-lying, and generally clayey, soils with a plentiful supply of moisture. Soils on which it does well are usually saturated with water throughout the growing season, but may become "dry bogs" during part of the year. The salt content of such soils is almost invariably high, sometimes reaching over 30,000 (1, 2) parts per million of total salts with a good growth of the plant. It has been found to make a good growth in the presence of 300 parts per million of sodium carbonate, 13,000 parts per million of sodium chloride, and 17,000 parts per million of sodium sulphate. It grows with a higher sodium chloride content than any other plant known at present. Soils on which this plant forms the major growth are usually hopelessly alkaline; even salt bushes fail on the soils on which *Allenrolfea* does best. The heavy soils make reclamation by drainage difficult so that such soils can seldom be used profitably.

Dwarf samphire (*Salicornia subterminalis* and other species) is a nearly leafless plant with cylindrical, fleshy, many-jointed, opposite branches. All soils upon which it has been found are excessively alkaline. It grows well on land with a total salt content of 27,000 (1, 2) parts per million in the upper four feet. Analyses of the soil on which it was growing well showed it to contain 757 parts per million of sodium carbonate, 7852 parts per mil-

lion of sodium chloride, and 19,627 parts per million of sodium sulphate. Thus, it resists larger quantities of sodium chloride and sodium sulphate than most other plants. Both the seashore and the inland species indicate land which is useless for farming until reclaimed by prolonged draining, which in many cases is at present uneconomical.

Greasewood (*Sarcobatus vermiculatus*) is one of the most common alkali-indicating plants found on moist saline

FIG. 11. — THE BORDER BETWEEN GREASEWOOD AND SALT GRASS. THE LAND INCREASES IN ALKALI TOWARD THE SALT GRASS.

flats of the intermountain country. Viewed at a distance the patches of greasewood have a pleasant bright-green color decidedly in contrast to much of the darker or grayish alkali vegetation. Besides the numerous sharp spines which protect the small fleshy leaves from browsing animals, the plant is bitter and salty so that no useful animal will eat it. Although it has not been found on soil containing more than 8000 (4) parts per million of total salts in the upper feet, its large taproot has been found penetrating soil with nearly double this amount of salt (mostly

sodium chloride). Hilgard (2) reports 1170 parts per million of sodium carbonate, 230 parts per million of sodium chloride, and 2260 parts per million of sodium sulphate as being characteristic quantities of the common alkali salts present where the plant does best and that its presence "invariably indicates a heavy impregnation of land with black alkali or carbonate of soda" (2, page 542). Although the latter statement is generally true, it has been found on land showing only sulphates, and Kearney and others (4) found it growing on land in Utah without sodium carbonate as a characteristic salt. Kearney says it is not an infallible alkali indicator as it was found making its largest and thriftiest growth on dunes of pure sand. It is usually associated with a rich silty or sandy soil, moist in the upper foot and containing excessive quantities of salts. It will endure larger quantities of alkali than most alkali plants. Greasewood soils are sometimes too alkaline to permit profitable reclamation.

Alkali-heath (*Frankenia grandifolia campenstris*) is a perennial herb with opposite or clustered simple leaves and with a deep-rooted, flexible, wiry, rootstock. It is a hardy plant which often persists as a weed on cultivated land. Although it generally indicates strong alkali where it is growing luxuriantly, it will grow with a great variation in alkali content — from about 200 to 31,000 (1, 2) parts per million of total salts. The optimum quantities found by Hilgard (2) ranged from about 4000 to 17,600 parts per million in the upper four feet of soil. Of this amount 43 to 1224 parts per million was sodium carbonate, 360 to 636 parts per million sodium chloride, and 2158 to 17,220 parts per million sodium sulphate. Hilgard regards land that grows this plant to be unfit for crops without reclamation, although Mackie (5) says it will generally

contain comparatively small quantities of alkali, and "where this bush is found growing uniformly over an area to the exclusion of the most resistant alkali indicators, the alkali is found below the surface from 1 to 3 feet in a free sand or sandy loam soil. This "land yields crops" of alfalfa and grain or orchards and can be kept free from injurious quantities of alkali by proper methods of irrigation and drainage."

Cressa (*Cressa cretica truxillensis*) is a perennial herb with a woody base from which many leafy branches extend. The leaves are almost sessile and are characterized by their silky, villous, and hairy nature. Cressa is a common sea-coast plant in many of the arid parts of the world. In the United States it is found along the Texas coast and scattered throughout California, extending at least to the Arizona line. Alkali-heath has been found growing with a higher total salt content than Cressa, but Cressa is a surer indicator of irreclaimable alkali land because the lower limit in which it grows is much higher. Although sulphates predominate in Cressa soil, it will be noticed that it does well with chlorides in quantities dangerous to ordinary crops.

Salt-bush, or Shadscale (*Atriplex* spp.), is of two types — the perennial, which is generally bushy or shrubby, and the type that occurs as an annual weed. The leaves are usually alternate, simple, and often silvery, scurfy, or having an ashen-gray color, the bush type often being mistaken for sagebrush. The bush belongs to the same family as the beet and it can readily be detected by its beet-like seeds. A number of the *Atriplex* species grow in soil which contains little or no alkali, but the moisture conditions are generally unfavorable on any soil which has a vigorous growth of them, and most of the common

species of the western arid country produce their most luxuriant growth in the presence of dangerous quantities of alkali. Land upon which saltbush — either bush or weed — grows best is generally light and free from alkali in the top foot or so; but is underlain by heavier soil which is likely to contain large quantities of alkali. Such soils are seldom underlain by hardpan and are usually porous

FIG. 12. — THE LAST PLANT TO ABANDON AN ALKALI FLAT

so that they may be reclaimed by flooding. Crops can as a rule be grown on the soil on which saltbush occurs, but there is likely to be a rise of alkali where great care is not taken to prevent it. The alkali is likely to be of the white type entirely, although it will grow with as much as 1200 parts per million (2) sodium carbonate in the soil. The annual *Atriplexes* are similar to the bushes in color and appearance of the leaves but do not have the persistent woody base of the latter. They range in height from about 1 to 4 feet. Land upon which *Atriplex* forms the principal vegetation should be looked upon with suspicion

until borings and analyses show it to be free from alkali, unless plans are laid for immediate drainage. Soils containing as much as 10,000 parts per million (3) of salts — mostly sodium chloride — but with the upper foot or so dry and free from alkali, have been found to produce excellent saltbushes. They grow equally well in the presence of nearly 8000 parts per million (2) of sodium sulphate. Because of the porous, dry, upper soil, and the tendency to have alkali beneath, such soils are ordinarily unfit for dry-farming.

Kochia, or White Sage (*Kochia bestita*), is a low-lying shrub with its branches close to the ground and with a strong taproot which, however, seldom penetrates to a greater depth than one foot. New shoots are sent up from its roots. Its leaves are alternate, sessile, villous, narrow, and entire. The branches as well as the leaves are frequently covered with short woolly hairs. It is found in the intermountain country from Colorado to Nevada. Land upon which it occurs is usually free from injurious salts in the upper foot or so, some observations showing the upper foot to contain about 1200 parts per million of total salts (4), but the soil beneath which its roots feed is almost invariably impregnated with so much alkali that deeper rooting plants, such as the sagebrush (*Artemesia tridentata*) cannot exist. Kochia itself is not alkali resistant, but where it exists to the exclusion of sagebrush and similar nonresistant plants the lower depths of soil are either high in alkali or underlain at shallow depths with a hardpan which prevents deep penetration of roots. Either condition makes the land undesirable for general farming because of the likelihood of a rise of alkali. Kochia land frequently contains some black alkali and the soil is often rather impervious so that reclamation is difficult.

Salt-grass (*Distichlis spicata*) occurs throughout the world, being the most common plant found on alkali lands. It grows well on land so free from alkali that some of the common alkali-loving plants such as greasewood fail, but can withstand and make a good growth with as much as 24,000 parts per million of total salts in the soil. No preference is shown for any of the alkali salts. The highest quantities found in soil on which it grew well are as follows:

Sodium carbonate	8517 parts per million
Sodium chloride	4398 parts per million
Sodium sulphate	2750 parts per million

These quantities are only suggestive, however, as great variations are found wherever the grass is found. It is a poor indicator of alkali either quantitatively or qualitatively, but when taken together with other plants growing with it something of the nature of the land may be indicated.

Other Plants. — A number of other plants which do well on alkali soils, but which are not so distinctive as a general rule, are the following: Rabbit brush or false golden-rod (*Chrysothamnus* spp.) which is cluster-flowered and woody-based; Plowman's wort (*Pluchea camphorata* (1) DC.), a spicy or salt march Fleabane found in the marshes of Texas and Mexico as well as on the eastern and southern coast of the United States; little rabbit brush (*Isocoma veneta Grey*) a perennial composite bush about 18 inches high with a sparse, smooth, dark-green foliage usually growing in deep loamy soils with a medium salt content; spike weed (*Hemizonia pungens*), a yellow-flowered spiny composite which grows in a dense mass to the exclusion of most other plants on comparatively weak alkali land with fair drainage; arrow or irrigation

weed (*Pleuchea borealis*), a composite with a brush-like head supported on a stem 4 to 8 feet high which tolerates a limited quantity of alkali on a porous, deep, well-drained soil. Plants other than those discussed above are characteristic of alkali lands in their respective districts, but sufficient data are not at hand to determine their exact reliability as to alkali resistance. Many other plants

FIG. 13. — PLANTS GROWING AT THE TOP OF SAND DUNES, THE ONLY PLACE WHERE THE ALKALI IS NOT TOO STRONG FOR PLANT GROWTH.

grow upon alkali land during the wet season when the soil solution is dilute, but none of them can be classified as distinctive in determining soil alkali conditions.

Description of Alkali-indicating Plants. — *Allenrolfea occidentalis* (*Watson*) *Kinitze.* — Bushy samphire or kern greasewood is a shrubby evergreen bush 1 to 4 feet high with numerous cylindrical, jointed, fleshy, practically leafless alternating branches. The leaves are triangular or scale-like in shape. It has a large taproot and but few lateral roots. Generally found in low-lying moist lands from the 40th parallel southward, the northern plants

generally being somewhat more dwarfed than those farther southward.

Artemesia spinescens (*Eat.*). — Bud brush has the woolly covering and the general appearance of common sagebrush, but is dwarfed — 4 to 16 inches high — and is spiny. Found throughout the West.

Aster angustus. — Perennial herb with stems 4 to 12 inches high, branching, leafy. It has the typical aster design of flowers, but they are smaller with the corolla of the ray flowers reduced to the tube and much shorter than the elongated style.

Aster pauciflorus. — Stems 8 to 10 inches high from a slender root-stock, single and bearing few heads. Leaves moderately fleshy and elongated in shape.

Aster xylorhiza. — Perennial with deep-set woody roots supporting several or solitary stems. The heads are large with conspicuous white rays. Stems leafy, about 4 to 8 inches high, terminating in a short flower stalk.

Atriplex. — Salt-bush or shadscale (*Atriplex* spp.), perennial and annual types — perennial usually bushy or shrubby, and annual usually taller and more weed-like. Leaves generally alternate, simple, and often silvery or white scurfy or having an ashen-gray color. Bush is often mistaken for sagebrush, but several species have spines or thorns.

Crepis glauca. — Perennial herb with few small yellow flowers borne upon a leafless or practically leafless long stem. It is from 8 to 24 inches high and characterized by its covering of white powdery material on leaves and elsewhere and lack of pubescence.

Chrysothamnus spp. — Rabbit brush, or false golden-rod, are shrubby plants with woody base on which shoots holding cylindrical, often hairy, but sometimes resinous

leaves, are found. Clusters of yellowish flowers like those of golden-rod but lacking the ray-flowers around the margin of the clusters as in the golden-rod. The most notable alkali-loving species of this group is *Chrysothamnus linifolius*, which is found along wet banks of alkali streams; *C. Wyomingesis* and *C. plattensis* are found more on alkali plains.

Cressa truxillensis. — A perennial herb with a woody base from which many leafy branches extend. The leaves are oblong or lance-shaped with very short stems, silky, hoary, or villous covering. It is found mostly near the seashore in Texas, but in California is found inland throughout the state.

Distichlis spicata. — Salt grass is the common salt grass of alkali soils.

Dodecatheon salinum. — Shooting star or American cowslip has a short crown from which spring numerous slender matted roots. Leaves about 1 inch in length, wide-spreading or ascending, smooth, and rather elliptic. Flowers borne upon a stem about 4 to 8 inches long are of a yellowish white with an indistinct purplish ring near the base and has segments of lilac-purple in places.

Elymus salinus (*Jones*). — Wild rye is a coarse perennial grass with flat rough leaves. It forms in dense bunches of rigid, wiry grass standing from 1 to 2 feet high. Found in Utah and Wyoming frequently in saline places.

Flaveria angustifolia. — This is a smooth-appearing herb with clusters of yellowish flowers and opposite stemless leaves. It is 8 to 20 inches in height.

Frankenia grandifolia. — Alkali-heath is a perennial herb with a woody base and deep-rooted flexible, wiry, root-stocks. Numerous opposite or clustered simple rather thick, lance-shaped leaves from 3 to 6 inches long. Largely

confined to the Southwest as far north as Arizona and southern Nevada.

Glaux maritima. — A salt marsh, small leafy-stemmed perennial herb propagated by slender running root-stocks. Stems about 2 to 4 inches high. Leaves oval-shaped. Flowers purplish or white.

Halerpestes cymbalaria. — Trailing buttercup is so named because of long-jointed stolons from which spring new plants at each node. Low-growing, rather hairy, with yellow flowers and oblong cylindrical heads of fruit; found in moist places. Leaves broadly egg-shaped, coarsely toothed and clustered at the base of the flower stems or nodes of the stolons. Flower stem 2 to 4 inches high.

Hemizonia pungens. — Spike-weed is a yellow-flowered much-branched spiny composite from a few inches to 2 or 3 feet high. The leaves are arranged opposite along hairy or bristly branches. Found in dense patches frequently to the exclusion of other plants on well-drained generally mildly alkali lands of southern California.

Hordeum nodosum (*L.*). — Wild barley, sometimes called foxtail, belongs to the same group as common barley, but is seldom taller than 24 inches. Has a narrow spike which is usually dark green or purple, and is awnless.

Kochia. — White sage (*Kochia vestita*), dull gray plant about 5 to 6 inches high with a shrubby base and roundish densely hairy leaves. Viewed at a distance, bunches give appearance of gray blanket. Flowers solitary or few in the axils. Ovary oblong nearly equaling the calyx. Ripened ovary membranous. Strong taproot to about 1 foot deep.

Lepidium montanum (*Nutt.*). — Pepper grass is a smooth appearing biennial herb with small white petals. The stems spring from the crown of the thick root and extend

to a distance of 4 to 8 inches from the base. The leaves are toothed or have numerous leaflets along the main axis of the leaf.

Myosurus apetalus (*Gay*). — Mousetail is a very small annual herb with a tuft of spatulate entire leaves, with no apparent stem, surrounding a simple solitary five-petaled flower borne on a stem 1 to 2 inches high. It is found in wet saline places throughout the western states.

Pluchea borealis. — Arrow, or irrigation, weed is a composite with a brushlike head supported on numerous hairy-covered, silvery, willow-like branches 4 to 8 inches high. Common along sandy or porous, deep, well-drained banks of streams or similar soils elsewhere.

Pluchea camphorata (*L*) *DC*. — Plowman's wort is a spicy, or salt marsh, Fleabane found in the marshes of Texas and Mexico.

Pyrrocoma (*Nutt.*). — Perennial herbs with alternate leaves and showy many-flowered heads of yellow flowers in the axils of the upper leaves or at the end of the branch. Plants generally from 4 to 8 inches high. Found throughout the Rocky Mountains.

Salicornia spp. — Dwarf samphire is a low scaly-leafed but nearly leafless fleshy plant with cylindrical, many-jointed stems, and opposite branches. Frequent on saline land near lakes and ponds.

Sarcobatus vermiculatus. — Greasewood of intermountain country found on moist saline flats, patches of which generally appear a much brighter green than most saline vegetation except in fall when it changes to a yellowish color. It has numerous sharp spines at the base of which are small fleshy leaves with a bitter salty taste. It is a rigidly branched shrub about 2 to 8 feet high with a smooth whitish bark.

Scirpus spp. — Rushes are tufted plants with creeping root-stocks, the stem sheathed or leafy at the base and the spikelets in lateral cluster. Saline soils growing these plants are generally irreclaimable without considerable expense.

Spartina gracilis. — Marsh grass is a perennial with simple and rigid slender reed-like stems coming from extensively creeping scaly root-stocks. Stems generally 8 to 23 inches high and somewhat taller than the spreading, two-ranked, rough, and rigid leaves at its base. Spikes 4 to 10, mostly sessile, closely appressed to the nearly smooth rachis.

Sporobolus airoides. — Tussock or dropseed, or purple top grass, has a stout coarse and rigid base or trunk often 18 to 20 inches high. The tufts of grass are often 1 to 3 feet in height. Open, feathery, pyramidal panicles with a purplish tinge in late summer are borne from the base trunk. Leaves smooth beneath but harsh above and taper gradually from base to a fine point somewhat rolled inwardly at the end.

Suaeda spp. — Inkweed, or saltwort, perennial shrub, with small, fleshy, stem-like leaves. Growing plants generally 1 to 2 feet in height but the dark-colored brush left when the plant ceases growth in the winter lies close to the surface of the ground.

Triglochin maritima. — Arrow grass gives the appearance of an arrow because of a naked jointless stem bearing an arrowhead shaped greenish flower and having cylindrical rush-like leaves at the base which are shorter than the flower stem. About 1 to 3 feet in height and rather stout appearing. *T. palustris* similar to above but seldom reaches a height greater than 1 foot and the basal leaves are narrower than 2 mm., while leaves of above are from 2 to 4 mm. wide.

Valeriana furfurescens (*Nels.*). — The roots of this plant are slender and peculiarly scented, leaves entire, flowers minute and numerous with greenish yellow corolla. Fruit hairless, rough, and scaly. Found mostly in saline meadow lands.

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Also consult standard books on Botany.

CHAPTER VII

CHEMICAL METHODS OF DETERMINING ALKALI

THERE are so many distinctly different methods of making chemical analyses of soils that it is very difficult to compare the work of the various investigators who have studied alkali under field conditions. The wide variations so often noted between results of investigators in different places may be accounted for in part by the differences in methods of determining the quantity of alkali present. It is necessary that the method used be known before intelligent interpretation of analyses can be made. In the interest of uniformity it would be highly desirable to adopt standard methods. Before this can be done, it will be necessary to make a careful study of the various methods in order that the best one to secure uniformly accurate results may be chosen.

Preparing the Solution. — Probably the greatest variation in methods of analyzing alkali soil is found in making the soil extract. The soluble salts are dissolved with water and not with the stronger dissolving agents that are used in making a complete analysis of a soil, since it is the water-soluble salts that come under the designation of alkali. The principal variation in methods consists in the relative quantities of water and soil used, the time of agitation, the time allowed for settling, and the method of filtering. There are certain other methods, such as ex-

tracting the solutions with oil or by pressure or centrifugal force, which are not in general use as yet, the great drawback being that little more than the free water can be obtained.

King and his associates in their studies of soil nitrates used a method which, with a number of amendments, has been used extensively by later investigators. Schreiner and Failyer (9) describe a modification of this method which has probably been used more widely than any other. They discuss it as follows:

"If comparable results are to be obtained, it is essential in preparing the soil extract to follow as nearly as practical a uniform procedure. The volume of water used and the time of its action are necessarily conventional. The ratio of five parts of water to one part of soil has been adopted in procuring solutions of the readily water-soluble salts in many of the soil studies. The mixture is agitated three minutes and allowed to stand twenty minutes before filtering. The exact procedure when the soil to be examined is still in the moist state as collected in the field varies slightly from that when it is air-dried or oven-dried. All results, however, are stated on a uniform basis, preferably on the dry soil. The results from a moist soil are not comparable with those obtained from a dried soil, although both be stated in terms of dry soil, owing to the fact that dried soils give a somewhat greater concentration of soluble salts in the soil extract.

"**From Moist Soil.** — The moist samples taken from typical and comparable portions of the field are well broken up and mixed in a granite-ware basin or porcelain dish. Two 100-gram portions of this composite are then weighed out on a balance capable of weighing accurately to within 0.1 gram. One of these portions is for the moisture de-

termination. It is thoroughly dried in an oven and the content of moisture thus obtained taken into consideration, if the results of the analyses of the solution are to be expressed in terms of the dry soil. The calculation to parts per million of dry soil is readily made by means of the following formula:

$$S = \frac{s(500 + W)}{(100 - W)},$$

where S is the parts per million of the dry soil, s the parts per million of the soil solution as found by analysis, and W is the amount of moisture in grams, in the 100 grams of the moist soil sample used in making the solution as described below. If it should be desired to calculate the strength in parts per million of the actual soil moisture as found in the above moisture determination, the following formula is applied:

$$M = \frac{s(500 + W)}{W},$$

where M is the parts per million of the soil moisture, s and W as in the previous formula.

"Measure out 500 cc. of water, and after transferring the other 100-gram portion of the moist soil to a mortar add enough of the water to make a thick paste, working well with the pestle so as to break down all granulations and to have the soil well puddled. The balance of the 500 cc. of water is then added and the mixture well stirred with the pestle during three minutes. If more samples are to be worked in the mortar, the mixture is transferred to a jar and is allowed to stand twenty minutes, during which the coarser particles settle. The supernatant turbid liquid is then poured into one of the filtering cham-

bers fitted up with a well-washed Pasteur-Chamberland filter tube.

"**From Dry Soil.** — If the soil sample to be used is already air-dry and it is desired to give the results in terms of the completely dried soil, it will be necessary to determine the amount of moisture still present by heating a 100-gram portion in the drying oven and making the proper allowance in the final calculation, using the formula given above. If the soil to be examined is oven-dried the whole composite is removed from the oven while hot and pulverized in a large mortar, screening through a 2-mm. seive. A 100-gram sample is then weighed out and poured into a glass-stoppered bottle. Add 500 cc. of distilled water to the soil in the bottle and shake vigorously for three minutes to insure a thorough puddling of the soil particles. The mixture is allowed to stand twenty minutes for the coarser particles to subside and is then filtered. The mortar may be used as described above, but it is more convenient to use the shaking bottle when working with dry pulverulent soils."

Methods differing from the above for extracting soil solutions, as summarized by Hare (7) are: the *Arizona* method in which 50 grams of soil are added to 800 cc. of water and heated on a water bath for 10 hours when enough water is added to make the solution up to 1000 cc. and the solution allowed to stand over night before being filtered; the *California* method in which 150 grams of soil are added to 300 cc. of water and after shaking allowed to stand 12 hours; the *Montana* method in which 50 grams of soil are added to 500 cc. of water, shaken and allowed to stand over night; the *Texas* method in which 200 grams of soil are added to 1000 parts of water and shaken occasionally for 2 hours; and the *Utah* methods, in the

TABLE XI. COMPARISON OF RESULTS OBTAINED BY DIFFERENT METHODS

Determinations	Soil No.	*A* California Method	Per cent of Arizona Method	*B* Montana Method	Per cent of Arizona Method	*C* Bur. Soils (Bul. 31) Method	Per cent of Arizona Method	*D* Texas Method	Per cent of Arizona Method	*E* New Mexico Method	Per cent of Arizona Method	*F* Utah Method	Per cent of Arizona Method	*G* Arizona Method
Total solids, per cent	5258	.531	65.0	.551	67.5	.528	64.7	.555	68.0	.584	71.6	.632	77.4	.816
Chlorides as NaCl, per cent	....	.112	90.3	.109	87.9	.105	84.6	.112	90.3	.107	86.2	.114	91.9	.124
Alkalinity as Na_2CO_3, per cent.	....	.230	65.7	.257	73.4	.221	63.1(1)	(4)	....	.283	80.8	.394	112.5	.350
Total solids, per cent	5259	.046	22.1	.070	33.6	.069	33.1	.068	32.6	.094	45.2	.116	55.7	.208
Chlorides, as NaCl, per cent	....	.004	100.0	.004	100.0	.004	100.0	.004	100.0	.004	100.0	.004	100.0	.004
Alkalinity as Na_2CO_3, per cent.	....	.023	32.3	.048	67.6	(2)	....	(5)	....	....	....	.081	114.0	o .071
Total solids, per cent	5260	3.008	67.9	3.715	83.9	3.618	81.7	3.698	83.5	3.429	77.4	4.192	94.7	4.426
Chlorides as NaCl, per cent	....	.283	88.4	.288	90.0	.297	92.8	.295	92.1	.304	95.0	.300	93.7	.320
Alkalinity as Na_2CO_3, per cent.	....	.017	....	.013	....	(3)	....	(6)	....	....	....	.038	....	(.604 $CaSO_4$)

(1) Not including .025% $NaHCO_3$
(2) " " .071% "
(3) " " .033% "
(4) 249.6 parts $CaCO_3$ per 100,000
(5) 44.0 " " " "
(6) 15.0 " " " "

first of which 50 grams of soil are added to 500 cc. of water and in one case agitated for 5 minutes, and in the other case shaken intermittently for 24 hours, while in the second method 50 grams of soil are added to 1000 parts of water and after shaking for 8 hours allowed to stand over night.

From comparisons of methods at the Utah Station, the proportion of soil to water influenced the quantity of carbonate found, but had little or no influence on chlorides or sulphates.

After the solution has been in contact with the soil for the desired length of time, it is poured into a Pasteur-Chamberland filter and filtered under an air pressure of 30 to 40 pounds per square inch. The first 50 to 200 cc. of the filtered solution are discarded, after which the desired quantity is collected and bottled until needed for making the tests of the different constituents.

Determining Total Solids. — The ordinary method of determining the total soluble salts in the extracted solutions is to evaporate 20 to 50 cc. of the solution to dryness in a weighed evaporating dish over a sand or steam bath. Some chemists gently ignite the residue further to purify the salts of undesirable material, while some re-dissolve the residue to get the soluble alkali salts and help eliminate calcium and magnesium salts. The Bureau of Soils does not determine the total salts by evaporation and declares it to be unreliable.

In Table XI is shown the total salts and the various constituents of alkali as determined by the different methods on alkali soils in Arizona (12).

Carbonate and Bicarbonate Determination. — The method for determining the carbonate and bicarbonate used by the Bureau of Soils (9) is described as follows:

"One portion of the solution will serve for the determination of both carbonate and bicarbonate. The method depends upon the different actions of phenolphthalein and methyl orange in the neutralization of these two substances. Potassium hydrogen sulphate solution is used for titrating, the first step being the phenolphthalein as indicator. The reaction is expressed by the following equation:

$$Na_2CO_3 + KHSO_4 = KNaSO_4 + NaHCO_3.$$

The point of neutrality is shown when all carbonate present is converted into bicarbonate. The second step is the titration of the bicarbonate formed in the first step together with that existing originally in the solution, using methyl orange as indicator. This reaction is expressed by the following equation:

$$NaHCO_3 + KHSO_4 = KNaSO_4 + H_2CO_3.$$

The point of neutrality is shown in this case when all bicarbonate has been decomposed." The total titration for bicarbonate, less the titration for the carbonate, gives the titration for the bicarbonate originally present.

This and certain other methods for determining carbonates does not always prove satisfactory as it does not distinguish between the sodium and the noninjurious calcium and magnesium salts.

The New Mexico Station uses the above method for determining the carbonates, but also determines the calcium and magnesium and combines these bases with carbonates before determining the sodium salts of the carbonate radical. With the exception that sulphuric acid is used in the place of potassium acid sulphate and that methyl orange is the indicator, this is also one of the methods used in Utah.

In the work at California no distinction has been made between the carbonate and the bicarbonate of soda. Their method of first evaporating the solution, then igniting the residue, and finally redissolving the salts before titrating with sulphuric acid, using methyl orange as the indicator, eliminates most of the calcium and magnesium. After this the solution is titrated with sulphuric acid, and the difference between the sodium carbonate added and that indicated by the titration shows the sodium carbonate present originally. If there is a deficit, the quantity of calcium and magnesium carbonate in excess is shown.

Acting on the assumption that all carbonates and bicarbonates were combined with sodium when in the soil, the Utah Station titrates the original solution with sulphuric acid and states the results as sodium carbonate. Where the solution remains in contact with the soil but a few minutes, it is assumed that the less soluble lime and magnesium salts will be present to only a slight extent, but where the agitation is continued for long the results are high compared with other methods on account of the presence of carbonate other than those of sodium.

Chloride Determination. — The method used in practically all places for determining chloride is to titrate 10 to 50 cc. of the original solution with standard silver nitrate solution, using potassium chromate as the indicator. The results are expressed as the sodium salt. As shown in Table XI, the results by the different methods are fairly uniform, although by heating to get the solution, as is done by the Arizona method, the results are somewhat higher in most cases than with the other methods. An excess of silver nitrate titrated back with ammonium sulfocyanide is sometimes used, but it is rather hard to read in brown solutions. The turbidity method for chlorides is little used.

Sulphate Determination. — The most common method in use for determining sulphates is to acidify the solution with a few drops of hydrochloric acid and after bringing the solution to boiling, to add a few cubic centimeters of boiling standard barium chloride. The solution is kept boiling for about an hour and then filtered through an ordinary filter paper and the precipitate thoroughly washed with hot water. The precipitate and the filter paper are then placed in a weighed crucible which is heated until all volatile matter is driven off. After this the crucible is reweighed and the difference as barium sulphate calculated first to calcium and magnesium and the remainder to sodium, if the former bases have been determined, but otherwise the sulphates are all expressed as sodium sulphate.

Turbidity and colorimetric methods for sulphate determination have been employed to a slight extent, but they are not in common use. In certain places, notably at the California Station, the difference between the total solids and the sum of the carbonates and the chlorides has been expressed as sodium sulphate. As the sulphates are least harmful, and in certain localities seldom present in injurious quantities, they are frequently omitted from analyses of alkali.

Nitrate Determination. — Nitrates are seldom determined in alkali investigations, but under a few conditions such as prevail in parts of Colorado and Utah, they reach toxic concentrations, and it is therefore desirable that the quantity present be known. The method for nitrate determination, which has been most extensively used in the past, is discussed by Schreiner and Failyer (9) as follows:

"The nitrates are best determined by means of the color produced by the action of phenoldisulphonic acid

and making alkaline with ammonia. Chlorides, when present in considerable quantities, interfere quite markedly with the determination of nitrates and must be previously removed. This is best accomplished by means of silver sulphate free from nitrates. This can be added in the solid form, thus avoiding dilution of the original solution. The silver sulphate is tested for nitrates by treating some of the solid salt with the phenoldisulphonic acid reagent, diluting with water and adding ammonia water. No yellow color should be produced. The silver sulphate as found in the market frequently contains nitrates in amounts sufficient to vitiate all results, and it is, therefore, advisable to prepare it specially for this work.

"The presence of some kinds of organic matter also interferes seriously with the determination of nitrates by this method. In some cases it is the foreign color only which is produced by the strong acid, but often the action is of more vital importance, as a considerable loss of nitrates occurs, possibly due to oxidation of the organic matter by the nitrate instead of the nitration of the phenoldisulphonic acid. In some cases it is advisable to reduce the nitrates to ammonia by means of the copper-zinc couple. The ammonia is distilled off and determined colorimetrically. The ammonia originally present in the solution must be determined separately and deducted. Nitrites are likewise reduced to ammonia and must be allowed for if present.

" **Analytical Process.** — Evaporate 50 cc., or other convenient quantity, depending upon the amount of nitrate present, to dryness in a porcelain dish on a water bath, removing the dish as soon as it is completely dry. Add 1 cc. of the phenoldisulphonic acid reagent and stir thoroughly with the rounded end of a glass rod so as to

loosen the residue and bring the acid well in contact with every portion of it. The time of action on the nitrate should be about ten minutes. At the end of this time the acid is diluted with about 15 cc. of water and made alkaline with ammonium hydroxide, a yellow color being developed when the solution becomes alkaline. This is then diluted to 50 cc. or 100 cc. and compared with the standard colorimetric solution. If the color is too intense for direct comparison with this standard, an aliquot portion may be taken and diluted to definite volume and the strength of this determined."

To clear the soil extracts, Greaves and Hirst (6) found the following methods to give good results: The addition of 2 grams of lime, ferric sulphate, ferric alum, sodium alum, or potassium alum to the soil-water mixture; filtering through Pasteur-Chamberland filter, or centrifuging.

To eliminate possible error due to the presence of chlorides or other inorganic materials, certain reduction methods have given better results than the above method. The iron reduction method, as described below, was found by Greaves and Hirst (6) to give more satisfactory results in the presence of inorganic salts and in the presence of organic matter than did other methods. The soil is first agitated for five minutes with five times its weight of water and clarified by one of the methods described above, preferably with alum.

"An aliquot part (100 cc.) of the supernatant liquid is pipetted off, and, together with 2 cc. of a saturated solution of sodium hydroxide, evaporated to about one-fourth of its original volume to free from ammonia. If urea is present, it is necessary to evaporate to dryness. To this is added 50 cc. of ammonia-free water, 5 grams of 'iron-by-hydrogen,' and 30 cc. of sulphuric acid (sp. gr. 1.35).

If less than 40 mg. of nitric nitrogen is to be determined, it is well to take a correspondingly smaller quantity of iron and sulphuric acid. The neck of the reduction flask is fitted with a 2-hole stopper through which passes a 50-cc. separatory funnel and a bent tube which dips into a vessel containing water to prevent mechanical loss. The acid is slowly added and allowed to stand until the rapid evolution of hydrogen is over and then heated to boiling for ten minutes. The contents of the side vessel should be returned to the reduction flask before the reaction is complete, thus insuring the complete reduction of any nitrates which may have been carried over with the first violent evolution of the hydrogen. The contents of the reduction flask are transferred to a Kjeldahl flask, neutralized with sodium hydroxide, and distilled into standard acid. The excess of acid is titrated back with standard alkali, lacmoid being used as indicator."

Nitrates should be determined immediately after sampling unless some sterilizing material, such as chloroform, is added to check bacterial activity.

Determination of Bases. — *Calcium.* — The common method for determining calcium is to heat a given quantity of the solution nearly to boiling, and, after adding a few drops of ammonia, to precipitate the calcium completely by adding, drop by drop, a hot solution of ammonium oxalate. The solution is kept at this temperature for about 2 hours after which two or three decantations with hot water from the beaker containing the solution are passed through a filter. The precipitate remaining in the beaker is dissolved with a few drops of hydrochloric acid, water is added, and the former process of adding ammonia and ammonium oxalate to reprecipitate the calcium is repeated. The solution, to-

gether with the precipitate, is then poured onto the same filter paper as before and thoroughly washed with hot water. Transfer paper to original beaker containing hot 1:10 sulphuric acid. After the paper has been immersed in the liquid it is brought up on the side of the beaker by means of a glass rod. Then the solution is titrated to the end point with potassium permanganate. The paper is now put back into the liquid and the titration finished. Some prefer to ignite to constant weight the precipitate left on the filter paper and calculate it as calcium oxide.

Magnesium. — Usually magnesium is determined by the method adopted by the Association of Official Agricultural Chemists which is as follows: "Evaporate the filtrate from the above determination on water bath to dryness and carefully heat to expel ammonium salts. Take up the residue, with 20 to 25 cc. hot water and about 5 cc. hydrochloric acid, filter, and wash. Concentrate to about 50 cc., cool, and add sufficient acid sodium phosphate to precipitate the magnesium; then add gradually ammonium hydroxide, with constant stirring, until the solution is distinctly alkaline. Test with acid-sodium-phosphate to be sure that sufficient has been added. Allow to stand one-half hour, then add gradually 10 cc. of strong ammonium hydroxide, cover closely to prevent escape of ammonia, and let stand in the cold. Filter after 12 hours, wash the precipitate free from chlorides, using 2.5 per cent ammonia water, dry, burn at first at moderate heat, then ignite intensely, and weigh as magnesium-pyro-phosphate ($Mg_2P_2O_7$)." If this precipitation is done from a hot solution there is less danger of tertiary magnesium phosphate being formed. Colorimetric and titration methods are used occasionally.

Sodium. — Sodium determinations are seldom made in

alkali studies because the process is long and because the quantity present can be roughly estimated by elimination when the other easier determinations have been made.

Other Methods of Determining Soluble Salts. — *The Electric Bridge.* — A modification of the Wheatstone bridge has been found of considerable value in determining the total salts in either soil or water in the field without chemical analysis. The theory upon which the instrument works is based upon the fact that the resistance of the solution varies with the concentration of its soluble salts. It has been found of great value for determining the total salts in soils which do not contain excessive quantities of organic matter, and especially where the salts are mostly sodium chloride and sodium sulphate. It becomes unreliable where the organic matter is high and it is necessary to determine the sodium carbonate separately from the other salts because the resistance is considerably different.

In using the instrument, the soil in the cup is first moistened until it becomes saturated or puddled and free from air, and if the soil is very dry it should be allowed to stand in this condition for about 20 minutes. The cup, which is just levelful of the saturated soil, is placed between the clips through which the current passes, and the pointer is moved back and forth until the neutral point is reached where the buzzing in the receiver is at a minimum. The instrument has coils with 10, 100, and 1000 ohms resistance, and it is necessary to adjust the coils until the proper resistance is found. "The resistance of the cup contents is found by multiplying the resistance of the comparison coil used, shown on the rotary switch, by the number on the scale opposite the pointer, when a balance is established. Thus, if the comparison coil

is 100 and the scale reading 0.92, the resistance of the cup is 92 ohms. When the extra 100-ohm coil is used with the cup, the 100 ohms added must be subtracted from the resistance read on the scale. Thus if the 100 ohms is in series with the cup and the scale reads 1.2, while the comparison coil shows 100 ohms, then the resistance of the cup and coil is 120 ohms. Subtracting the 100 ohms of the coil leaves 20 ohms as the resistance due to the cup. The resistance of the cup contents must be corrected to a temperature of 60° F. To do this, immediately after reading the resistance, a thermometer is stuck into the cup and read after two minutes. The resistance at the temperature found is then corrected to 60° F. (by means of Table XII). Having found the resistance of the cup contents, the percentage of salt may be determined for soils by use of Table XIII, and for soil solutions by Table XIV." In making temperature corrections, which must be done before determining the parts per million of salts present, the column containing the temperature of the soil is found. The sum of the resistances of the separate digits corresponding to the resistance at the given temperature of the soil is found and the sum of the resistances of the separate digits corresponding to the resistance at the given temperatures is added. "As an example of its use, suppose the resistance to be 1349 ohms at 72° F. On the left-hand side of the table find 72° F., then opposite under the columns marked '1000' will be found 1170 ohms at 60° F. as the value of 1000 at 72° F.; 3000 ohms at 72° F. will be found equal to 3510 at 60° F.; hence 300 is equal to 351 at 60° F., 40 is equal to 46.8 ohms at 60° F., and 9 is equal to 10.5 ohms at 60° F.," and the sum of these resistances at 60° F. is equal to 1578.3 ohms, which is the desired resistance.

TABLE XII. REDUCTION OF THE ELECTRICAL RESISTANCE OF SOILS TO A UNIFORM TEMPERATURE OF 60° F.

°F.	1000	2000	3000	4000	5000	6000	7000	8000	9000
32.0	625	1,250	1,875	2,500	3,125	3,750	4,375	5,000	5,625
32.5	632	1,265	1,897	2,530	3,163	3,795	4,425	5,059	5,691
33.0	640	1,280	1,920	2,560	3,200	3,840	4,480	5,120	5,760
33.5	647	1,294	1,941	2,588	3,235	3,883	4,530	5,177	5,824
34.0	653	1,306	1,959	2,612	3,265	3,918	4,571	5,224	5,877
34.5	660	1,320	1,980	2,640	3,300	3,960	4,620	5,280	5,940
35.0	668	1,336	2,004	2,672	3,340	4,008	4,676	5,344	6,012
35.5	675	1,350	2,025	2,700	3,375	4,050	4,725	5,400	6,075
36.0	683	1,366	2,049	2,732	3,415	4,098	4,781	5,464	6,147
36.5	690	1,380	2,070	2,760	3,450	4,140	4,830	5,520	6,210
37.0	698	1,396	2,094	2,792	3,490	4,188	4,886	5,584	6,282
37.5	704	1,408	2,112	2,816	3,520	4,224	4,928	5,632	6,336
38.0	711	1,422	2,133	2,844	3,555	4,266	4,977	5,688	6,399
38.5	717	1,434	2,151	2,868	3,585	4,302	5,019	5,736	6,453
39.0	723	1,446	2,169	2,892	3,615	4,338	5,061	5,784	6,507
39.5	729	1,458	2,187	2,916	3,645	4,374	5,103	5,832	6,561
40.0	735	1,470	2,205	2,940	3,675	4,410	5,145	5,880	6,615
40.5	742	1,484	2,226	2,968	3,710	4,452	5,194	5,936	6,678
41.0	750	1,500	2,250	3,000	3,750	4,500	5,250	6,000	6,750
41.5	757	1,514	2,271	3,028	3,785	4,542	5,299	6,056	6,813
42.0	763	1,526	2,289	3,052	3,815	4,578	5,341	6,104	6,867
42.5	770	1,540	2,310	3,080	3,850	4,620	5,390	6,160	6,930
43.0	776	1,552	2,328	3,104	3,880	4,656	5,432	6,208	6,984
43.5	782	1,564	2,346	3,128	3,910	4,692	5,474	6,256	7,038
44.0	788	1,576	2,364	3,152	3,940	4,728	5,516	6,304	7,092
44.5	794	1,588	2,382	3,176	3,970	4,764	5,558	6,352	7,146
45.0	800	1,600	2,400	3,200	4,000	4,800	5,600	6,400	7,200
45.5	807	1,614	2,421	3,228	4,035	4,842	5,649	6,456	7,263
46.0	814	1,628	2,442	3,256	4,070	4,884	5,698	6,512	7,326
46.5	821	1,642	2,463	3,284	4,105	4,926	5,747	6,568	7,389
47.0	828	1,656	2,484	3,312	4,140	4,968	5,796	6,624	7,452
47.5	835	1,670	2,505	3,340	4,175	5,010	5,845	6,680	7,515
48.0	843	1,686	2,529	3,372	4,215	5,058	5,901	6,744	7,587
48.5	850	1,700	2,550	3,400	4,250	5,100	5,950	6,800	7,650
49.0	856	1,712	2,568	3,424	4,280	5,136	5,992	6,848	7,704
49.5	862	1,724	2,586	3,448	4,310	5,172	6,034	6,896	7,758
50.0	867	1,734	2,601	3,468	4,335	5,202	6,069	6,936	7,803
50.5	874	1,748	2,622	3,496	4,370	5,244	6,118	6,992	7,866
51.0	881	1,762	2,643	3,524	4,405	5,286	6,167	7,048	7,929
51.5	887	1,774	2,661	3,548	4,435	5,322	6,209	7,096	7,983
52.0	893	1,786	2,679	3,572	4,465	5,358	6,251	7,144	8,037
52.5	900	1,800	2,700	3,600	4,500	5,400	6,300	7,200	8,100
53.0	906	1,812	2,718	3,624	4,530	5,436	6,342	7,248	8,154
53.5	912	1,824	2,736	3,648	4,560	5,472	6,384	7,296	8,208
54.0	917	1,834	2,751	3,668	4,585	5,502	6,419	7,336	8,253

TABLE XII. (*Concluded.*)

°F.	1000	2000	3000	4000	5000	6000	6000	8000	9000
54·5	925	1,850	2,775	3,700	4,625	5,550	6,475	7,400	8,325
55·0	933	1,866	2,799	3,732	4,665	5,598	6,531	7,464	8,397
55·5	940	1,880	2,820	3,760	4,700	5,640	6,580	7,520	8,460
56.0	947	1,894	2,841	3,780	4,735	5,682	6,629	7,576	8,523
56.5	954	1,908	2,862	3,816	4,770	5,724	6,678	7,632	8,586
57.0	961	1,922	2,883	3,844	4,805	5,766	6,727	7,688	8,649
57·5	968	1,936	2,904	3,872	4,839	5,807	6,775	7,743	8,711
58.0	974	1,948	2,922	3,896	4,870	5,844	6,818	7,792	8,766
58.5	981	1,961	2,942	3,923	4,903	5,884	6,864	7,845	8,826
59.0	987	1,974	2,962	3,949	4,936	5,923	6,910	7,898	8,885
59·5	994	1,988	2,982	3,976	4,971	5,965	6,959	7,953	8,947
60.0	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000
60.5	1,006	2,013	3,019	4,026	5,032	6,039	7,045	8,052	9,059
61.0	1,013	2,026	3,039	4,052	5,065	6,078	7,091	8,104	9,117
61.5	1,020	2,040	3,060	4,080	5,100	6,120	7,140	8,160	9,180
62.0	1,027	2,054	3,081	4,108	5,135	6,162	7,189	8,216	9,243
62.5	1,033	2,067	3,100	4,134	5,167	6,201	7,234	8,268	9,302
63.0	1,040	2,080	3,120	4,160	5,200	6,240	7,280	8,320	9,360
63.5	1,047	2,094	3,141	4,188	5,235	6,282	7,329	8,376	9,423
64.0	1,054	2,108	3,162	4,216	5,270	6,324	7,378	8,432	9,486
64.5	1,060	2,121	3,181	4,242	5,302	6,363	7,423	8,484	9,545
65.0	1,067	2,134	3,201	4,268	5,335	6,402	7,469	8,536	9,603
65.5	1,074	2,148	3,222	4,296	5,370	6,444	7,518	8,592	9,666
66.0	1,081	2,162	3,243	4,324	5,405	6,486	7,567	8,648	9,729
66.5	1,088	2,176	3,264	4,352	5,440	6,528	7,616	8,704	9,792
67.0	1,095	2,190	3,285	4,380	5,475	6,570	7,665	8,760	9,855
67.5	1,102	2,205	3,307	4,410	5,512	6,615	7,717	8,820	9,922
68.0	1,110	2,220	3,330	4,440	5,550	6,660	7,770	8,880	9,990
68.5	1,117	2,235	3,352	4,470	5,587	6,705	7,823	8,940	10,058
69.0	1,125	2,250	3,375	4,500	5,625	6,750	7,875	9,000	10,125
69.5	1,133	2,265	3,398	4,530	5,663	6,795	7,928	9,060	10,193
70.0	1,140	2,280	3,420	4,560	5,700	6,840	7,980	9,120	10,260
70.5	1,147	2,285	3,442	4,590	5,737	6,885	8,032	9,180	10,327
71.0	1,155	2,310	3,465	4,620	5,775	6,930	8,085	9,240	10,395
71.5	1,162	2,325	3,487	4,650	5,812	6,975	8,137	9,300	10,462
72.0	1,170	2,340	3,510	4,680	5,850	7,020	8,190	9,360	10,530
72.5	1,177	2,355	3,532	4,710	5,887	7,065	8,242	9,420	10,597
73.0	1,185	2,370	3,555	4,740	5,925	7,110	8,295	9,480	10,665
73.5	1,193	2,386	3,579	4,772	5,965	7,158	8,351	9,544	10,737
74.0	1,201	2,402	3,603	4,804	6,005	7,206	8,407	9,608	10,809
74·5	1,208	2,416	3,624	4,832	6,040	7,248	8,456	9,664	10,872
75.0	1,215	2,430	3,645	4,860	6,075	7,290	8,505	9,720	10,935
75·5	1,222	2,445	3,667	4,890	6,112	7,335	8,557	9,780	11,002
76.0	1,230	2,460	3,690	4,920	6,150	7,380	8,610	9,840	11,070
76.5	1,237	2,475	3,712	4,950	6,187	7,425	8,662	9,900	11,137

TABLE XII. (*Continued.*)

°F.	1000	2000	3000	4000	5000	6000	7000	8000	9000
77.0	1,245	2,490	3,735	4,980	6,225	7,470	8,715	9,960	11,205
77.5	1,253	2,506	3,759	5,012	6,265	7,518	8,771	10,024	11,277
78.0	1,261	2,522	3,783	5,044	6,305	7,566	8,827	10,088	11,349
78.5	1,269	2,538	3,807	5,076	6,345	7,614	8,883	10,152	11,421
79.0	1,277	2,554	3,831	5,108	6,385	7,662	8,939	10,216	11,493
79.5	1,285	2,576	3,856	5,142	6,427	7,713	8,998	10,284	11,569
80.0	1,294	2,598	3,882	5,176	6,470	7,764	9,058	10,352	11,646
80.5	1,302	2,609	3,906	5,208	6,510	7,812	9,114	10,416	11,718
81.0	1,310	2,620	3,930	5,240	6,550	7,860	9,170	10,480	11,790
81.5	1,318	2,637	3,955	5,274	6,592	7,911	9,229	10,546	11,866
82.0	1,327	2,654	3,981	5,308	6,635	7,962	9,289	10,616	11,943
82.5	1,335	2,670	4,005	5,340	6,675	8,010	9,345	10,680	12,015
83.0	1,343	2,686	4,029	5,372	6,715	8,058	9,401	10,744	12,087
83.5	1,351	2,702	4,053	5,404	6,755	8,106	9,457	10,808	12,159
84.0	1,359	2,718	4,077	5,436	6,795	8,154	9,513	10,872	12,231
84.5	1,367	2,735	4,102	5,470	6,837	8,205	9,572	10,940	12,307
85.0	1,376	2,752	4,128	5,504	6,830	8,256	9,632	11,008	12,384
85.5	1,385	2,769	4,153	5,538	6,922	8,307	9,691	11,076	12,460
86.0	1,393	2,786	4,179	5,572	6,965	8,358	9,751	11,144	12,537
86.5	1,401	2,802	4,203	5,604	7,005	8,406	9,807	11,208	12,609
87.0	1,409	2,818	4,227	5,636	7,045	8,454	9,863	11,272	12,681
87.5	1,418	2,836	4,254	5,672	7,090	8,508	9,931	11,344	12,762
88.0	1,427	2,854	4,281	5,708	7,135	8,562	9,989	11,416	12,843
88.5	1,435	2,870	4,305	5,740	7,175	8,610	10,040	11,480	12,915
89.0	1,443	2,886	4,329	5,772	7,215	8,658	10,091	11,544	12,987
89.5	1,451	2,903	4,354	5,806	7,257	8,709	10,155	11,612	13,063
90.0	1,460	2,920	4,380	5,840	7,300	8,760	10,220	11,680	13,140
90.5	1,468	2,937	4,405	5,874	7,342	8,811	10,279	11,748	13,216
91.0	1,477	2,954	4,431	5,908	7,385	8,862	10,339	11,816	13,293
91.5	1,486	2,972	4,458	5,944	7,430	8,916	10,402	11,888	13,374
92.0	1,495	2,990	4,485	5,980	7,475	8,970	10,465	11,960	13,455
92.5	1,504	3,008	4,512	6,016	7,520	9,024	10,528	12,032	13,536
93.0	1,513	3,026	4,539	6,052	7,565	9,078	10,591	12,104	13,617
93.5	1,522	3,035	4,567	6,090	7,612	9,135	10,657	12,180	13,7 2
94.0	1,532	3,064	4,596	6,128	7,660	9,192	10,724	12,256	13,788
94.5	1,541	3,083	4,624	6,166	7,707	9,249	10,790	12,332	13,873
95.0	1,551	3,102	4,653	6,204	7,755	9,306	10,857	12,408	13,959
95.5	1,560	3,121	4,681	6,242	7,802	9,363	10,923	12,484	14,040
96.0	1,570	3,140	4,710	6,280	7,850	9,420	10,990	12,560	14,130
96.5	1,580	3,160	4,740	6,320	7,900	9,480	11,060	12,640	14,220
97.0	1,590	3,180	4,770	6,360	7,950	9,540	11,130	12,720	14,310
97.5	1,600	3,201	4,801	6,402	8,002	9,603	11,203	12,804	14,404
98.0	1,611	3,222	4,833	6,444	8,055	9,666	11,277	12,888	14,499
98.5	1,620	3,240	4,860	6,480	8,100	9,720	11,340	12,960	14,580
99.0	1,629	3,258	4,887	6,516	8,145	9,774	11,403	13,032	14,661

TABLE XIII. SOLUBLE SALTS IN SOIL SOLUTIONS OF VARIOUS RESISTANCES AT 60° F.

R. at 60° F.	Parts per million	R. at 60° F.	Parts per million	R. at 60° F.	Parts per million	R. at 60° F.	Parts per million	R. at 60° F.	Parts per million	R. at 60° F.	Parts per million	R. at 60° F.	Parts per million
68	3500	118	869	168	268	218	945	268	731	318	620	366	549
69	400	119	851	169	260	219	940	269	728	319	618	366.5	548
70	300	120	834	170	252	220	935	270	725	320	616	367	547
71	250	121	817	171	244	221	930	271	722	321	614	367.5	546
72	200	122	800	172	236	222	925	272	719	322	612	368	545
73	150	123	783	173	228	223	920	273	716	323	610	368.5	544
74	100	124	766	174	220	224	915	274	713	324	608	369	543
75	50	125	749	175	212	225	910	275	710	325	606	369.5	542
76	3000	126	732	176	205	226	905	276	707	326	604	370	541
77	2950	127	715	177	198	227	900	277	704	327	602	370.5	540
78	900	128	1700	178	191	228	895	278	701	328	600	371	539
79	850	129	685	179	184	229	890	279	698	329	598	371.5	538
80	800	130	670	180	177	230	885	280	696	330	596	372	537
81	767	131	655	181	170	231	880	281	694	331	594	372.5	536
82	733	132	640	182	163	232	875	282	692	332	592	373	535
83	700	133	626	183	156	233	870	283	690	333	590	373.5	534
84	667	134	613	184	149	234	865	284	688	334	588	374	533
85	633	135	600	185	142	235	860	285	686	335	586	374.5	532
86	600	136	587	186	135	236	855	286	684	336	584	375	531
87	571	137	574	187	128	237	850	287	682	337	582	375.5	530
88	542	138	562	188	1121	238	845	288	680	338	5°0	376	529
89	513	139	550	189	1114	239	840	289	678	339	578	376.5	528
90	484	140	538	190	107	240	835	290	676	340	577	377	527
91	456	141	527	191	100	241	830	291	674	341	576	377.5	526
92	427	142	516	192	93	242	825	292	672	342	575	378	525
93	400	143	505	193	86	243	820	293	670	343	574	378.5	524
94	375	144	494	194	80	244	815	294	668	344	573	379	523
95	350	145	483	195	74	245	810	295	666	345	572	379.5	522
96	325	146	472	196	68	246	805	296	664	346	571	380	521
97	300	147	461	197	62	247	800	297	662	347	570	380.5	520
98	276	148	450	198	56	248	796	298	660	348	569	381	519
99	253	149	440	199	50	249	792	299	658	349	568	381.5	518
100	230	150	430	200	44	250	788	300	656	350	567	382	517
101	208	151	420	201	38	251	784	301	654	351	566	382.5	516
102	186	152	410	202	32	252	780	302	652	352	565	383	515
103	164	153	400	203	26	253	776	303	650	353	564	383.5	514
104	142	154	390	204	20	254	773	304	648	354	563	384	513
105	121	155	380	205	14	255	770	305	646	355	562	384.5	512
106	100	156	370	206	8	256	767	306	644	356	561	385	511
107	79	157	360	207	2	257	764	307	642	357	560	386	510
108	59	158	350	208	996	258	761	308	640	358	559	386.5	509
109	39	159	341	209	990	259	758	309	638	359	558	387	508
110	90	160	332	210	985	260	755	310	636	360	557	387.5	507
111	2000	161	324	211	980	261	752	311	634	361	556	388	506
112	1981	162	316	212	975	262	749	312	632	362	555	389	505
113	962	163	308	213	970	263	746	313	630	363	554	390	504
114	943	164	300	214	965	264	743	314	628	364	553	390.5	503
115	924	165	292	215	960	265	740	315	626	364.5	552	391	502
116	905	166	284	216	955	266	737	316	624	365	551	391.5	501
117	887	167	276	217	950	267	734	317	622	365.5	550	392	500

TABLE XIII. (*Continued.*)

R. at 60° F.	Parts per million	R. at 60° F.	Parts per million	R. at 60° F.	Parts per million	R. at 60° F.	Parts per million	R. at 60° F.	Parts per million	R. at 60° F.	Parts per million	R. at 60° F.	Parts per million
392.5	499	433.8	449	483.2	399	549.5	349	636	299	754	249	924	199
393	498	434.6	448	484.4	398	551	348	638	298	757	248	928	198
393.5	497	435.4	447	485.6	397	552.5	347	640	297	760	247	932	197
394	496	436.2	446	486.8	396	554	346	642	296	762	246	936	196
394.5	495	437	4 5	488	395	555.5	345	644	295	765	245	940	195
395	494	438.0	444	489.2	394	557	344	646	294	768	244	944	194
396	493	439.0	443	490.4	393	558.5	343	648	293	771	243	948	193
397	492	440.0	442	491.6	392	560	342	650	292	774	242	953	192
398	491	441.0	441	492.8	391	561.5	341	652	291	777	241	958	191
399	490	442	440	494	390	563	340	654	290	780	240	962	190
400	489	442.8	439	495	389	565	339	656	289	783	239	966	189
400.8	488	443.6	438	496	388	567	338	658	288	786	238	971	188
401.6	487	444.4	437	497.5	387	568.5	337	661.5	287	789	237	976	187
402.4	486	445.2	436	499	386	570	336	663	286	792	236	981	186
403	485	446	435	500.5	385	571.5	335	665	285	795	235	985	185
403.8	484	447	434	502	384	573	334	667	284	798	234	990	184
404.6	483	448	433	503	383	574.5	333	669.5	283	801	233	995	183
405.4	482	449	432	504	382	576	332	672	282	804	232	1000	182
406.2	481	450	431	505.5	381	578	331	674	281	807	231	1005	181
407	480	451	430	507	380	580	330	676	280	811	230	1010	180
407.8	479	452	429	508	379	581.5	329	678.5	279	814	229	1016	179
408.6	478	453	428	509	378	583	328	681	278	817	228	1022	178
409.4	477	454	427	510.5	377	584.5	327	683	277	820	227	1027	177
410.2	476	455	426	512	376	586	326	685	276	824	226	1032	176
411	475	456	425	513	375	587.5	325	687.5	275	827	225	1038	175
411.8	474	457	424	514	374	589	324	690	274	830	224	1044	174
412.6	473	458	423	515.5	373	591	323	692.5	273	834	223	1049	173
413.4	472	459	422	517	372	593	322	695	272	837	222	1055	172
414.2	471	460	421	518.5	371	594.5	321	697.5	271	841	221	1060	171
415	470	461	420	520	370	596	320	700	270	844	220	1067	170
415.8	469	462	419	521	369	598	319	702	269	848	219	1073	169
416.6	468	463	418	522	368	600	318	704	268	851	218	1079	168
417.4	497	464	417	523.5	367	601.5	317	707	276	854	217	1085	167
418.2	466	465	416	525	366	603	316	709	266	858	216	1091	166
419	465	466	415	526	365	605	315	712	265	862	215	1097	165
420	464	467	414	527	364	607	314	715	264	865	214	1104	164
421.0	463	468	413	528.5	363	609	313	717	263	869	213	1110	163
422.0	462	469	412	530	362	611	312	720	262	872	212	1118	162
423.0	461	470	411	531.5	361	612.5	311	722	261	876	211	1125	161
424	460	471	410	533	360	614	310	725	260	880	210	1132	160
424.8	459	472.2	409	534.5	359	616	309	727	259	884	209	1140	159
425.6	458	473.4	408	536	358	618	308	730	258	887	208	1147	158
426.4	457	474.6	407	537.5	357	620	307	732	257	891	207	1154	157
427.2	456	475.8	406	539	356	622	306	735	256	895	206	1161	156
428.0	455	477	405	540.5	355	624	305	738	255	899	205	1168	155
429.0	454	478	404	542	354	626	304	740	254	903	204	1176	154
430.0	453	479	403	543.5	353	628	303	743	253	907	203	1184	153
431.0	452	480	402	545	352	630	302	746	252	911	202	1192	152
432.0	451	481	401	546.5	351	632	301	749	251	915	201	1200	151
433	450	482	400	548	350	634	300	751	250	920	200	1208	150

TABLE XIII. (*Continued.*)

R. at 60° F.	Parts per million	R. at 60° F.	Parts per million	R. at 60° F.	Parts per million	R. at 60° F.	Parts per million	R. at 60° F.	Parts per million	R. at 60° F.	Parts per million	R. at 60° F.	Parts per million
1216	149	1394	129	1629	109	1972	89	2522	69	3450	49	5340	29
1224	148	1404	128	1645	108	1991	88	2555	68	3508	48	5500	28
1232	147	1414	127	1661	107	2011	87	2593	67	3576	47	5660	27
1240	146	1423	126	1678	106	2033	86	2631	66	3648	46	5820	26
1248	145	1433	125	1695	105	2055	85	2670	65	3717	45	6020	25
1257	144	1443	124	1712	104	2079	84	2712	64	3788	44	6260	24
1265	143	1453	123	1729	103	2103	83	2755	63	3858	43	6560	23
1274	142	1464	122	1746	102	2128	82	2798	62	3935	42	6980	22
1283	141	1475	121	1763	101	2152	81	2842	61	4005	41	7240	21
1292	140	1486	120	1780	100	2177	80	2886	60	4090	40	7600	20
1301	139	1498	119	1797	99	2203	79	2032	59	4180	39	7900	19
1310	138	1509	118	1814	98	2232	78	2978	58	4275	38	8250	18
1320	137	1520	117	1831	97	2259	77	3025	57	4375	37	8800	17
1328	136	1533	116	1848	96	2288	76	3071	56	4475	36	9300	16
1337	135	1546	115	1865	95	2320	75	3120	55	4580	35	9700	15.5
1346	134	1559	114	1882	94	2351	74	3170	54	4695	34	10087	15
1355	133	1572	113	1900	93	2383	73	3220	53	4810	33	10200	14.9
1365	132	1585	112	1918	92	2416	72	3277	52	4925	32		
1374	131	1599	111	1936	91	2451	71	3336	51	5050	31		
1384	130	1614	110	1954	90	2486	70	3394	50	5195	30		

TABLE XIV. PERCENTAGE OF MIXED SALTS IN SOIL TYPES WITH A GIVEN RESISTANCE

Resistance at 60° F.	Sand	Loam	Clay loam	Clay	Resistance at 60° F.	Sand	Loam	Clay loam	Clay
Ohms	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Ohms*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
18	3.00	3.00	....	....	95	.35	.37	.39	.42
19	2.40	2.64	3.00	....	100	.33	.35	.37	.39
20	2.20	2.42	2.80	3.00	105	.31	.33	.35	.37
25	1.50	1.70	1.94	2.20	110	.30	.32	.33	.35
30	1.24	1.34	1.46	1.58	115	.28	.29	.31	.33
35	1.04	1.14	1.22	1.32	120	.27	.28	.29	.32
40	.86	.94	1.04	1.14	125	.25	.26	.28	.30
45	.75	.78	.88	.98	130	.24	.25	.26	.28
50	.67	.71	.77	.86	135	.23	.24	.25	.27
55	.60	.64	.69	.77	140	.22	.23	.24	.26
60	.55	.58	.63	.70	145	.21	.22	.23	.25
65	.51	.54	.57	.63	150	.21	.21	.22	.24
70	.48	.50	.53	.59	155	.20	.21	.21	.23
75	.45	.47	.50	.55	160	.20	.20	.21	.22
80	.42	.44	.47	.51	165	.19	.20	.20	.21
85	.39	.42	.44	.48	170	.19	.19	.20	.20
90	.37	.39	.41	.45					

In using the bridge, Beam and Freak (2) found it possible to eliminate calcium sulphate from the total salts by using 40 per cent alcohol in extracting the salt and comparing the resistance with that found for this solvent under known conditions. By determining both alcohol and water extraction results, the difference shows the calcium sulphate.

FIG. 14. — DETERMINING SOLUBLE SALTS WITH THE ELECTRIC BRIDGE IN THE FIELD.

Freezing-point Method. — A method for determining the total soluble salts in soils by means of differences in the lowering of the freezing point due to differences in concentration of the soil solution, has been worked out by Bouyoucos and McCool (3). About an inch of the soil is placed in an isolated tube surrounded by salt-ice water with a temperature of about $-4.5°$ C. and a delicate Beckmen thermometer inserted in the soil. The soil is first supercooled to about 1 degree C. below its freezing point and is then disturbed so that the temperature rises

until it remains constant for some time. This maximum temperature is recorded as the freezing point of the soil. By this method, as by the electric bridge, the quantity of moisture in the soil plays an important part in the concentration of the solution, hence it is essential that a constant quantity of water be present. Fine soils show the influence of changes in moisture content much more than do sands or other coarse soils. In this method, as with the bridge, the determination is indirect and to get the total salts the depression of the freezing point must be referred to the depression of soils under similar conditions with known quantities of salts. The limitations of the method have not been worked out as yet, but much is hoped from it.

Biological Method. — Another indirect method being developed by biologists is based on the effect of alkali salts on bacterial action. This method has been extensively used by Lipman, Greaves, and Brown and their co-workers and depends on the influence of soluble salts on the ammonifying, nitrifying, and nitrogen-fixing organisms. Several experimenters have noted that the change in the quantity of salts present in soils affects the soil flora somewhat in proportion, but to what extent this activity may be taken as an indication of the salts present is yet to be seen.

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CHAPTER VIII

CHEMICAL EQUILIBRIUM AND ANTAGONISM

THE soil is not static but is in a state of constant change. The numerous chemical compounds of which it is composed are made to react with one another by the continuous variation in such factors as temperature, moisture, decomposition of organic matter, the growth of plant roots, and the activities of microörganisms. These agencies of change make it practically impossible to maintain in the soil for any length of time a stable equilibrium. This renders an understanding of the alkali problem very difficult, since the concentration of salts in any particular

TABLE XV. PARTS OF SALTS SOLUBLE IN 100 PARTS OF WATER [1]
(Compiled from Handbook of Physics and Chemistry, 1919)

Temperature	Na_2CO_3		Na_2SO_4		$CaCl_2$		$MgCl_2$		$MgSO_4$		$CaSO_4$	NaCl	$NaNO_3$
0°	7.1	$10H_2O$	5.0	$10H_2O$	59.5	$6H_2O$	52.8	$6H_2O$	26.0	$7H_2O$	.179	35.6	73.0
20	21.4		19.4		74.5		54.5		35.6		.206	35.8	88.0
30	40.9		40.0		101.0		....		40.9		.....	36.1	.....
31.8	46.0		....		.....		....		....		.....	....	.....
32.4	....	$7H_2O$	49.9	Anhydrous	.....		....		....		.....	....	.....
35.1	51.0		....		.....		....		....		.....	....	.....
50	47.5		46.8		132.0	$2H_2O$	....		50.4	H_2O	.....	36.7	114.0
80	45.6		43.7		147.0		66.0		64.2		.....	38.0	148.0
100	45.2	$1H_2O$	42.7		159.0		73.0		73.8		.178	39.1	175.5

[1] The figures are given in terms of the anhydrous salt, but the solubilities quoted are for those hydrates which are stable at the stated temperature.

zone of the soil is not always the same. Salts readily move through the soil and, on coming in contact with other salts, chemical changes result. The toxicity of the salts is also altered by the presence of other salts.

Solubility of Alkali Salts. — The solubility of the salts commonly concerned with alkali work is presented in Table XV.

The wide difference in the solubility of the salts and the importance of temperature is brought out from the above figures. It will be noticed, however, that the quantity of salts which may dissolve in water is several times the quantity ordinarily found in extracts of soil from alkali lands.

Mass Action. — In the discussion of alkali it is generally assumed that the salts are stable or retain the same composition as they do in a simple solution. This stable condition is not found, however. Analyses of different depths of alkali soil, for instance, have indicated an apparent change, under certain conditions, of part of the harmful sodium carbonate into the much less toxic sodium bicarbonate as it was brought close to the surface where there was more carbonic acid.

In order that a clearer understanding of the conditions favoring changes in the nature of the salts in the soil may be had, a short discussion of the "Law of the Mass Action" seems desirable. This law states that the amount of chemical action is proportional to the active mass, or molecular concentration of each of the reacting substances, in unit volume. Quantitatively, this law may be expressed in its most general form as follows:

Assume the reaction

$$nA + mB + \cdots \leftrightarrows pX + qY + \cdots$$

to take place so that n moles of A are capable of reacting with m moles of B to form p moles of X and q moles of Y, or vice versa if the number of moles of A, B, . . . X, Y, . . . actually present in unit volume of the reacting mixture are represented respectively by C_1, C_2, . . . d_1, d_2, . . ., and further if sufficient time be allowed to permit the system to come to equilibrium, then at a given temperature the condition of the system is expressed by the equation

$$\frac{d_1^{\,p}\, d_2^{\,q} \ldots\ldots}{c_1^{\,n}\, c_2^{\,m} \ldots\ldots} = \text{a constant.}$$

This relation is readily understood when one considers that a chemical reaction takes place as a result of very minute particles (molecular or ionic) of the reacting materials coming into intimate contact with each other. Obviously the amount of chemical action will depend on the number of these particles present in a given volume. Moreover, if one of these materials is in great excess in the system, it would be expected that the substance with which it tended to react would at equilibrium be nearly all used up.

In the case of solutions of inorganic salts, the reactions are for the most part ionic and take place therefore with great rapidity. It also frequently happens that one of the reacting bodies is only slightly soluble, and this fact predisposes the reaction in favor of its continued formation. But as no salt can be said to be completely insoluble, it is quite possible for a reaction to take place, having a so-called insoluble substance as one of the starting materials.

For example, consider the reaction

$$Na_2CO_3 + CaCl_2 \leftrightarrows 2\ NaCl + CaCO_3$$

which normally proceeds from left to right on account of

the insolubility of calcium carbonate. The mass law states that at a given temperature

$$\frac{(NaCl)^2(CaCO_3)}{(Na_2CO_3)(CaCl_2)} = \text{a constant},$$

where each one of the factors of the equation represents the concentration in moles of that constituent in unit volume. Though the factor ($CaCO_3$) is very small it is not zero and accordingly if water containing a large amount of sodium chloride were passed over limestone there would be a tendency for calcium carbonate to be changed into sodium carbonate and calcium chloride, in order that this equation might be fulfilled.

This latter condition has been found to exist in certain parts of Egypt where the soil contained excessive quantities of sodium chloride and also contained calcium carbonate. Instead of the reaction being $Na_2CO_3 + CaCl = 2\ NaCl + CaCO_3$, as is generally the case where these substances are brought in contact with each other in somewhat equal molecular concentrations, the reverse reaction took place, forming black alkali and calcium chloride. As seen in the above table of solubilities, calcium chloride is very soluble and might easily be washed from the soil so that the above reaction might under certain conditions result in the formation of considerable black alkali. In like manner, other apparently stable salts might, by changes in molecular concentrations, react to form new substances not possible under ordinary conditions, and in case one or both of the end products were taken from the active mass, there might be a profound change in the composition of the chemical compounds.

California experiments (4) show that up to a strength of about 4000 parts per million of sodium sulphate, this

substance could be made to change into sodium carbonate in the presence of precipitated calcium carbonate through which carbon dioxide was being forced, but that the action was most vigorous when the strength of sodium sulphate was only 750 parts per million. This is the probable explanation of the fact discovered by certain investigators (5) that black alkali was formed about the roots of plants growing on white alkali. The carbon dioxide given off by the roots of the plants made the calcium carbonate soluble so that it would react with the white alkali to form the black.

Salts concentrated in some part of the soil by former reactions might be acted upon by solutions borne from different sections containing other types of salts making possible incessant and complete exchanges of ions of the different salts. Referring again to the table of solubilities, it is seen that salts do not maintain the same relative solubility at all temperatures. This disturbs the equilibrium as the temperature of the soil changes.

Absorption of Salts by Soils. — The alkali problem would be much simplified if the soluble salts were simply held in the active part of the soil solution. With such a condition it would take but a few leachings of the soil to free it of excessive salts. Through absorption and adsorption, however, the soil tends to hold part of the salts when it is drained. With high concentrations the soil has little power to hinder free movement of salts, but with lower concentrations the soil retains a larger proportion of the salts.

Part of this difficult movement is thought by some to be caused by a mechanical adherence of the salts immediately in contact with the soil particles; others consider that an actual chemical reaction takes place. If no chemical

reaction occurs the salts held in a mechanical manner are probably within the inner circle of the capillary film where very little movement is possible; consequently, unless there is long-continued and excessive washing of the soil, little of this salt is lost except by diffusion which is a very

FIG. 15. — ALKALI COMING TO THE SURFACE WHERE SEEPAGE WATER FROM A CANAL COMES TO THE SURFACE AND EVAPORATES. THE CANAL RUNS THROUGH A SHALE THAT IS HIGH IN SOLUBLE SALTS.

slow process in case the salts are not promptly removed from the point of concentration. This adherence, or adsorption, may account for the great quantities of salts that are slowly yielded to water leaching through soils. As more and more of the salts are given up to the solution and carried away, the remaining portion is with greater and greater difficulty yielded to the free, or percolating, water. Because of the greater surface exposed, fine clays, loams, and soils rich in organic matter hold the salts by absorption more tenaciously than the coarser-grained sands.

Soils such as the clays, which are high in colloidal material, are also affected by an interchange of ions. The

colloidal material appears to be in weak chemical combination with certain bases. When the alkali salts are brought in contact with these colloids, there is an apparent exchange of the sodium of the alkali for calcium or magnesium. The calcium and magnesium appear in the drainage water in greater quantities where the alkali is present than where it is not, and the sodium is recovered only with great difficulty if at all by leaching. This action is apparently selective in nature. The weaker acids yield their sodium to the colloids much more easily than do the stronger ones, so that where equal quantities of each of the salts are added to a soil when recovered the quantity of acid assignable to each base will be different. Each soil, and different parts of the same soil, frequently differ considerably so that this interchange may vary both in nature and magnitude in soils not greatly differing from each other. The colloids of organic matter act much the same as those of the soil so that added organic matter may change the nature of an alkali soil. Whether it is due to this exchanging of sodium for calcium in the colloids and the consequent precipitation of calcium carbonate when sodium carbonate is added to soils rich in colloids or in organic matter is not known, but much of the alkalinity of sodium carbonate disappears when added to such soils. In sand where colloids and organic matter are absent, practically all of the carbonates added can be recovered by extraction with water.

Equilibrium in Soil Solution. — That a complete state of equilibrium is ever established in a soil is hardly probable. The constant removal of water by plants, evaporation from the surface of the soil, addition of water by rains or irrigation, percolation of free water, and all the other causes of movement of water in the soil, cause an incessant

change in the position of the soluble salts. Layers of compact soil or heavy clay ordinarily contain more soluble salts than looser ones; and where there is movement of water between different soil layers, there is a change in the concentration of the solution and reactions take place between the salts which have been dissolved from the two types of soil. Small quantities of alkali in the irrigation water may cause profound changes in the chemical composition of the soil solution. Changes in temperature cause changes in the solubility of salts so that salts may be thrown out of solution or new ones brought into solution. Carbon dioxide and oxygen are frequently brought into the soil by rains, and carbon dioxide is constantly being formed in soils. This disturbs equilibrium of the compounds by changing the solubility or causing the oxidation of certain compounds. These and numerous other factors cause the soil solution constantly to vary in concentration and composition.

In studying alkali, however, these minute and troublesome changes are not ordinarily of sufficient importance to warrant consideration. The quantity of alkali when it becomes troublesome is generally so large that small changes are practically negligible. Changing a few pounds to the acre of sodium chloride into calcium chloride would make so little difference in the toxicity of the alkali that it could not be noticed.

With sodium carbonate the condition is somewhat different. This salt is relatively unstable when compared with sodium chloride and sodium sulphate. In the presence of solutions of carbon dioxide, as found in the upper soil, sodium carbonate would probably form the unstable sodium bicarbonate to a considerable extent. Sodium carbonate and bicarbonate, on account of their solubility,

react readily with other salts and may form the relatively insoluble carbonates. The well-known reaction $Na_2CO_3 + CaSO_4 = Na_2SO_4 + CaCO_3$, or the conversion of black alkali into white, is of the latter type of change. Black alkali, however, is thought to remain practically in fairly stable equilibrium where the soil has become so puddled that air and carbon dioxide are largely excluded. Puddling the soil apparently causes the conversion of sodium nitrate into sodium carbonate where the conditions are favorable, but this reaction is rapidly brought to an end because of lack of sodium nitrate or the other agents under ordinary conditions.

Antagonism between Alkali Salts. — In some of the early work of Kearney and Cameron (5) it was noticed that plants grown in solutions of single salts common in alkali soils showed a much greater toxic effect for magnesium sulphate and magnesium chloride than for the sodium salts which ordinarily cause the greatest trouble on alkali land. When there were two salts, especially where one was a calcium salt, in the same solution, however, the toxic effect was not the sum of the two separate toxicities but was in some cases considerably less. This ameliorating or antagonistic effect was shown differently for different combinations of salts and for different concentrations of the same combinations; but the greatest effect was for combinations containing calcium and magnesium. The antagonism between magnesium sulphate and calcium sulphate was particularly strong and led to the belief that a specific balance between calcium and magnesium must exist for proper growth of plants despite the fact that in soils such a relationship did not exist. Some of the ameliorating effect, such as that where calcium chloride and sodium carbonate were in the same solution, might

be assigned to the formation of new and less toxic compounds; but magnesium sulphate with sodium sulphate, sodium sulphate with magnesium chloride, sodium chloride with magnesium sulphate, and similar combinations which exist as stable compounds in contact with each other were also corrective of each other. It was further found that when the different salts were present in certain proportion to each other the effect was different than where other apparently less toxic proportions were used. When 398 parts per million of sodium carbonate and 710 parts per million of sodium sulphate were in the same solution, some of the plants lived; but when the sodium sulphate was reduced to half this quantity, all the plants died.

A number of other experimenters have noticed the antagonistic action between calcium and magnesium salts when in solutions with sodium salts. Miyake (16), working with rice plants, found that there was a slight antagonism between the monovalent anion, chloride, and the divalent anion, sulphate, but it was small compared with that between the cations. He found potassium antagonistic to sodium when the two salts were together in the form of sulphates, chlorides, or nitrates.

The quantity of salts which caused injury to the plants growing in the solutions of these experiments is much below the quantities ordinarily found to cause injury in field or soil experiments, especially where the unmixed solutions were used. It has been suggested that the reason for the lower toxicity in the soils is because the soil contains calcium and other salts which ameliorate the effect of the injurious salts. Whether this explanation is sufficient to account for all of the difference is questionable, however. That lime is a good corrective for magnesium, as reported above, is shown by the fact that certain Canadian soils (19)

containing 50,000 parts per million of magnesium sulphate were made to produce much better growth by adding lime than without it. Most alkali soils contain considerable lime. This may account for the large quantities of alkali sometimes present without serious injury to crops growing upon them.

The work of Lipman and Gericke (11) indicates that even in a clay soil of the arid region there was antagonism

FIG. 16. — BLACK ALKALI CRUST FORMING WHERE THE LAND HAS BEEN WET.

between sodium chloride and sodium sulphate, and between sodium chloride and sodium carbonate in the second crop of barley, although none was shown in the first. That the time of contact might have had some effect is shown from the observation that neither sodium chloride nor sodium sulphate was stimulating in concentration of 1000 parts per million for the first crop but were toxic for the second. Calcium sulphate was antagonistic even in comparatively small quantities when added to a soil containing 4000 parts per million of sodium sulphate.

Lipman and Sharp (14), in an experiment with a natural soil containing 6400 parts per million of total salts com-

posed of 4590 parts per million sodium chloride, 980 parts per million sodium sulphate, and 830 parts per million of sodium carbonate, found that applying sulphuric acid at the rate of about 119 parts per million was especially beneficial, and up to about 451 parts per million, the highest quantity added, the treatment was beneficial. Gypsum also caused a higher yield of barley. The treatments were thought to be helpful both by neutralizing the sodium carbonate and also by causing a beneficial shrinkage of colloids.

A number of investigators have noted an antagonistic effect of the heavier metals, such as calcium, copper, and zinc, on the common alkali salts. Caldwell (1) thinks from his observations that this antagonistic effect is due to a dilution of the active salts and not to an actual antagonism. He did not find an antagonistic action between sodium and potassium, but on the contrary he found a decrease in the stimulating effect when certain concentrations of potassium salts were diluted with sodium salts. Ammonia and sodium in the proportion of 1 to 1 gave the best growth in highly concentrated solutions.

The author (3) found the antagonistic effect in solution cultures to be greater than when the same mixtures were present in soils.

Some of the most positive antagonistic results in soils appear in the work of Lipman and his associates on soil bacteria. On the ammonification organisms he (9) found no antagonism between mangesium and calcium nor between sodium and calcium, but there was an antagonistic effect both for these and the nitrifying organisms when any two of the three alkali salts — sodium chloride, sodium carbonate, and sodium sulphate — were in the soil together. There was antagonism between toxic as well as between stimulating concentrations of these salts. The nitrogen-

transforming powers of the soil were better than the checks when two salts, one of which was present in toxic quantities, were present in the soil, or where both were in toxic quantities for the single salts. The nitrogen-fixing organisms showed slight antagonism except between sodium sulphate and sodium carbonate which showed no antagonism.

The exact cause of antagonism between the ions has not been fully explained. Osterhout (17) found the permeability of the protoplasm was rapidly increased until death occurred when in solutions of sodium chloride. With calcium chloride the permeability decreased to a certain point after which it increased as with sodium chloride until death occurred. He thinks that when a substance like sodium chloride is brought in contact with one like calcium chloride where the tendency is to cause permeability in opposite directions, there is an antagonistic effect. He (17) thinks this interference of the ions of the salts attempting to enter the cell may be the real cause of the antagonism. Hansteen (2) thinks calcium acts as an external protection to the roots of the plants, which is essentially that of the above view. Le Clerc and Breazeale (8) claim that lime overcomes the toxic effect of the sodium salts without preventing the absorption of sodium chloride by the plant.

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CHAPTER IX

RELATION OF ALKALI TO PHYSICAL CONDITIONS IN THE SOIL

The entire physical condition of the soil is changed by the presence of large quantities of certain soluble salts. All salts in fact bring about some physical changes but certain of the alkali salts, particularly the carbonates, cause complete transformations. Each soluble salt that is present in large quantity produces some typical condition, which is usually bad. The effect of one salt may be in part neutralized by another, so that the final effect is somewhat uncertain. It depends on the nature of the soil and on the combination and concentration of the salts present.

The chief manifestations of salts on the physical condition of the soil are: (1) The change in structure or tilth; (2) an altering of the colloidal substances; (3) the formation of a hardpan; and (4) a change in the moisture relations.

Changing Soil Structure. — The tilth, or structure, of a soil has much to do with its crop-producing power. Soils containing an equal amount of plant-food may vary greatly in their power to yield. The soil must do more than furnish a supply of food for growing plants; it must also be a good home for them. Plants, like animals, even though they have sufficient food to nourish them will not thrive unless other factors affecting growth are favorable. Air must be present for the roots, and the soil particles

should be so arranged that the roots may easily secure food and moisture.

Soils vary greatly in their tilth. Those made up of coarse-grained particles are less affected in structure by various agencies than those composed of fine-grained particles. With coarse-grained soils the keeping of a good tilth presents no serious problem. With fine-grained soils, on the other hand, the maintaining of a good structure requires constant attention. It may be affected by several factors, one of which is the presence of soluble salts.

The ideal structure is usually one in which there is a maximum of air space. This condition also favors the various cultural operations. If fine soil particles are packed tightly together, there is not sufficient air space for the best root development and the soil is difficult to till. When plowed, it becomes cloddy instead of mellow. In order to secure the best condition, the fine particles should be clustered together, or flocculated. This gives air space between the groups of particles as well as between the individual particles in the group and establishes lines of weakness in all directions. This enables the soil to break up readily into a crumb-like structure when cultivated instead of into clods. Anything that promotes flocculation improves tilth; likewise anything that promotes deflocculation injures tilth.

The effect of soluble salts on tilth has been a subject of considerable study. Sachsse and Becker (17) showed that nitrate of soda not only prevented flocculation but also separated floccules that had already been formed. It was thought that this result might be due in part to the formation in the soil of carbonate of soda, which in turn acts upon the hydrated silicates, producing colloidal silicates which reduce the permeability of the soil to water.

Hall (10) found that when nitrate of soda was applied in large quantities to heavy soils at Rothamsted the tilth of the land was destroyed. He concluded that this result came about by the production of the deflocculating salt, sodium carbonate.

The presence of alkali salts was early observed by Loughridge (15) and Hilgard (13) to have a bad effect on the soil by puddling or deflocculating the particles and a consequent compact condition which prevents the rapid rise of water. Puddling was accompanied by large contraction of volume. A similar action particularly in clays was also observed by Bemmeln (1).

Masoni (16) showed that not all soluble salts have a deflocculating effect. Some of them have a decidedly flocculating effect which is not dependent on the quantity of salt but rather on ionic concentration and the degree of dissociation. He considers the flocculating power to be a function of the cation, the anion being without influence. If the value of the flocculating power for the sodium ion be taken as 1, then for the potassium or ammonium it is 2.4, and for the calcium ion 5.7.

Free (7) has pointed out that flocculation and deflocculation are relative terms and that the action of salts, acids, and alkalies in this connection are twofold and depend on the mutual interpenetration of particle and medium and on the electrical charge on the surface of the particle.

Davis (6) has shown that even small quantities of soluble salts are important in modifying the physical properties of the soil including the apparent specific gravity which is affected directly by the flocculation of the particles. The effect of salts is shown to be very much greater in soils of finer particles than in sands. It is usually in the finer, heavier soils that alkali is found; consequently, it is usually only in these soils that the problem becomes troublesome.

The acute form of deflocculation manifests itself in the crust at the surface of the soil resulting from sodium carbonate or black alkali. Only slightly less troublesome is the brown crust found where large quantities of sodium nitrate are present. Where these crusts are found it becomes almost impossible to raise crops successfully. Not only is the land difficult to till but the crust that may form after a tender plant comes up is so hard that the plant cannot make a normal growth. There is an actual physical impediment in addition to any chemical corroding which the salt may exert on the plant.

Effect of Colloids. — All agricultural soils contain some particles called colloids so small that they have properties entirely different from the larger particles. The colloidal material acts somewhat like dissolved salts and yet it obeys some of the laws that apply to the larger particles. During recent years it is being recognized that many of the effects of alkalies on the physical conditions of soils come about through this colloidal material.

Kellerman (12) showed that the impermeable condition of an alkali soil at Fallon, Nevada, was due largely to the condition of the colloidal matter in the soil.

Gedroits (9), as a result of extensive experiments on the relation of salts to soil colloids, found that many of the physical changes ordinarily brought about in soils by salts come from their effect on colloids.

Important as are the investigations already made on the relation between alkali and soil colloids, they may be considered as only pioneer work in view of what the future promises.

Hardpan. — Under the surface of many of the soils in arid regions, particularly in sections of abundant alkali, a hard layer is found which obstructs the penetration of

both roots and water. Hardpans are not always caused by alkali, but are more likely to be formed if it is present. Hardpan differs from the ordinary impervious subsoil in that it has a limited thickness, usually varying from 2 to 18 inches with an average of 3 to 6 inches. A good example is described by Gardner and Stewart (8). A number of explanations of the genesis of hardpans have been given.

Hilgard (13) has the following to say about the cause of hardpan: "The recognition of the cause of hardpan is of considerable importance to the farmer because of the influence of the nature of the cement and the causes of its formation upon the possibility and methods of its destruction, for the improvement of the land.

"It may be said in general that inasmuch as the cause of the formation of hardpan is a stoppage of the water in its downward penetration, the reëstablishment of that penetration will tend to prevent additional induration; moreover, experience proves that whenever this is accomplished even locally, as around a fruit tree in an orchard, the hardpan gradually softens and disappears before the frequent changes in moisture conditions and the attack of roots. The use of dynamite for this purpose in California has already been referred to; it seems to be the only resort when the hardpan lies at a considerable depth. When it is within reach of the plow, it may be turned up on the surface by the aid of a subsoiler and will then gradually disintegrate under the influence of air, rain, and sun. But when the hardpan is of the nature of moorbedpan, containing much humic acid and perhaps underlaid by bog-iron ore, the use of lime on the land is indicated, and will in the course of time destroy the hardpan layer. This is the more desirable as in such cases the surface soil is

usually completely leached of its lime content, and is consequently extremely unthrifty."

Cameron (5) gives the following explanation of the origin of hardpans: "The application of the present views regarding solutions to the study of hardpan phenomena gives promise of valuable as well as interesting results. A hardpan may be defined as a layer of the soil, usually near the surface, having the texture of the soil just above and below it, but more or less closely cemented by some material. In general, hardpan is a characteristic of soils where drainage is very poor or where standing soil waters may accumulate. The cementing material is often lime carbonate, but may be other material, as the hydrates of iron and alumina or silica. Hardpans vary much in their physical properties. They are sometimes as dense and close-grained as a well-characterized rock, requiring blasting or similar methods to break them up. In other cases they may be partly porous, and when brought to the surface disintegrated with ease, and there are all grades between these extremes.

"The objections to their presence in the soil are evident. They prevent the penetration of plant roots, and, more important, they prevent the moisture from rain, irrigation, etc., sinking into the soil and thus being conserved for future use. They also prevent the water that may be beneath them from being drawn to the surface and made available for the plants.

"The formation of a calcium carbonate hardpan is the most readily understood, and this has been dwelt upon at some length in a paper by Gardner and Stewart (8). It is there pointed out that resolution and reprecipitation are important factors. But when the calcium carbonate does not exist, as such, in the soil or in the vicinity, so as

to be brought by water, while a limestone hardpan might form, under favorable conditions, it seems more probable that the cementing material would be one of the other substances mentioned, or a mixture of them.

"The mineral constituents of the soil are for the most part salts, but with a few exceptions salts with a very limited solubility. Nevertheless, to some extent at least they are soluble, as are other salts, and their solubility may be increased or diminished by the presence of another salt solute, as has been indicated in a former part of this paper. These salts — carbonates, silicates, aluminates, ferrates, etc. — are without exception salts of weak acids and may be expected to be much hydrolized in as far as they are soluble at all. This has been very beautifully illustrated in recent experiments by Clark, who has treated a large number of minerals carefully pulverized with pure water. On the addition of a few drops of dilute alcoholic phenolphthalein a marked alkaline reaction could be observed in the great majority of the cases investigated. The reaction may be indicated thus, assuming a very simple example to exist:

$$RSiO_3 + HOH \rightleftarrows ROH + H_2SiO_3.$$

"All these other substances are very slightly ionized in comparison with ROH. If R be a well-marked base, such as sodium or calcium, the solution will therefore be alkaline, as has been shown to be the case with calcium carbonates, sodium silicates, etc. The fact that the silicate is complex will not alter this general property. Precisely similar conduct is to be expected of aluminates and ferrates. This means that there will actually exist in the solution some of the hydrates of alumina, silica, or iron, as the case may be, which will remain as such on evaporation, though the absolute amount may be very

small. The bases will be more or less readily removed, as they will be brought in contact with the carbonic acid and other acids (organic?) of the soil to form comparatively readily soluble salts.

"This process probably plays an important part in the formation of bog-iron ore, which may be regarded as strictly analogous to a hardpan. The deposition of bauxite, for example, or the formation of a silicious conglomerate is essentially of the same nature. But it should be remembered that in these latter cases when the action has been deep-seated with hot water as the solvent, the reagent has been much more ionized and so is much more efficient as a solvent.

"An interesting case from southern California has recently come to our attention. The soil was shown to have been somewhat compacted under the plow sole. When the irrigating water was applied, this packed region of the soil caused a more or less temporary accumulation of the waters. This soil, as can be readily seen under the microscope, contains a large proportion of unaltered mineral fragments, rich in iron and alumina and therefore well adapted to yielding these materials under the influence of the solvent action of the water; and, as a matter of fact, this packed material is found to rapidly become cemented with iron and alumina, as an examination in this laboratory showed. It is to be regretted that at the time this examination was in progress it was not deemed expedient to determine what constituents the irrigating water held which might augment its solvent power.

"That other agencies are at work in the production of these phenomena may well be the case. For instance, oxidations undoubtedly have a significant rôle in this connection in breaking up the original minerals. But it

seems equally certain that the part that solutions play has not been given the consideration that it merits, mainly because solution phenomena have not been understood until comparatively recent years.

"The study of hardpan formation necessitates a consideration of certain physical phenomena; for instance, the movement of water and various solutions in the soil. This subject is receiving attention in this laboratory; but while a good many observations have been made and much valuable data collected, it is yet too soon to formulate a complete hypothesis for this subject. The views here described are put forward in the hope of furnishing an incentive to more widespread interest and work on this important subject."

Heileman (12) gives in Table XVI the composition of a typical hardpan in the Kittitas Valley, Washington.

TABLE XVI. COMPOSITION OF HARDPAN

	TOTAL LIME AND MAGNESIUM CARBONATE IN HARDPAN		WATER-SOLUBLE SALTS IN HARDPAN		
	Calcium Carbonate, Per cent	Magnesium Carbonate, Per cent	Total Salts Per cent	Black Alkali Per cent	White Alkali Per cent
No. 8	21.15	1.72	.343	.174	.018
21	14.93	3.09	.136	.029	.023
43	21.79	2.97	.133	.109	.011
56	63.22	2.45	.350	.145	.041

Breazeale (2) shows that the idea that hardpan under a soil high in sodium carbonate has resulted from the sodium carbonate may not be true. In fact the sodium carbonate accumulation may have come from a decomposition of the calcium carbonate in the hardpan and a combination with sodium to form the black alkali. He succeeded in bringing about this interchange in the laboratory.

Effect on Moisture Movements. — The somewhat unusual moisture conditions in alkali soils have long been observed by students of alkali. Briggs and Lapham (4) investigated the effect of various soluble salts on rate of capillary movements through the soil and as a result of their studies came to the following conclusions: "(1) Dissolved salts in general do not increase the capillary rise of soil waters; (2) neutral salts in dilute solution have practically no influence on the extent of capillary action; (3) concentrated or saturated solutions of all salts materially diminish capillary activity; (4) this effect appears to be due (*a*) to the increased density of the solution which more than offsets the increased surface tension, and (*b*) to the resistance of a film to a tangential shearing stress which retards capillary action and offers in addition a permanent resistance to the movement of the solution through films, thus increasing the angle of contact, or (*c*) to an increase in the tension of the liquid-solid surface, as the concentration is increased; (5) sodium carbonate differs from neutral salts, the capillary rise being considerably greater than for neutral solutions of equal concentration; (6) this may be due in part to the saponification of traces of grease on the surface of the soil grains through the hydrolysis of the sodium carbonate, thus forming clean surfaces for capillary action; (7) the same effect should consequently be observed with all salts which undergo an alkaline hydrolysis, viz., potassium and sodium carbonates, borates, phosphates, etc.; (8) this action is characterized in the soil tubes by indistinctness of the upper boundary of the capillary column."

Capillarity is dependent on surface tension. Since the capillarity does not seem to be greatly influenced by soluble salts it seems evident, as pointed out by Davis (6),

that the profound physical changes brought about in the soil by alkali are due largely to forces other than surface tension. This is illustrated by the fact that while in the experiments of Briggs and Lapham (4) sodium carbonate increased the capillary rise of water, it is a well-known fact in field practice that the presence of large quantities of sodium carbonate, or black alkali, interfere with the passage of water through the soil. In an experiment conducted by the author, there was added to a fertile loam soil 5 per cent of sodium carbonate. The soil was then placed loosely in percolators so that the total depth of soil was four feet. The same soil containing no sodium carbonate was arranged in similar manner. Water was then added to each soil and kept six inches deep over the surface. In the normal soil the water percolated through the four-foot column in two hours, whereas it failed to penetrate the four feet containing carbonate in a year. The organic matter was dissolved from the upper layer and washed to a lower level where it made the soil impenetrable.

Excessive nitrates in the soil act in much the same way as the carbonates except that the crust they form has a brown, instead of a black, color and it is not so impenetrable. The nitrates also interfere much less with the passage of water. Alkali spots are often found where the soil remains permanently dry several inches below the surface even though irrigation water is run over them every week for several months. It is very evident therefore that though the salts may not exert a strong influence of direct capillary action they do very materially affect the absorption of irrigation and rain water in practice.

Where gypsum is present in large quantities in an irrigated soil, it is gradually washed out, causing the soil to

sink and leave typical holes. Sodium and magnesium chlorides and sulphates have less marked, but very distinct, effects on moisture movements.

Evaporation of Moisture. — The vapor tension of water is reduced by the presence of dissolved salts; hence the presence of alkali reduces the rate of evaporation. The rate of decrease of evaporation produced by the various salts is shown by Briggs (3) and by Harris and Robinson (11). It is not equal to the reduction in the vapor tension of the solution since the air at all times contains some moisture. The results of Harris and Robinson showed an evaporation of 190 grams from distilled water and only 100 grams from an equal surface of water in which had been dissolved 30 per cent of sodium chloride. Sand moistened with distilled water had a loss of 80 grams, whereas that with a 2-normal solution of sodium nitrate evaporated but 53 grams of water.

In an experiment by the author a loam soil, to which had been added various quantities of the sodium chloride, sodium sulphate, and sodium carbonate, was placed in petri dishes in a closed chamber in which the air was kept saturated. The soils all took moisture from the air, the rate of absorption depending on the salt and the concentration. In the higher concentrations so much moisture was absorbed that free water covered the surface of the soil. A condition similar to this is often found in nature where the soil of an alkali spot is wet constantly during the season even though the surrounding soil is dry.

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CHAPTER X

RELATION OF ALKALI TO BIOLOGICAL CONDITIONS IN THE SOIL

The effect of soil alkali in reducing the growth of crops or in changing completely the type of native vegetation is easily recognized. There are, however, equally as important changes produced in the microörganisms. These changes cannot be detected without special study of a technical nature and are therefore not so well understood. The micro-flora of the soil is probably as varied and as complex as the plant growth on the surface, but the response of these smaller organisms has not been as thoroughly studied as that of the higher plants. However, a few rather definite facts have been established.

Relation of Soil Organisms to Fertility. — It has long been known that bacteria and fungi in the soil are essential to continued growth of the higher plants. The constant tearing down of dead organic matter furnishes new material for assimilation by living plants. Most plants require nitrogen in the form of either ammonium salts or nitrate nitrogen. One of the important sources of such salts is vegetable matter of the soil which has been reduced to the proper form by decomposition. Certain microörganisms attack and break up the complex organic tissues of plants as soon as their resistance has been decreased by death or otherwise. Different organisms act on the different compounds as decomposition proceeds until the material is finally reduced to the simple compounds such

as are required by plants. Fungi and putrefying bacteria reduce the vegetable proteins to a form which can be acted upon by the ammonifying bacteria which finally leave the nitrogen in the form of ammonia; it may then be either combined into an ammonium salt and utilized by the plant or oxidized by other organisms into nitrous, and then nitric, acid. The latter combines with bases in the soil to form nitrates. Where the proper organisms are in the soil in sufficient numbers to carry this process smoothly to a finish the soil is usually highly productive.

Desirable organisms other than of the class mentioned above are the symbiotic nitrogen-fixing bacteria which live in the nodules of legume roots and synthesize atmospheric nitrogen into forms which can be utilized by the host plant. A number of different kinds of bacteria fix atmospheric nitrogen without symbiosis with higher plants; still other organisms are known to break up and make available certain insoluble compounds in the soil which are essential to profitable crop production.

The desirable microörganisms do best under practically the same soil conditions as do crop plants. They thrive or grow most luxuriantly in soils rich in organic matter, well aërated, and with about the optimum moisture content for most crops. Where the soil is water-logged, puddled, or contains injurious matter, the more desirable nitrifying and nitrogen-fixing bacteria are largely replaced by denitrifying and putrefying organisms which rapidly deplete the soil of available nitrogen.

Biological Inactivity and Soil Sterility. — Alkali salts which injure or prevent the production of crops on certain lands also injure the activities of the desirable soil organisms. Taylor (18) found that at least part of the sterility of certain Bengal soils was due to scarcity of bacteria and

nitrogen. Some soil students go so far as to say that an important part of the injury to crop production on alkali lands is due to decreased bacterial activity. They hold that this is shown by the fact that crop yields do not always decrease to the full extent when alkali is first brought in contact with the soil, but continue to decrease as time allows the microörganisms to die gradually. They also point out that soils do not become at once productive after being drained of alkali, but gradually increase in productiveness as the desirable organisms are given time to multiply. Whether the changes which soils undergo subsequent to drainage are due largely to bacterial activities or almost wholly to physiological changes is not at present known.

From preliminary experiments by Lipman and Fowler (13) in which soils were treated with 500 parts per million of sodium carbonate, 1000 parts per million of sodium chloride, 2500 parts per million of sodium sulphate and mixed salts, and then leached free of the salts, it was found that nitrification was affected profoundly by the leaching. The characteristic effects of the salts on the organisms remained after the salts had been almost entirely leached out. The soil receiving the mixed salts was most toxic, with sodium carbonate, sodium chloride, and sodium sulphate in the order named. This same action was noted for the nitrogen-fixing bacteria, although it was not so characteristic as with the nitrifying ones. The results with the ammonifiers was not so distinctive.

Barnes and Ali (1) found that the ammonifying bacteria, and to a less extent the nitrifiers, might be used to measure the toxicity of the alkali or its crop-producing power much more quickly and at less expense than by growing crops. They believe that the alkali merely causes the organism to lie dormant until favorable conditions

again prevail. By determining the ammonifying, nitrifying, and nitrogen-fixing power of the organisms they propose to classify land that is being drained as to its ability to grow crops.

Concentrations of Alkali which Limit Biological Activities. — The quantity of alkali that will cause injury to the ammonifying and nitrifying bacteria as determined by different investigators varies from a minimum of 250 parts per million of sodium carbonate, which was found by Lipman (10) to inhibit growth of these organisms, to a maximum of 4000 parts per million of this salt as found by Kelley (8). The nature and concentration of the nitrogenous material used to determine the activity of the organisms has been found to make a great difference in the rate of nitrification. Kelley found that where 1 per cent of dried blood was used as the nitrogenous material, 500 parts per million of sodium carbonate was distinctly toxic, but where only 0.1 per cent of dried blood was used the organisms were apparently not affected by the presence of 4000 parts per million of sodium carbonate. He also found that while 1000 parts per million of sodium carbonate were toxic to nitrification in the presence of 0.15 per cent of ammonium sulphate, this concentration was markedly stimulating in the presence of 0.0625 per cent of ammonium sulphate. The large discrepancies in the quantities of alkali which these bacteria withstand are probably due in part to the differing quantities and kinds of nitrifying materials used as well as the kind and differing natures of the soils. Dried blood, cottonseed meal, ammonium sulphate, and numerous other materials have been used; this makes comparisons of the different experiments difficult. Standard methods are needed in this regard as they are in other alkali work. It is probable

that absorption of the sodium carbonate by the organic matter of the soil plays a considerable part in these experiments, as the salts were added to the soil, and, as mentioned in Chapter V, loam soils, especially those high in organic matter, do not hold in solution all of the sodium carbonate added.

The various experiments agree pretty well that about 1000 parts per million of sodium chloride is a toxic quantity. Greaves, Carter, and Goldthorpe (6) found a stimulation with this salt up to a concentration of about 1000 parts per million above which there was a marked toxicity Other investigators have found stimulation where the quantities of sodium chloride were lower than this.

From the available experiments, the toxic limits of sodium sulphate appear to lie between 2500 and 5000 parts per million. Small quantities of this salt were found to be stimulating to nitrifying bacteria by Brown and Hitchcock (2), but Greaves and his associates (6) found no stimulation even in soils containing very small quantities of sodium sulphate.

Greaves found the toxic limits for sodium nitrate to be only a little greater than 200 parts per million, or much more toxic in comparison with its toxicity to wheat than are the other sodium salts. The quantities of sodium carbonate, sodium chloride, and sodium sulphate present in soils producing half the quantity of dry matter of normal wheat plants and those in soils producing half-normal nitrification were found to be nearly the same. The salts which stimulated wheat most also stimulated nitrifying bacteria.

From the low quantities of sodium carbonate and sodium nitrate which cause injury to nitrifying bacteria, it appears that the puddling effect of these salts may play an im-

portant part in their toxicity. In Colorado (17), however, soils containing rather large quantities of nitrates were found to be still active in nitrifying, although when the nitrates became excessive the organisms were destroyed or greatly checked in their activity.

Kelley (8) found that the nitrite-forming organisms were still active in soil containing so much alkali that nitrate formation had practically ceased.

Nitrogen-fixing organisms were found by Lipman and Sharp (14) to be inhibited by the presence of 4000 to 5000 parts per million of sodium carbonate. The toxic limits for sodium chloride were 5000 to 6000 parts per million, and for sulphate about 12,500 parts per million. Much smaller quantities were found injurious where the soil was leached of its salts, the quantity in this experiment being nearly the same as with the nitrifying bacteria (13).

Hills (7) reports that 1500 parts per million of sodium nitrate stopped multiplication and probably killed many of the nitrogen-assimilating organisms. Symbiotic bacteria (15) on peas were retarded in their activities when sodium salts in cultural solutions with a strength of 3333 parts per million were used. Alkaline nitrates at a concentration of 100 parts per million and ammonium salts at a concentration of 500 parts per million checked the production of root tubercles.

Ammonification organisms have been found by investigators who have experimented with them in comparison with those concerned with nitrification and nitrogen-fixation to be more tolerant of alkali than these other nitrogen-working organisms. Lipman found the toxic points for ammonification to be at 20,000 parts per million of sodium carbonate, 1000 to 2000 parts per million of sodium chloride, and 4000 parts per million

of sodium sulphate. For one-half normal ammonifying power, Greaves found the points to be at 11,660 parts per million of sodium carbonate, 1170 parts per million of sodium chloride, and 8520 parts per million of sodium sulphate. The results of Brown and Johnson (3) indicate a lower limit, but all show that sodium chloride is the most toxic. The relationship of the three salts is nearly reversed to that in their action on plants. Greaves (5) found sodium nitrate to be toxic at about 426 parts per million. He noticed a stimulating effect of sodium carbonate, sodium nitrate, and sodium chloride in decreasing order when only small quantities of these salts were present, but found none with sodium sulphate. His experiment also showed that some salts increase in toxicity with increasing quantities of salts much faster than others.

Lipman (9) noticed antagonism between the anions of the sodium salts, the action being strongest between 7000 parts per million sodium carbonate and 2000 parts per million sodium chloride, next between sodium carbonate and sodium sulphate, and weakest between sodium chloride and sodium sulphate. Antagonism was noted "between toxic and stimulating salts as well as between two toxic salts." A reduction of the stimulating effect of sodium carbonate on ammonification was noticed by Brown and Johnson (3) when calcium carbonate was added to the soil, but the toxic effect was also reduced. Both sodium chloride and sodium sulphate showed more stimulation and certain toxic quantities became stimulating when calcium carbonate was added. "Combinations of various salts in non-toxic individual amounts in the presence of calcium carbonate became toxic to ammonification."

Other soil organisms have been little studied. Munter's (16) experiments show that Actinomycetes were

stimulated by the addition of 50,000 parts per million of potassium chloride or sodium chloride, but that spore formation was decreased, while 100,000 parts per million usually arrested development.

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CHAPTER XI

MOVEMENT OF SOLUBLE SALTS THROUGH THE SOIL

THE greatest problem connected with the utilization of alkali lands is control of the movement of soluble salts. Were it possible to handle the land economically so that the movement of the alkali would be continually downward into the subsoil, or better, into the drainage system where it would be permanently removed from the feeding zone of the plants, the alkali problem would be solved. The upward translocation of enormous quantities of soluble salts into the top foot or two of soil has ruined vast areas of the most productive lands of the arid regions.

Salts in Natural Soils. — Where undisturbed by flooding and where the water-table is a considerable distance below the surface, soluble salts tend to accumulate at some distance beneath, rather than at the surface of arid soils. The rainfall is light and frequently so distributed that the moisture penetrates to a distance of only 3 to 4 feet in most soils. Much of the water that enters the soil is needed by the plants growing upon it and this water is extracted some distance below the surface. A large part of the movement of salts is in connection with capillary action, and because the capillary movement of moisture to the surface of the soil is reduced by the rapid drying out of the surface soil, little of the water is allowed to evaporate at the surface and deposit its soluble salts. Since there is little movement of water except through

roots in deep arid soils, and since the first flush of water passing through a soil usually carries considerably more salts than the subsequent water, the usual movement of alkali under natural conditions is toward the lower point of rain penetration. In sandy soils or in regions where the rainfall is greater, the penetration of the water is greater than on the more impervious soils or where the rainfall is light, and the accumulation of the salts at different depths varies accordingly. It was found in California (16) that on a sandy loam soil with a rainfall of 8 inches the greatest accumulation of salts was at a depth of 3 to 4 feet, whereas in a coarse sandy soil in the same place the depth of greatest salts was below 4 feet. Where the rainfall was only 3 inches the maximum salt was at about 18 inches in a sandy loam soil, whereas with 15 inches the bulk of the salts was at 5 feet.

Salt Movement with Water. — When these arid lands are brought under irrigation, however, this balanced condition is frequently upset. The soil is kept so much more moist that capillary action is much easier, and not infrequently seepage and over-irrigation raise the water-table so high that upward movement is possible from the free water in the soil. Under such conditions, the alkali accumulations of the lower depths are moved to the upper zone of soil where they become of greatest injury to plants. It is in this manner that many of the formerly productive irrigated lands have been rendered useless.

Diffusion of the salts in the soil plays a local part in the movement of alkali, but, according to the laboratory work of McCool and Millar (23) and others, diffusion causes changes for only a few inches about concentrated salt solutions, and the field observations of Mackie (24), Headden (14), Hansen (7), and others show that because

of the differences in the character and concentration of alkali in short distances vertically or horizontally, there must be movement of water before significant movements of salts are possible.

The extent to which salts move with water passing through a soil has been studied by a number of investi-

FIG. 17. — CULTIVATED LAND THAT HAD TO BE ABANDONED BECAUSE OF THE RISE OF ALKALI.

gators. In laboratory experiments, with alkali soils kept so continually moist that there was constant water movement, the author (9) has shown that alkali, principally sodium chloride, is very readily transported from one portion of the soil to another, either upward or horizontally. The salts became very concentrated in the upper inch or two of soil where the water was allowed to evaporate. The first water percolating through alkali soil contained several times as much salts as was found later. Tulaykov (30) found salts moved gradually and more or less

completely to the surface of a column of soil 150 cm. in height supplied with water at the bottom. Hilgard as well as Puchner (28) and others have noted a migration of salts upward and downward as the moisture changed places.

The latter experimenter, using quartz sand, loam, and rich humus soils, found the movement to depend somewhat on the chemical and physical properties of the soils. Powdery soils allowed the salts to move more readily than crumbly soils. Kossovich (20) reports a greater movement on a loess clayey soil than on a sandy soil and that sodium chloride hastened the rise of water while sodium carbonate impeded it. It is probable that the differences both in nature of the salts and their concentration so often noticed in fields containing alkali are, in part at least, due to changes in the nature of the soils which in turn modify the rate of capillary action. In studies of the movement of moisture, Briggs and Lapham (2) conclude that "concentrated or saturated solutions of all salts materially diminish capillary action," but that in dilute solutions the neutral salts had very little influence on capillary action. They found sodium carbonate to have a greater influence on capillarity than the neutral salts.

The extent of the fluctuation of salts upward and downward under irrigation in the field has not been determined with any degree of accuracy. Hilgard considered the movement to be mostly in the top four feet. Considering the ease with which the salts move with the water and from observations of the movement of soluble salts with irrigation water when no alkali was present (11), it is very probable that the salts are frequently moved to great depths where not prevented by impervious soils or by a water-table. Investigations show that water is seldom

drawn to the surface by capillary action from a depth greater than 2 or 3 feet, so that the greater part of the alkali which penetrates beyond this depth never again reappears at the surface unless the water-table rises to within a few feet of the surface. Water movement below the top 2 or 3 feet is probably caused by moisture removed by the plants or by the action of gravity so that it is improbable that there is such movement of salts other than local diffusion and movement with the gravitational, or free, water.

Effect of Water-table. — Where the drainage is poor so that there is a rise of the water-table the conditions are modified accordingly. With a water-table near the surface, the soluble salts dissolved from the soil by downward movement are held where they may be drawn by capillarity to the surface and again accumulate. Headden (14) observed that the water in shallow wells rose in salt content from 2871 parts per million before an irrigation to 4444 parts per million twelve days following and then gradually fell to 2590 parts per million just before the next irrigation.

He and also Mackie (24) noticed that the concentration of the top of the water-table was greater than the lower depths and that there was a rather gradual decline in the soluble salts in the water with depth. As the water-table rises the most concentrated solutions are presented for upward translocation. Headden (14) made a rather detailed study of the effect of seasonal movement of water-tables from which he concluded that as the water fell much of the salts in the free water was retained by the soil so that the free water gradually became weaker as it sank and again increased as it rose. He (15) found that the kind and quantity of salts in the soil solution differed markedly from those found in the free ground water or

from the alkali incrustations on top of alkali soil. Certain of the soluble salts were absorbed by the soil, while others moved somewhat more freely. Calcium sulphate was the most abundant salt in the soil solution with magnesium sulphate second, while sodium sulphate formed considerable of the efflorescent matter on the surface, and the salts next the surface. Sodium chloride did not separate as readily as some of the other salts. Very little calcium sulphate left the soil to form part of the incrustation.

Movement of Various Salts. — It has been noticed by numerous observers that the different salts move somewhat independent of each other so that in comparatively short distances either vertically or horizontally rather marked differences are found. Experimenters have come to varying conclusions as to the ease of movement of the different alkali salts. Practically all field investigations have shown that the chlorides are the most sensitive to water movement. Both under arid alkali soils and where irrigation has shifted the salts to other positions, sodium chloride is generally found in its highest concentration at the point where the total salts are highest. Headden (12, 13) states that while retention of salts differs with the soil, sodium sulphate was most markedly retained, sodium chloride slightly, and sodium carbonate hardly at all, and that "there is a tendency for the 'white alkali' to pass into the deeper seated waters" and out of the region where there is good drainage. King (18) reports sodium sulphate as being readily absorbed by the soil, while sodium chloride was not retained. The soil has a slight retentive power for the acid radical of sulphates but none for nitrates, chlorides, nor carbonates according to Warington (32). Dimo (4) noticed accumulations of sodium chloride and sodium sulphate at a depth of 50 cm. in a

field soil, while in the deeper layers sodium bicarbonate and sodium carbonate gradually replaced the former salts.

The work of Mackie (24) in California indicated that sodium carbonate was readily absorbed by the soils and therefore held its position in the soil well. On irrigated soils he usually found sodium carbonate in the greatest quantities near the surface, but on virgin soil its location varied in depth down to the hardpan. From results on

FIG. 18.—ALKALI EATING AWAY THE FENCE POSTS.

land irrigated 4 or 5 years presented by Hilgard and Loughridge (16) it appears that sodium chloride moved upward to the first foot relatively faster than sodium sulphate and considerably faster than sodium carbonate.

Few data are at hand to show to what extent this difference in the rate of movement of the different salts proceeds under field conditions. Analyses of drainage water from alkali land near Salt Lake City, Utah, reported by Dorsey (6) show that in the course of three years the chloride was removed relatively faster than the other alkali salts when it constituted by far the greater part of

the alkali. Drainage of a soil in California (22) removed about 85 per cent of the sodium chloride, 83 per cent of the sodium sulphate; drainage and conversion to sulphate reduced the sodium carbonate content to 65 per cent of the original quantity.

Rate of Alkali Movement. — Theoretically, the alkali salts are so soluble that their removal from the soil by drainage should take only a short time, but in practice it often takes several years to reduce the salt content of seriously affected alkali lands sufficiently to produce crops. Dorsey (5) attempts to explain the difficult movement by the theory that the salts from the descending free-water solution are drawn into the capillary spaces of the soil where rapid downward movement is prevented. Subsequent downward percolation is attributed to diffusion of the salts outward into the free-water spaces.

Warington (32) states that the first water percolating through land containing soluble salts at the surface was much more concentrated than subsequent leachings but that where the chloride was first incorporated in the soil and then leached its concentration in successive leachings gradually increased. He explains this by assuming that the first water that comes from a drain passes through cracks and burrows of insects and comes direct from the surface, while that passing through the soil spaces alone does not arrive until later.

To explain the extremely slow movement of soil solutions through alkali soils, especially those under laboratory or other conditions where the alkali is added to the soil as a single salt, Sharp (29) offers the theory that the alkali salts react with the colloids of the soil causing diffusion. He found that where solutions of sodium chloride or sodium sulphate were in constant contact with the soil the rate of

percolation was increased, but that where soils treated with these salts were leached the rate of percolation was diminished. In one experiment it was noticed that the quantity of suspended matter leached from soil containing sodium chloride was ten times that from the check and that the rate of percolation had been diminished to about one-tenth that of the check. It was further learned that once the sodium chloride was leached from the soil a larger quantity was required again to flocculate the soil and that it was more difficult thereafter to repair the deflocculated condition. A large number of investigators have noted an increase of calcium and magnesium and a decrease in sodium in alkali water after it had percolated through a soil. This exchange of bases is said by Sharp to result from displacement of calcium and magnesium by the sodium in the colloidal substances of the soil and the resulting increased diffusibility to be the cause of the retarded movement of the water. The removal of the calcium and magnesium from the soil is thought by him to be of less importance than the increased diffusibility of the colloids, although these bases are recognized as being important in the deflocculation of the colloids and in maintaining the proper physical properties of the soil. Contrary to Sharp's results, Pagnoul (26) did not find the sodium of sodium sulphate, nor to an appreciable extent sodium carbonate, to replace lime of the soil, and other experimenters do not report sodium sulphate as replacing lime except where sodium chloride was also present. Pagnoul agrees with Sharp that lime replaces the bases of chlorides of potash, soda, and ammonia. If the degree of permeability to water can be taken as a measure of the deflocculation of soils, experiments by Beeson (1) show sodium chloride to be more than twice as powerful as

sodium carbonate as a deflocculating agent but less than one-half as powerful as sodium nitrate. Percolation was at the rate of 1.2 cc. per hour for soil containing 1886 parts per million of sodium chloride and at the rate of 4.1 cc. per hour for soil containing 11,457 parts per million of sodium sulphate, while that of the untreated soil was at the rate of 10.2 cc. per hour. Hare (8), however, found sodium chloride much easier to leach into the deeper layers of the soil than sodium sulphate and that the difference was many times greater in an adobe soil than in a sandy loam. It was with great difficulty that the sodium sulphate was leached downward in the adobe soil, the depth being 2 inches for three six-inch irrigations, while this amount of irrigation washed the sodium chloride to a depth of 32 inches, and four three-inch irrigations washed the sodium carbonate to a depth of 20 inches. The sodium chloride moved more freely than the other two salts in both adobe and sandy loam.

The above experiments were performed with pure salts. Cameron and Patten (3) found that when using black alkali soils brought from the fields and containing notable quantities of sodium sulphate, besides the sodium carbonate and small quantities of chlorides, the "neutral salts such as the chlorides in the presence of carbonates can be comparatively readily and completely leached from the soil. With continued leaching of soils containing 'black alkali' there is an increase in the rate at which percolation takes place, due probably to the reduction of the amount of alkali present and its effect on the physical structure of the soil. Soils containing 'black alkali' can be reclaimed by leaching, but the time and the amount of water required are probably much greater than in the case of white alkali."

Very little attention has been given to the effect of the different alkalies on the physical conditions of field soils; consequently, it is not known whether or not the rate of movement of salts under field conditions is checked by washing the salts out of the soil as in the above laboratory experiments. The last-mentioned experiment apparently indicates that when the salts are mixed, as under field conditions, the deleterious action of the neutral salts is not so great as under the laboratory mixing conditions.

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CHAPTER XII

METHODS OF RECLAIMING ALKALI LANDS

No single method of reclamation is adapted to all alkali lands. Many conditions must be considered in deciding what methods to adopt. The source of the alkali, the texture of the soil, the slope of the land, the depth of the water-table, the price and supply of reclaiming materials, the kind of crops that will grow in the climate, the value of the reclaimed land, and a number of other factors must be taken into account before deciding the advisability of reclaiming a given alkali soil and the methods to be used in case reclamation appears economical. Whatever the method, the goal is the same; each aims to check any increased accumulation of salt and to reduce the present harmful quantities of alkali to a point at which the growth of crops will not be hindered.

The Source of Contamination. — The first step in the reclamation of alkali land is to discover the source of the salt. Intelligent systems of improvement first discover and remove the cause of the accumulation. As with human disease, an ounce of preventative is worth a pound of cure. Most of the effort spent in securing temporary relief is wasted if the trouble soon returns. Work is done to much better advantage if done with the idea of securing permanent results.

As pointed out in Chapter X, alkali comes to the soil in a number of very distinct ways. These must be recognized in deciding which method of reclamation is best

adapted to the conditions. Where an irrigation canal passes through a formation that is high in soluble salts the water becomes alkaline and carries the soluble material to the land where the water is applied. A canal in a formation of this kind becomes porous when the salts are dissolved. This allows seepage water to percolate more readily from the canal, increasing the quantity of water which comes out on land below; this in turn causes water-logging together with deposition of alkali salts. Lining the canal with cement over the salt-bearing formation will do more toward permanent reclamation than any number of temporary devices on the land itself which do not remove the source of the trouble.

Often a large area becomes water-logged from a single source, and in arid soils water-logging is generally followed by alkali accumulation. A ditch across the head of the land to cut off the water in cases of this kind will often prevent or overcome the difficulty without applying methods of reclamation on the land itself.

Some soils contain a layer several feet below the surface in which the salt is very concentrated. Where this is the case, every effort should be made to prevent a rise of the salt to the surface where it will hinder crop growth. If it remains at considerable depth, it may be entirely harmless, whereas it might entirely prevent plant growth if it rose to the root zone. These examples show the relation of reclamation methods to the source of alkali.

Reducing Evaporation. — The chief method by which alkali accumulates at the surface of the soil is through evaporation. The author (4) has shown the ease with which salts move with moisture through the soil. Whenever water evaporates from the soil surface more water is moved to the surface by capillarity and the process re-

peated. Thus, there may be a constant stream from the subsoil to the surface, particularly if the water-table is

FIG. 19. — TYPICAL HARD PAN FOUND IN ARID SOILS.

within two or three feet of the surface. All the water that moves transports some salt, and since none of the salt can be evaporated, all of it remains as a surface ac-

cumulation. If the soil is very low in soluble salts no harm may be done, but arid soils usually contain sufficient salt to render high evaporation dangerous.

If virgin soil contained 3000 parts per million of alkali, the growth of most crops would not be greatly hindered; but if through a constant movement of salt to the surface the salt of the top four feet were concentrated in the upper six inches, it would contain 24,000 parts per million, which would make it entirely unsuited to crop production without reclamation. If evaporation is reduced to a minimum, an accumulation of this kind is checked. In the reclamation of alkali land by any method, it is desirable to prevent evaporation as nearly as possible, because evaporation causes the salt to accumulate where it will do most harm.

In practice, many devices to reduce evaporation are employed. These usually consist of cultivating the soil, shading it, or the establishing of a good mulch by adding manure, straw, leaves, or sand. Of the various materials to be added, manure is usually to be recommended since it has sufficient beneficial effect in addition to the mulching to pay for its use, while others are of questionable economic importance.

The most practical means of preventing evaporation is through cultivation. An unstirred soil, particularly if it is heavy — as many alkali soils are — forms a crust which acts as an excellent conductor of moisture. Breaking up this crust by cultivation leaves the soil loose and with but few points of connection with the lower layers of soil. As a result evaporation is slight even though the subsoil remains moist. It is particularly important that the land be cultivated soon after irrigation since evaporation at that time is especially high.

Harris and Robinson (5) have shown that shade is very effective in reducing evaporation. This suggests the desirability of keeping alkali land constantly shaded, preferably by a crop, which not only shades the soil but also causes the water to pass into the air through the plants without coming to the surface. A growing crop may therefore be considered as one of the most important agencies in the reclamation of land containing small quantities of alkali.

A water-table near the surface is the chief cause of harmful evaporation. It is difficult to prevent the passage of large quantities of water to the surface when there is an unlimited supply 2 or 3 feet below. The prevention of alkali accumulation calls for a lowering of the water-table to several feet from the surface. The growing of green manure crops instead of leaving the land uncropped is one way of reducing the surface accumulation of alkali.

Plowing Under of Surface Alkali. — Hilgard (9) has shown at the Tulare Substation, California, that the injury caused by alkali was reduced by plowing the surface accumulation under. Part of a very bad alkali spot was trenched to a depth of two feet and the surface soil thrown to the bottom. The spot thus treated produced good wheat crops for two years, which was the time required for the alkali to return to the surface. Ordinary plowing is to some extent similar to the above treatment; hence the tendency of salts to accumulate at the surface by evaporation of water is in part overcome by ordinary field practices.

In order that this operation may be effective, the plowing should be as deep as possible, since salt turned under only 3 or 4 inches deep would return rapidly to the sur-

face, or even worse, the highest concentration would be in the soil layer where young plants were getting their start. The plowing under of alkali cannot be considered in any sense as getting rid of it. The most that can be claimed is that injury is retarded till drainage or some other permanent means of elimination begins to operate.

Removing from Surface. — In certain cases where most of the salts have accumulated at the surface, it is possible to remove large quantities without the use of covered drains. Surface removal is accomplished by scraping or sweeping off the salt or by dissolving it and then draining off the solution. Scraping and sweeping, in order to be practical, would call for a higher concentration of salt than can be removed by dissolving.

Where the salt is to be removed in solution, as may be done in exceptional cases, the land may be diked in such a way that water can be made to stand several inches deep over the surface for a number of hours till most of the salt is dissolved. The solution is then drawn off carrying with it a large percentage of the alkali. Water may in this way be added and drawn off several times in order to make the treatment effective. It is not necessary to let the water stand more than a short time since the salt dissolves quickly and if allowed to stand would reënter the soil with percolating water. This method is not to be recommended under many conditions.

A method of reclamation somewhat similar to the above requires water to stand on the land for long periods. By this means the salt is gradually washed down into the soil out of the reach of plants. Where conditions are favorable, however, it is much better to carry the salt entirely out of the land by drainage, since it will rise again if simply washed down.

The reclamation of land by flooding is used extensively in the lower Nile Valley in Egypt. Details of the methods used are described by Means (12). After land has been reclaimed by flooding it is desirable to raise a crop that can endure alkali and water till the soil is in a proper condition for other crops. Rolet (12) recommends rice for climates in which it will grow. White sweet clover (*Melilotus alba*) is also an excellent crop for this purpose.

Neutralizing Sodium Carbonate. — The methods used in removing most of the salts are not entirely satisfactory for sodium carbonate, or black alkali. This salt dissolves organic matter from the soil and deflocculates the particles, thereby injuring the soil structure and making the penetration of water very slow. The high direct toxicity of this salt also renders it much more harmful than the sulphates. Hilgard and his associates (8), working in California, found that under suitable conditions sodium carbonate can be made to react with gypsum to form sodium sulphate and calcium carbonate. The reaction is as follows:

$$Na_2CO_3 + CaSO_4 = Na_2SO_4 + CaCO_3.$$

This changes the alkali from a very injurious to a much less harmful salt.

Shinn and Hilgard (15) used 3000 pounds of gypsum to the acre in Tulare, California, with good results. The best results were secured on plats treated with gypsum in connection with drainage. Later reports of the experiments made by Hilgard and Loughridge (8) and by Shinn (14) show that the treatment continued to be successful. In some cases gypsum was used at the rate of 7.7 tons to the acre annually for thirteen years with a gradual amelioration of the alkali spots. In the four

years following 1897 a six-acre vineyard received 34,000 pounds of gypsum or about $4\frac{1}{2}$ tons a year. This was applied at a cost of less than four dollars an acre each year which was a small cost in proportion to the returns.

As a result of experiments in the San Luis Valley, Colorado, Headden (7) suggests the use of nine pounds of gypsum for each pound of black alkali in the soil and the removal of the alkali by surface irrigation.

Extensive experiments by Breazeale (1) are reported as showing that the field application of gypsum probably has no effect in overcoming black alkali if the soil already contains soluble sulphates in appreciable quantities or if the irrigation water contains these salts. It seems, therefore that while gypsum is useful under some conditions, it is not by any means a universal panacea for all black-alkali troubles.

Other Chemical Treatments. — The use of chemical substances other than gypsum has frequently been tried in overcoming alkali. Symmonds (17) found in pot experiments that alkali soil that was treated with 0.2, 0.5, and 1 per cent of nitric acid produced more than 5 times the yield of wheat that was produced by the untreated soil. He (16) later carried on a similar experiment in the field where 600 pounds of nitric acid to the acre of land were mixed with artesian well water and sprinkled on the soil. The results showed a great increase in yield due to the treatment.

Lipman (10) has obtained excellent results in treating alkali soil with small quantities of sulphuric acid.

The use of stable manure on alkali land has long been known to improve it for crop production. It has indirect value in reducing evaporation as well as the more direct action on the soil and plants.

Cropping with Alkali-resistant Crops. — Allowing land to remain uncropped promotes accumulation of alkali at the surface. It is desirable, therefore, to maintain some kind of plant growth on land that is being reclaimed even though the plant is not the most desirable. Any plant growth is better than none. In soils that are so highly alkaline that no ordinary crops will grow, certain salt weeds will thrive. It is much better to have them growing than for the land to be bare. When these weeds cover the land the temptation is to burn them, but such a practice leaves the alkali absorbed by the plant on the top of the land with the ash. Some alkali-resistant plants take up large quantities of salts, which might be permanently removed from the land if the weeds were harvested and hauled off rather than being burned where they grew.

In Chapters VI and XIV there is a full discussion of the crops that do well on alkali land. From these lists, crops may be selected for use during the various stages of reclamation.

Drainage. — The only permanent way to reclaim alkali land is to remove the excessive salt. This can best be accomplished by some system of drainage, the various types of which are described in Chapter XIII. It may be said, therefore, that alkali reclamation and drainage are almost synonymous terms. Of course drainage is not equally effective under all conditions. Heavy, compact soils containing large quantities of black alkali respond slowly to drainage, whereas open soils which may contain large quantities of sulphates and chlorides may have these salts effectively washed out in a short time.

A good example of the rate of removal of salts is had in the Swan Tract (3) near Salt Lake City. Work was begun in 1902 on this forty-acre farm by the U. S. Department

of Agriculture Bureau of Soils and the Utah Agricultural Experiment Station coöperating. By the end of 1903, 5,651,776 cubic feet, or 51.8 per cent, of the water added to the tract came out through the drains. This water carried

TABLE XVII. ALKALI SALTS REMOVED BY DRAINAGE DURING THREE YEARS. SWAN TRACT NEAR SALT LAKE CITY

MONTH	WATER ADDED PER ACRE			SALTS ADDED IN IRRIGATION WATER (Pounds per acre)	SALT IN DRAINAGE WATER (Pounds per acre)	NET SALTS LOST FROM SOIL (Pounds per acre)
	Rain and Snow (Acre inches)	Irrigation (Acre inches)	Total (Acre inches)			
1902						
September	.....	1.96	1.96	696.1	3,805	.....
October ..	.....	6.47	6.47	2,288.0	4,878	2,583
November	1.18	.....	1.18	.....	8,845	8,845
December	1.15	.....	1.15	.....	4,695	4,695
1903						
January..	2.01	.....	2.01	.....	9,780	9,780
February.	.94	.....	.94	.....	5,370	5,370
March ...	.91	.....	.91	.....	14,768	14,768
April.....	.77	.....	.77	.....	663	663
May.....	3.97	5.23	9.18	1,858	14,178	12,320
June.....	.73	4.66	5.38	1,655	8,630	6,975
July	.25	11.65	11.98	4,138	13,912	9,774
August...	.....	14.62	14.58	5,192	30,544	25,352
September	.....	16.20	16.17	5,754	41,353	35,599
October ..	.....	2.42	2.42	859	21,025	20,166
November	.....	3.88	3.87	1,378	3,159	1,781
December	.....	.28	.28	99	1,099	1,000
1904						
January..	.....	1.50	1.49	533	473	60
February.	.....	2.06	2.06	732	11,891	11,159
March ...	.....	1.29	1.29	458	13,049	12,591
April.....	.....	1.76	1.76	625	9,558	8,933
May.....	.....	2.64	2.63	938	1,537	599
June.....	.31	4.26	4.55	1,513	787	− 726
July	.60	11.09	11.66	3,939	9,634	5,695
August...	.25	13.23	13.35	4,692	17,776	13,084
September	.14	5.52	5.65	1,960	14,480	12,520
Total ..	13.21	110.72	123.69	45,572	265,889	223,586

out 3648 tons of salt over the measuring weir in addition to the salt washed to lower depths by percolating water.

Tables XVII and XVIII show in detail the rate of removal of the salts.

TABLE XVIII. QUANTITIES OF ALKALI AT DIFFERENT DEPTHS OF SOIL ON CERTAIN DATES AND COMPOSITION OF DRAINAGE WATER. SWAN TRACT NEAR SALT LAKE CITY

Soil Section	September, 1902		May, 1903		October, 1903		October, 1904	
	Alkali in Soil (p.p.m.)	Part of 4 ft. Total (per cent)	Alkali in Soil (p.p.m.	Part of 4 ft. Total (per cent)	Alkali in Soil (p.p.m.)	Part of 4 ft. Total (per cent)	Alkali in Soil (p.p.m.)	Part of 4 ft. Total (per cent)
First Foot....	17,038	20	6,238	14	1,263	8	475	4
Second Foot..	19,250	23	8,125	19	2,288	15	1,600	13
Third Foot...	22,075	27	13,325	31	4,125	28	2,650	24
Fourth Foot..	24,775	30	15,813	63	7,608	49	6,250	57
Total.....	83,138	..	43,501	..	15,284	..	10,975	..
Average....	20,785	..	10,875	..	3,821	..	2,744	..

Chemical Analysis of Drainage Water (in Parts per 1,000,000)

Constituent	Seepage Water from Tile Drain before Irrigating, Oct. 9, 1902	Drainage Water, June 18, 1903	Drainage Water, April 4, 1904	Drainage Water, May 10, 1905	Drainage Water, June 26, 1906
Ca.....	45	72	61	37	37
Mg.....	96	257	162	70	89
Na.....	6,966	11,771	7,262	3,660	3,924
K.....	319	260	269	108	126
SO_4.....	3,870	8,886	3,531	2,143	2,288
Cl.....	7,650	12,070	8,881	3,958	4,312
HCO_3.....	1,329	937	800	666	695
CO_3.....	71	55	40	59	60
Total Solids .	20,346	34,308	21,006	10,701	11,531

Hart (6) gives an example of a tract on which before drainage the ground water stood within 2 feet of the surface. A white crust of salts covered the surface and nothing of value grew on the land, the only vegetation being an occasional salt weed. The average salt content for the first 4 feet of depth was 2.25 per cent. A drainage system was installed and in a month so much of the excess water in the soil was removed, that the water-table was practically down to the level of the drains. The drainage water was very high in salt. By the end of the month an analysis showed the salt content of the soil to have been reduced to 1 per cent. The ground surface was cultivated and irrigated with a limited supply of water and crops were planted. These gave only fair results. Meanwhile the higher temperature of summer had increased evaporation and the average salt content for 4 feet was found to have increased to 1.28 per cent in spite of drainage. A near-by uncultivated and unirrigated spot which had been affected to some extent by the drainage system showed an average salt content for the first four feet of 1.51 per cent. It was evident that drainage alone would never reclaim the tract; hence, a heavy flooding was given which reduced the average salt content for the first 4 feet to 0.43 per cent, less than one-fifth of the original content. At the same time the near-by uncultivated spot showed an average salt content for the first 4 feet of 1.73 per cent, an increase which was caused by percolation from flooding the adjacent land.

Thousands of examples could be given to show the effectiveness of drainage in reclaiming alkali lands. Many failures have also been recorded. These have resulted from improper methods which were decided on before all conditions were studied and also from the fact that the drainage system was expected to do everything.

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CHAPTER XIII

PRACTICAL DRAINAGE

During the early years of irrigation in America no provision was made to remove the excess water that always collects in the lowlands of irrigated districts. This is one of the chief reasons for the accumulation of alkali. The modern up-to-date irrigation system should include some method of drainage whereby any excess of water is carried out of the land; for there are always a few farmers who, to the detriment of themselves and their neighbors, use too much water. A drainage system laid out at the same time as the irrigation system will in some cases be more simple than one installed after the land becomes a bog. In swampy places drain ditches are constructed with difficulty and tile cannot be laid evenly and securely. Unfortunately, the reclamation of most alkali land is not undertaken until after the condition has become bad. This means that many difficulties are encountered. Of course it would not be wise to install drainage when the irrigation system is put in unless there is likelihood of water-logging. The problem is doubly complex since not only must the excess soil water be removed but the alkali must also be washed out.

Advantages of Drainage. — Where drainage systems are installed on land there is generally a complete transformation; many conditions favoring crop growth are improved. Most important in an alkali soil is the removal of the excessive salt. In many soils where the salt content is

not high enough entirely to prevent crop growth, there is sufficient to reduce the yield to a point that is unprofitable. The expenses are practically the same in raising half a crop as a full one. In the one case farming is carried on at a loss, and in the other a good profit may be realized. Thus, removing alkali by drainage may make highly productive millions of acres of land that is only moderately

FIG. 20. — FIELD READY FOR LAYING TILE.

successful. There are also millions of acres at present wholly unproductive that may be made to yield bounteously by removing the alkali.

Drainage removes the excessive water from the soil. By lowering the water-table the plant is given a larger root zone from which to draw both food and water. If only the surface foot or two can be drawn on for food the plant cannot be expected to be so well supplied with nourishment as it would with a feeding area of five or six feet.

Strange as it may seem, drainage increases the water supply of the plant and reduces the injury that is likely to be caused by drought. Roots do not readily penetrate into the ground water. They are confined to the zone above the water-table from which they absorb capillary water. Free water is unavailable to them. A water-table near the surface means, therefore, that the plant can absorb water from only a limited area. In case of drought when the water-table is likely to be lowered rapidly the plant has but a shallow root system which is unable to endure drought so well as a root system which extends well into the soil and is able to take up moisture from a deep soil zone.

Drainage allows the soil to become warm early in spring. The high specific heat of water makes it slow to become warm. This has great practical significance since a slow, cold soil delays spring work and retards the development of the young plant at a critical period in its life history.

Roots require air for their normal functioning. If free circulation of air through the soil is retarded by water-logging, the plant does not get sufficient air for its best growth. This condition reflects itself in the yield. Covered drains promote the free movement of air through the soil; this may help to account for the wonderful results that follow drainage in cases where the water-table is not close to the surface and alkali is not injurious.

Going hand in hand with better aëration is the better condition for the growth of desirable microörganisms. Decay of vegetation in absence of sufficient air takes place as putrefaction which results in products toxic to plant growth. Nitrification, nitrogen-fixation, and normal plant decay require air. If it is not present the organisms promoting these beneficial processes will be replaced by undesirable ones.

Water-logged land has a tendency to heave in freezing. This results in the winter-killing of such crops as alfalfa, clover, and fall grains. Where the soil is not covered with a protective layer of snow, winter-killing may be one of the most serious handicaps to farming. Anything that reduces it will add greatly to the farmer's profits.

The tilth, or structure, of the soil is benefited by drainage. An undrained soil puddles readily, whereas one that is drained tends to form the crumb-like structure which is sought by the farmer.

Determining the Need of Drainage. — As with all other expenses, that required for drainage should be investigated before it is incurred. It would of course be folly to spend 15 or 20 dollars an acre draining land that would not be benefited thereby. Drainage is usually carried on to remove either excess water or excess alkali. In spite of secondary benefits, it is doubtful if it would pay to drain in most cases unless one of these undesirable conditions existed.

An excess of water can easily be determined by boring test holes with a soil auger. The surface indications are not an absolutely reliable guide. In many soils having a dry, baked crust at the surface, borings will reveal free water 2 or 3 feet below the surface. The color and thrift of the vegetation are valuable aids in determining the need of drainage, but the final test should be made by the use of an auger.

Excessive quantities of alkali can readily be determined by a chemical analysis. Water extracts of the soil can easily be tested for chlorides, sulphates, carbonates, and nitrates. With information of this sort available it is possible to say whether or not some of the salts should be removed. The electrolytic bridge is very useful in this

connection to determine the approximate concentration of total soluble salts. For exact work, chemical methods should be resorted to, but for general reconnoissance work the bridge can be used to advantage.

Types of Drains. — After deciding that the land needs drainage, the next point to settle is the type of system to

FIG. 21. — BOGGY ALKALI LAND THAT IS DIFFICULT TO DRAIN WITH SHORT TILE.

install. No one system is best for all conditions. On some projects a combination of systems can be used to advantage.

The open drain on account of its low initial cost has been used rather extensively. It has some advantages and many disadvantages. Among its advantages is the fact that its action is at all times under the observation of the farmer. Any obstruction can easily be found and removed. The fact that the farmer can do most of the

work himself at odd times and does not have to pay for materials makes it possible at times to put in an open ditch, whereas a closed drain would be beyond his reach. Among the disadvantages of the open drain are the facts that the original cost does not represent the total outlay. Every year, and often several times during the year, open drains must be cleaned. The banks cave off or other obstructions fall in and interfere with the effective-

FIG. 22. — OPEN DITCH USED TO CARRY AWAY THE DRAINAGE WATER FROM A LARGE AREA. COVERED DRAINS EMPTY INTO THIS DITCH.

ness of the drain. Weeds growing on the banks and in the bottom of the ditch are a constant source of annoyance. Considerable land that could be cultivated if the drain were covered is made useless by the open ditch, which also cuts the land up into smaller fields causing inconvenience in plowing and performing the other farming operations. Open ditches are always a source of danger for farm animals that may fall in them and be injured. These many disadvantages usually turn the preference toward some form of covered drain, except in such cases

as require a main drain to carry off large quantities of water. Several closed drains may open into a main open ditch.

Many types of closed drains are in operation. The main requirement is to preserve through the subsoil an open channel that will carry off percolating waters. A

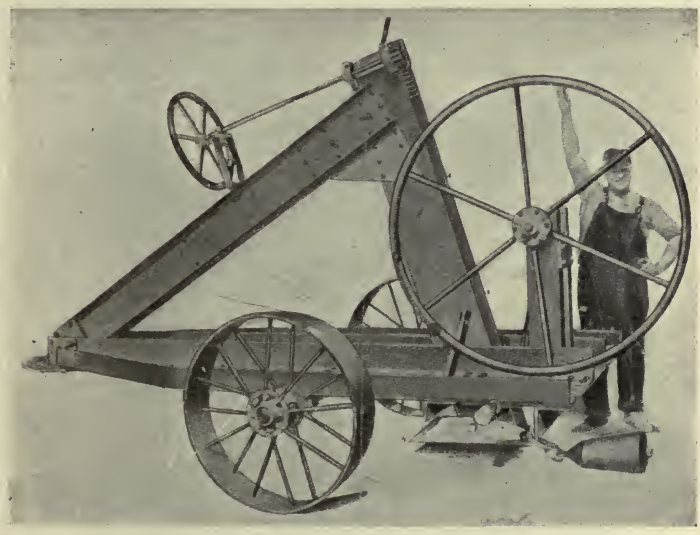

FIG. 23. — MACHINE FOR MAKING DRAINS IN HEAVY SOIL WITHOUT THE USE OF TILE.

ditch is dug and some material that will maintain the channel open placed in it. Rocks, brush, straw, timber, and tile are all used.

In certain heavy gumbo soils a special device known as a gopher machine, shown in Fig. 23, makes a hole through the soil that does not require filling. In this device a torpedo about 8 inches in diameter is attached to a subsoiling point, which is held in the ground by a heavy wheeled frame. The depth at which the torpedo is pulled through

the soil can be regulated by the operator. In making drains this machine begins at the outlet end and moves toward the higher land leaving a gopher-like hole through which the drainage water passes. Such drains can be made 25 feet apart for about $5 an acre. These will last 5 or 6 years in the right kind of soil. If any of them happen to become clogged, new ones may be made between the others.

The type of covered drain to use depends on a number of factors. In wet brush land where rock and lumber are scarce and where tile cannot be had, rush and straw may be used to good advantage, although usually less efficiently than some of the more permanent types.

Brown and Hart (3) found lumber drains to be very effective in a swamped soil that would not remain firm enough to hold tile. Rock properly placed in the trench has long been used to keep open the water channel.

These various unusual types of drains are unimportant in comparison with tile. The most common kinds are clay tile, either porous or vitrified. Many types of clay tile are to be had. These are so well and favorably known that further discussion seems unnecessary here. Cement tile is being used to some extent, but its use on alkali land is attended with some risk which is explained below.

Cement Tile for Alkali Land.— The ease with which cement tile can be made in some localities has encouraged its use for drainage. This has often resulted in failure, because it has been found that under certain conditions the cement is attacked and destroyed by some of the alkali salts. This observation has led to considerable study on the relation of soluble salts to cements and their deterioration.

Burke and Pinckney (4) found that to cause weakening it was necessary for salt solutions to penetrate the concrete.

Weakening results from the formation of compounds that expand and break up the concrete. Later the soluble compounds leach out leaving the material not nearly so

FIG. 24. — POORLY MADE CEMENT THAT IS BEING CRUMBLED BY ALKALI.

strong. Neat cement that excluded absorption was not injured by alkali solutions. Meade (9) found that even very dilute solutions of the salts of magnesium and the sulphates in general have a destructive action on concrete. Cements low in alumina were less affected than others.

Work done at the U. S. Bureau of Standards (1, 14) shows how Portland cement concrete mortar, if porous, can be disintegrated by the mechanical force exerted by the crystallization of salts in its pore spaces. Mixtures leaner than one part cement to three parts of aggregate were found to be unsuitable for use in localities having a soil high in alkali.

Headden (6) found that in the presence of solutions of sodium sulphate and sodium carbonate a chemical decomposition of the cement takes place with a removal of silicic acid and lime which destroys the cohesiveness of the concrete.

Steik (12) found that, of the great number of solutions tested, the 5 per cent sodium sulphate had the greatest disintegrating action. Solutions containing chlorides, sulphates, and carbonates all had some effect. Mortars were found to disintegrate faster than neat cement, which is similar to the findings of Sims and Dieckman (11). The latter author found that density and age are very important factors in helping cement to resist alkali. Steik believes that the ultimate cause of the disintegration of cement by alkalies is due to the formation of compounds in the cement, which subsequently are removed by solution.

These experiments all show the necessity for care in the use of cement tile to drain alkali land, but if the cement is properly made it is fairly satisfactory.

Preliminary Survey. — Before actual trenching is begun it is important to make a preliminary survey to determine the nature of the subsoil and the slope of the land to be drained. A great many test holes made with an auger will reveal the location of pervious and impervious strata. This information is necessary in deciding the depth, location, and direction of the drains. A system

installed without taking account of these conditions is likely to be inefficient and expensive.

Laying out the System. — After the preliminary survey is made the system can be laid out and the location and depth of each drain determined. The district should be

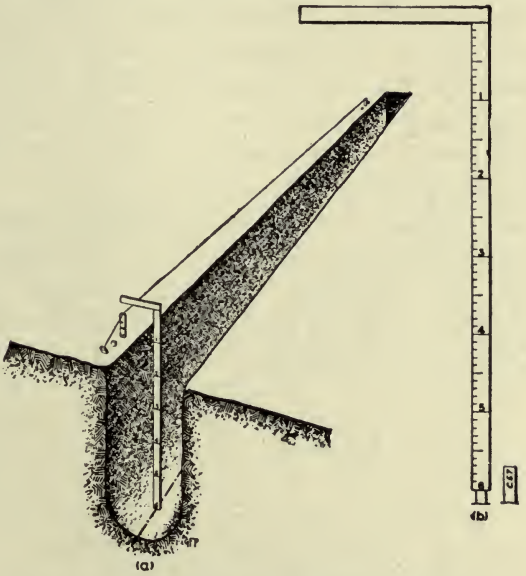

FIG. 25. — METHOD OF ESTABLISHING GRADE OF DRAINS

mapped in such a way that the data obtained in the preliminary survey will show the contour of the surface, the texture of the soil and subsoil, and the ground-water condition. On this map the drainage system may be drawn in such a way that intersecting joints, the sizes of tile, and other data can be preserved for future use. These data are extremely valuable in locating trouble. The memory is not sufficiently accurate to be relied on for this

information, and it is a good idea to preserve the record for the use of some one besides the original drainer of the land.

In laying out the system the depth of the drains, the size of tile, the slope of the drain, and the distance apart must be given careful consideration and will vary with each set of conditions. These factors depend somewhat upon each other. For example, the steeper the grade the smaller the tile may be, and the deeper the drain the farther apart they may be placed. In general, tile should be placed from 5 to 7 feet deep and the space between tile lines will usually vary from 200 to 1000 feet.

Size of Drains. — A number of formulas have been worked out to help in deciding the size of tiles that will be efficient and economical. Poncelet's formula for determining the velocity of flow in drains, which has found considerable use, is as follows:

$$V = 48\sqrt{\frac{D \times F}{L + 54D}}$$

in which

V = Velocity in feet per second,
D = Diameter of tile in feet,
F = Total fall of drain in feet,
L = Length of drain in feet.

Knowing the velocity of flow in a tile of given diameter the discharge may be determined by using the general formula:

$$Q = AV$$

in which

Q = Discharge in cubic feet per second, and
A = Cross-section area of tile in square feet.

The number of acres drained is found by dividing the discharge by a constant representing the number of cubic feet per second necessary to relieve one acre of a given depth of water in 24 hours. The constants most used are:

0.0052	cu.	ft.	per	second	=	$\frac{1}{8}$	in.	per	acre	in 24	hours
0.0105	"	"	"	"	=	$\frac{1}{4}$	"	"	"	" 24	"
0.0140	"	"	"	"	=	$\frac{1}{3}$	"	"	"	" 24	"
0.0210	"	"	"	"	=	$\frac{1}{2}$	"	"	"	" 24	"
0.0315	"	"	"	"	=	$\frac{3}{4}$	"	"	"	" 24	"
0.0420	"	"	"	"	=	1	"	"	"	" 24	"

In using the formula, the number of acres in the watershed multiplied by the assumed constant may be substituted for Q and the formula solved for the diameter of the tile. Other methods of computing sizes, such as the Chezy-Kutter formula given by Parsons (10), are used.

Hart (5) has the following to say about the size of drains for irrigated lands and construction methods:

"The spacing of drains in the irrigated section usually is much greater than in humid sections and frequently a single line of drain may effect the reclamation of a considerable acreage. From this it will be concluded that larger drains will be required in the drainage of irrigated lands. It has been found that they need not be proportionately large, however, since the amount of water which it is necessary to take care of is smaller for a given acreage. In the arid section, there is likely to be a continuous discharge of drainage water throughout the year, and frequently the discharge is very uniform at all times. However, there are certain maximum flows, usually during the period of greatest irrigation application, and it is necessary to provide a drainage capacity that will take care of such flows.

"If only the required capacity of the drain were considered, it would be found feasible to do a great deal of drainage with 4-inch and 5-inch tile, but experience has shown that the use of tile smaller than 5-inch is not satisfactory, while 5-inch should be used only for short branch lines or at the upper ends of branch lines. The following

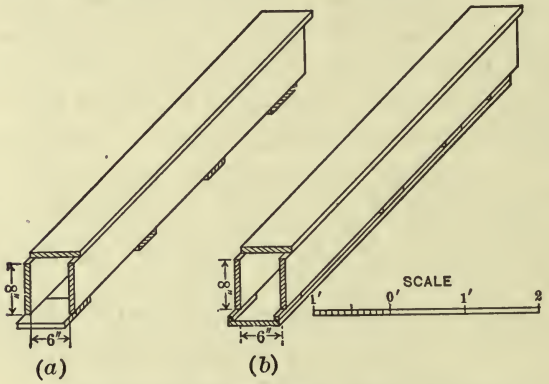

FIG. 26. — TYPES OF LUMBER DRAINS USED TO RECLAIM BOGGY ALKALI LAND.

table is offered for purposes of comparing the carrying capacity of tile lines of different sizes, on the assumption that all are laid on the same grade.

TABLE XIX. RELATIVE CARRYING CAPACITIES OF TILE OF DIFFERENT SIZES

One	Will carry the discharge of
6-inch tile	Two 5-inch tiles
7-inch tile	One 6-inch and one 5-inch tile
8-inch tile	Two 6-inch tiles
10-inch tile	One 8-inch tile and one 7-inch tile
12-inch tile	One 10-inch, one 8-inch, and 5-inch tile; or three 8-inch tiles; or seven 6-inch tiles; or twelve 5-inch tiles

"As a rule, tile larger than 12 inches in diameter is not used in individual farm drainage.

"The size of tile required depends on the amount of water to be carried and on the slope of the drain. The latter can be decided upon when the survey of the land is made and the fall to the outlet is measured. The former is not so easy to determine. It depends on the location of the tract, the nature of the soil, the slope of the ground both on the tract and above it; on the quantity of water used in irrigation and on the method of irrigating, both on the tract and on higher land; on the rainfall and evaporation; on the seepage from reservoirs, canals, and ditches; and on many other factors. Indeed, the determination of the required capacity of a drainage system is the most difficult problem confronting drainage engineers, and demands their best efforts. Intricate measurements and calculations must be made in each instance. It is therefore impossible to give definite instructions in regard to this important matter. It is possible, however, to give a general idea of required sizes based on a wide experience under a great variety of conditions. The following table is intended to apply to fairly uniform land

TABLE XX. SIZE OF TILE REQUIRED TO DRAIN GIVEN AREAS HAVING DIFFERENT TYPES OF SOIL

AREA OF TRACT (in acres)	SIZE OF TILE REQUIRED		
	Clay with Sand Stratum	Sand	Gravel
320	10-inch	.....	.....
160	8-inch	12-inch	.....
80	7-inch	10-inch	12-inch
40	6-inch	8-inch	10-inch
20	5-inch	7-inch	8-inch
10	5-inch	6-inch	8-inch

not located at the foot of steeper slopes or benches, nor in pockets or depressions, nor in flat river bottoms where it will receive surface run-off from higher land, nor where it will receive water from deep sources by pressure. The assumed slope of the tile is 2 feet per thousand feet.

"If the soil be compact clay, a given size of tile will drain larger areas than indicated. If the subsoil be joined clay, the 'sand' table should be used. If the drain be located at the foot of a bench or in a gravel pocket, none of the above bases will apply. A better basis for design in such cases is the length of a given size of tile which it is safe to use. A slope of 2 feet per 1000 feet is assumed, as before. The following table will give a rough idea:

TABLE XXI. SIZES OF TILE REQUIRED FOR DRAINS OF DIFFERENT LENGTHS

SIZE OF TILE	MAXIMUM LENGTH	
	Sand Stratum	Gravel
	Feet	*Feet*
12-inch	5580	1250
10-inch	3350	750
8-inch	1790	400
7 inch	1250	280
6-inch	800	180
5-inch	450	100

"For greater slopes smaller tile is required, and for flatter slopes, larger tile is necessary, the variation in capacity being as the square root of the slope. If lumber boxes are used, the openings should be about the square of the tile diameter.

"For open ditches the bottom width should be 4 feet and the side slopes should be at least 1 to 1. Thus for a depth of 6 feet the top width would be 16 feet or more,

and for a depth of 8 feet the top width would be 20 feet or more.

"In the installation of a drainage system it should be borne in mind that the improvement is permanent, and that after the tile is once covered up it is more expensive to uncover and relay it with larger tile than to install a new drain, so it is false economy to cut down on the size of tile. It is much better to err on the side of too great capacity than too small.

"**Construction Methods.** — In many instances owing to lack of humus the soils of the arid region are very fluxible when wet and the construction of drainage systems is very difficult and requires painstaking care and ingenuity. Special methods and devices have to be employed, and special machinery has been developed.

"Drain lines must be laid out carefully and grade stakes set. The completed drain must be true to grade and as straight as possible. For hand trenching it is advisable to stretch a cord on the ground along one edge of the proposed trench, to obtain good alignment. To insure accurate grade at all points, grade plants should be set up at each station at a uniform height above the grade of the drain. A stout cord then may be stretched over the middle line of the trench from plank to plank and every point on this cord will be the given height above grade. Grade may be established at one end of each tile with a grade pole having a length equal to the distance from the cord to the proper location for the tile. This may be accomplished by keeping the cord taut by suspending a tile or other weight at each end and measuring down from the cord at the desired points.

"Construction work always should start at the outlet of each line and proceed up the slope, so that the water developed will drain away.

FIG. 27. — WOOD DRAINS BEING USED TO DRAIN BOGGY ALKALI LAND.

"In installing covered drains either hand labor or trenching machinery may be used. Frequently, on small projects, hand trenching is cheaper, but usually on larger projects machines can do the work more rapidly, economically, and satisfactorily. It is preferable to let a contract for the work to an experienced and capable contractor.

"If hand labor is used it usually is necessary to operate with small gangs, ordinarily about a half dozen men to the line, as the trench must be opened from the top to the bottom as rapidly as possible and the tile laid and blinded before caving takes place. The men should work as closely together as practicable and not even the first spading should be taken more than a rod in advance of the tile laying. Each man should remove a spading, moving backward at the same time. The man removing the last spading should also grade the bottom. He should not step on the finished bottom and no one should stand near the edge of the trench, nor should wagons or material of any sort be permitted near the trench. The soil removed from the trench should be placed as far back as it conveniently may be. The tile should be laid at once and blinded by means of a few inches of earth caved from the edges of the trench. If the banks tend to cave off in large chunks or slabs it will be necessary to brace them apart with planks separated by stout cross-pieces or trench jacks.

"A very troublesome condition is that in which the presence of a wet, pervious stratum near the bottom of the trench causes a lateral and upward movement of the soil in the bottom of the trench. In such a case it is necessary to provide a tight cribbing to shut out the oozing material. It consists of two heavy timbers held apart by trench jacks, behind which is driven lumber sheeting

properly matched and beveled at the lower ends to insure a tight fit. The sheeting may be driven by means of a heavy maul and may be removed with a three-legged derrick and a special grabhook.

"If the soil in the bottom of the completed trench is so soft that it will not support a man's weight, wooden racks or cradles should be laid under the tile to keep it in line

FIG. 28. — DRAINAGE MACHINE WITH THE DIGGING WHEEL ABOVE THE GROUND.

and on grade. If conditions are exceedingly bad it often is advisable to use sewer pipe in place of drain tile, as the bells aid in keeping the line intact. Second quality sewer pipe is suitable and generally may be purchased at about the same price as drain tile. Under ordinary conditions, however, the use of sewer pipe is not recommended, since the cost of freight and hauling is higher than for drain tile and it is heavier and more difficult to handle. Also, in stable ground it is necessary to dig out places for the bells, which considerably increases the cost of trenching.

"Tile should be laid with extreme care. The joints should be as close as possible, and if the soil is semi-fluid and contains much fine sand and silt, it will be necessary to provide some means of keeping the oozing material from entering the tile joints. Almost all the water entering tile lines makes its way through the joints, practically none entering through the walls of even the more porous

FIG. 29. — DRAINAGE MACHINE WITH THE DIGGING WHEEL IN THE TRENCH.

tile, so the covering for the joints must provide for the ready passage of water. Straw makes a very good filter when new, but it is likely to decompose and form a sticky, impervious mass over the joints. Brush and willows are not satisfactory and render any subsequent removal of the tile very difficult. Graded gravel, ranging in size from sand to pebbles an inch in diameter, makes an excellent filter, but it is not always available. Cinders also are satisfactory. Strips of burlap wrapped about the joints give good service. The custom of laying strips of building paper over the joints cannot be commended,

since the greatest tendency is for the sand and silt to enter at the bottom and if paper is wrapped tightly entirely around the joints the water itself will be shut out. For genuine quicksand, perhaps the best material is cheesecloth, which should be doubled once or twice and wrapped carefully about the joint. This material soon decomposes, but in the meantime the soil becomes compacted so that the purpose is served.

"The more pervious materials should be placed adjacent to the tile. The backfilling may be done with a plow with three or more horses and a long pole evener, or with a scraper, road grader, or go-devil. Recently power backfillers have been placed on the market. All the soil should be returned to the trench and be banked up over it, so that future settling will not leave a depression over the drain.

"In machine trenching it generally is necessary to draw a portable shield after the machine in which the tile may be laid and blinded before caving takes place."

Outlets and Silt Basins. — The efficiency of a drainage system may be greatly lessened by an ineffective outlet. When the water leaves the drain it should flow away freely and not be allowed to back up in the mouth of the drain, since this condition causes silt to deposit and finally clog the drain. The effectiveness of the drainage system throughout its entire length may be lessened by standing water at the outlet. If the fall of the land does not permit of rapid flow from the outlet it may be necessary to let the water run into a pit and then pump it out. This method is in successful operation at Kearney Park, California, in the system described by Weir (13). Here the pumps are turned on by an automatic switch operated by a float.

Provisions should be made to keep stock from tramping on the outlet and destroying it. In drains that are dry part of the time, screens to keep out rodents and other troublesome animals should be placed over the outlet.

Manholes at intervals in the system assist in locating trouble. These manholes may be constructed in such a

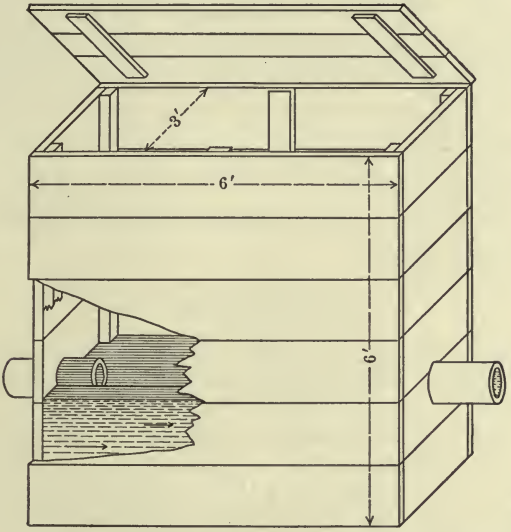

FIG. 30. — SILT BOX WITH LID. THE SILT THAT SETTLES IN THE BOX CAN BE SPADED OUT.

way that they serve as silt basins and thus eliminate from the system silt that might clog the tile. These silt basins are particularly necessary if the fall of the drain has to be reduced. A good type of combination silt trap and manhole is shown in Fig. 30.

Cost of Drainage. — The cost of installing a drainage system varies so much with conditions that definite figures cannot be given. Hart (5) estimates the drainage of irrigated land to vary from $15 to $30 with $20 as an

average. If the land is so wet as to require cribbing of the trench the cost may run up to $50 an acre or even higher. He says that the price of tile may be figured at about 1 cent per inch of inside diameter for each foot of length for small sizes and about 2 cents for large sizes. Hand trenching costs from 15 to 25 cents a linear foot for six feet deep. Machine trenching is considerably cheaper but usually costs more than a dollar a rod. The system installed at Kearney Park, California, with its pumping system cost $59.59 an acre, but since it was to be used for experimental purposes it was permissible that it be more expensive than a system installed by the farmer for strictly economic purposes. These figures must all be revised to meet post-war prices.

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CHAPTER XIV

CROPS FOR ALKALI LAND

PLANTS differ greatly in their resistance to alkali. Certain crops, such as the beet, will withstand very large quantities and still produce good yields, whereas others, like blue-grass, resent even comparatively small quantities of any alkali salt. It is therefore of great importance to choose the proper type of plant for the particular conditions.

Factors Affecting Resistance. — Certain fundamental problems such as the nature of the alkali-resistant plants, the nature of the soil, climatic conditions, and economic considerations, should be carefully studied before deciding finally on which crop to plant. Perhaps the first thing to consider is the difficulty in getting the plants started in the alkali soil. Some of the best crops for alkali resistance when once started well, of which alfalfa and beets may be taken as examples, must be planted shallow and if the alkali tends to concentrate at the surface during their tender seedling stage, it is very difficult to secure a stand. If, however, the alkali can be kept below the feeding zone of such plants by washing or in other ways while they get a start, satisfactory crops can be secured. As alkali is not so concentrated when the soil is kept well moistened, this condition should be sought while the plants are young. Some varieties of each crop are best suited to resist alkali during the seedling stage; hence it is important to choose seed from successful crops on similar soils where possible.

The character of the root system of different plants needs consideration. Shallow-rooted crops, like the cereals

and most cultivated grasses, may fail to give a satisfactory crop because the alkali tends to concentrate near the surface if evaporation is active. This accumulation makes the salts very strong throughout the feeding zone of the plant and, therefore, toxic even when the total quantity of salts in the upper three or four feet is rather small. Deep-rooted plants, like alfalfa and trees, may penetrate the alkali strata by growing in the upper soil while the alkali is beneath and gradually feeding lower as the alkali accumulates at the surface. In this way some plants not exceptionally tolerant may withstand what seem to be excessive quantities when the whole feeding zone is not considered. Where alfalfa, cotton, and other deep-rooted plants get a good start but encounter a strong alkali stratum at a short distance below, these plants may prove less resistant than the cereals which may feed in the upper less alkaline soil. The latter condition is especially marked when alkali is accompanied by a hardpan or heavy clay subsoil. The same may also be said of soils that are underlain by a shallow water-table, pasture or meadow grasses and grains making much better crops than the deeper, more resistant crops.

Another important factor is the resistance of the plants to reclamation methods. A few crops, among which are alfalfa after once well started, sorgo, rice and berseem clover, can endure the frequent heavy irrigations that may accompany reclamation. The best crop of course depends on the particular conditions, alfalfa doing well with good drainage but not in a soil containing excessive quantities of water, whereas some of the other crops like sorgo may do best where drainage is not so good. During the reclamation process it is a great aid to have the land shaded or cultivated in order to prevent alkali from rising. Alfalfa

and other plants which shade the soil during the great part of the season are preferable to those like grain which leave the land unshaded during spring and again during fall. Beets, fruits, and other crops that are grown in rows and require cultivation are useful because of the mulching, which helps check surface accumulations of alkali. For this purpose it is better to have annual crops which allow the ridges to be leveled down occasionally than perennials which allow alkali to accumulate at the top of the ridges year after year instead of being washed out of the soil.

The nature of the soil also has some influence on the choice of crops. With a lifeless clay it is preferable to grow some crop such as rye rather than one like beets which requires considerable organic matter and much working of the soil to produce a satisfactory crop. It is frequently profitable to raise rye as a green manure crop to improve the soil conditions before a more exacting crop is grown. A soil without good drainage and where artificial drainage is impractical may often be planted to some of the more resistant forage or meadow grasses which will endure water-logged conditions. Soils with considerable organic matter are frequently more moist and the alkali apparently less toxic than in the ordinary alkali soil so that more profitable and less resistant crops may prove best.

It is unfortunate that the most tolerant cultivated crops are not well adapted to grow in the climate of most parts of the United States where alkali is found. The date palm, which is perhaps the most tolerant crop for soils containing chloride and sulphate salts, rice, cotton, berseem clover, and several other desirable crops are adapted only to the warmer alkali regions. Australian salt-bush,

which withstands larger quantities of alkali than almost any other desirable alkali-resistant plant, does not do well where winters are severe.

Economic Factors Affecting Choice. — After knowing the relative tolerance of the various crops and their adaptability to the particular conditions, certain economic considerations further modify the choice. With cheap lands in some of the grazing sections, for instance, it might be preferable to plant the land to some permanent grass giving only a medium yield than to use the more resistant crops such as sugar-beets and other high-yielding plants which do best under certain other economic conditions. As a general rule, forage crops are more suited to alkali lands than crops in which quality is more important. Land in the neighborhood of large cities or other places where there is a good market for intensive crops, such as the vegetables and fruits, is often more economically planted to these crops even though they may be somewhat less tolerant of alkali than other crops.

The use to be made of the crops also governs the choice for alkali lands. Grain crops will produce a heavy growth of fairly good hay in soil considerably too strong to give satisfactory yields of grain. Likewise, although cotton grown upon certain kinds of alkali lands does not give the fine-textured fiber so desirable in the manufacture of the high-class cotton goods, it may produce a profitable yield of the coarser grade suitable for other purposes. Sugar-beets will produce excellent yields of roots on land that is high in alkali, but if the quantity of salts, especially sodium chloride, be too large the beets may be so poor in quality that they are fit only for stock feed and not for sugar-making. The quality of sugar cane and of various fruits is impaired when grown upon soils impregnated with

certain kinds of alkali, but as long as the yield is sufficiently high to prove economical when used for any purpose conditions may warrant the use of such a crop in preference to crops not injured materially by the alkali but which do not fit economically into the cropping system.

Where the main object is to reclaim land quickly and put it in condition for the common crops, it is frequently desired to green manure the land, to get good aëration of the soil, to retain a mulch, and to keep all moisture moving downward. For such purposes where the soil contains salts in quantities so large that most ordinary crops fail, sorgo, rye, millet, barley, rape, kale, and a few other high-resistant crops which yield a large quantity of dry matter are used. When the alkali content does not exceed about 5000 parts per million of white alkali, less resistant but more desirable legume crops (sweet clover, alfalfa, Canada field peas, vetch, and horse beans) should be preferred to the above crops, provided the seed-bed can be prepared so that a good stand may be secured.

Tolerance of Alkali by Various Crops. — In studying the figures given for the quantities of salts that various crops have been found to endure safely, it should be kept in mind that the character of the plants, feeding system in relation to the alkali, and the nature of the soil as above mentioned will often cause enormous differences with the same plant. Soil, moisture, climate, and perhaps other things will often change the relative tolerance of the different crops to some extent so that slight differences in tolerance mean little or nothing. Unless otherwise mentioned, the salt as given is understood to be the proportion found in the soil to a depth of four feet. Although this arbitrary unit will be misleading when the concentration of the salts varies at different depths in the soil, as is often

the case, it is the most satisfactory method available for comparing the different crops as a whole. Not only is the root system of most ordinary crop plants within the four-foot zone, but also this is the region where a large part of the alkali is concentrated. On most alkali lands the salts in the first four feet of soil may be drawn toward the surface where they will concentrate.

Forage Crops have given more satisfaction for use on rather strong alkaline soils than other cultivated crops as a general rule. Quality in fruit, vegetable, sugar, fiber, and grain crops is frequently so impaired by alkali that the crop is practically worthless for the product ordinarily obtained, but since quantity is the chief requisite for forage the crop serves its purpose when a good yield is obtained. Leguminous plants as a family are very sensitive to alkali, especially sodium carbonate. Hilgard (12) states that alkali even when present in quantities as small as 200 or 300 parts per million is generally harmful to most of the legumes. Alfalfa and sweet clover, especially the latter, however, are among the crops generally recommended as being resistant to alkali.

Alfalfa sometimes fails to give satisfactory results on alkali land because it is rather sensitive in the seedling stage. A good stand and healthful growth in its first stages are sometimes secured by driving the alkali below the seed-bed by means of a heavy irrigation. Hilgard places the limit for unaffected growth at about 1650 parts per million total salts, about 300 parts per million of sodium carbonate, or about 1390 parts per million of sodium sulphate. Kearney (17) places the highest successful amount at 4000 parts per million of white alkali, while Means and Gardner (22) state that 4000 parts per million of white alkali caused young alfalfa to become sickly or

unhealthy. It is a very sensitive plant to black alkali when in the seedling stage.

The limits for an old stand of alfalfa range between 2000 and 7100 parts per million of total salts, according to the various authors. The lower of these limits was for a sandy soil, and Sanchez (25) states that on a loam soil a higher concentration may successfully be withstood. That the crop should produce a heavy mature crop on soil containing 7100 parts per million, most of which was sodium chloride, might have been due to the fact that there was standing water at a depth of four feet and that the salt was considerably diluted by the moisture. Most estimates place the limits between 3000 and 4000 parts per million of white alkali.

With black alkali, or sodium carbonate, the observations on old alfalfa land vary between 300 and about 900. These differences are partly due to the differences in the nature of the soil and to the different methods of determining and expressing the results of the analyses. As this salt is generally found in connection with other alkali salts the limit can hardly be expected to be a definite quantity even in soils of like character. Likewise, the quantity of sodium chloride and sodium sulphate endured successfully vary through a wide range modified by the presence of other salts. Where the salt was mostly sodium chloride, the variation assigned by the authorities ranges from 2000 parts per million on a sandy soil to 7100 parts per million on a loam soil well supplied with moisture. It is probable that on a loam soil handled so as to protect it from accumulation of alkali when the crop is not shading the ground and kept well irrigated will support a satisfactory growth of alfalfa when it contains as much as 4000 parts per million of sodium chloride. On a sandy loam

in Montana Neill (23) reports a diminished yield where the alkali content was about 4000 parts per million, mostly of sodium sulphate, while Kearney (17) places the highest quantity under which alfalfa will succeed at 6000 of this salt. Very few important crops will grow with larger quantities of these alkalies in the soil. In most soils, there is a mixture of the salts in various proportions so the limits of the separate salts serve only for general purposes. The high resistance of alfalfa may be assigned to its deep feeding habits in many cases, the feeding roots not being in the alkali zone but being in the purer solutions below.

Sweet clover (*Melilotus alba and M. officinalis*) is widely recommended for alkali lands. It is as resistant as alfalfa and is often preferred to alfalfa for alkali land. Coe (1) states that it will withstand so much black alkali that salt grass is the only other crop that can compete with it on this kind of land. It gives more satisfaction than alfalfa on alkali lands which are water-logged or have a shallow water-table. Sweet clover is not ordinarily so satisfactory a forage crop as alfalfa because it is necessary to reseed it every alternate year, whereas alfalfa yields well for years. It is so difficult to secure a good stand of these crops under alkali conditions that it is very desirable to have a continuous or perennial crop. Sweet clover is easier to get started on alkali land than alfalfa. It requires more care in harvesting because if it is allowed to grow too long it acquires a disagreeable flavor and it is not so readily eaten as alfalfa. The few observations on the resistance of sweet clover to alkali show it to rank about with alfalfa, so that other conditions being equal alfalfa is the preferable crop. However, on water-logged land or where alfalfa does not thrive for other reasons,

and where the crop is desired more as a means of reclaiming the land for other crops in a few years, sweet clover is preferable. It is an excellent green manure to be used in upbuilding alkali land.

Other Clovers. — The only other clover that has been found to do well in the presence of large quantities of alkali is berseem, or Egyptian clover. It has been found to endure 4000 to 6000 parts per million of alkali, mostly sodium chloride, under Egyptian conditions, but it has not been used to any extent in this country. It requires mild winters and is sensitive to cold. In Egypt it finds favor in reclaiming alkali land because it withstands flooding and an excessive water content of the soil which accompany reclamation methods. Loughridge (19) found the limit for burr clover to be about 1130 parts per million of black alkali, which is exceptionally high for this salt. Crimson clover and Birdsfoot clover both withstood 530 parts per million, and white clover 630 parts per million of black alkali according to this author. Red clover was not found growing in concentrations greater than 670 parts per million of total salts.

Vetch (*Vicia saliva and V. villosa*) has met with considerable favor in certain districts because it germinates well on land which will not give a good stand of other resistant crops without considerable trouble. Kearney (17) places the limit for good germination between 4000 and 6000 parts per million of white alkali, and Loughridge (19) found it growing unaffected in a soil containing 4340 parts per million of total salts, 160 parts per million sodium carbonate, 200 parts per million sodium chloride, and 3980 parts per million of sodium sulphate. It may be used for pasture or as a green-manuring crop, but since it does not do so well under most alkali conditions and since other crops

such as sweet clover meet the conditions better it has found little use on alkali lands.

Field peas (*Pisum stavium*) are said by Kearney (17) to germinate and produce normal seedling growth in the presence of 2000 parts per million of white alkali, mostly sodium sulphate. He states that a good crop of peas can be grown in the presence of 4000 parts per million of this type of alkali, but that this quantity is near the upper limit for the seedlings and consequently a poor stand might be expected.

Beans are ordinarily considered to be rather sensitive to alkali, but Kearney (17) classifies broad beans as producing pods in the presence of 4000 parts per million of white alkali. They are sometimes grown as a green manure on alkali lands but have not found much favor because other crops are better adapted both on account of climatic conditions and because other crops produce more forage. The seed being large, germination is better than with most legumes, but where the growing season is not cool the growth is not satisfactory. Neill (23) considers 2000 to 4000 parts per million of alkali, mostly sodium sulphate, as being too much for the seedling stages of beans, but states that 2000 parts per million or less will allow all ordinary Wyoming crops to do well.

A number of *other leguminous plants*, including lupines, lentil, esparcet, and other minor forage plants, have been studied under alkali conditions by Loughridge in California (20), but none have given promise of competing with alfalfa and sweet clover.

Grasses. — True grasses are as a family more resistant than the legumes. Some of the wild varieties, such as salt grass and tussock grass mentioned in Chapter VI, rank as the most resistant plants known. The cultivated grasses

are generally more sensitive than the wild ones. Observations of the more important meadow and pasture grasses have been made, but the number of different conditions or combinations of salts under which they have been studied makes the limits indicated for them of less value than for plants which have had a larger number of studies made of them.

Timothy (*Phleum pratens*) is reported by Kearney (17) to succeed in the presence of 4000 to 6000 parts per million of white alkali and perhaps more where the distribution of alkali is uniform. Traphagen (29) places the limit below 10,000 parts per million where the salts are mostly of the sulphate type. Near Baker City, Oregon (3), an average crop was produced on land containing 700 parts per million of sodium carbonate. Timothy, like almost all of the grasses, has very small seed, and it is very important in getting a stand with such seed that the seedbed be free from alkali. Unless the alkali can be washed out of the seedbed until the grasses get a good start, it is almost useless to seed these crops on alkali land. Timothy can be kept moist throughout the year, and because keeping the soil moist dilutes the alkali the growth is much more satisfactory than where less water is used.

Orchard grass (*Dactylis glomerata*) is probably a little more resistant to white alkali than timothy. Kearney (17) places the limit for successful growth between 4000 and 6000 parts per million for the white type of alkali. In California the highest alkali in which it was found growing unaffected was 1260 parts per million total salts, 580 parts per million of sodium carbonate, and 550 parts per million sodium sulphate.

Brome grass (*Bromus inermis*) is one of the most resistant of the tame grasses. It has been found (17) to grow un-

hindered in the presence of as much as 5000 parts per million of white alkali and to make a good growth and produce seed with 7000 parts per million. In California (20) it was unaffected with 3170 parts per million of total salts, 630 parts per million of sodium carbonate, 230 parts per million of sodium chloride, or 2230 parts per million of sodium sulphate. This is one of the best pasture grasses of the western part of the United States where the land is not kept too wet.

Red top (*Agrostis alba*) has not been tried extensively under alkali conditions but Kearney (17) reports it to succeed in the presence of 4000 to 6000 parts per million of white alkali and to do better than timothy or orchard grass. It grows well on excessively wet lands, lands too wet for even timothy, and in such land can probably withstand as much alkali as any of the important cultivated grasses.

Bluegrass (*Poa pratensis*). — In California bluegrass withstood successfully 670 parts per million of total salts, 380 parts per million sodium carbonate, and 220 parts per million of sodium sulphate. It is ordinarily regarded as very sensitive to alkali and this apparently shows it to be one of the most tender tame grasses. In rather extensive tests made by Harris and Pittman (7) it was found to be the most nonresistant crop under investigation.

Western wheat grass (*Agropyron*) may be regarded as one of the most resistant grasses, as it can be grown successfully upon soil containing at least 6000 and 8000 parts per million. It is very difficult to get started because of low germination of the seed. The lack of popularity is partly due to this difficulty of getting a start.

Japanese wheat grass (*Agropyron japonicum*) was found by Loughridge in California (20) in the presence of 2330

parts per million of total salts, 840 parts per million of sodium carbonate, 820 parts per million of sodium chloride, or 820 parts per million of sodium sulphate.

Rye grass is one of the favorite grasses of Italy and England, but it has not met with much favor in this country except in a few places on the Pacific Coast. Italian rye grass (*Lolium italicum*) is said by Kearney (17) to succeed in soil carrying 6000 to 8000 parts per million of white alkali. Other observations indicate it falls considerably below this quantity, however. Shutt (26) found a good growth with 1387 parts per million of total salts, 900 parts per million of which was sodium sulphate, and Loughridge (20) places the limit at 1090 parts per million of total salts, 580 parts per million sodium carbonate, 120 sodium chloride, or 640 parts per million sodium sulphate. The latter author gives 1410 as the limit for good growth on English rye grass (*Lolium perenne*).

Fescue, like rye grass, is an important grass of Europe but has not been able to compete with the other forage crops in this country. Kearney (17) regards it as more resistant to alkali than most cultivated grasses, the limit being between 6000 and 8000 parts per million of white alkali. It is hard to get started and therefore rather unsatisfactory where the more profitable grasses can be grown. Observations by Loughridge (20) indicate the different varieties to resist from 1190 parts per million to 2180 parts per million of total salts, up to 630 parts per million of sodium carbonate and up to 1100 parts per million of sodium sulphate. Meadow fescue (*Fescue pratensis*) was found by the latter to be adapted to alkali land.

Tall meadow oat-grass (*Arrhenatherum elatins*) is another European grass not grown to any extent in this country,

but it seems to withstand rather large quantities of alkali. Growth was unhindered in a soil containing 5000 parts per million of white alkali and a good growth was found where 7000 parts per million were present according to Kearney (17). He regards it as about equal to brome grass in alkali resistance, or slightly below western wheat grass.

A number of new or minor grasses have been tried on alkali lands in California, but none of them have proved close competitors of the higher-producing standard grasses of the United States, such as timothy and alfalfa.

Wild or native grasses are frequently found growing on soil which is very high in alkali. These grasses seldom do well in pastures or meadows and generally do not produce very large quantities of feed. Many of them are hard to get started on new land; their value is likely to be mainly as range grasses of poor pastures on highly alkaline soil.

Salt grass (*Distichlis spicata*) is probably the most important of the native grasses. It occurs throughout the world under a great variety of conditions. It was observed in the Bear River Valley, Utah (16), growing on soil containing from 30,000 to 50,000 parts per million of salts, a large part of which was sodium chloride, and yet it does well in soils containing practically no salt. It shows hardly any preference for the type of alkali nor the concentration. It has been found growing apparently unaffected on land charged with 8516 parts per million of sodium carbonate (13), a quantity so great that hardly any other kind of vegetation could survive. Of course where the nature of the soil is unfavorable, these large quantities of salts would be too great for the plants to do well, but most alkali land does not contain excessive quantities of salts for this plant. It produces little seed so that it is very difficult to propagate artificially and it is seldom planted.

Blue-stem grass (*Agropyron occidentale*) was found growing in a Montana soil (29) containing in the surface foot 320 parts per million of sodium carbonate, 1649 parts per million of sodium chloride, and 24,080 parts per million of sodium sulphate. The average for the upper four feet was 384 parts per million of sodium carbonate and 10,360 parts per million of sodium sulphate. There was a good growth of mixed grass, mainly blue-stem, in this meadow (29).

Tussock grass, or purple top (*Sporobolus airoides*), mentioned in Chapter VI as an alkali-indicating plant, withstands very large quantities of alkali. It is relished by stock but will probably not do well except on the ranges.

Alkali meadow-grass (*Puccinellia airoides*) (24), also mentioned in Chapter VI, may furnish good browsing for stock and if available at the proper time it may furnish profitable hay on moist alkali lands.

Prairie grasses were observed by Shutt and Smith (26) in Canada to withstand 700 parts per million of sodium sulphate in the upper 6 inches of soil even where the soil beneath this held over 6000 parts per million and the upper 3 feet averaged 6717 parts per million. Where the upper 6 inches of soil contained 4320 parts per million of sodium sulphate and the average for the upper 3 feet was 9773 parts per million of total salts, there was a poor growth, however.

Modiola (*Modiola procumbens*), a weed introduced into California from Chile, is reported by Loughridge (20) to withstand 13,100 parts per million of total salts, composed of 1190 parts per million sodium carbonate, 10,210 parts per million sodium chloride, and 1700 parts per million of sodium sulphate in the upper foot of soil. It has been found to make an acceptable pasture where alfalfa could

not be started well. Were it not for the fact that it is a troublesome weed where not wanted, it would probably find more favor as a pasture grass.

Salt-bushes (*Atriplex spp.*), as noted in Chapter VI, make an acceptable forage where the land is too alkaline to permit successful growth of the better classes of forage plants. There have been a number of attempts to introduce these plants as cultivated crops for alkali land. The Australian salt-bush (especially *A. semibaccata*) is said to be well adapted to California conditions and to be easily propagated. Hilgard (13) regarded it as being one of the most promising forage crops for alkali lands, being a quick-growing and high-yielding plant as well as producing hay which is readily eaten by all animals. It is not adapted to climates with severe winters nor to places frequented by summer fogs. It would be of little value outside of a mild climate. Other varieties of salt-bushes have been tried for the more severe interior country and, although where once started, they yield a fairly large quantity of good forage, these plants have received almost no recognition in a practical way. They are so difficult to get started that farmers will not take the trouble to plant them.

Giant rye-grass (*Elymus condensatus*) is reported by Hilgard (12) as being in about the same class as tussock grass for alkali resistance (3000 to 31,000 parts per million — tussock). In its wild state it grows in large clumps, but where sown at the rate of about twenty-five pounds per acre it makes a rather uniform growth of coarse but palatable grass or hay for sheep or cattle. When grown on alkali land it generally contains considerable salt which makes it somewhat laxative for horses. Although it is at present not receiving much attention as a cultivated crop, it should occupy more of the soils containing too

much alkali for alfalfa, and similar crops. Being a large yielding grass, it is grown as a hay crop on some of the less desirable lands of Oregon and Washington as well as a few other places.

Sedges and rushes frequently form the main growth of alkali swamps or low moist lands. The tuber bulrush (*Scirpus paludosus*) is recommended by Nelson (24) as being the best of these plants for forage on alkali lands of the moist type.

Millets, especially the stout rooted varieties, are among the resistant cultivated grasses. Common, or foxtail millet (*Chaltochloa italica*) is classified by Kearney (17) as withstanding 6000 to 8000 parts per million of white alkali, a good crop usually being secured where not more than the lower quantity is present and a fair crop between the two points or even a little above. Barnyard grass (*Panicum crus-galli*) resists white alkali fairly well according to Hilgard (13). Proso, or broom-corn millets, (*Panicum miliaceum*) will produce a good crop in the presence of less than 4000 parts per million of white alkali, but since other crops are usually more profitable with this quantity, and since an excess of alkali is likely to reduce the yield of grain to an unprofitable point, its value on such lands is questionable. Loughridge (20) found Egyptian millet (*Elusine coracana*) growing unaffected in the presence of 1140 parts per million of total salts, 580 of sodium carbonate, and 480 of sodium sulphate, and many-flowered millet (*Milium multiflorum*) in the presence of 1090 total salts, 210 sodium carbonate, 120 sodium chloride, and 440 parts per million of sodium sulphate. Other millets that were tested resisted less than 1000 parts per million.

Sorghums are rather resistant, can endure flooding, and are readily cultivated so that they are among the better

crops for reclaiming alkali lands. If the soil can be kept moist by irrigation while the plants are in the seedling stage the crop apparently does not suffer. Kearney (17) places the limit for the saccharine sorghums between 6000 and 8000 parts per million of white alkali or for an almost assured crop just below these points. He states that these sorghums are among the most resistant plants when in the seedling stage. An Hawaiian (5) experiment showed cane to endure 3357 parts per million of alkali, mostly sodium chloride, the growth being unchecked when the roots of the plants were drawing from free water, but that when the moisture content of the soil fell to 28 per cent there was no growth on a soil containing 1980 parts per million of this salt. The highest quantities of alkali on which Loughridge (19) found sorghum growing unaffected was 5100 parts per million of total salts, 620 parts per million of sodium carbonate, 610 parts per million of sodium chloride, and 3870 parts per million of sodium sulphate. These limits show that where sorghums are adapted they may be expected to grow on soil too strongly alkaline to permit most ordinary crops to survive.

Rape (*Brassica napus and B. oleracea*), while practically unknown to the farmers of the United States, is a rather alkali-resistant crop which is extensively used for forage in Europe. The seedling of this crop is very delicate or sensitive to alkali and there is difficulty with the stand where a crust is formed before the plants break through the upper soil. By keeping the soil moist and paying close attention to the seedlings little attention will need to be given rape on account of alkali thereafter. The plants withstand, and make a fair growth with, as much as 6000 to 8000 parts per million of white alkali and will grow practically unchecked with 4000 parts per million,

according to Kearney (17). This crop is not well adapted to the present economic conditions of the United States and it is too troublesome in its seedling stage to gain popularity with the American farmer.

Grain crops have been tried under a great variety of alkali conditions both as a grain and a forage crop. They may successfully produce forage or green manure on land too strongly impregnated with alkali to yield grain profitably. During hot weather, unless the moisture conditions are favorable, grain is likely to become shriveled and hard where the soil contains considerable alkali. Under certain other conditions the alkali may cause the plants to spend most of their energy in leaf production rather than seed.

Wheat has been grown for hay on land too strong for alfalfa to either germinate or grow (27). According to Kearney (17), the highest quantity of white alkali permissible for the successful production of wheat hay was 4000 to 6000 parts per million, while for a grain crop it could successfully endure only 1000 to 4000 parts per million. The author (6), however, found wheat doing moderately well as a grain crop where the top foot of soil contained 8756 parts per million of total salts, 1146 parts per million of sodium carbonate, 1577 parts per million of sodium chloride, and 5840 parts per million of sodium sulphate, the average salt content of the top four feet of soil being 11,829 parts per million of total salts, 1121 parts per million of sodium carbonate, 2334 parts per million of sodium chloride, and 7512 parts per million of sodium sulphate. These quantities are the average of determinations in four different fields in different sections of Utah; enormous quantities of sulphates amounting in some cases to 20,000 parts per million were found in soil growing wheat, but where sodium chloride became a promi-

nent salt the quantity was much less. Observations by Shutt and Smith (26) show that on a loam soil with a heavy clay subsoil, wheat made a good growth where the upper six inches of soil contained practically no alkali salts, but the next foot contained 1780 parts per million, and below this over 8000 parts per million of salts most of which was sodium sulphate. When the upper six inches contained 1230 parts per million of salts and the

FIG. 31. — ALKALI SPOT IN A GRAIN FIELD.

soil beneath this 7000 parts per million the growth was poor, apparently showing that the upper six inches of soil was the injurious portion. In the Bear River Valley, Utah, Jensen and Strahorn (16) found wheat doing well in a soil the top foot of which contained 5000 to 5600 parts per million of alkali, mostly sodium chloride. Loughridge (19) places the limits for unaffected growth at 1520 parts per million total salts for Gluten wheat and 1080 for ordinary wheat.

For sodium carbonate Headden (8) states that 400 parts per million in the soil will prove injurious to wheat, while

Jensen and Mackie (15) place the limit of profitable production below 500 parts per million. The quantity of sodium chloride that may be tolerated without notable injury to wheat has been placed at from 100 to about 5000 parts per million by the various investigators. Few observations have been made where sodium chloride or sodium sulphate were the main salts. Traphagen (29) states that the danger limit for wheat when the salts consist of sulphates, two-thirds sodium sulphate, and the rest magnesium sulphate is about 10,000 parts per million. Considering only the sodium sulphate, this estimate is nearly the same as the figures of Shutt (26) and the author (6), but much above these of Loughridge (19). It is probable that the great discrepancies shown in these observations are partly due to a number of factors such as the nature of the soils, mixtures of the salts, and feeding zone of the roots. The variety of grain, as indicated in the seedling tests noted in Chapter V, would probably have some influence but not so much as the figures indicate.

Barley is the high-yielding grain of the West which corresponds to corn in the central states. It is commonly looked upon as being the most tolerant of the ordinary grains for alkali. A number of observations have indicated that this crop grows practically unhindered with 2000 to 4000 parts per million of white alkali and that it frequently produces a good crop of grain with as much as 6000 parts per million of white alkali in the soil. When grown as a forage crop, there will be a satisfactory yield when the soil contains from 6000 to 8000 parts per million, provided the seedbed is kept fairly free at first, according to Kearney (17). Jensen and Mackie (15) found a poor stand of barley on soil containing 500 parts per million of sodium carbonate, but Holmes (14) states that this

quantity will be withstood fairly well. Loughridge (19) found it to do well in the presence of 740 parts per million of sodium carbonate. Although Dymond and Houston (4) state that barley was growing on soil having been flooded by sea water and containing 16,000 to 20,000 parts per million of salt in the upper six inches of soil, it is probable that the plant roots were not feeding in the zone containing the salts. It withstands black alkali better than wheat. The highest sodium chloride content of soil that barley has been observed to tolerate unaffected was 640 parts per million in a California soil (19) which also contained other salts. Traphagen (29) places 10,000 parts per million of sulphates as the danger limit for barley where two-thirds of this was sodium sulphate. Barley should be more important as an alkali land crop.

Oats are generally considered to be intermediate between wheat and barley in alkali resistance. Kearney's observations (17) indicate wheat and oats to be about equal in this respect, but most others show oats to be the more tolerant, especially of sodium carbonate and sodium chloride. The author (6) found 5000 to 10,000 parts per million of total salts in the upper foot and 6000 to 8000 parts per million for the average of the top four feet in soils producing a medium crop of oats. Others indicate much less than this to have caused serious trouble. A very wide difference is noted for the effect of sodium carbonate, but it appears that from 600 to 700 parts per million of this salt is as much as is safely withstood. No figures are available for the tolerance of oats to sodium chloride alone or where this salt composes the main alkali, but where much carbonate is present 700 to 1400 is more than the crop can withstand safely. Traphagen (29) places the limit for sulphates the same for oats as for wheat and barley.

Rye has been highly recommended as a crop to produce forage and green manure for alkali lands too strong for most ordinary crops. Hansen (5a) used it with good success in reclaiming land containing about 17,100 parts per million of alkali, mostly sodium sulphate, and was able to reduce the alkali content of the soil considerably by turning the crop under as green manure. The seedbed for rye should not contain more than about 5000 parts per million of white alkali, however, or a poor growth will result. With rye, as with other crops to be grown on alkali lands, the quantity of seed sown should be greater than for crops on ordinary land and the seedbed made as free from salts as possible by cultural methods and irrigation. Kearney (17) regards rye as being about equal to barley in alkali resistance, or withstanding for a successful grain crop between 4000 and 6000 parts per million of white alkali.

Corn has been found (12, 13, 17) to fail on very weak alkali soils and its production on soils containing large quantities of alkali is not ordinarily to be recommended.

Rice has been found to do well in Egypt (17) where the alkali content of the soil was as high as 10,000 parts per million, a large part of which was sodium chloride, but this was under very favorable conditions. The soil can be kept moist or wet in growing rice so that more alkali may be present without injury than where a lower soil moisture content is maintained.

Emmer is usually considered to be about equal to wheat in its resistance to alkali. Grain crops other than the above mentioned have not given promise on alkali lands.

Sunflowers were found by Loughridge (19) to endure 3740 parts per million total salt of which 3290 parts per million were sodium sulphate.

Root and vegetable crops often do well on alkali lands, although some are rather sensitive and some, such as beets and potatoes, suffer in quality when excessive alkali is present.

Sugar-beets have been found to be one of the most satisfactory crops grown on alkali lands in the United States. After they are once well started they will endure enormous quantities of alkali. Trouble is sometimes experienced in getting a stand where the soil contains more than 2000 to 3000 parts per million of white alkali or about 500 parts per million of black. The quality of the roots is impaired for sugar-making when the alkali consists of sodium chloride or nitrates in appreciable quantities. In alkali soils, such as those of certain sections of Colorado and California in which nitrates form an appreciable quantity of salts, the beets are often over-sized and low in sucrose and purity of the juices. Headden (9) holds that ordinary alkali, essentially sulphates, are not detrimental, but even comparatively small quantities of nitrates cause injury to the quality of the beets.

As sugar-beets, after passing the delicate seedling stage, feed rather deep in the soil the quantity of alkali that may be present in the surface of the beet land may be very great. Jensen and Strahorn (16) found beets apparently doing well in a soil, the top foot of which contained about 30,000 parts per million of alkali, a large part of which was sodium chloride. During the earlier part of the season, these beets were barely able to withstand 15,000 parts per million of alkali in the upper foot even though the moisture content of the soil was rather high. It is frequently possible to get a stand of beets by giving the land a heavy irrigation to drive the alkali below, just before planting. After getting started beets will endure

and yield well with 4000 to 6000 parts per million of alkali, provided it consists mostly of the white type. With sodium carbonate or sodium chloride composing a considerable portion of the alkali, however, the quantity endured will be less. Beets will endure considerably more sodium carbonate than most of the other important crops of western United States. They have been found doing well on land containing from 500 to over 700 parts per million of this salt. Where the soil is crusted due to the action of sodium carbonate, however, or where it becomes strong about the seedlings, the stand will be imperfect and the yield poor.

Sodium chloride has been found to have a deleterious effect on the quality of sugar-beets and where this constituent of alkali exceeds 400 to 500 parts per million the quality is likely to be inferior, although the growth may be excellent. Beets will endure sodium chloride in the soil in strengths of 2000 to 4000 parts per million, but they will not be fit for sugar-making when grown on such soils. Neither the quality nor the quantity of beets produced in the presence of 4000 to 6000 parts per million of sodium sulphate is likely to suffer after the plants once get a good start.

Potatoes have not been found to do well on alkali land. Their quality is usually poor, especially where part of the salts consist of sodium chloride or nitrates. These salts also seem to cause the skin of the potato to be poorly developed so that the keeping quality of the tubers is impaired. Potatoes may be apparently doing well in the presence of as much as 2000 to 4000 parts per million, but they are likely to be watery and of poor keeping quality when even as much as 1000 parts per million is present. It is best to plant crops other than potatoes on even the weak alkali land.

Onions may be regarded as fairly tolerant of alkali, at least in the form of sodium carbonate and nitrates. They were observed (2) making a good growth in a soil containing 4500 to 5700 parts per million of total salts, a large part of which was calcium nitrate. With white alkali, Kearney (17) places the limit as between 4000 and 6000 parts per million. Shutt (26) found them growing well in a sandy loam soil containing 1080 parts per million of total salts of which 530 parts per million was sodium carbonate in the upper six inches, the soil to a depth of 5 feet containing 1800 parts per million total salts of which 1350 parts per million was sodium carbonate. The highest quantity observed by Hilgard (13) was 2405 parts per million of total salts.

Asparagus is said by Kearney (17) to do well in soil containing as high as 6000 parts per million of white alkali and to be benefited by sodium chloride when in small quantities.

Celery will grow practically unaffected where the total salt in the soil does not amount to more than about 4000 parts per million and is said to withstand sodium chloride very well.

Radishes were found by Loughridge (19) to be unaffected by 3930 parts per million of total salts, 550 parts per million of sodium carbonate, or 3240 parts per million of sodium sulphate.

Other vegetables have not been found to withstand alkali in large quantities. Sodium chloride seems particularly injurious to vegetables such as radishes, carrots, parsnips, and artichokes, the quality being very poor. The seeds of most of the vegetables are small and the seedlings delicate so that vegetable growing on alkali land is very hazardous.

Fiber crops are not of great importance in most alkali sections of the United States at present. There are, therefore, few data for these crops.

Flax (*Linium usitatissimum*) is reported by Kearney (17) as having produced a good crop where the surface foot of soil contained 4000 parts per million of salts. "The presence of an excessive quantity of salts in the soil below the first foot apparently had no injurious effect."

Cotton is being grown in parts of the Southwest where considerable alkali is found. It has been produced extensively under alkaline conditions in Egypt where it was found to be rather resistant to alkali. The quality of the cotton is impaired and the production is considerably reduced where the quantity of alkali is great. For the short-staple varieties where quality is not so important the soil may contain 4000 to 6000 parts per million without serious injury, according to Kearney (17). As with the vegetables, cotton is injured in quality more by sodium chloride than the other salts. Like sugar-beets, it is a crop which requires considerable cultivation and it shades the land during its maturity so that the cultural methods tend to keep the alkali from concentrating at the surface.

Trees and shrubs have been studied as to alkali resistance in the United States very little except in California. It is so difficult to determine whether the death of trees and shrubs is due to alkali or to other unfavorable conditions that data of practical value are almost unobtainable. A rising water-table is one of the common conditions accompanying alkali, and as the roots of trees and shrubs are in undrained soil which might kill the trees were no alkali present at all, to what extent the injury can be assuredly due to alkali is a difficult question. Where the alkali is not evenly distributed the feeding zone of the

trees is so difficult to determine that the resistance of trees is a much more uncertain matter to determine than it is for the smaller cultures.

Fruit trees and shrubs which might tolerate large quantities of alkali frequently do not give satisfaction because the quality of the fruit is injured by certain kinds of alkali. This is especially true of the more delicately flavored fruits, such as the peach. In case there is a very appreciable quantity of alkali in the soil it is usually better to grow the more resistant forage or grain crops until the land has been reclaimed for fruit.

Date palms are the most resistant of fruit trees and perhaps the most resistant of cultivated plants. They are unfortunately not adapted to the alkali lands of the United States with the exception of certain of the southwestern regions. The date palm has been known to grow in the presence of 30,000 to 40,000 parts per million of alkali, largely sodium chloride. Where there are layers of soil containing only 6000 to 10,000 parts per million, this palm will produce abundant crops even where the surrounding or surface soil contains enormous quantities of alkali. There is no apparent injury where the soil contains no more than 5000 parts per million of the white alkali, although where black alkali is encountered the resistance is less. About 600 parts per million of sodium carbonate, 5000 parts per million of sodium chloride, and 20,000 to 50,000 parts per million sodium sulphate have been successfully withstood. Palm groves are found flourishing where the upper soil contains 15,200 parts per million of alkali and the surface of the ground is white with alkali. The quality of the fruit is apparently not greatly impaired even where the alkali, which is about one-half sodium chloride, reaches a concentration of 10,000 parts per million.

Grapes, according to the California observations, are the most resistant fruit which does well in many of the alkali sections. They were found to grow well in soil containing 2860 parts per million of total salts, 630 parts per million of sodium carbonate, 770 parts per million of sodium chloride, or 2550 parts per million of sodium sulphate.

Olives were unaffected in a soil containing 2520 parts per million of total salts, 180 parts per million of sodium carbonate, 420 parts per million of sodium chloride, or 1920 parts per million of sodium sulphate.

Other fruits tolerated very small quantities of salts, so small that even the mildest alkali land would cause trouble. Orange, almond, fig, pear, and apple trees withstood between 1000 and 2000 parts per million most of which was sodium sulphate, whereas the toxic limit for prune, peach, apricot, lemon, and mulberry trees was below 800 parts per million for this type of alkali. Hecke, De Greeff, and Heime (11) found that apricot, peach, and similar fruit trees did not suffer from gummosis when there was salt in the soil about the trees. This would indicate that small quantities of salt in the soil would be advantageous, but the quantity could not be large enough to be called alkali land without causing injury at least to the quality of the fruit.

Other trees tested by California experimenters and which withstood over 1000 parts per million of total salts were Kolreuteria 4600 parts per million, Oriental sycamore 2670 parts per million, and eucalyptus trees 2530 parts per million. The former two trees withstood 620 and 200 parts per million of black alkali, respectively, and 790 and 1270 parts per million of sodium chloride, respectively. Eucalyptus trees will withstand very large quantities of

white alkali and up to about 400 parts per million of black alkali without apparent injury. Washingtonia palm and camphor trees were rather sensitive to alkali even in small quantities, especially of sodium carbonate and sodium chloride.

As these trees are adapted only to the warmer sections with mild winters, they are of little value outside of the Southwest. For the other sections certain of the poplars or cottonwoods are probably the best adapted to alkali lands. Locusts are also likely to do well where the alkali is not too strong.

Plants recommended by Kearney (17) as being suitable for hedges and windbreaks are Russian olive (*Elaeagnus songorica*) (Bernh.) (Gray, F. F. and G.) for moderate alkali, golden willow (probably *Salix vitellina aurea*) for regions having severe winters, pomegranate (*Punica granatum*), and tamarisk (*Tamarix gallica*) which are decidedly resistant, for the southwestern alkali lands, as well as certain of the larger salt-bushes. *Atriplex breweri* and *A. longiformis* are the species especially recommended for this purpose.

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CHAPTER XV

ALKALI WATER FOR IRRIGATION

ONE source of alkali trouble may be from irrigation water which carries in solution large quantities of soluble salts. Water passing over or seeping through alkali land gradually dissolves the soluble material which it retains in solution. Drainage water coming from land that is high in soluble salts should therefore be thoroughly examined before being used for irrigation.

Streams that flow through rock formations, such as the Mancos shale, which contain large quantities of salts are often so strongly impregnated that their waters are rendered injurious for irrigation. Springs or wells are often found containing sufficient soluble salts to make the use of their waters dangerous. A limited quantity of alkali in the water would not be so serious if it were not for the fact that the land on which it is used may already have sufficient alkali so that the addition of any more would make it unfit for crops.

Variation in the original salt content of the soil makes it very difficult to determine just how much alkali can be present in irrigation water before it becomes dangerous. Notwithstanding the difficulty of giving exact figures, the problem is so important that it merits the most profound study. This is realized when the extensive use of irrigation water is known.

About 95,000,000 acres of land, or about 7 per cent of the total area under cultivation in the world, is farmed

by irrigation. This area will be greatly enlarged in the future. The 25 or 30 per cent of the earth's surface which receives too little rainfall to allow farming without irrigation includes some of the richest known farming land. The southwestern parts of Africa, South America, and Australia; the northern part of Africa; the northern and western parts of North America and Asia; and parts of eastern, southern, and western Europe are all too dry to permit of successful farming without the use of more water than falls naturally on the land. The successful farming of these areas is possible only through irrigation. There is much more land needing irrigation than there is water to supply the need. For this reason, it is important to be able to utilize all available water. Even water that would not be used if sufficient pure water could be had must be utilized. It becomes necessary therefore to know just what are the danger limits of alkali in irrigation water. If the farming of certain lands requires irrigation with water that will render the land unproductive, it is highly desirable to prevent the erection of expensive structures for diverting the water and laborious operations in bringing the land into a state of cultivation.

Sources of Contamination. — Much valuable information has been gathered in the past on the different phases of the alkali-irrigation-water problem. It has been observed that most of the contamination of irrigation streams is due to seepage and drainage waters which find their way back into the rivers and canals. Observations by the U. S. Geological Survey and the U. S. Department of Agriculture show that 65 per cent of the Gila River water (27) and 30 to 40 per cent of the Salt River water (3) (32) found its way back into the rivers after being used for irrigation.

Numerous analyses of river and canal waters show the great quantities of soluble salts added to the streams by seepage water. In Colorado, a river increased in total salts from 110 parts per million to 1178 parts per million in traveling 20 miles (28); the Jordan River, Utah, in a course of 14 miles changed from 890 parts per million total salts to 1970 parts per million (11); the Sevier River, Utah (12), in running from Junction to Sigard, a distance of 60 miles, had its total salt content increased from 205 parts per million to 831 parts per million and by the time it had reached Delta, 150 miles from Junction, its salt content had reached 1316 parts per million; the Pecos River, at Roswell, New Mexico, contained 760 parts per million total salts, and about 30 miles below 2020 parts per million were found and there were corresponding increases until at a point about 150 miles below the last-mentioned place, the river contained over 5000 parts per million (11) (8). These rivers all illustrate the amount of contamination from seepage water that may occur in almost any river.

At places where drainage water from strongly alkali soils empties into streams even greater pollution of the water may be expected. Water passing through a soil containing 20,000 parts per million of alkali in the upper four feet has been found to contain over 34,000 parts per million of salts when it reached the drainage outlet (5). Such water emptying into the bed of a small stream, as is frequently done during the height of the irrigation season, may make the further use of this water extremely dangerous. The water of the Arkansas River is very pure at Canon City, Colorado, but it is entirely diverted for irrigation further down. At a point about 120 miles below where seepage had increased the stream to consider-

able size again, it held about 2200 parts per million of salts (15).

Evaporation from free water surfaces is the direct cause of the high alkali content of certain irrigation waters. Lake Tulare, California, which has no outlet, was once

FIG. 32. — THE MORE TENDER TREES ARE BEING KILLED WITH RISING ALKALI, WHILE ALFALFA IS STILL UNAFFECTED.

considered a source of irrigation water. Due to evaporation its waters increased in concentration from 1400 parts per million in 1880 to 3500 parts per million in 1888, and to 5200 parts per million in 1889 (20). Irrigation water for the Carlsbad district, New Mexico, is stored in a large reservoir or lake fed by the Pecos River. It was found that for several weeks in May and June, 1899, the evaporation of this water which already contained between 2000 and 3000 parts per million of total salts, was equal to over

200 second-feet (11). The Gila River (18) was found to contain 1200 parts per million of total salts on June 5. By June 23 it had risen to 1546 parts per million and by July 8 to 1921 parts per million.

Water from torrential rains not having time to sink into the ground, especially on rather impervious soils, dissolves the surface salts and carries them into the streams below. Where much alkali is concentrated in the upper soil and surface of the catchment basin of the rivers, the high flood waters may become somewhat saline. During 1899 and 1900, studies of the Salt and Gila Rivers of Arizona showed them to contain more salts during flood periods, caused by these sudden showers, than during the low stages when the salt content might ordinarily be expected to be highest (8). Similarly, observations of the Pecos River showed the first flood waters to contain 5100 parts per million of salts, whereas later it contained only 2430 parts per million. The Salinas River, California, affords another example of this type of concentration of salts (48). It therefore cannot be safely stated that high waters are best for irrigation purposes.

Streams with their beds running through portions of an alkali stratum of soil may become excessively alkali. Salt Creek, Utah, passes over a part of the bed of old Salt Lake which contains large deposits of common salt. After doing so, its water was found to contain 2300 parts per million of total salts, of which 1629 parts per million are common salt.

Observed Toxic Limits. — The exact quantity of alkali which renders water unsuitable for irrigation is uncertain; it varies with the soil, the crop, the rainfall, the amount of water used, the drainage conditions, and a number of other factors.

Hilgard (17) (19) states that although 685 parts per million (40 grains per gallon) of the common alkali salts should be the limit under most conditions, the nature of the salts will modify the limits considerably. As little as 342 parts per million of sodium carbonate has in some instances caused serious injury in three or four years, while as much as 2739 parts per million of the less toxic salts would not be harmful. From his work in California, Mackie (24) states that where the salts are principally bicarbonate and chloride of sodium, irrigation water containing more than 600 to 700 parts per million of salt should not be applied except to porous, well-drained soils. Guthrie (13) considers 500 parts per million of sodium carbonate as a tolerable quantity of this salt even when as much as 150 parts per million of sodium chloride are also present.

Where the salts are more of the sodium-sulphate type, larger quantities are permissible. Forbes (18) states that with good drainage 1000 parts per million of salts in irrigation water is an objectionable but permissible degree of salinity for the soils of the Salt River, Arizona. In the Pecos Valley (26) 2500 parts per million to 3000 parts per million of salts were considered the danger zone where about 50 per cent of the salts in the water were of sodium — mostly sodium chloride and sodium sulphate. Good drainage in the upper part of the valley makes possible the use of water of higher salinity than is possible in lower parts of valleys where the soil is heavier and likely to contain more alkali. Land, after being irrigated five years with water containing 3900 parts per million of salts, was abandoned because of the accumulation of alkali and seepage water.

Experiments in Wyoming (31) show that where only small quantities of water are added, practically all of the

salts in the water are retained by the soil. Large quantities of water applied weekly or semi-weekly kept the salts moving downward continually. Means (25) states that the Arabs in the Desert of Sahara raise good crops of dates, deciduous fruits, and garden vegetables when irrigated with water containing as high as 8000 parts per million of total salts, 50 per cent of which in some cases was sodium chloride. Such alkalinity, however, would not be permissible except with very resistant crops on light, sandy, or well-drained soils and where great care is given to keep the water from evaporating and concentrating the salts at the surface.

Without special attention to drainage, a California soil irrigated with water containing 766 parts per million sodium chloride, 327 parts per million sodium carbonate, and 315 parts per million sulphates was proving injurious to an orchard after three years (19). Impervious clay soils might be injured with water too weak in alkali to have any noticeable effect on well-drained ones, because of the cumulative effect.

Even in a soil with good drainage in Arizona, it was found that when water containing over 1000 parts per million of salts, two-thirds of which was sodium chloride, was applied, 50 to 60 per cent of the salts added in the water were retained by the soil or at least never appeared in the seepage water of the district (8). Soils flooded by sea water for 6 to 8 hours were found to contain 2000 parts per million of sodium chloride in the surface soil where unflooded land contained only 100 parts per million. However, in a drainage experiment on the Swan Tract, Utah, an alkali soil containing less than 3000 parts per million of salts in the upper 4 feet of soil, when flooded with water containing about 1500 parts per million of salts yielded

drainage water containing over 11,000 parts per million of salts. The applications of water were large, sometimes as much as 16 inches being applied at one time, which makes a great difference in the retention of the salts by the soil (5). Hawaiian experiments with water containing 2000 parts per million of salts show that on a moderately porous soil there was very little accumulation of salt provided occasional heavy irrigation was given (4). Washing the salts out of the soil occasionally with the relatively pure winter and spring waters has proved very beneficial to some alkali districts.

In semi-arid sections, the salt content of irrigation water may be much higher than in the arid without causing trouble because the amount of water necessary to supplement the rainfall is smaller and the larger precipitation washes the salts out of the soil much more readily. The U. S. Geological Survey (32) has attempted to classify irrigation waters as good or bad by use of a formula based on the toxicity of the individual alkali salts to field crops. Such formulæ, while instructive as to the relative injuriousness of the waters, are subject to criticism because the factors mentioned above modify the limits through a wide range. A formula to be of much practical value must consider these factors.

Composition of Typical Alkali Waters. — To show the variation in the salt content of some of the principal streams of the West, the analyses given in Table XXII are presented. It should be kept in mind that these results will not hold strictly for different seasons and different sections of the stream, but they are useful in gaining a general idea of the nature of the alkali in different streams.

TABLE XXII. ANALYSES OF SOME CHARACTERISTIC ALKALINE RIVER AND LAKE WATERS OF WESTERN UNITED STATES

	Percentage of Salts								Total Solids
	Cl	SO_4	CO_3	Na	K	Ca	Mg	SiO_2	*P.P.M.*
(July) Salt River, Ariz.	59.4	9.2	13.1	40.7	1.1	6.5	3.3	3.5	1,391
(Oct.) Gila River, Ariz.	36.5	14.6	12.8	27.2	1.5	9.4	2.5	5.1	1,085
(Oct.) Colorado River, Ariz.	17.4	35.6	12.2	18.2	2.1	12.4	2.8	2.2	1,045
(June) Colorado River, Ariz.	17.5	12.5	28.6	13.1	1.5	15.4	5.1	5.3	321
(Low water) Pima Ditch, Ariz.	....	....	....	....	...	....	...	(a)	1,210
Buckeye Canal, Ariz.	39.9	7.3	9.6	24.9	.6	6.6	2.9	2.7	1,972
1880, Lake Tulare, Cal.	17.4	16.9	26.5	33.5	1.8	1.5	1.8	.5	1,360
1889, Lake Tulare, Cal.	20.3	20.8	19.5	35.8	2.4	.3	.3	.6	4,910
1891, Lake Elsinore, Cal.	....	....	....	....	....	....	...	(b)	1,444
Salinas River at San Lorenzo Creek, Cal.	11.7	48.6	7.9	16.7	1.0	4.5	4.9	.6	3,689
Estrella River, Cal.	15.4	30.9	22.3	17.9		6.3	4.3	2.8	1,131
San Benito River, Cal.	13.8	29.0	38.3	13.1	5.4	6.6	7.7	2.6	936
Cache la Poudre, 2 mi. above Greeley, Col.	2.5	60.0	7.3	9.8	.3	12.3	6.6	...	1,571
Platte River below Cache la Poudre, Colo.	3.8	55.3	8.8	12.0	.4	13.2	4.7	...	1,011
Arkansas at Rocky Ford, Colo.	4.9	60.7	2.6	14.5	.3	12.8	3.8	.4	2,134
Mill Creek (cold spring), Mont.	7.4	17.3	35.1	23.5	1.4	10.1	2.2	.7	3,747
Walker Lake, Nev.	23.8	21.3	17.3	34.6	trace	1.1	1.6	.3	2,476
Pecos River, N. M.	22.6	43.7	1.5	14.0	.8	13.4	3.6	...	2,384
Arkansas River, Salt Fork, Okla.	51.3	8.6	1.2	36.7	...	1.6	.6	...	5,962
Cimarron, north of Kingfisher	53.5	6.2	.7	38.3		.2	.1	...	11,392
Brazo River, Texas	30.9	25.5	7.1	20.8	.7	11.1	1.7	2.0	1,136
Rio Grande River, Texas	21.6	30.1	11.5	14.8	.8	13.7	3.0	3.8	791
Jordan River, Utah	35.5	26.5	2.7	26.1	...	7.6	1.5	...	892
Utah Lake, Utah	26.9	30.1	8.5	18.3	1.8	5.3	6.9	2.2	1,254
Sevier River at Delta, Utah	25.0	24.1	17.9	16.4	...	5.3	6.5	...	1,316
Beaver River, Utah	23.8	25.4	12.1	25.5	...	2.8	1.9	...	990
Malad River, Utah	50.0	2.9	4.7	37.4	...	....	...	...	4,395
Salt Creek, Utah	46.2	3.6	12.7	28.9	1.8	3.3	1.6	...	2,180

(a) 47.9% NaCl.

(b) 16.1% Na_2CO_3, 69.0% NaCl, Na_2SO_4, etc., 7.1% $CaCO_3$, $MgCO_3$ and silica.

No analyses of well waters used for irrigation are presented because well waters have been found to vary so greatly even in short distances that each well must be tested separately. There are certain large artesian basins

like that of the upper San Luis Valley, Colorado, — the waters of which all contain larger or smaller quantities of sodium carbonate,— which permit of rough classification. Irrigation well waters seldom change in composition as do open streams because the water is not subject to the various factors causing fluctuations.

To show the seasonal fluctuations in the salt content of rivers, analyses of the Salt and Gila Rivers of Arizona (8) are given in Tables XXIII and XXIV. These are exceptional variations but illustrate how little a single analysis might mean. The Sevier River, Utah, shows a somewhat less fluctuation because not influenced by flood waters. This is shown in Table XXV (33).

TABLE XXIII. SEASONAL VARIATION IN SALT CONTENT OF SALT RIVER, ARIZONA, EXPRESSED AS PARTS SALT PER MILLION OF WATER

DATE	TOTAL SALTS	COMPOSITION OF THE WATERS							
		Na	Cl	SO_4	CO_3	Ca	Mg	K	SiO_2
(a) Aug. 1–Sept. 1, 1899.....	724	122	279	979	...	679	174	129	206
(b) Sept. 2–Sept. 9, 1899.....	1100	183	315	481	154	102	233	141	111
(c) Sept. 10–Oct. 9, 1899.....	1142	274	441	727	802	724	279	109	583
(d) Oct. 10–Oct. 17, 1899.....	952	...	...	...	...	...	...	...	...
(e) Oct. 18–Dec. 30, 1899.....	1026	309	409	748	117	402	284	153	465
(f) Feb. 17–May 30, 1900.....	1069	327	437	764	115	437	292	123	529
(g) June 1–Aug. 4, 1900.....	1391	407	594	919	131	651	328	112	355

(a) High and low summer water. Average of four weekly composites of samples taken daily.
(b) Summer flood water. One weekly composite of daily sample taken.
(c) High and low summer waters. Average of four weekly composites of daily samples.
(d) Winter flood water. One composite of daily samples taken.
(e) Low winter water. Average of ten weekly composites of daily samples.
(f) Low winter water. Average of thirteen weekly composites of daily samples.
(g) Very low summer water. Average of eight weekly composites of daily samples.

TABLE XXIV. SEASONAL VARIATION IN SALT CONTENT OF GILA RIVER, ARIZONA, EXPRESSED AS PARTS SALT PER MILLION OF WATER

DATE	TOTAL SALTS	COMPOSITION OF THE WATERS							
		Na	Cl	SO_4	CO_3	Ca	Mg	K	SiO_3
(a) Nov. 28, 1899–Jan. 18, 1900. .	1168	312	401	155	653	524	264	178	752
(b) Feb. 1–Mar. 7, 1900.	1136	280	383	165	693	663	289	138	652
(c) Aug. 1–Aug. 14, 1900.	541	. . .	965	947	. . .	686	175	. . .	. . .
(d) Aug. 15–Aug. 28, 1900.	925	. . .	. . .	130	. . .	836	157	. . .	. . .
(e) Sept. 1–Sept. 28, 1900.	471	823	574	964	110	571	121	226	266
(f) Sept. 29–Nov. 5, 1900.	1085	271	364	145	127	937	248	151	511

(a) Low winter water. Average of seven weekly composites of samples taken daily.

(b) Low winter water. Average of five weekly composites of samples taken daily.

(c) Summer flood water. Average of two weekly composites of daily samples.

(d) Summer low water. Average of two weekly composites of daily samples.

(e) Summer flood water. Average of four weekly composites of daily samples.

(f) Summer low water. Average of five weekly composites of daily samples.

TABLE XXV. SEASONAL VARIATION IN SALT CONTENT OF SEVIER RIVER, UTAH, EXPRESSED AS PARTS SALT PER MILLION OF WATER

DATE	TOTAL SALTS	COMPOSITION OF THE WATERS						
		Ca	Mg	SO_4	K	Cl	HCO_3	NN
July 29.	958	74	100	222	10	58	278	1.7
August 12.	1104	84	87	272	12	90	290	1.6
August 24.	1268	82	87	288	8	115	284	1.1
September 18. . . .	1190	92	79	256	10	101	292	1.7
September 21. . . .	1426	86	83	329	4	221	264	.4
October 5.	1406	74	75	328	4	210	249	.8
October 19.	1436	84	74	334	11	223	284	.9
November 9.	1376	84	74	326	10	204	290	.9

Factors Modifying Toxic Limits of Salt. — Under ordinary conditions irrigation by the flooding method with

saline water has been found better than by the furrow method. This is especially the case where such good drainage prevails that large quantities of water may be applied to leach out any accumulation of salts. Experiments have shown that land flooded every 8 days with alkali water contained less than one-third the quantity of alkali found in the temporary ridges under furrow irrigation and about 27 per cent of that found in uncultivated tree rows.

Hawaiian experiments (7) show that with large applications of water containing about 3430 parts per million (200 grains per gallon) of common salt, large quantities of lime, magnesia, and potash are rendered available. Excessive irrigations to prevent the alkali from accumulating at the surface washed out large quantities of lime and magnesia. Soils not well supplied with lime are injured much more by alkali than those well supplied. It was found in Wyoming (31) that alkali irrigation water caused a considerable loss of calcium sulphate and calcium carbonate from the soil. Experiments in Oregon (1) show that calcium carbonates and nitrates wash out of the soil faster than supplied in the irrigation water.

It has been found in some regions that the dissolving action of alkali — the chloride and sulphate salts — on lime destroys the impervious hardpan layer often found a foot or two beneath the surface, thus allowing drainage to go on more freely.

In the Southwest, especially in New Mexico, certain of the streams carry calcium sulphate in solution some of the time. The salt neutralizes and makes less toxic the sodium carbonate found at times in the soils of the district. If but little or no black alkali is present, as is the case in that of the Pecos River irrigation water may contain

much larger quantities of total salts than would otherwise be permissible. On soils where an impenetrable hardpan exists, sometimes caused by sodium carbonate, the permissible salinity is generally lower than without such a condition.

During dry years, a single irrigation with alkali water may mean the difference between a crop and a failure, provided the crop can withstand the alkali in the water. The limits in such cases might be much higher than in cases where it is necessary to irrigate frequently. On a clay loam soil containing a medium quantity of alkali in the Bear River Valley, Utah, the use of irrigation water containing 4395 parts per million of total salts, 3625 parts per million of which was sodium chloride, caused almost immediate wilting or death of grain. In the Carlsbad district, New Mexico (26), water containing 4352 parts per million total salts consisting of 1682 parts per million sodium chloride and 600 parts per million sodium sulphate injured young sugar-beets when freely applied.

In Europe (37) the use of irrigation water containing 5000 to 10,000 parts per million of salt caused dwarfing of the better grasses and legumes so that the yield was considerably reduced. Seedling grass was killed with these concentrations and even 500 to 1000 parts per million injured the stand.

Corn (2) suffered during its vegetative period when irrigated with chloride and carbonate waters in concentrations as high as 7389 parts per million, but tomatoes did not. Sugar cane (6) (7), when irrigated with pure water, yielded 11 tons more sugar per acre than when irrigated with water containing 3430 parts per million of salts. The density of the cane juice was lowered and the salt content raised by the use of the alkali water so that

the purity of the juices and the quantity present was reduced. In these experiments 6.75 and 8.79 acre-feet of water were applied during the season and occasional heavy irrigations were given to keep the salts from accumulating. When the quantity of water used was reduced considerably so that the strength of the soil solution became high such a large quantity of alkali proved fatal (6) (7).

Using coffee, cocoa, and other plants to determine the concentration of water that may be used with safety (22), it was found that the limits were between 5000 and 15,000 parts per million although the result were somewhat complicated by rainfall.

From a survey of a number of localities along the Potomac River, Scofield (30) assumes that the salt water limit for wild rice is about 1754 parts per million (0.03 normal) for sodium chloride. The growth was just about proportionate to the strength of the solution when less than this amount was present.

Water to be used in irrigating rice should never contain more than 3000 parts per million of salt, according to Fraps (9) of Texas.

Harris and Butt (14), after a rather extensive study of the use of alkali water for irrigation, concluded that under average conditions more than 500 parts per million of sodium carbonate, 1000 parts per million of sodium chloride, 4000 parts per million of sodium sulphate, and 4000 parts per million of the ordinary mixture of salts are dangerous. In case there were no drainage from the land, lower limits than those mentioned would have to be used.

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CHAPTER XVI

JUDGING ALKALI LAND

A KNOWLEDGE of the physical phases of alkali is not sufficient; the economic questions in connection with it must also be given consideration. Alkali has no special practical interest except in its relation to the soil, which it may render entirely worthless if present in certain forms and in sufficient concentration. In its less injurious forms and at low concentrations it may reduce the value of the land but slightly. It is important, therefore, to be able to judge the extent of reduction in value of land due to the presence of alkali. Many tracts have been settled, and, after the expenditure of large sums of money, abandoned. This loss might have been saved had a proper examination of the soil been made.

Geology of Region. — In regions free from alkali no particular attention need be given to it in judging land, but in regions where alkali is known to exist, it must be kept constantly in mind by prospective purchasers of land. Since practically all of the arid parts of the world have more or less alkali, the ability to judge alkali land is very important. One of the first steps is to look into the origin of the soil to see if it came from geological formations that are high in soluble salts. Soils derived from sandstones and shales of certain formations are practically always so highly charged with salts that crop production is difficult until the salts are leached out. A soil coming from a formation of this kind, even though it has a salt

content similar to that of a soil from a limestone formation, should be regarded with greater suspicion than the latter soil because of the possible recontamination from

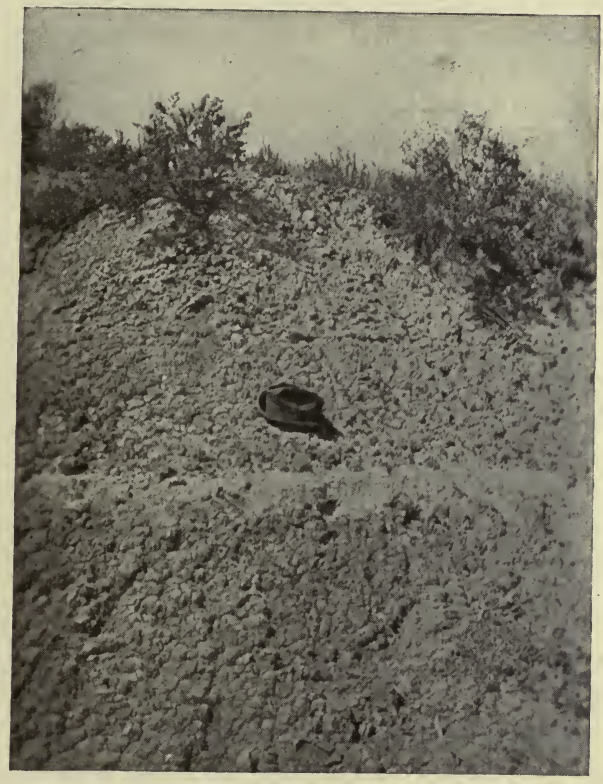

FIG. 33. — A LAYER OF ALKALI SEVERAL FEET BELOW THE SURFACE. THE POSSIBILITY OF SUCH A LAYER MAKES AN ANALYSIS OF THE SOIL NECESSARY BEFORE IT CAN BE PROPERLY JUDGED.

the unlimited supply of salt in the country rock. A knowledge of the geology of a region, therefore, is a valuable supplement to other information in judging alkali land.

General Appearance. — One who is familiar with alkali can tell a great deal by the general appearances of the land. The presence of surface accumulations of salts, the nature of the crust, the general condition and kind of vegetation, the appearance of the subsoil in cuts and excavations, the slope of the surface, the soil texture and structure, and numerous other general appearances are helpful in judging alkali conditions. These superficial observations, however, must not be relied on completely. For example, a soil having a high gypsum content and being free from the highly soluble salts may, through constant evaporation of water at the surface, cause the soil to be covered completely with white powdery crystals which would seem to indicate a serious alkali condition. Land of this character could easily be undervalued since the gypsum is not sufficiently soluble to cause injury to vegetation and its presence might not be undesirable.

On the other hand, a soil may show very little surface indication of alkali; it may contain a good growth of certain kinds of vegetation; yet an analysis might show that at some distance below the surface there is a layer of soil that is highly charged with salts. This land would only need to be brought under cultivation and irrigated to make the subsoil alkali a real source of danger. Appearances are helpful, but alone they are not sufficient.

Native Vegetation. — As already discussed in considerable detail in Chapter VI, the native vegetation is one of the most valuable indicators of the presence of dangerous quantities of alkali. It is probably the best single means of judging alkali land. Certain plants such as sagebrush (*Artemesia tridentata*) do not live in the presence of high concentrations of salts and where these plants are found growing vigorously the land may

be considered to be comparatively free from alkali. Certain other plants such as salt grass (*Distichlis spicata*) are seldom found except on land highly charged with salt, and where found the soil should be thoroughly investigated before an attempt is made to use it for agriculture. Since this question has already been so fully discussed, no details will be given here. Chapter VI should be consulted for further information.

The Water-table. — Alkali lands are often wet. Surface accumulations of salt usually result from a rapid evaporation of water which rises from a water-table that is comparatively near the surface. There are soils high in alkali with a water-table hundreds of feet below the surface. In these soils the ground water has nothing to do with the alkali accumulation. Soils are frequently found containing a medium quantity of salt distributed through considerable depth. With the introduction of irrigation and a consequent raising of the water-table to within a few feet of the surface, an ideal condition is provided for a concentration of these diffused salts at the surface. This may render entirely unproductive a soil that previously raised good crops. A thorough knowledge of ground-water conditions is, therefore, important before a person is able to make an intelligent judgment regarding alkali land.

Analysis of the Soil. — It is impossible to get an adequate idea of alkali land without having a chemical analysis of its water-soluble material. As has already been explained, a superficial examination may be somewhat deceiving, and it is necessary to know the nature and concentration of the salts to considerable depth before being able to tell definitely how the soil will act and whether or not the alkali is likely to cause trouble. The depth to which the soil

should be analyzed depends on a number of factors. Four and 6 feet are often taken as standards but 10 feet is better. At least an occasional sample should be taken to this depth to see that in the deep subsoil there is not a layer of high concentration that will cause trouble later.

The exact determinations to be made will depend on the thoroughness of the investigation desired. A complete chemical analysis of all the water-soluble material would be desirable, but a fair idea can be had with much less work. An absolutely necessary determination to any sort of intelligent diagnosis would include total soluble salts, chlorides, carbonates, and sulphates. In comparatively few regions where nitrates are high, they should also be determined. Where any large part of the sulphates are calcium sulphate, calcium should be determined in order that the calcium sulphate may be subtracted from the total soluble salts and the sulphates. Calcium sulphate is not sufficiently soluble in the soil solution to be toxic to vegetation, but where comparatively large quantities of water are used in extracting the soil for analysis, considerable calcium sulphate is contained in the solution, and where it forms any large part of the dissolved material it should be taken into consideration. It is also desirable to have determinations made of other bases such as magnesium and sodium, but these determinations are not so valuable as the others that have been mentioned.

The methods of analysis, particularly the method of making extractions, must be taken into consideration in interpreting the results. Different methods give different results; consequently the methods should always be known. Details of the various methods are given in Chapter VII.

Possibility of Reclamation. — The value of alkali land is affected very materially by the possibility and the ex-

pense of reclaiming it. Some alkali lands are so situated that reclamation is practically impossible or would be so expensive as to be prohibitive. Very flat land that does not have an outlet for drainage is difficult to reclaim. Land that is so heavy that drainage water percolates slowly has its salts washed out with difficulty. Some lands have a good slope and the soil has a texture suitable for drainage, but there is no available supply of water to aid in the process of reclamation; hence, drainage is useless. It is apparent, therefore, that not only the quality of the soil itself must be taken into account, but also the conditions associated with its reclamation.

Economic Factors. — Physical features of the soil must be used in connection with a number of economic factors in judging an alkali soil. The soil has no particular value aside from the economic returns it will yield. These depend not alone on actual crop yields, but also on cost of production, market conditions, and a number of other factors. Distance from market and from suitable farm help may make it unprofitable to cultivate even a fertile soil, much less a soil the productivity of which is decreased by any unfavorable condition such as the presence of alkali. Climatic conditions may not be such as to make possible the raising of profitable crops that are resistant to alkali. A soil of a given alkali content might be suitable for agriculture in a region where date palms could be produced at a profit and yet be entirely worthless for the crops of the temperate zone. It is evident, therefore, that alkali soil of any particular type or composition cannot be said to be suitable for agriculture without taking into consideration numerous conditions other than those associated with its merely physical features.

The demand for an increased acreage of land to supply

food for the world will make it necessary to use more and more the lands that were previously not considered worthy of cultivation. This will demand that greater attention be given to alkali lands, and that more intelligence be put into understanding and reclaiming them.

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