

Soil

ALKALI and ALKALINITY

Related to Irrigation Water -

GYPSUM a Soil ALKALI Corrector

By

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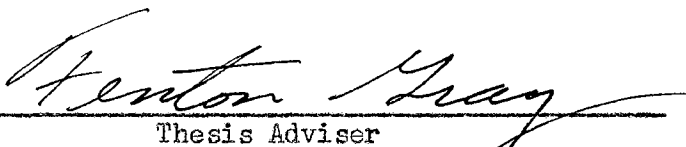
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## I PART

### INTRODUCTION

All life depends upon the soil. The soil is one of very few factors of man's existence. The quotation, "There can be no life without soil and no soil without life: They have evolved together.", from Kellogg (28) shows the importance of the soil. The soil which has such an importance in our existence is the same soil that several times daily we walk on without giving any attention to its so important role in our life.

First of all man obtains from the soil his food. The direct obtainment is such as vegetables, fruits, seeds or grains, or indirectly such as feeding the animals and using their products as milk, meat, or fat. Therefore, the soil because of being an indispensable factor of life, should be known and recognized as well as possible in order almost to bend it for necessary plant growth or to change the unfavorable soil conditions to favorable ones.

Soil which is a natural medium for the growth of plants is a compound of fragments in varying proportions of weathered or unweathered rocks, organic matter, minerals, water and air. Because of the dynamic character of soils, they will undergo a change, except when in equilibrium state. Also in this state there will be changes when there is a change in the environment.

One of the very important influential factors in soil characteristics, beside the parent material or climatic factors, is drainage condition in soil. Due to the amount of rainfall one might expect to have a leaching or accumulation problem in soils.

As it is well known, the fundamental characteristic of soil is its productivity, that is, its capacity to produce green plants. If temperature is favorable, from the production standpoint or even from the standpoint of plant growth, there are many other factors such as moisture and natural characteristics of soil that make different kinds of soil.

Going back to the history of agriculture, primitive man was physically adapted to the food which nature was furnishing for him, or moved on to a more agreeable place. By moving from place to place, it was possible, to some extent, to get satisfactory food. However, because of development of civilization, increasing of world population, and progress of science, the man of today, having knowledge of necessary food types, wants to get his desirable and necessary food. Man and animal get their food from the plants, which have a very important influence upon the physical formation of both. The food which furnishes the diet for both man and animal depends upon the soil that produces these plants; therefore, improvement of the soil becomes a necessity. The continuously increased needs of man extend far beyond that which nature can furnish him. Abandonment of land damaged by any cause is a serious loss to agriculture.

Through the accumulation of experience and knowledge, man gradually learns to bend natural forces to his advantage and, thus, reduces the hazardous, natural environmental factors of plants, which in turn, reduce the hazards of life. The man of today, with advancement of knowledge, improvement of technique and progress of science, is able to improve the production of soil, according to his requirements and taste, by careful plant breeding and fertilization. No matter how complicated the agricultural techniques are or are becoming, man can produce his particular necessities through the use of these techniques. The important fact which exists and which will not

change is the relationship between the plant and the soil. The basic agricultural techniques used are to produce a relationship between soil and plant suitable to the aims of man. From this adjustment standpoint, theoretically, there are two ways, changing the soil or choosing plants to fit the soil, but usually man combines these two to some extent.

Back several hundreds of years, by experience, man has gathered a lot of knowledge of soil physics, but it was not until the eighteenth century that soil chemistry started to develop. Centuries before that time, some chemical reactions, such as decoloring or deodorizing of manures in soil, were known, however causes or factors having such influence upon the manures were unknown. Also, the reason that the ocean water became fresh when passed through sandy beds was unknown. Although during the last two centuries, particularly the last few decades, this branch of science has improved very much and has enlightened a lot of dark points, but there are still a lot of undiscovered points in soil chemistry.

The soil, from the chemical reaction standpoint, is comparable to a large and vast chemical laboratory, in which complicated changes are going on continually. It is very difficult to describe what occurs in this great laboratory. Due to these complicated chemical reactions and because of the influence of different climatic factors and conditions, we find a lot of soils unfavorable for plant growth. Even by means of certain agricultural practices, such as continuous cropping of the land, we damage our soils. The point is one to seek a practical remedial method of securing our soils, and to improve its productivity to a desirable stage.

It was 1850 when Thompson (46) through his field experiment, and Way (49) by his experience and investigation, found the exchange base properties of soils. During the period of 1855 and 1858, Liebig (30) wrote two of his very



important reports, in which the soil power to absorb cations of neutral salts and case of replaceable bases were understood. It is still by this discovery that man knows what kind of reaction takes place when different chemical fertilizers are added to the soil, and also knows to a certain extent how much one must treat the soil in order to replace the amount of the plant nutrients which are lost through leaching and cropping, in order to keep the soil productive. It is through this discovery that it is made possible to find reasons for unfavorable soils and also methods, to some extent, to improve these soils. Among the many harmful and unfavorable soils for plant growth, the ALKALI soils are probably the important ones. Alkali soils, despite the fact of being very harmful for plant production, occupy a vast area of the earth particularly in arid and irrigated areas. One is justified, therefore, in paying more attention to this problem than to other soil problems.

The term ALKALI SOILS denotes the salt-saturated soils, or the soils which contain an excess of salt.

### ALKALI SOILS

Because by accumulation of water soluble or insoluble salts, the soil becomes white and dark brown or black colored; therefore, it is called a saline soil in the first instance and alkali or "black alkali" in the second instance. In the case of saline, by some practical means such as washing by excess water and draining by drainage channels, it is possible to reclaim the soil to some extent. However in the case of black alkali, the problem of correction is not so easy. Sodium in black alkali soils acts as an exchange cation and forms sodium carbonate and the pH of soil rises above 8.5. The soil obtains an unfavorable structure for water infiltration and the colloids become dispersed.

The alkali soil problem is one of the most interesting of research or scientific problems of today's agriculture. This problem has received more attention, particularly in irrigated areas. Water, as it passes through different zones or areas, carries different soluble salts. In irrigated areas if most of these salts are leached out by drainage water there remains some which may return to surface zone of soil by evaporation. In some cases, when these salts contain sodium, there will be more harmful soil known as "black alkali."

The important problem of these soils is to correct the damaged soils and find out how to prevent further damage. Even though there has been a great deal of work done on this problem, there still remains a big problem to be solved. In spite of the more recent work on this problem, treating the alkali soils with gypsum, there is still no satisfactory method of using gypsum. The idea is to replace the sodium by calcium of gypsum. To some extent good results from using gypsum are obtained, but the ratio needed and how, where, and when to use it in order to get better practical results, have not been entirely answered.

#### THE RESEARCH OBJECTIVES

The main objectives of this research work are to review the pertinent papers dealing with alkali soils, to conduct laboratory experiments in connection with alkali soils and exchangeable bases, and to study the relationship of calcium and sodium of varying proportions on the properties of soils of different texture.

## PART II

### EXCHANGEABLE CATIONS

Considering all soil aspects, from a developed and improved agricultural soil standpoint, the soil property of "adsorption" (cation exchange) is the most important and interesting one. It is through this discovery that man is able to recognize the influencing factors that cause changes in soils. Through this discovery also man is able to bend a lot of harmful influencing factors in soil conditions, and in some manner try to change the unfavorable soil conditions.

Because of its importance and because this basic soil property is an influencing factor of our research work, it seems very important that a historical summary of the discovery of the cation exchange property of soils, its identification, and properties as an influencing factor or as a factor acting upon the different changes in soil compounds, be reviewed.

### HISTORICAL SUMMARY

Historically the absorption property of soil was recognized since very early times. Centuries ago it was well known that the soil decolorizes and deodorizes the liquid manures. Freshing the sea water through the sand beds was known by Aristotle (39). Lord Bacon (39) in 1582 in his publication *Sylva-Sylvarum* discussed the question of making sea water palatable by filtering it through sand. From an agricultural standpoint Gazzeri (1819) observed that "the soil, especially clay, takes up soluble substances, which

he considered an advantage inasmuch as they may become available later as the plants need them." (12)

The first quantitative experimental work was carried on in 1845, by H. S. Thompson (46). As shown in Table I, he worked out that ammonium sulphate solution when filtered through soil, exchanged its ammonia for lime. In his experiment, he leached a short column sandy loam soil, to which he had added 0.64 gram of ammonium sulphate or ammonium carbonate. Another experiment that he ran was similar to the first one, except he poured back the leachates again on the soil and leached them for the second time. Results were as follows:

In the first case:

By $(\text{NH}_4)_2 \text{SO}_4$		By $(\text{NH}_4)_2 \text{CO}_3$	
Leachate contained		Leachate contained	
$\text{CaSO}_4$	0.256	$\text{CaSO}_4$	0.064
$(\text{NH}_4)_2 \text{SO}_4$	0.154	$\text{NH}_4 \text{Cl}$	0.083
other sub.	0.038	$(\text{NH}_4)_2 \text{SO}_4$	

In the second case when he poured back and leached again:

By $(\text{NH}_4)_2 \text{SO}_4$		By $(\text{NH}_4)_2 \text{CO}_3$	
Leachate contained		Leachate contained	
$\text{Ca SO}_4$	0.403	$\text{CaSO}_4$	0.006
$\text{MgCl}_2$	0.064	$\text{CaCl}_2$	0.016
		$\text{MgCl}_2$	

TABLE I

These experimental results were not published until 1850, when J. T. Way

(49) published his first important paper. Way had made a detailed study of this subject by allowing solutions of ammonia and nitrates, chlorides and sulphates of ammonia, potassium, sodium, and magnesium percolate through soils. He found through the soil infiltration that the bases were largely removed from the solutions and replaced by lime of the soil. He demonstrated the active part of soil was clay and attributed this activity to a particular clay which in his idea was a hydrated alumino-silicate of alkali or alkaline earth "zeolite."

#### DIFFERENT CONCEPTS OF BASE EXCHANGE UNTIL THE RECENT CONCEPT OF CLAY MINERALS

From the time of discovery, the soil cation exchange property was studied from two important and completely different phases: Whether the reaction was a chemical or a physical one, and what materials of soils go to the interchange action and by what solutions.

After the publication of experimental work of Way, the scientists became very interested in the subject and those experiments have been repeated by a lot of other workers. Many of these workers accepted the chemical explanation of Way. Warrington (51) regarded (1868) the aluminum and iron oxides as being involved because of the absorption powers of these oxides for phosphates, as well as the soil.

The early development of the subject started in 1855-1858, when Liebig (30) published his very important first and second papers, and he criticized (23) the view of Way's followers. Liebig believed this absorption being a physical character due to the surface attraction and through the capillary holes such as holding water into a sponge and the materials to be regarded as plant food. Because of his dominating position in chemistry at that time,

the physical viewpoint of Liebig prevailed. Liebig believed that many kinds of substances have this power.

Peters in 1860 (38) published his paper discussing that natural soils may contain exchangeable Mg and Na ions in addition to calcium and that the replacement of these cations is influenced by the concentration of the solution and ratio of solution to soil.

The publications of Lemberg on the subject of cation exchange which were started to be issued by 1870, might be said were the most important papers on this subject. He proved conclusively that many other silicate minerals have the same properties of base exchange in salt solution as the Zeolites (31).

According to Fisher (11), "This work of Lemberg is probably the most important that has been done on this subject, and it is unfortunate that it is not more accessible and familiar to agricultural workers."

The most striking experiments of Lemberg were with leucite ( $\text{KAlSi}_2\text{O}_6$ ) which was converted into analcite by adding NaCl-solution and analcite plus KCl-solution became leucite.

One of the most important results obtained from Lemberg's experiments is that Sodium-silicate minerals are less stable in salt solutions than the corresponding potassium minerals; or it might be said that, under similar conditions potassium will replace sodium more easily and completely than sodium replaces potassium. The fact that ocean water is a solution of NaCl rather than KCl suggests the strong absorption of K by soils. (32)

Van Bemmelen in 1878, and 1879, (47) published two papers. As pointed out by Gedroiz (1918), "Van Bemmelen fully joined those believers in the chemical nature of exchange reactions in the soil; even more than that none of these previous investigators expressed himself so definitely in favor of this theory." (23) In 1888, Van Bemmelen revised radically his views. Because of

his studies on hydrogels, he abandoned the chemical explanation, but traces the exchange or absorption power of the soil to its content of hydrogels. As Kelley (23) explains, Van Bemmelen's theory was that the acids decompose the hydrogels, therefore destroying the absorption power of them. According to Van Bemmelen the hydrogels are composed of indefinite proportions of  $\text{Al}(\text{OH})_3$ ,  $\text{Fe}(\text{OH})_3$ ,  $\text{SiO}_2$  and humus, any one of which can itself form a hydrogel, and each one has a peculiar absorption power. The absorptive power varies depending on the amount of each. Therefore soils containing equal total amount of colloidal material may vary considerably in absorptive power. The exact word translation of Van Bemmelen's colloidal concept made by Kelley is as follows: "Absorption compounds are formed from components with variable molecular ratios. They may be distinguished from chemical compounds, but they may change into chemical compounds. Colloidal substances form such absorption compounds with water and other liquids, with bases, acids, and salts." According to Fisher the outstanding facts of Van Bemmelen's work are that in no case is there absorption of neutral salt as a whole, but always an interchange of bases already present, and that the seat of the action is in the colloidal silicates that are present.

In 1905, (8) Cushman by means of the microscopic examination and from the formation of soluble alkali silicates, showed that a certain amount dispersion (peptisation) occurs when water and orthoclase or some other minerals are ground together. This proved the viewpoint of Van Bemmelen. The important thing at that time was that Van Bemmelen made distinction between reactions involving crystalline substances and those with colloidal substances. He was not aware that crystalline substances may also be highly colloidal, and that the soil colloidal substances are definitely crystalline.

For a period of about 20 years after the last publication of Van Bemmelen

there was a lot of work done by different workers, but nothing new on this subject of cation exchange was developed.

It was just 20 years later or in 1912, when Wiegner (52) concluded that cation exchange is an adsorption reaction rather than a chemical reaction. He stated that the exchangeable cations are held on the surface of particles, and within capillaries and not by chemical attraction but by adsorption. The later publications of Wiegner and his students on cation exchange subject discussed the subject from the standpoint of colloidal phenomena. According to him (1931), cation exchange is an adsorption reaction and not an ordinary chemical reaction. He also emphasized ion size and ion hydration as factors in exchange and as a general rule he concluded that the smaller the ion the greater its replacing power. According to Kelley (23), "The importance of ion size in exchange reaction is by no means certain, obviously any ion, whatever its size, must be able to gain access to the so-called exchange spots, that is, the electric field in which the adsorbed ion is held by the solid particle."

According to Wiegner, each particle of exchange material, is made up of three different parts: (1) a Kernel "micron" or "ultram micron," (2) a layer of adsorbed anion external to the kernel but lying in contact with it and they consist of OH or  $\text{SiO}_3$  or both ions, and (3) exchange cations attracted to the particle by the adsorbed anions. It is supposed that the cations form a sort of swarm around the particle and they are more or less hydrated in an aqueous medium. Thus Wiegner explained the electronegativity and the cation exchange power of soil colloids on the basis of the adsorption of (OH) hydroxyl ions or ( $\text{SiO}_3$ ) mono-silicate ions.

According to Gedroiz (15), the inorganic exchange material of soils has two possible sources, either from extremely fine-grained rock fragments,



or from mutually precipitated colloidal silicic acid,  $\text{Al}(\text{OH})_3$ , and  $\text{Fe}(\text{OH})_3$ . He suggests that during the course of weathering rocks and minerals are broken down into finer and finer-sized particles culminating in particles of colloidal size. The particles absorption power gradually increases, reaching a maximum in the colloidal range owing to the high specific surface. Gedroiz published a series of very comprehensive and valuable papers during 1912-1925, and he discussed many different aspects of cation exchange. (54)

Mattson's publications are somewhat different from most of the other investigators. Within certain limits he found (34) the exchange capacity of permutite-like precipitates to increase somewhat parallel to the Silica-alumina ( $\text{SiO}_2:\text{Al}_2\text{O}_3$ ) ratio; the same is true about the soil colloids. One point emphasized by him is important to know: At a given pH the exchange capacity is a definite quantity for a given sample, but different from that at another pH. It means due to the influence of pH in determining of exchange capacity, the pH should be determined in each case. (35)

#### THE CLAY MINERAL CONCEPT

The cloudy soil aspect of cation exchange started to enlighten in 1930, when Hendricks and Fry (19) discovered that the inorganic colloidal material of the soil is commonly crystalline. This discovery also was made in 1931, by Kelley, Dore and Brown (24). This was a new period in soil science. Through this discovery soil scientists were able to recognize the substances responsible for soil cation exchange.

By the aid of this new discovery scientists of soil found that the responsible materials of soil for exchange cations are chiefly clay materials, such as montmorillonite or beidellits, kaolinite, hydrous mica, and

halloysite.

Crystal and isomorphic structure, as explained by mineralogists, and the key methods by which to study the cation exchange materials. The publication of Pauling in 1930, and other mineralogists (37) gives the basic information on the clay minerals, and the publications of Hofman (1933), Ross and Hendrick (1941-1945), and others give good explanation concerning the relationship of cation exchange to the crystal structure of clay minerals.

From the standpoint of crystalization of the clay minerals and the property of exchange cations, it is very important to identify them and to describe their cation exchange character through their formation and function. The picture of these two different phases of clay minerals as given by Kelley (23) may be one of the best because of his very comprehensive knowledge.

The clay minerals are platy resembling in this respect pyrophyllite, the micas and talc. They are characterized by a lattice structure. The layers are composed of planes of silicate ions in which each silicate ion is situated at the center of a tetrahedron formed by four oxygen ions, and planes of Al-, Fe- or Mg-ions surrounded by six oxygen or OH-ions arranged in the form of an octahedron. In kaolinite the lattice layer consists of one plane of Si tetrahedra bound to one plane of Al-octahedra. In contrast, montmorillonite, beidellite and hydrous mica-type clays, the most important cation-exchange clays contain lattice layers composed of two tetrahedral planes bound together by one octahedral plane. With montmorillonite, Si-ions occupy the vast majority of the tetrahedral positions, possibly all of them, and the octahedral positions may be occupied by Al-, Fe- or Mg-ions and some of them may be vacant. A substantial percentage of the tetrahedral positions of beidellite are supposed to be occupied by Al-ions.

In the case of isomorphism it may be said that the crystalline shape is the same as the original shape except different ions of same size may enter into the framework. The isomorphism implies the substitution of one ion for another in the crystals.

This is a description of how the clay minerals act and also why they differ in cation exchange property. Some of them on account of purity may

not contain this property at all or in the least. It appears noteworthy to give some practical pictures of their structures.

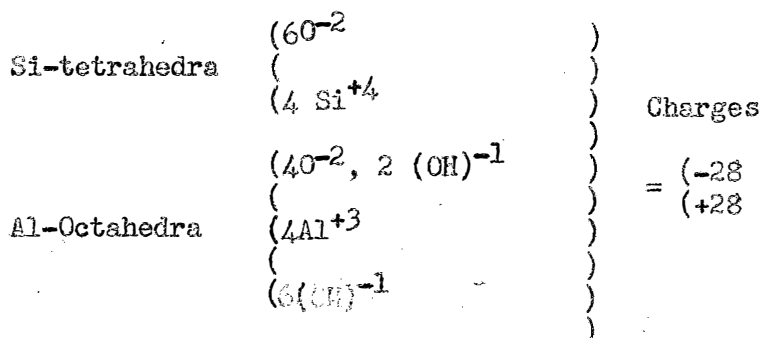
Pyrophyllite,  $\text{Al}_2 \text{Si}_4 \text{O}_{10} (\text{OH})_2$  -- In a lattice layer the order of atomic planes is:

Si-tetrahedra	(6O <sup>-2</sup>	-12)		
	(4Si <sup>+4</sup>	+16)		
		)	Charges	
	(4O <sup>-2</sup> , 2(OH) <sup>-1</sup>	-10)		
Al-Octahedra	(4Al <sup>+3</sup>	+12)	=	(-44 +44)
	(4O <sup>-2</sup> , 2(OH) <sup>-1</sup>	-10)		
Si-tetrahedra	(4Si <sup>+4</sup>	+16)		
	(6O <sup>-2</sup>	-12)		

Because of equality of the negative and positive <sup>Charges</sup> the lattice is electrically neutral. In the case of being pure, pyrophyllite contains only traces of K, Ca, Mg, or Na. The electrical neutrality makes it unable to attract the cations of solutions and therefore the exchange capacity is very low.

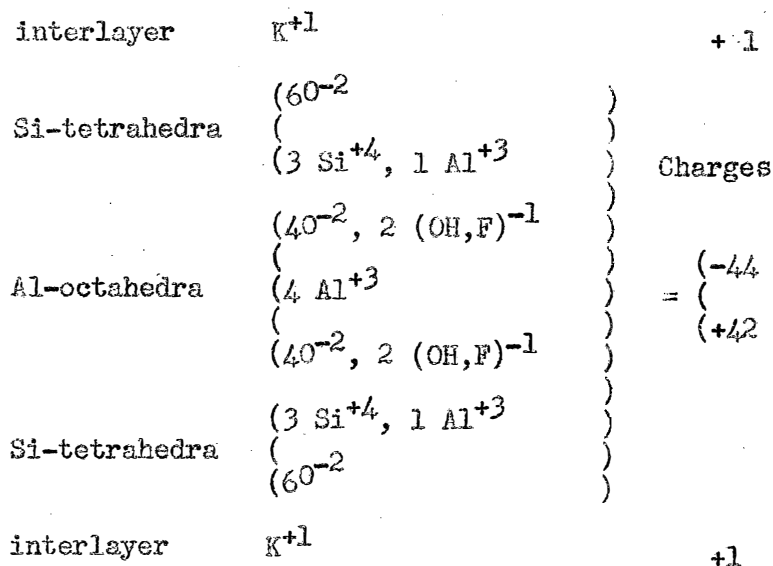
Kaolinite,  $\text{Al}_2 \text{Si}_2 \text{O}_5 (\text{OH})_4$  -- This is known to be found in leached soils in humid climates and in some relatively dry climate soils. If it is pure or the humus content of the soil is low, exchange capacity is very low.

The sequence of atomic planes is:



Because of internal charges balance, the crystals are unable to attract external cations, except by the negative charges of terminal oxygen ions on the lattice edges.

Muscovite, KAl<sub>3</sub> Si<sub>2</sub> O<sub>10</sub> (OH,F)<sub>2</sub> -- The atomic planes order are as follows:



As the framework of lattice shows, the planes electrically are out of balance by two negative charges, but the two positive charges of K neutralizes them. According to Pauling (37) the K-ion share the charges between adjacent layers, thus binding them together. In this case because of strong bond, the entering of H<sub>2</sub>O between the lattice layers is almost impossible, and this is the reason why crystals do not expand in water.

Montmorillonite,  $\text{Na Al}_5 \text{Mg Si}_{12} \text{O}_{30} (\text{OH})_6$  -- This clay as shown by X-ray analysis is very similar to pyrophyllite and muscovite, although similar in some features it differs from them by some very important characteristics such as exchange capacity of this clay is higher; water can pass in between lattice layers as a result causing the crystals to expand like an accordion (23); the crystals of this clay are thinner and are found being smaller irregular-shaped plates. The principle of isomorphism is applied to this type of clay. Among different methods for calculating the distribution of ions in lattice position, is the method proposed by Marshall (33). It was suggested by several soil scientists, that  $\text{Fe}^{+2}$  or  $\text{Fe}^{+3}$  and several other elements may proxy for  $\text{Al}^{+3}$  in octahedral; also limited amounts of  $\text{Al}^{+3}$  may proxy for  $\text{Si}^{+4}$  in tetrahedral position. It was found by means of different tests this formula does not represent or show the average of the samples of the clay. The excess negative charges of the clay has been found by so many investigators to vary at least twofold, but never equals much more than half of charges of muscovite which is one charge per 12 oxygenatoms. The average of negative charges of montmorillonite clay is suggested to be about  $1/3$  of muscovite or 0.33 per 12 oxygen. The cation exchange capacity of montmorillonite is very high so that it is not comparable. Ross and Hendricks (41) by calculating samples from many sources came to the conclusion that Al in the tetrahedral is limited and is less than one ion per 5 unit cells, so it is believed that the cation exchange property of this mineral is due largely to high amount of negative charges in the octahedral layer of the lattice, as shown below:

Si-tetrahedra	(90 <sup>-2</sup>	-18)	
	(6 Si <sup>+4</sup>	+24)	
Al, Mg-octahedra	(60 <sup>-2</sup> , 3(OH) <sup>-1</sup>	-15)	Charges
	(5Al <sup>+3</sup> , 1 Mg <sup>+2</sup>	+17)	
	(60 <sup>-2</sup> , 3(OH) <sup>-1</sup>	-15)	= (
	(6 Si <sup>+4</sup>	+24)	
Si-tetrahedra	(90 <sup>-2</sup>	-18)	
interlayer	Na <sup>+1</sup>	+1	

### ROLE OF ORGANIC MATTER

It is important to remember that the organic matter has a very important role in exchange cation reactions, and humus plays a significant part which because of lack of evidence and lack of knowledge its role is not very clear. According to almost all agriculturalists and soil investigators both scientist and practical, the organic matter and humic acid have very important roles in soil cation exchange, but the way of acting and the different reactions are not clear.

### THE PHYSICAL PROPERTIES OF SOIL RELATED TO EXCHANGEABLE CATIONS

The particle size, texture and combination order of the particle, structure are responsible for physical properties of soils. Difference in physical properties between a sand and a clay soil is the result of coarse and fine particles, and the arrangement of these particles. The very important difference between these two soil classes is in the amount and the

nature of the clay material. Sokolowski (44) in 1926, has stated that the physical properties of soils are controlled almost entirely by the colloidal material, which from knowledge of today is almost accepted. Considering the complex-physical composition of the soil, the different physical phenomena such as water holding capacity, water absorption, heat of wetting, plasticity, flocculation and deflocculation observed in the soil are not only the result of amount but may be the result of amount and nature of colloids: "The colloidal material may be present as discrete particles or as coatings around the larger soil grains. The physical phenomena are perhaps dependent upon the state in which these colloids exist. They may be present in the gel or sol form (3)." According to Baouyogou (4), nature of their respective surfaces upon which their relative chemical or physical activities depend may be different.

As a matter of fact, if the nature of colloidal or clay plays an important part in properties of soil conditions, one is expected to see differences in the behavior and activities of soil clays as a result of specific cations that probably can be found in replaceable compounds. According to Hissink (21), "There is undeniable relationship between the structure of the soil and the relative proportion of the adsorbed bases. As Na comes into the evidence soil structure deteriorates." Gedroiz (13) stated that, "The degree of colloiddality of any soil depends on the state of saturation of the soil and on the nature of the exchangeable bases." Sharp in 1916 (43) mentioned that, "Substitution of Na for Ca, Mg and other bases in the silicate complex or the direct addition of Na to such a complex results in the formation of new jelly-like colloids, capable of becoming highly dispersed when in contact with water." Kelley and Brown in 1925 (25) showed that soils saturated with Na are sticky when wet and harsh when dry.

Calcium salts, on the other hand, produces a relatively porous soil. Bayer (3), through different experiments and careful review of literature shows there is a relationship that exists between the exchange cations on the soil-absorbing complex and its physical properties.

The following results also were obtained from the experiments made by Bayer.

1. The Ca-ion produced no significant effect on the moisture equivalent, hygroscopic coefficient, and on the heat of wetting. It had a marked flocculating action on soils containing a high percentage of clay. It had a tendency to increase the plasticity number of the soil.
2. K-ion produced no significant change in the moisture equivalent value. It decreased the hygroscopic coefficient as well as the heat of wetting. It had a deflocculating effect on the soil suspension, and it lowered the plasticity number of all the soils.
3. The H-ion showed no effect on the moisture equivalent, hygroscopic coefficient, and heat of wetting. It caused a decrease in the state of flocculation of the soil suspensions. In soils highly saturated with bases it decreased the plasticity number. The plasticity number was increased in soils with a low degree of saturation.
4. The Mg-ion showed no marked effect on the moisture equivalent, hygroscopic coefficient, or heat of wetting. It decreased with one exception, the state of flocculation. It had a tendency to increase the plasticity number.
5. Mn-ion produced no significant effect on the moisture equivalent, hygroscopic coefficient and heat of wetting. It produced a strong flocculating action below the neutral point and a little tendency



to increase the plasticity number.

6. The Na-ion increased the moisture equivalent, due to the highly puddled condition of the soil. It decreased the hygroscopic coefficient as determined over 30%  $\text{H}_2\text{SO}_4$  as well as the heat of wetting. It had no pronounced effect on the hygroscopic coefficient with 2% acid. It caused a deflocculation of the soil suspensions. It increased the plasticity number of the soil by lowering the lower plastic limit.

Kelley (26) concludes that, most soils are granular when Ca-saturated; tilth of this soil is favorable, except when the clay content is excessive. Soils containing exchangeable Na-ions tend to be dispersed, they are relatively impermeable to water and the tilth of these soils are almost contrast of Ca-saturated. The very remarked contrast between Na-saturated and Ca-saturated clay is the large difference in their settling volumes. In case of saturating the exchange material with Na-ion, as shown by Gedroiz (14) in 1924, the amount of finest-sized particles as found through mechanical analysis, was greatly increased. He found that substantial part of the silt and fine sand particles was broken down by Na-saturation into ultra-fine particles. Ca-ions seem to bind the fine-sized particles into aggregates, whereas Na-ions cause dispersion.

Under the title of alkali soils more information will be given about Sodium clay.

### III PART

#### ALKALI SOILS

Any sufficient quantities of water soluble accumulated salts in the soil that is injurious to plant growth is called "alkali." The origin, and how or why this term, alkali in referring to soluble salts accumulation is not known. It might be suggested in two ways. (1) In previous time, or even now in some countries, from burning of native bushes such as grease wood, cedars, or pines, of these salty areas they make their necessary caustic soda for soap making, and because of very similarity between these ashes and surface soil salt deposits, it might be the reason of using this term for these salty areas. (2) Another suggestion (45) is that this term may have been given first by the hunters or travelers of these areas. Because of scarcity of water in these salty, dry and warm areas, the wind carrying salts was causing or injuring the thirsty throats and parched mouths similar to caustic of soda.

Because of unavailability to any references about the data of the first scientific investigation of alkali in other countries, the writer prefers to have a few words about its scientific development only in the United States.

Perhaps the first scientific investigation in the United States was made by Dr. Edward Palmer in 1870, (45). Eastern India in 1876, organized a committee to investigate the reasons of increasing of the injurious salt "reh." But important development of this problem started in 1874 in California when Hilgard got his association with the California University. For the immediate source of the alkali Hilgard reported that water, when it rises

from below and evaporates at the surface salts accumulate at the soil surface.

The classification of the alkali soils also is made by Hilgard, who mentioned two different classes, white and black alkali. All salts are more or less white and they give a white color to soil, so it is called white alkali. Except the sodium carbonate which dissolves organic matter from the soil and produces a black color, thus gets the name black alkali. In some similar ways the nitrates cause a brown color in the soil (10).

### SOURCES OF SOLUBLE SALTS

The soluble salts of alkali soils consist of various proportion of calcium, sodium and magnesium cations, and the sulphate and chloride anions. The cation, potassium, is in minor amount as are carbonates, bicarbonate and nitrate anions. The direct sources of these soluble salts are the parent material or primary minerals found in soil. During the chemical weathering of earth, or during the soil formation processes, gradually these salts were formed. Carbon dioxide, whether of biological or atmospheric origin, is a very active chemical agent and acts upon the cations to make carbonates. The pH value of solution is a good measure of existence of carbonates or bicarbonates. The carbonate exists at pH 9.5 or even higher. While the carbonate is the most injurious salt in soil, there are places where excess nitrates are even more injurious than carbonates. Until now the origin of excess nitrate is not satisfactorily explained (10).

As mentioned before, the first and direct source of all soluble salts is the weathered primary minerals, but in most cases the saline soils occur in those places that receive these salts from the water which carry them while passing from place to place. By two ways, ocean may become a source

of salt; first by laying down of marine deposits in early geological period and secondly by making saline the sea margin soils. However, it is necessary to mention that the most direct source of salts is water. Either the ground or surface water carries the water soluble salts of soils that come in contact with water. The water in irrigation areas act as a source of salts. In the case of flooding or rising of ground water to the surface which is a natural process, the water adds certain amount of salt to the soil.

### SOIL SALINIZATION

As a geological process the rocks by the function of weathering break down in to fine particles known as soil. The minerals composing these rocks through these processes and thus, chemical changes that occur, quantities of soluble salts will be set free. Because of the solubility of these salts in the water, they will be carried and transported by the movement of water, and they may become deposited in the soil or on its surface when the water evaporates.

Depending on the amount of rainfall in humid areas the salts present in the soil originate or are formed by the weathering process, and are carried downward into the ocean. The contrary is true in arid or semi arid areas, where water leaching process is not sufficient to leach out the salts. As a general rule, in regions having less than 20 inches annual rainfall (9) there will be alkali in the soils. The occurrence of alkali due to the evaporation of sea water bodies, that have been or might be, is an exceptional case and it may be done by various causes.

It was discussed that alkali is readily soluble in the water and only remains in dry soil. But as it dissolves in the water it soaks into the

soil, then through the evaporation it returns back to the surface.

The phenomena of the soil becoming alkali after several years of irrigation have been regarded by many farmers. The general action in this case first of all is that the irrigation water as it penetrates to the deep subsoil dissolves the soluble accumulated salts held there, and through the surface evaporation carries them to the surface, depositing them as water itself evaporates. Sometimes due to the irrigation water that contains the soluble salts, the water carries the salt from one area to another.

The essential and more effective reason for the soil salinization might be said is the poor drainage condition of the soil. The poor drainage condition might be due to one of the following factors or in some cases to both of them: the presence of high water table or low permeability of the soil. The low soil permeability reduces the water downward movement sometimes to an indefinite degree thus causing poor drainage. Due to the unfavorable soil texture, structure, clay pan, silica hardpan, or a caliche layer, the low permeability takes place. The presence of an impermeable soil layer in Hungary as De Sigmond states (10) is due to the salinization of soils.

#### SOIL ALKALIZATION

The soil colloid (clay and organic matter) properties in case of exchange bases according to intensive information given in second part of this paper is well known. Depending on the amount of clay and organic matter present in soil, each soil has a definite base exchange capacity. Because of free interchange of soil adsorbed and solution cations, the proportion of various soil solution cations, determine in some degree the relative amount of each cation held by colloids. The calcium and magnesium are the two

principal cations of soil solution. But when normal soils are in contact with excess soluble salts, sodium frequently becomes the dominant cation. In such case a part of the calcium and magnesium are replaced by sodium. The process through which the amount of sodium in soil solution or colloid content increases has been termed alkalization. In the case of concentration of soil solution through water absorption of plants or evaporation, the solubility of calcium sulphate and calcium and magnesium carbonate decrease and to some extent might be precipitated out of solution, and at the same time causing a very remarkable increase in relative proportion of sodium, or in other words the sodium may become the dominant cation in soil solution.

Calcium and magnesium are the two principle cations adsorbed by soil colloids, and this is a real agricultural fortunate, because if sodium was in their place, we could say the farming difficulties would be beyond any expecting degrees. However, an appreciable amount of sodium would be adsorbed by soil colloids, where more than half of soluble cations is sodium. (5)

According to Kovda (29), the salinity of ground water seldom exceeds 100-150 grams of salt per liter of water even in very strong salinized soils. He states, that by some other powerful factors the salt concentration in soil solution may reach 300-400 grams per liter. The high salinity of soil solution as compared with ground water is greatly due to the high temperature of the soils upper horizons. Amount of different soil solution salts, varies with degree of solution concentration. As the concentration increases, the less soluble compounds such as iron oxides, silica and lime begin to precipitate. Sesquioxides, silica and lime follow the gypsum and precipitate in the deeper horizons of soils, whereas salts such as  $\text{Mg SO}_4$ ,  $\text{NaCl}$  or even  $\text{Na}_2\text{SO}_4$  may be carried to the surface of soil. He emphasizes that  $\text{NaCl}$  will not precipitate except when content of solution reaches 300-350 grams per

liter. Lime, gypsum, and to some extent sodium sulphate precipitate in an irreversible state, whereas the precipitation of  $\text{NaCl}$  and  $\text{MgCl}_2$  may pass into solution during the rainy period. When the fixed accumulation of sesquioxides, silica and  $\text{CaCO}_3$ ,  $\text{CaMg}(\text{CO}_3)_2$  and  $\text{CaSO}_4$  occur in soil horizons, there will be a concentration of  $\text{NaCl}$ ,  $\text{MgCl}_2$ ,  $\text{MgSO}_4$  and some  $\text{Na}_2\text{SO}_4$  in soil solution and ground water. In his discussion Kovda points out that an accumulation of lime and gypsum individually or by the silica and sesquioxides combination develop hardpan. His idea about the salinization development is that a certain geomorphic and topographic condition cause a high ground water table, and there is a high evaporation ratio over leaching.

Previously, the manner that the sodium is adsorbed by soil colloids and acts as an exchangeable cation was discussed. The injurious characteristics of sodium carbonate also was somewhat reviewed. Now it is necessary to show the relationship of these two different sodium aspects. As a general acceptance, when due to the concentration of solution  $\text{Ca}$  and  $\text{Mg}$ , precipitate out, because of large amount of water and an occasional freedom, some of the exchanged sodium hydrolyses. Because of presence of the  $\text{H}_2\text{CO}_3$ , one of the chemical active agents in the water, and due to the chemical reaction between these two substances, sodium carbonate is made.

#### CHARACTERISTICS OF SALINE AND ALKALI SOILS

In order to get a possible available description of saline soils and their relative characteristics, it is necessary to follow a classification. The following one seems to be one of the best of the recent classification (10).

Because of two different types of alkalinity, and due to their different

characteristics, there are ordinarily two different standard measurements used for clarifying the discussion.

1. Saline Soils -- In these soils the exchangeable sodium percentage is less than 15, and electrical conductivity is more than 4 millimhos/cm. (10) In this white alkali or as Russian's "Solon-Chaks" pH is less than 8.5. These soils, through an adequate drainage establishment, and leaching the salts by excess water become normal soil. Depending upon the kind and amount of the salts, the chemical characteristics of the soils differ one from another. In this class of salty soils seldom does the amount of sodium exceed more than half of the soluble salts. However the amount of adsorbed sodium in this class is very low. The K-cation is in minor stage. The important anions are, chloride, sulphate, and occasionally nitrates. Because of very least amount of exchangeable sodium in these soils, they have a favorable structure and are readily permeable for water and air intake.
2. Saline - Alkali soils. -- As the term means, in this class of soils, exchangeable sodium is more than above class of soils, and soils are saturated by soluble salts and there is somewhat an appreciable amount of exchangeable sodium. Conductivity is higher than 4 millimhos/cm. The pH seldom is higher than 8.5 when excess salts are present. The appearance of these soils and perhaps the properties are similar to those of saline soils. In the case of removing

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\* Mho(mo), is the reversed word of "ohm" and is a unit of electrical conductivity of a body whose resistance is one ohm. "Ohm" is the unit of resistance; the resistance of a conductor in which one volt produces a current of one ampere.

Ampere = current strength, volt = unit of electromotive.



the excess soluble salts, as the concentration of soil solution is lowered, some of the exchangeable sodium might be hydrolysed to form  $\text{NaOH}$ , which by contact of water containing carbonic acid will form  $\text{Na}_2\text{CO}_3$ . In this case the soil becomes very strongly alkaline, and pH is higher than 8.5, and the soil structure comes very unfavorable for plant growth (hard for entry of water and hard for good tillage). If the soluble salts return back the pH lowers and colloids come to a flocculated position, even though this kind of soil continuously is a problem before the exchangeable sodium and excess salts are leached.

3. Non-saline - alkali soils. --- The pH values range between 8.5-10. The conductivity is less than 4 milli mhos/cm. The percentage of exchangeable sodium is greater than 15. The occurrence of this kind of soil is mostly in small irregular areas in arid or semiarid regions, and is called "Slick spots." Leaching of excess soluble salts leads to the development of the black alkali soils except in the presence of gypsum or other soluble calcium sources. As mentioned before, the sodium carbonate dissolves the soil organic matter, therefore the organic matter is highly dispersed and distributed over the soil particles, thereby darkening the color. In the case of high organic matter content in the soil, there will be approximately a development of black color, hence the term "black alkali."

If there is sufficient time, the sodium saturated clay, because of being highly dispersed, migrates through the soil, downward where in lower levels it accumulates. This is the situation to be found in some areas that although soil is completely alkali, its appearance is coarse and friable.

Unfortunately this coarse layer is not thicker than a few inches, below which the dispersed clay colloids develop a dense and low permeable layer by column or prismatic structure (10). As a common result the alkali soils may develop by irrigation. In this case because of lack of enough time for the development of above structure the soil tends to be low permeable and hard to till. Although the relatively amount of soluble salts in the soil solution is very low it consists of the anions as chloride, sulphate, and bicarbonate and a small amount of normal carbonate. In these alkali soils, because of high pH value, and presence of the normal carbonate, magnesium and calcium precipitate, leaving in the solution of this soil only traces of two mentioned cations.

In some alkali soils (nonsaline alkali soils) an appreciable amount of potassium as an exchangeable or soluble salt is found. The properties of this kind of alkali soil is not well studied yet. According to pH value and dispersion degree, these properties might be something between sodium and calcium.

The pH value, in spite of soil being alkali, sometimes especially in the surface soil, may be below 6; this is due to exchangeable hydrogen and absence of lime in the soil.

#### EFFECT OF ALKALI ON THE CROPS

The alkali salts in soils have a toxic influence upon the crops when they are in a considerable amount. The quantity and quality of these salts have different influence. Although this affect differs by the kind of salts, even though it varies with the kind of plants. There are some plants resistant to alkali soils. Among these plants are some crops as, some varieties of barley, sorghum, and some sugar beets that are resistant, while

corn and wheat are very sensitive. (9) It is still a practical cropping method in Iran, that after washing the salt saturated soil with excess water, barley and sorghum are planted. But when the drainage channels are developed in a necessary position, they give winter flood water to the land and keep the land full of water (several or few inches) for several weeks, or make it possible for the water to move on the land for several weeks. These lands are available for spring wheat where they may support a very great yield.

Different salts have different influence on the different plants. Most times the presence of 0.2 or even 0.1 per cent salt in water may cause an osmotic pressure of about 10-15 atmospheres in soil solution, (10) which for some plants as alfalfa will stop the growing because of being unable to take up the soil moisture. But, because of amount of moisture, it is very difficult to determine the exact total amount of salts that any given crop can withstand. In a heavily incrustated soil with alkali, a plant might be grown or a seed germinate. The reason is that the rain or irrigation waters may leach down the salts a few inches and thus enable the growth and in some cases the roots for water and food uptake, penetrate deeper than accumulation layer of alkali. In this case the plant may not be affected by alkali at all.

One of the affective cases in alkali soils is retarding germination, but usually it does not affect the vitality. If the condition, by the leaching of salts below the seed level, is changed the seed will germinate (9). The exceptional case is when we have black alkali or sodium carbonate, which can decompose the seed or plant, it might even destroy completely the hard outer bark of mature trees.

According to Hilgard (20), the injured plants in alkali soils are damaged near the base of the trunk, or root crown, very rarely at any

considerable depth in the soil itself. In the case of green herbaceous stems, the bark is found to have changed to a brownish tinge for half an inch or more so as to be soft and easily peeled off. The rough bark of trees change to a dark almost black tint, and the green layer underneath has, as in the case of a herbaceous stem, been turned brown color to some extent. Hilgard states, "In either case the plant has been practically 'girdled' the effect being aggravated by the diseased sap poisoning more or less the whole stem and roots. The plant may not die, but certainly is unprofitable to the grower."

According to Harris (17), the soils which contain more than 0.5 per cent of soluble salts, where the larger part is in form of chlorides, carbonates, or nitrates and one per cent where sulphate predominates are without reclamation and are unsuitable for crop production. Of course, many conditions may modify these figures.

#### EFFECT OF SODIC CARBONATE

On the previous pages it has been reviewed that sodium carbonate is very injurious to plants. As to its amount and degree of injury, and especially the way that sodium carbonate injures the plants, and because of its necessity and important interest, it is necessary to have more studies on it.

According to Headen (18), the sodium carbonate is injurious in rather small amounts. He states that, contrary to nitrates, that there is no idea about their amount, when they are dangerous for plants, in case of sodium carbonate, there is a definite idea that how much of this salt present in the soil will be injurious for plants. The amount shown is 0.04 per cent of soil for wheat, while beet plants will endure it up to 0.05 per cent. But it is

doubtful that beet in this soil containing 0.05 per cent of soil sodium carbonate can live and produce beets. These percentages when put in pounds and compared by acre foot soil, 1,600 or 2,000 pounds of  $\text{Na}_2\text{CO}_3$  in 4,000,000 pounds of soil. If concentrated in upper part of soil even less than 1,600 pounds will cause damage. A smaller amount of sodium carbonate may cause the soil to bake very badly, which will interfere with the growing of crops. He also emphasizes that even the smallest amount of  $\text{Na}_2\text{CO}_3$  that may cause the soils to bake is not known. The sandy soil, that was taken to the laboratory for studying, had become so hard and firm that it was impossible to break it by one's finger and it only contained 0.017 per cent sodium carbonate.

To the ordinary observer, as Breazeale and Burgess (5) state, the presence of black alkali in soils is indicated in three ways, first by the toxic effect upon the crop, second by the dissolving of organic matter in the soil and formation of soluble black substances, the third by effecting upon soil colloids and dispersing or flocculating them, which in turn makes the soil impermeable to water. They state that in a great majority of soils affected by black alkali, the amount of sodium carbonate is not sufficient to be toxic to plants. When there are 800 parts per million of  $\text{Na}_2\text{CO}_3$  in solution which is a concentration higher than one might find in black alkali solutions, wheat plants will endure. Soils, when digested with large amount of water for ordinary analysis, may show a relatively high amount of black alkali, but really the percentage is very small in field conditions. The reason is that by large amount of water sodium gradually hydrolyses. The hydrolysed sodium is from the soil zeolites or sodium aluminum silicates.

Many soils become dispersed where the soil containing black alkali is not enough to give the soil black color. A very small amount of sodium carbonate may cause the soil to be dispersed, when this condition appears in

the top soil or subsoil it is one of the best indications of the presence of sodium carbonate.

The dispersed soils, depending on the quantity of sodium carbonate, amount of soil colloids and other conditions make layers at different levels, in the soil which vary in thickness from a few inches to the entire depth, or these layers appear in the subsoil at different levels. Sometimes even the thickness of the dispersed layer is a few inches, but they tend to close out the air from the lower levels of the root zones, this action is in addition to low permeability or impermeability of soils to take the water. When aeration of soils is excluded, the action of aerobic bacteria is stopped. During the organic matter decomposition, aerobic bacteria split-off carbon dioxide, which has an important influence upon crop production. Only a dispersing or deflocculating effect of black alkali according to Breazeal is responsible directly or indirectly for about two thirds of the injury that may be caused by it.

The injurious salts, according to their harmfulness order, may be put in the following arrangement:  $\text{Na}_2\text{CO}_3$ ,  $\text{MgCl}_2$ ,  $\text{MgSO}_4$ ,  $\text{NaCl}$ , and  $\text{Na}_2\text{SO}_4$ . (9)

## THE APPEARANCE CHARACTERISTICS OF CROPS

### GROWN IN ALKALI SOILS

Because of salts, plants growing in alkali soils have a characteristic appearance. The important and common features are BARREN SPOTS which may be due to bad leveling of the soil, unavailability of the irrigation water to move to the high points or a salinity index in which the concentration of salts in those bare spots have prevented the germination. Secondly there is considerable variability in size of plants. This irregularity of vege-

tation is somewhat used as an index of the concentration of salts. Third point is the deep blue-green coloration of plants. Through the low fertility there is a change on the color of plant, but this is usually yellowish-green (10). The cause of the bluish appearance of the plants growing on saline soils is due to a heavy waxy coating on the surface of the leaves.

#### PLANTS AS AN INDICATOR

It is almost impossible to know, just by looking, how serious a soil is affected by alkali. Gypsum or calcium chloride when present in soil may have the same appearance on the soil surface as alkali, and as we know they are not injurious to plant growth. Besides the chemical analysis, the native vegetation is one of the best indicators. Each alkali soil according to its salt quantity and quality grows special kinds of plants. Between so many workers of this subject perhaps the quantitative study of Kearney et al (27) is one of the best. In their study they have determined the moisture equivalent, wilting coefficient, and salt content for six different plants in the Tooele Valley of Utah. According to their study each alkali soil supports some different plant which can use as an estimating measure for crop production in that soil. The land, for example, growing sagebrush, is capable for crop production with or even without irrigation. The land supporting greasewood-shadscale, for making it available for crop production, the excess salt of land should be leached out with irrigation water. According to Harris, such plants as greasewood, saltweed, and salt grass show very high and dangerous amount of salts. He emphasizes that the chemical analysis of the soil to a depth of at least six feet with native vegetation together makes a very excellent understanding of degree of soil salt content.

IV PART  
RECLAMATION OF ALKALI SOILS  
A GENERAL REVIEW

The alkali soils, as a general rule, according to the results obtained from a very intensive experimental and scientific information given in the previous part, are injurious for plant growth. The harmfulness of the salts present in these soils, depending on their quality and quantity, changes from one to another. Soils are almost saturated by several salts, and somehow, one may not find any single salt saturated soil. A single soil may have different physical and chemical characteristics due to the presence of different salts. For example, in the case of saline-alkali soils, the low permeability is due to the exchangeable sodium, where toxicity is caused by soluble salts. Sometimes the presence of different salts together in a soil may prevent the formation of some more injurious conditions, such as  $\text{CaCl}_2$  when present in solution of sodium salts, if it is in a sufficient amount, will prevent the adsorption of sodium by soil colloids.

Because of different influencing factors in the alkali soils and presence of different salts, their reclamation is and also becomes very difficult. Although the necessary practical reclamation methods are not developed, unluckily because of different conditions, each or different alkali soils may need a peculiar reclamation as well as a recommendation.

In the previous part it was clarified that the soils may become soluble salt saturated, or exchangeable sodium, or both. Because these salts have different characteristics, the reclamation of alkali soils depends on the



kind of salt present. The alkali soil problem, even though it looks to be clear and very easy to solve is a difficult one. Even though diagnostic methods are not developed there are a lot of influencing factors in the soil that it is almost impossible to recognize most of them. One needs to study all possible factors present for a special land or area which may not be worth it. Sometimes, if the factors that cause the injurious conditions are recognized, even though fighting by them and preventing their influence by practical methods that are available is somewhat very difficult or almost impossible. For example, a high ground water table, or a hard subsoil condition might be changed but is a very hard and difficult problem.

It should be brought to mind that in spite of difficulties in alkali soils reclamation, the practical methods that have been practiced for a very long time with some recent modifications, in most cases give successful results. By the development of soil science, it is well known that the water carries the soluble salts and spreads them in new areas or evaporation brings them to the surface from lower layers, or ground water causes the accumulation of salts. This is the point that we oppose by two different problems, first to prevent the accumulation of salts in the soil, second how to save the diseased soils. Now we want to discuss these two problems individually.

#### PREVENTING THE ACCUMULATION OF THE SALTS

By two different means the accumulation of the salts in a soil may take place. The first and important active factor is the irrigation water which contains the different soluble salts and carries them from one place to another place. The second effective cause is the drainage condition of the

soils. If the water table is below the capillary reach, and if the infiltration rate of the soil exceeds the evaporation rate, the accumulation of the salts in an injurious and effective position will probably not occur.

### THE IRRIGATION WATER

Ordinarily the waters are divided into two main groups: 1 - Well water or underground water, 2 - Soft water. Well water, depending upon the type of material that this water percolates, contains different proportion of minerals. If the water contained minerals, are calcium and magnesium salts, the water is known as hard water and common soaps hardly form suds in it. This water from an agricultural irrigation standpoint is the good type except when the concentration of those salts become high so as to be toxic to plants.

The soft water may have two different sources; one, the rain water which contains the runoff and snowmelt or excessive rains which could not be in contact very much by soils, contains a few minerals. The second is the water containing the sodium salts. The low concentration of these salts may cause the soil structure to change, thus to lower the permeability. When the accumulation of these salts is to some extent high, it may become toxic for plant growth. With continued use of these waters even the salt content may not be too high, the surface of the soil will seal and prevent the deep penetration of water, which in returning back, may cause also a high concentration of salts. To omit this condition, gypsum is used as a remedy (1).

The following data is the result of a study in California University Agriculture Experiment Station, (1) which might be very helpful to clarify the above point. This study was made by low salt content water, but most salts in form of sodium, (90-92) per cent, and area of extremely low permeable.

Field No.	No. of Tests Made	Treat- ment	Amount of gypsum added lbs. per acre ft.	per cent Sodium	Infiltration	
					gallons per minute	per cent increase
A	10	Check	0	92	2.59	65
		Treated	660	57	4.26	
124	17	Check	0	91	4.58	70
		Treated	365	67	7.79	
124	11	Check	0	91	7.59	40
		Treated	191	77	10.63	
126	5	Check	0	92	5.55	33
		Treated	187	75	7.36	
122	19	Check	0	90	3.76	168
		Treated	297	60	10.08	
123	4	Check	0	92	2.66	83
		Treated	572	50	4.87	

The following experiment made by Gunnar Hallgren (16), explains how different salts by varying quantities influence on the soil when they are carried on by applied water. This test was run in a laboratory on a 4 Cm. columns of a sandy soil, a clay loam and a clay muck. The irrigation water was the same as used in ordinary irrigation locations and was from the Baltic Sea. The salt content of this water was NaCl - 0.39%, MgCl<sub>2</sub> - 0.05%, MgSO<sub>4</sub> - 0.03%, CaSO<sub>4</sub> - 0.02% and KCl - 0.01%. Three different amounts of salt solution 25, 50, 75 mm were applied, followed by enough distilled water to bring the total amount to 200 mm. The obtained results had shown that : the permeability increased until the soil was saturated with salt water then remained constant until flushed out with the distilled water when it became less permeable than it was originally. As Hallgren states, the soil colloids seemed to have been first precipitated electrostatically and then redispersed but partially saturated with sodium ions instead of calcium. He had recognized all soils swelled somewhat, and colloids washed down. Loss of calcium

was observed in all cases, one third by the largest application. Easily soluble potassium as pointed out in this experiment tended to increase, but no change in the amount of available  $P_2O_5$ .

Another experiment was made by Reitemeier and Christiansen (40) by an irrigation water with a high sodium content. In this experiment the infiltration rate and permeability of a soil was checked upon the influence of organic matter, gypsum, and drying. The results were as follows:

The addition of gypsum or chopped alfalfa to a fine sandy loam soil approximately doubled the infiltration rate of a high sodium water content. Prolonged drying between times of infiltration was even more effective in increasing the infiltration rate.

#### DRAINAGE

Establishment of an adequate drainage system is the first principle in any prevention or reclamation program. The ground water table must be maintained in a depth below the soil surface, so far enough to minimize the upward movement of water. Also a depth of 6-10 feet is generally desirable, but there are so many factors that may cause the need of more deeper water tables. In the case of establishing a good drainage system in order to decrease the ground water level to a depth non-effective to soil-salt accumulation, several points should be recognized. The cutting off of seepage water from higher land, from leaky canals and laterals. It may be that cutting off the seepage of canals and laterals, the prevention of water loss will be worth as much as preventing the injury of good lands by rising of water table. Another important problem in the water table and drainage condition that is very considerable, is the method of application of water, in other words the proper use of irrigation water. An excessive use of

water is as much responsible for high water tables generally as any other single factor. Any amount of water applied over and above the soil moisture capacity to a depth that the root of growing plants arrive, must be regarded as being lost and at the same time as a help directed toward the rise of the ground water level. Water must be applied to provide the necessary or required amount of moisture for crop growth, and at the same time allow enough water to pass through the soil to leach out the excess salts. But through excessive leaching, plant nutrients, especially nitrates, may be removed from the soil (10). Over-use of water, as mentioned above, adds to drainage problem and raises the water table. According to many very important points, the irrigation methods should be maintained in a favorable condition to fit almost all these points.

#### THE POSSIBLE PRACTICAL METHODS OF RECLAMATION

For development of any remedial method it is necessary to develop diagnostic methods. Still, there exist a lot of dark points in the alkali soil problem itself or the controlling of factors influencing their development. Therefore, there is no developed method practical and sufficient for all alkali soil reclamation.

For the reclamation of alkali soils, because they consist of different types it is better to talk under their classification order.

Saline, or white alkali soils -- The saline soils, because they are water soluble salt saturated, can be reclaimed by simple leaching and providing a good drainage system.

The satisfactory results can be produced when enough excess water for

washing of these salty areas is available, and the infiltration rate of soil is somewhat higher than its evaporation rate; which may cause the turn back of dissolved salts; and the water table is deep enough.

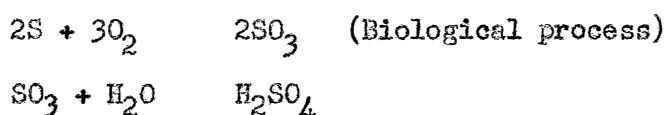
Saline - alkali soils -- These soils contain both soluble salts and exchangeable sodium, therefore their reclamation consists of both methods practiced in case of soluble salts, and exchangeable sodium. The reclamation of exchangeable sodium saturated soil will be discussed in the case of alkali soils. Here it is interesting to bring to mind that in the reclamation case of these soils, one might first wash the soluble salts and then practice the alkali soil reclamation method or in contrary. From the efficiency standpoint it is better to leach the soluble salts and then apply the necessary amendments. But sometimes it may be that the permeability of these soils are too low, then it is necessary to apply the amendment before leaching the soluble salts, in order to increase the infiltration rate.

Non saline - alkali soils -- The soluble salt content of these soils are relatively low, so that they are not effective for plant growth. As in the case of saline-alkali soils (10) nearly all of soluble salts are sodium constituents. The exchangeable sodium is a water insoluble element, which by excess water may hydrolyse and later on by reaction of water,  $H_2CO_3$  may form sodium carbonate which is very dangerous for plants.

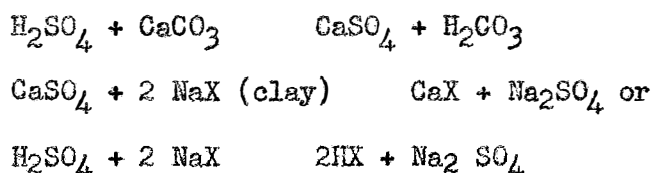
The reclamation of these soils is based upon the idea to apply some chemical to these soils in order to replace the exchangeable sodium where the sodium may form a soluble constituent. Calcium is one of the best elements that can produce satisfactory results if used for reclaiming of these soils. Calcium, according to the soil adsorption power, is much more adsorptive than other elements. Its accumulation, except in a very high order, will give a good physical condition to the soil, and also the calcium

is used as plant nutrient and soil corrector. Its preparation is almost available and to some extent less expensive. Although the solubility of calcium chloride is very high, therefore its reaction in soil is very fast and satisfactory but because of its very high price the use of  $\text{CaCl}_2$  should be said to be almost impossible. Second to  $\text{CaCl}_2$  is gypsum, even it is not very soluble, but to some extent that it is soluble gives very satisfactory results. Besides gypsum other elements such as sulphur or iron sulphate, even sulfuric acid, have been tested. Also lime-stone which is an insoluble salt has been tried. The use of sulfuric acid, in the first hand because of its price and its handling, in the second hand in case of absence of  $\text{CaCO}_3$  it will make the soil acid, is not practical.

Sulfur has the same acid formation reaction in the soil. Its chemical equation which illustrates the manner that it acts is as follows:



If soil contains calcium carbonate it will act on it, producing  $\text{CaSO}_4$ , which will later replace the exchangeable sodium, if there is no calcium carbonate, the sulfuric acid directly will act upon the sodium clay by forming acid clay and sodium sulphate. The equation is:



Following the application of amendments, except in the case when sulfur is used, alkali soils should be leached. Leaching dissolves and carries the amendment downward and also removes the soluble sodium salts which form as a result of cation exchange. In the case of applying sulfur, leaching

should be delayed until sulfur oxidizes and forms gypsum, but, for oxidation of sulfur, the soil should be kept moist.

Gypsum is one of the important agricultural agents which may act in different ways. Because of its importance it might be interesting to give some more details. The experimental results gained from its application in alkali soils are in first range of satisfactory results.



## V PART

### GYPSUM

What is gypsum? - A hydrated calcium sulphate  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  is called gypsum or plaster of paris. It contains 18.6% sulfur, 23.2% calcium, and 20.9% water when it is almost pure (36). Naturally gypsum has two different forms, powder or small grains form called gypsite, and crystalline or rock form called gypsum. The purity of the last one is higher than the first one. Very fine ground minerals are satisfactory for agricultural uses. Gypsum is not very soluble in water but at ordinary temperature a saturated solution contains 0.2 per cent of gypsum which is 2 grams per liter.

Interesting thing is that in the presence of kitchen salt its solubility may increase over three times. The high solubility of gypsum is at  $100^\circ \text{F}$  and is lower either below or above  $100^\circ \text{F}$ . Another important characteristic of gypsum is its solubility at water\* boiling and water freezing temperature which is about the same.

#### HOW GYPSUM FOUND ITS WAY INTO AGRICULTURE.

##### A SHORT HISTORICAL REVIEW

When gypsum was first introduced into agriculture it was evaluated as the best fertilizer. In some localities the obtained results from the application of gypsum exceeded expected yields, so it was called a magic

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\* Water boils at  $212^\circ \text{F}$  and freezes at  $32^\circ \text{F}$ .

fertilizer. Even though gypsum has lost its general fertilizer value, it has another agricultural role in the alkali soil problems which may be no less important than the first one. Beside its very favorable influence in the alkali soils, gypsum has other important characteristics when applied to a soil.

According to Crocker (7), the fertilizer value of gypsum was discovered about the same time, during the second half of the eighteenth century, in Germany and France. From these countries spread to other ones, but early to America, and later to England.

The following statements, in 1808, were given to Agricultural Board of England in the U. S., by Dr. Forthergill.

In the year 1768, the reverend A. Meyer of the Canton of Berne, by a fortunate accident, discovered the fertilizer value of gypsum, and liberally disclosed the secret to neighboring farmers. To their great surprise, experiments soon convinced them of its efficacy, which they considered little short of magic. . . . From Germany it reached their German friends in Pennsylvania, where Judge Peters, after subjecting it . . . communicated to the public the result of his experiments.

The following quotation as mentioned by Crocker, is from the Syracuse Journal in 1872. It was an appendix to a book on gypsum fertilizer that was written under the request of the late General Washington by Judge Peters.

The exact date when gypsum or plaster of paris was found to be one of the best agencies that could be employed in promoting growth of grains and grasses is not known, but . . . discovery was accidental somewhere in France. Man engaged in working in alabaster found that the grass where they were accustomed to shake the dust from their clothing was of stouter growth than elsewhere, and rightfully attributed the cause to the dust which is now known as plaster of paris . . . It was introduced into the United States by Benjamin Franklin and first was used by him in his country on his farm near Philadelphia.

Gypsum, as the result obtained through the study of different publications, was looking in that period of time as a very important fertilizer. Following quotation from Ruffin Edmund, An essay on calcareous manures,

gives the best explanation of the value of gypsum.

I do not pretend to explain the mode of operation by which gypsum produces its almost magic benefits; it would be equally hopeless and ridiculous for one having so little knowledge of successful practice, to attempt an explanation, in which so many good chemists and agriculturalists both scientific and practical have completely failed . . . ." (42)

The following is another quotation from the preface of Benn's little book (7) which gives his almost emotional idea or belief in the high fertilizer value of gypsum:

Having been frequently requested by several of my friends and acquaintances as well as sundry persons from a distance to publish my experiences in farming generally, and more especially on the use of plaster of paris (the use of which has made my farm from that of being tired down or the natural soil entirely worn out, a rich and fruitful one); I have been induced to present them the following pamphlet. . . ."

#### MODIFICATION OF THE FERTILIZER

##### VALUE OF GYPSUM

Through the recent experiments and developed methods for analysing the plant nutrients, and plant contents, it has been found that sulfur is one of 13 plant nutrients and is one of the elements of plant protein and oil content. Calcium is very important in a soil as a corrector as well as a plant nutrient. The legumes need these two elements Sulfur and Calcium terrifically, so gypsum is one of the best sources. The increasing development of leguminous plants as the result of gypsum application will increase the nitrogen content of the soil, which will act upon other crops in the rotation. In another hand sulfur stimulates the activity of ammonifying and nitrofixing bacteria, and there by increases the availability of the nitrogen of the soil which influences the plant growth. Gypsum is also an excellent preserver of volatile nitrogen of manure especially liquid

manure as the urine. Also it will soften tight soils and maintain good soil structure.

## GYPSUM AS A SPECIFIC FOR BLACK ALKALI

The lack of necessary references made it somewhat impossible for the writer to get any idea about first pioneers, who reclaimed the alkali soils by gypsum application. In the United States the most important investigation and development on alkali soil problems was made by Hilgard, and he pioneered and probably originated the use of gypsum on alkali soils. First use was about 1880, in California (36), and still after about seventy years, gypsum is looking as the best soil corrector. According to the data of hundreds of soil experimental and investigator workers in every part of the world, the gypsum reclamation in the alkali soils gives satisfactory or sometimes excellent results. The exceptional cases that sometimes the obtained results are not satisfactory it should be remembered that the distinction of so many influencing factors in the soil is sometimes so difficult that it may cause a confusing of the factors or facts. For example, one of the cases that recently was discovered is that gypsum does not completely neutralize black alkali, but only partially neutralizes it. No matter how much gypsum was added to the soil the reaction will go so far and then stop. In this case something should be done in order to start again the reaction. By floody-irrigation and leaching it is possible to get the reaction started between gypsum and black alkali.

This point is really full of interest that by our advanced knowledge and developed methods we now recognize so many properties of black alkali

soil in its formation or influencing acts, still gypsum keeps its importance and fits almost to the new theories as well as the old ones. But another interesting thing is that in recent reclamation the use of gypsum, even in case of white alkali soils, is recommended. In spite the white alkali soils compose of different water soluble salts, but simply by leaching, sometimes the removing of salts does not come out. The reason is that when most salts are removed from the soil, the soil will freeze up, especially if the leaching water is low in salt content. The reclamation of gypsum in the white alkali will prevent this freezing up.

The reclamation of gypsum in black alkali soils has both a chemical and physical reaction. Chemically gypsum replaces the exchangeable sodium in the soil colloids by its calcium, where the  $\text{SO}_4$  composed by sodium forming  $\text{Na}_2\text{SO}_4$ , a soluble and least injurious salt. Physically gypsum will influence the soil structure making it favorable for plant growth. The presence of exchangeable sodium causes the soil to get a dispersed and gelatinlike structure, and also soil gets sticky when wet and very hard when dry, so hard that soils crack badly and tear the roots.

The following equations are supposed when gypsum is added to black alkali.



But what happens in the presence of  $\text{Na}_2\text{CO}_3$  if gypsum is added to black alkali soils. The new concept of black alkali soils is different from the old one. In the early days assumption was that only sodium carbonate is injurious and a trouble causer in black alkali, and so a recommendation was based on its amount and position. But now it is well understood that adsorbed sodium is a reserve supply of black alkali and even more serious than sodium

carbonate and also a source of sodium carbonate formation. So, according to new concept the reclamation methods are also somewhat changed. By former concept the equation for chemical reaction was the following:



In the new concept as described by the first above equation, the floody irrigation is so important as the application of gypsum. Because with the water, excess salts are removed, and as gypsum dissolves in water, it comes in contact with soil particles and the reaction takes place for displacing sodium.

According to McGeorge (36) in case of application it should be kept in mind that because the solubility of gypsum is 2,000 parts per million parts of water, in a heavy application only so much as the water can dissolve will have an immediate effect. Another important thing is to find out whether the problem in a land is to prevent or to reclaim.

According to diagnostic methods, reclamation needs good information on all soil phases such as: Soil salt content; because it may change by horizons, the sampling should be good; conductivity of extractions, kinds of salts and amounts, exchangeable cations, percentage of exchangeable sodium and soil exchange capacity, soil structure, water infiltration rate, soil pH, amount of carbonates and gypsum in soil (it might reduce the use of gypsum), the quality of irrigation water. Of course by so many difficulties in determining these different phases, especially by lack of developed methods in many cases, and affection of different factors, it is somewhat impossible today to make complete data from all phases and then give necessary recommendations.

In case of the management of alkali soils, the control of exchangeable sodium is very important, but improving the structure is not less important.

Because the excess use of gypsum will not have any injurious effect action on plants, therefore, the use of more of it, if economical conditions permit, will be profitable. However, in case of black alkali, at least 2,000 pounds per acre is advisable where in old times, 20 tons per acre were mostly recommended. Anyway after removing excess exchangeable sodium, for building good structure, because of root action, planting of grass, freezing and thawing, wetting and drying, application of organic matter and so developing microbial activities are believed to promote the development of good soil structure. (10)

## VI PART

### THE RESEARCH WORK

In the irrigated agriculture, even if there is not any alkalized land because of water carrying soluble salts or by raising the water table, the farmer never is free of the danger of black alkali creeping into his land. The gypsum, as previously mentioned, for all salty soils generally, and black alkali especially is the best remedial element. In reclamation, even in prevention and rebuilding the soil physical conditions the gypsum probably is the best material to be applied.

The purpose of this research work, in different soil textures, is to see what physical and especially chemical important changes take place, when various sodium and gypsum solutions are leached. The most interesting thing through the leaching of these various sodium salt and gypsum from varying soil texture, is to find out the more available amount of sodium to be replaced with calcium of gypsum in order for the sodium to be leached out.

### METHODS AND PROCEDURES

The soils, their properties and location--The three different soil textures used in this experiment as determined through mechanical analysis (Table II) are, clay loam, fine sandy loam, and the third one although it is not exactly a silty loam, however, here, because of being so close, is called silty loam. The clay loam is a dark gray soil from a cultivated land in section 25 of Noble County; the fine sandy loam is from an uncultivated land from section 7 of Noble County; the silt loam soil is from a corn field in



in Oklahoma Agricultural and Mechanical College Experiment Station in the eastern part of Stillwater Creek. Table II shows the result of several textural mechanical analysis of these soils.

Table II Results of Mechanical Analysis  
of These Three Soil Classes

Soil No.	Percentage of Content		
	Clay	Silt	Sand
Clay loam	33.5	29.5	37.0
Silt loam	28.0	43.0	29.0
Sandy loam	18.0	17.0	65.0

The moisture content of these soils as shown in Table III was determined from the oven dried samples of these air dried soils (24 hours under 105° C). The pH values of these soils as determined by the glass electrode method are also shown in the Table III. For the pH determination 20 grams of each soil was dissolved in 50 ml distilled water. The organic matter by the method of potassium dichromate and sulfuric acid through titration by 0.051 N ferrous ammonium sulfate solution were determined.

Table III Moisture Content, pH Value  
and O. M. of the Soils

Soil No.	Percentage of Moisture	pH Value	O. M. %
Clay loam	1.60	6.4	2.69
Silt loam	1.020	6.9	1.39
Sand loam	1.048	5.7	1.00

The exchange capacity - The determination of exchange capacity of these soils was made by the normal neutral ammonium acetate method. This solution was made by mixing about 1356.6 ml of ammonium hydroxide (specific gravity 0.90), and 1104 ml of acetic acid 99.5% (analytical reagent) and adding distilled water to dilute to 18 liters. This solution was adjusted to pH = 7.0. Ten grams of each air dried and very fine rolled soil was leached with 250 ml of above solution and then finally washed by methyl alcohol. Using the Kjeldahl flask, the ammonia was gathered in a bottle of 25 ml N/10 HCL which was titrated by N/10 NaOH. The methyl red and methylene blue was used as indicator. This test for each soil was run several times. The results from the determination of exchange capacities are as follows: Clay loam 19.65 m.e., silt loam 12.45 m.e. and sandy loam 8.06 m.e. per each 100 grams of soil.

The Leaching Tubes and Their Setting - The tubes used in this experiment are cylinder shaped, except in the bottom end which is funnel shaped. The size of the cylinder part is about 51 cm in length and 10 cm in diameter. Each tube contained about 900 grams of sand (flat volume of 250 ml beaker) above the fiber glass, where the thickness of sand in the cylinder shaped part was about 3 cm. One kilogram of air dried and very finely rolled soils was poured into each tube. After very smoothly and carefully leveling the soils in the tubes, about 350 grams of sand in the same way was leveled upon the soils, in order to keep them from disturbing, particularly, when the solutions were poured. The thickness of this sand was about 1.5 cm. Because of accuracy in the leaching situation, for each solution two tubes from the same soil were set up. The pouring of soil, sand and solutions were through the funnel, which in time of pouring was turning around in order to have flat level or in case of solutions to pour by

sides of tubes, keeping the soil surface level and the pressure almost the same for all parts of soil.

The plant materials and sand particles during rolling of the soils were almost entirely removed from the soils.

#### PREPARATION OF SOLUTIONS

Sodium salt used in this experiment was NaCl and another salt was a G. P. gypsum. The sodium salt solution was made of 1000 parts per million (1000 milligrams per liter) which is almost equal to 17 milliequivalent of Na. In order to get the same milliequivalent of calcium in gypsum solution, because each molecule of calcium sulphate is combined with two molecules of water, the sum of 1462 parts per million (1462 milligrams per liter) of gypsum which is about 17 m.E. of Ca/l was used.

Dissolving of gypsum in cold water although ordinarily is 0.20 gram in 100 ml. of water, however for dissolving less than this amount it was necessary to heat the water gypsum solution on a hot plate 36-48 hours, and sometimes it was necessary to break the hardened grains in the water in order to be dissolved and to go to solution.

The five different solutions made of these two elements (sodium chloride and gypsum) were as follows: 1 - gypsum 100% and sodium salt 0.0%; 2 - gypsum 75% and sodium salt 25%; 3 - gypsum 50% and sodium salt 50%; 4 - gypsum 25% and sodium salt 75%; 5 - gypsum 0.0% and sodium salt 100%. In the same manner as the solutions, each soil texture was leached by distilled water with the same volume as was used in the solutions.

In this experiment the 60% of whole exchange capacity of each soil was leached with the necessary amount of solutions.

Although the idea in this experiment was to leach each soil by the necessary solution of each salt separately, or in other words almost to saturate with one salt and then when another necessary salt solution was used the obtained physical and chemical results would be similar to the natural processes. However, because of very low leaching ratio of sodium soils and the shortage of necessary time, it became almost impossible.

#### THE CHEMICAL PROCEDURES OF ANALYSIS

In this experimental research work, as previously mentioned, the idea was to find the amount of replaceable sodium with calcium in different percentage conditions in different soil texture, in order to find their relationship. Therefore the chemical analysis in the leachates were made for determination of calcium and sodium. Leaching soils with water was to check the amount of water soluble calcium and sodium present in these soils.

The determination of calcium in this work is made through the method of precipitating calcium with ammonium oxalate. Before titrating the solution with a standard potassium permanganate, to the precipitated calcium was introduced a necessary amount of 2% sulfuric acid solution which liberates oxalic acid and produces calcium sulfate.

The sodium was estimated by the aid of flame photometer where the used samples should not contain more than 400 p.p.m.

#### EXPERIMENTAL RESULTS

##### PHYSICAL OBSERVATIONS

Regardless of their high exchange capacity in case of clay and silt loam, in order to check all similar physical properties of these soils

connected with different solutions and to prevent the influencing factors; at first all soils were leached with a constant amount of solutions necessary for sandy loam (lowest in exchange capacity). Thus the pressure of solutions which could influence differently almost was omitted.

The following table shows the data from the leaching of clay loam soil with various solutions of the same amount.

TABLE IV THE CLAY LOAM LEACHED WITH DIFFERENT SOLUTIONS

Tube No.	Solutions	Amount solution in each tube	Time of pouring		Time of starting to leach		Time of checking leach-ates		Amount of leach-ate from both tubes	Total amount of leachate from both tubes
			Hr.	Min.	Hr.	Min.	Hr.	Min.	L	L
A <sub>1</sub> +A <sub>2</sub>	100% gyp-sum 0.0% NaCl	2.845	9	40	10	15	6	35	2.970	4.760
B <sub>1</sub> +B <sub>2</sub>	75% gyp. 25% NaCl	2.845	11	10	11	30	4	30	3.720	4.730
C <sub>1</sub> +C <sub>2</sub>	50% gyp. 50% NaCl	2.845	12	20	12	41	5	20	3.390	4.720
D <sub>1</sub> +D <sub>2</sub>	75% gyp. 25% NaCl	2.845	1	35	1	56	6	55	3.057	4.727
E <sub>1</sub> +E <sub>2</sub>	0.0% gyp. 100% NaCl	2.845	4	40	4	48	7	16	2.309	4.669
F <sub>1</sub> +F <sub>2</sub>	H <sub>2</sub> O	2.845	1	30	1	49	7	25	3.251	4.642

The first column of the table under the tube number such as A<sub>1</sub> + A<sub>2</sub> indicates the two tubes from one soil that were set up for one solution. The amount of solution indicated in the table (2.845 liter) is for each tube,

but the checked amount of leachate in a special time is from both tubes of same kind solution and it is the same in case of total amount of leachate.

Previously the m.e. of exchange capacity of each soil per 100 gram of sample was determined. Because in this work each tube contains 1000 grams or one Kilogram of soil, and on the other hand only 60% of this exchange capacity is leached, therefore the determination of 60% capacity of soils was necessary. The calculated results are as follows: Clay loam 117.90/1000 m.e.; silt loam 74.70/1000 m.e.; and sandy loam 48.36/1000 m.e. Because of equation of m.e. salt solutions, the necessary amount of solutions for leaching the 60% of the exchange capacity of these soils are: Clay loam 6.935 liters; silt loam 4.394 liters; and sandy loam 2.845 liters.

TABLE V THE SILT LOAM LEACHED WITH VARIOUS SOLUTIONS

Tube No.	Solutions	Amount solution in each tube	Time of pouring the solutions	Time of starting to leach	Time of checking leach-ates	Amount of leach-ates from both tubes	Total amount of leach-ates
1/1	100% gyp.	L	Hr. Min.	Hr. Min.	Hr. Min.	L	L
+							
1/2	0.0% NaCl	2.845	10 00	10 17	3 40	3.860	4.840
2/1	75% gyp.						
+		2.845	11 25	11 46	6 05	3.745	4.845
2/2	25%NaCl						
3/1	50% gyp.						
+		2.845	12 27	12 51	5 00	3.554	4.854
3/2	50% NaCl						
4/1	25% gyp.						
+		2.845	1 48	2 17	7 10	3.430	4.850
4/2	75% NaCl						
5/1	0% gyp.						
+		2.845	4 51	5 08	7 35	1.893	4.823
5/2	100% NaCl						
6/1							
+	H <sub>2</sub> O	2.845	4 05	4 29	7 48	1.886	4.763
6/2							

Although, by all precautions that were necessary to keep or to produce similar physical conditions, the time and ratio of leaching between two tubes of the same soil for the same solution in a very few cases were different.

The notable difference in case of clay loam for time was between tubes  $D_1$  and  $D_2$  about 14 minutes delay in starting to leach, and it was about 11 minutes between  $F_1$  and  $F_2$ . The variation in the amount of leachates at the time of checking was about 500 m.l. between  $B_1$ ,  $B_2$ ;  $C_1$ ,  $C_2$ ; and  $F_1$ ,  $F_2$ ; whereas it was about 400 m.l. in the case of  $E_1$ ,  $E_2$ . The leaching ratio between  $A_1$  and  $A_2$  was entirely the same. In other cases if there were some variation in the time and ratio of leaching, they were not important. In case of time the average time of the two tubes was figured, and these figures in all the tables are used to express the time of leaching.

In a similar manner the silt loam was leached by necessary solutions as in the case of clay loam. The obtained results in Table V are shown.

Variation in the time of leaching, between two tubes of one purpose, occurred between 3/1, 3/2; 4/1, 4/2 and 6/1, 6/2 which was about 5 minutes. The important variation in the leaching ratio was between 3/1, 3/2, where one leached about 900 m.l., in a checked time, more than the other did. This difference between 6/1, 6/2 was 200 m.l., and it was 100 m.l. between 5/1 and 5/2.

The sandy loam as shown by Table VI was leached with necessary various solutions. In this case the amount of solutions used is the same necessary amount for 60% of the exchange capacity.

TABLE VI THE SANDY LOAM LEACHED WITH DIFFERENT SOLUTIONS

Tube No.	Solutions	Amount Solution in each tube	Time of pouring the solution	Time of starting to leach	Time of checking leach-ates	Amount of leach-ates from both tubes	Total amount of leach-ates
$a_1+a_2$	100% gyp. 0% NaCl	2.845	Hr. Min. 10 15	Hr. Min. 10 30	Hr. Min. 2 10	L 4.148	L 4.860
$b_1+b_2$	75% gyp. 25% NaCl	2.845	11 45	11 59	3 18	3.990	4.850
$c_1+c_2$	50% gyp. 50% NaCl	2.845	12 55	1 08	5 35	4.025	4.905
$d_1+d_2$	25% gyp. 75% NaCl	2.845	2 37	2 51	6 25	3.870	4.893
$e_1+e_2$	0% gyp. 100% NaCl	2.845	2 09	2 18	5 15	3.510	4.890
$f_1+f_2$	H <sub>2</sub> O	2.845	4 15	4 26	6 15	2.684	4.872

The variation between two tubes of one solution in the case of time was between  $d_1$  and  $d_2$  about 4 minutes and the same was true for  $f_1$  and  $f_2$ . Difference in the rate of leaching was between  $d_1$  and  $d_2$  of about 300 ml., and between  $e_1$  and  $e_2$  almost 600 ml., and between  $f_1$  and  $f_2$  almost 300 ml. It is necessary to emphasize that the time variation means the necessary time after pouring the solutions, the tubes started to leach out; the rate variation is in the amount of leachates between two tubes in a special checked time. The moisture holding capacity was checked when the leaching was entirely stopped.



TABLE VII THE SOILS WHEN LEACHED BY SOLUTIONS OF 60%  
THEIR EXCHANGE CAPACITY

Solution Content	Tube No.	Soil texture	Amount of solutions used in both tubes	Amount of leachates from both tubes	Soil held moisture in ml.
100% gypsum + 0.0% NaCl	A <sub>1</sub> + A <sub>2</sub> 1/1+1/2 a <sub>1</sub> + a <sub>2</sub>	Clay Silt Sand	13.870 liters 8.790 liters 5.690 liters	12.775 liters 7.878 liters 4.860 liters	1095 ml. 912 ml. 830 ml.
75% gypsum + 25% NaCl	B <sub>1</sub> + B <sub>2</sub> 2/1+2/2 b <sub>1</sub> + b <sub>2</sub>	Clay Silt Sand	13.870 liters 8.790 liters 5.690 liters	12.795 liters 7.866 liters 4.850 liters	1075 ml. 924 ml. 840 ml.
50% gypsum + 50% NaCl	C <sub>1</sub> + C <sub>2</sub> 3/1+3/2 c <sub>1</sub> + c <sub>2</sub>	Clay Silt Sand	13.870 liters 8.790 liters 5.690 liters	12.755 liters 7.884 liters 4.905 liters	1115 ml. 906 ml. 785 ml.
25% gypsum + 75% NaCl	D <sub>1</sub> + D <sub>2</sub> 4/1+4/2 d <sub>1</sub> + d <sub>2</sub>	Clay Silt Sand	13.870 liters 8.790 liters 5.690 liters	12.702 liters 7.876 liters 4.893 liters	1168 ml. 914 ml. 797 ml.
0.0% gypsum + 100% NaCl	E <sub>1</sub> + E <sub>2</sub> 5/1+5/2 e <sub>1</sub> + e <sub>1</sub>	Clay Silt Sand	13.870 liters 8.790 liters 5.690 liters	12.747 liters 7.772 liters 4.890 liters	1123 ml. 1018 ml. 800 ml.
100% H <sub>2</sub> O	F <sub>1</sub> + F <sub>2</sub> 6/1+6/2 f <sub>1</sub> + f <sub>2</sub>	Clay Silt Sand	13.870 liters 8.790 liters 5.690 liters	12.769 liters 7.823 liters 4.872 liters	1101 ml. 967 ml. 818 ml.

The above table explains about the soils when they were leached by necessary solutions of 60% their exchange capacity. The last column of this table shows the amount of moisture that remained in the soils when the leaching was stopped. The interesting thing was the variation of moisture holding capacity of these different soils with the different solutions. The remaining moisture was in case of clay a minimum when leached with 75% of gypsum, and it was maximum when leached by 25% gypsum solution. In case

of silt loam the moisture holding capacity was almost minimum when leached with solution of 50% gypsum, and it was maximum when leached with 100% NaCl or 0% of gypsum solution. However, the case of sandy loam is somewhat between the two above mentioned loams. It was a minimum at 50% gypsum solution and it was maximum when leached with 75% gypsum solution. This is interesting that the minimum in case of sandy loam is similar to the case of silt loam and maximum was similar to the minimum case of clay loam.

## CHEMICAL RESULTS

The parts per million of calcium and sodium in the solutions were calculated, according to the amount of the salts used in their preparation. In the leachates these bases, according to the chemical procedures that are previously mentioned, were determined. The p.p.m. of calcium and sodium in the solutions and the leachates are shown by Table VIII. The sum of solution for leaching the 60% exchange capacity of two kilogram of each soil and also the amount of their leachates are shown by the same table.

The p.p.m. of calcium and sodium of leachates are the average of three tests in case of sodium and two tests for calcium. It is worthy to mention that there was not any notable differences in these different tests, and the results almost were the same.

According to the obtained data, the p.p.m. of calcium and sodium in the leachates of the same solution of these three soils in some cases were about the same. For example, the p.p.m. of calcium in the leachates of 100% gypsum solution, and the sodium in the leachates of 100% NaCl solution in case of clay and silt loam were the same. Whereas the p.p.m. of sodium in the leachates of 50% NaCl and 75% NaCl solutions in the case of clay and sandy loam were the same. Similar figures of sodium p.p.m. in case of sandy loam and silt loam were obtained when they were leached with 25% NaCl solution.

In this experiment the data was obtained from leaching of the three soils with several solutions of the salts to 60% of their base exchange capacity. Table IX shows this data calculated to 100% base exchange capacity for one kilogram of each soil. According to the parts per million of sodium and calcium, and amount of solutions used, and the leachates gathered,

TABLE VIII. THE p.p.m. OF CALCIUM AND SODIUM IN SOLUTIONS AND LEACHATES.  
THE AMOUNT OF SOLUTIONS USED FOR LEACHING TWO KILOGRAM OF EACH SOIL WITH  
60% OF THEIR EXCHANGE CAPACITY AND AMOUNT OF THEIR LEACHATES

Solutions		100% gyp. 0% NaCl	75% gyp. 25% NaCl	50% gyp. 50% NaCl	25% gyp. 75% NaCl	0% gyp. 100% NaCl	H <sub>2</sub> O	
Clay	Amount liter	13.870	13.870	13.870	13.870	13.870	13.870	
	Solu- tion	Con- tent	Ca	340	255	170	85	0
	p.p.m.	Na	0	98.29	196.58	294.87	393.16	0
Loam	Amount liter	12.775	12.795	12.755	12.702	12.747	12.769	
	Leach- ate	Con- tent	Ca	223	184	130	92	66
	p.p.m.	Na	8.6	97.4	183.4	237	277	5.4
Silt	Amount liter	8.790	8.790	8.790	8.790	8.790	8.790	
	Solu- tion	Con- tent	Ca	340	255	170	85	0
	p.p.m.	Na	0	98.29	196.58	294.87	393.16	0
Loam	Amount liter	7.878	7.866	7.884	7.876	7.772	7.823	
	Leach- ate	Con- tent	Ca	222	177	132	96	85
	p.p.m.	Na	5.4	100.8	188.6	241	277	5.4
Sandy	Amount liter	5.690	5.690	5.690	5.690	5.690	5.690	
	Solu- tion	Con- tent	Ca	340	255	170	85	0
	p.p.m.	Na	0	98.29	196.58	294.87	393.16	0
Loam	Amount liter	4.860	4.850	4.905	4.893	4.890	4.872	
	Leach- ate	Con- tent	Ca	194	155	115	84	73
	p.p.m.	Na	7	100.8	183.4	237	269	5.4

the milliequivalents per kilogram of soils are calculated.

The m. e. of soil absorbed cations are their proportional differences in the solutions and the leachates.

Result:

According to the data in Table IX, the absorbed m. e. of calcium when the soils were leached with 100% gypsum solution are about 39.59%, 41.44%, 51.11% of their exchange capacity in order of clay, silt and sandy loam. When these soils were leached with 100% NaCl solution, the absorbed m. e. of sodium were about 34.87%, 37.35%, 40.81% of their exchange capacity in order of clay, silt, and sandy loam.

As a general rule, as long as one of these bases is dominant in a solution, its absorbed m. e. is more than other one. However, the soil absorbs calcium more than it does sodium. Comparing the absorbed m. e. of these two bases by their proportional ratio in the solutions somehow it will be clear. For example, in comparing the two cases, that one of these bases is 100% in the solution, (Table IX, columns 2 and 6), the absorbed calcium by each one of these three soils was more than sodium.

A very interesting thing appeared when these soils were leached with 50% solution of each of these bases. In this solution the m. e. of these two bases was equal, or in other words, from m. e. standpoint, in this solution they had a balancing power. However in each of these soils, the absorbed m. e. of calcium was double the m. e. of sodium plus approximately two. For example, in Table IX, column 4, in case of silt loam, when it was leached with solution of 50% gypsum and 50% NaCl, the absorbed m. e. of sodium was 8.3, whereas, the absorbed m. e. of calcium was 18.9.

According to the data, from the prevention standpoint, the obtained results give a very clear practical idea. When the m. e. of these two

TABLE IX THE EFFECT OF LEACHING ONE KILOGRAM OF EACH THREE SOILS WITH DIFFERENT SALT SOLUTIONS IN AN AMOUNT EQUIVALENT TO THE EXCHANGE CAPACITY OF THE RESPECTIVE SOILS

Solutions		100% gyp. 0% NaCl	75% gyp. 25% NaCl	50% gyp. 50% NaCl	25% gyp. 75% NaCl	0% gyp. 100% NaCl	H <sub>2</sub> O
Clay Loam	Solution content	Ca	196.49	147.368	98.258	49.122	0
	m. e.	Na	0	49.122	98.258	147.368 **	196.49
	Leachate content	Ca	118.700	98.095	69.039	48.690	35.054
	m. e.	Na	3.980	45.153	84.755	109.066	127.931
	Soil absorbed	Ca	77.79	49.273	29.169	0.432	*-35.054
	m. e.	Na	*-3.980	3.969	13.503	38.302	68.559
Silt Loam	Solution content	Ca	124.525	93.393	62.262	31.131	0
	m. e.	Na	0	31.131	62.262	93.393	124.525
	Leachate content	Ca	72.870	58.011	43.361	31.503	27.525
	m. e.	Na	1.540	28.727	53.873	68.771	78.001
	Soil absorbed	Ca	51.655	35.382	18.901	*-0.372	*-27.525
	m. e.	Na	*-1.540	2.404	8.389	24.622	46.524
Sandy Loam	Solution content	Ca	80.608	60.456	40.304	20.152	0
	m. e.	Na	0	20.152	40.304	60.456	80.608
	Leachate content	Ca	39.285	31.322	23.502	17.125	14.873
	m. e.	Na	1.232	17.712	32.593	42.013	47.659
	Soil absorbed	Ca	41.323	29.134	16.802	3.027	*-14.873
	m. e.	Na	*-1.232	2.440	7.711	18.443	32.949

\* Amount of soil content bases that is leached out as water soluble or as exchangeable.

\*\* The decimal point of NaCl m. e. in solutions was omitted, whereas, it was about 1.09 more in each 196.49 m. e.

bases in a solution was equal, the soil absorbed calcium twice as much as sodium, but, even so, the absorbed amount of sodium was appreciable. It is necessary to mention that from prevention standpoint, the calcium content of irrigation water should be at least three times that of its sodium content. In recommendation of gypsum for the prevention of sodium accumulation, regarding to its solubility, and water content soluble calcium, the necessary amount of gypsum should be so much to produce enough calcium in order that water content calcium could be three times more than of its sodium content.

This point should be kept in mind that as long as sodium is a dominant base in a solution it can replace a significant amount of calcium. According to the obtained data, (Table IX, column 6,) sodium about 17.81% of its amount in solution could replace of clay loam content calcium, and in case of silt loam it was 22.08%, in case of sandy loam about 18.44%.

From the reclamation standpoint, the obtained results of this experiment, as long as relationship of calcium and sodium is concerned, are valuable. However in this case because of other influencing factors in salt saturated or base accumulated soils, it is necessary to prepare some more experimental data.

## SUMMARY

### Literature:

All the pertinent available literature in regard to the following subjects was reviewed.

(1) Soil base exchange from its historical and scientific viewpoints including the more recent clay mineral concept along with related physical soil properties.

(2) The alkali soils, their origin, formation, development, reclamation and prevention.

(3) Gypsum, its historical recognition of agricultural value, its remedial action in the alkali-diseased soils, its value in reclamation and prevention of alkali soils.

### Research:

There is always in irrigated agriculture the danger of alkali creeping into the lands. This might be done by water carrying soluble salts or raising the ground water table, or even both. The gypsum as a preventive and reclaimer amendment is mostly recommended.

In the reclamation of alkali soils, particularly the black alkali soils, the application of gypsum has been recommended by several of the experimental and scientific workers. However, the amount, time, or the method of treatment have not been practically determined. The percentage of soil exchangeable sodium that can be replaced with calcium of gypsum, necessarily, has not been clarified. Briefly, the relationship between



sodium (water soluble and exchangeable) and calcium has not been practically recognized.

The purpose of this research work with different soil textures was to study the important base exchange relations, chemical and physical changes that probably take place when these soils were leached with various solutions of gypsum and sodium salts.

In this experiment, three soil textures, clay loam, silt loam, and sandy loam, were leached with five different mixed solutions of gypsum and sodium salt. The content of each solution was 17 m. e. of salt per liter. Each soil depending upon its exchange capacity was leached with enough solution to obtain a 60% capacity. The pH value, organic matter, and soil moisture were determined. The textures were determined by Bouyougos method of mechanical analysis, and base exchange capacity by the normal neutral ammonium acetate method.

The prepared solutions were as follows: (1) 100% gypsum and 0% NaCl; (2) 75% gypsum, 25% NaCl; (3) 50% gypsum, 50% NaCl; (4) 25% gypsum, 75% NaCl; 0% gypsum, 100% NaCl; and finally in the same manner as for the solutions, the soils were leached with distilled water. In the preparation of these solutions, C. p. gypsum and NaCl were used.

The time of leaching, ratio of leaching, and amount of leachates all were measured and recorded. The retention of moisture in the different soils varied with different solutions. It was somewhat interesting that the minimum moisture holding capacity of sandy loam was as well as the silt loam when they were leached with 50% gypsum solution; the maximum was when the sandy loam was leached with 75% gypsum solution, which was a minimum in the case of the clay loam.

The chemical results were full of interest. Any time these two bases

were together, relatively with their proportion in solutions, calcium was more powerful or in another word it was more soil absorbable. Proportionately, in all soils calcium was absorbed more than sodium.

The most interesting thing happened when these two bases were of equal m. e. content in a solution. In spite of their equal milliequivalence, the absorbed calcium was almost twice of the sodium plus two in all soils. When sodium was the dominant base in a solution, almost all the calcium in the solution was leached out in the case of clay and silt loam soils. If the solution contained 100% NaCl, the amount of sodium present in the used solution could leach out around 17.8 - 22.0% of its m. e. of the calcium in the soil. Another point that should be mentioned is the case that sandy loam and clay loam were leached with 100% NaCl solution. In this case, although of low pH value and low O. M. of sandy loam, the amount of calcium leached out in both loams, comparatively with the amount of sodium present in their leaching solutions had almost the same ratio.

#### Result:

Calcium replaces the sodium as long as it is dominant. When both bases are in an equal m. e. in a solution, although soil absorbs calcium more than twice that of sodium, the soil still absorbs an appreciable amount of sodium.

In prevention, even reclamation of alkali soils, regarding to the solubility of gypsum, in order to obtain good results, it is necessary to treat the soils with the amount of gypsum that can produce about more than one half calcium than the soil or water content of sodium.

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Water - GYPSUM a Soil ALKALI Corrector

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