AN INVESTIGATION OF RECLAMATION PROCEDURE FOR SALINE AND ALKALI SOILS IN OKLAHOMA

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1958
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1960

Submitted to the Faculty of the Graduate School of
the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
May, 1960

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ACKNOWLEDGEMENTS

The author wishes to express sincere appreciation to Dr. Lester W. Reed, thesis adviser, for his encouragement and helpful criticisms in connection with this research and in the preparation of this thesis. He is also indebted to Dr. H. F. Murphy for his helpful advice throughout the author's academic study at Oklahoma State University.

Appreciation of financial help is expressed to Dr. M. D. Thorne, Head of the Agronomy Department and to other members of the staff and students for their friendship and assistance, especially Mr. C. C. Schaller for his help and inspiration during the course of this investigation.

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INTRODUCTION

The quotation from Kellogg (25)[1] "There can be no life without soil and no soil without life: They evolved together" succinctly describes the importance of the soil. The process of soil formation is complex. Soil is defined as a loose earthy material which supports or has supported the growth of plants. Most of the important agronomic characteristics of the soil depend upon the quantity and kind of clay minerals present in the soil. Clay minerals are the end product of the rock mineral weathering cycle and each soil may have several clay mineral types. Many of the clay minerals in soils disperse and swell when they are treated with saline solutions.

A soil containing soluble salts in concentrations sufficient to cause interference with plant growth is designated a saline soil if it contains more than 0.1% (14) soluble salts. Salinity is a special problem for irrigators because all irrigation waters contain some soluble salts. Many irrigation waters in the lower rainfall regions of the world contain considerable amounts of sodium salts. These sodium salts may by continual irrigation give rise to sodic or alkali soils (18). Progressive changes in soil salinity and sedimentation probably contributed materially to the dissolution of ancient

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[1] Figures in parenthesis refer to literature cited.

civilizations of the Middle East. One of the most famous was the ancient civilization on the Mospotamian Plain of Iraq (38); "The southern part of the alluvial plain appears to have never fully recovered from the general decline of crop yield which accompanied the salinization process started at least three millennia in the past. Although the land was never completely abandoned cultural and political leadership passed permanently out of the region with the rise of Babylon in the eighth century B. C. and many of the great Sumerian cities dwindled to villages or were left in ruins. There is no historical event of this magnitude for which a single explanation is adequate, but that increasing soil salinity played an important part in the breakup of the Sumerian civilization seems beyond question."

There are hundreds of millions of acres of land in the world that are at present not used for agricultural purposes, but could be of great value if salinity could be eliminated. The need for more land to feed the world's rapidly increasing population brings the day closer when these soils must be reclaimed. Therefore, research on procedures for reclaiming these soils must be pursued with great vigor. The objectives of the research reported in this thesis were: to investigate the important chemical changes in a soil that had been irrigated for several years with saline water; to investigate the changes in soluble salts and exchangeable sodium when the soil was leached with saline irrigation water with and without additions of gypsum to the soil.

LITERATURE REVIEW

It was known by Aristotle (13) that sea water lost some of its taste by filtration through sand. Godfrey (13) in 1737 filtered sea water through a stone and reported that the first water that ran through was like pure water, although the next pint was salty as usual. Lambruchini (13) in 1830 suggested a special kind of combination between plant nutrients and the soil which was neither too weak to allow them to wash out nor yet so strong as to interfere with their absorption by the plant.

From 1845 to 1850 Thomson (37) made the first quantitative experiments on cation exchange and discovered that when soil was mixed with ammonia for a while and leached with the water, the greater part of ammonia was held by the soil. Way (45) published his first paper in 1850 on cation exchange and followed this report by a great number of reports on his experiments. Liebig (13) compared the action of soil on salts with that of charcoal and regarded the attraction of the soil for salts was a purely physical phenomena rather than chemical. Van Bemmelen (42) concluded that zeolitic silicates were responsible for cation exchange and that cation exchange was a true chemical reaction.

Oden (30) defined clay as "disperse fraction of mineral fragments in which particles of smaller dimension than 2 microns predominant." Truog and his associate (41) showed that very few unweathered primary minerals exist in the clay fraction below 2 microns in diameter. Baver (3) modified the definition of Oden to; "Clays are disperse systems of the colloidal products of weathering in which secondary mineral particles of smaller dimensions than 2 microns predominant." In soil chemistry the clay minerals are referred to as the active fraction because of their high specific surface and exchange properties and the silt and sand are considered the skeleton of the soil.

Baver (3) reports that divalent ions are absorbed more strongly than monovalent, and weakly hydrated ions are held more tightly than ions like sodium with its large water hull. Marshall (27) classified the clays and related minerals into four groups: (1) the koalin group (1:1 lattice type), (2) hydrated mica group (2:1 lattice type), (3) montmorillonite or expanding lattice group (2:1 lattice type), and (4) fibrous clays.

Cation exchange has been shown to be a true chemical reaction and a property of all clay minerals. When the clay is exposed to saline solutions for an extended period of time it becomes saturated with sodium to an extent not normally encountered in soils from humid regions (14).

According to Kelley (18) soils which contain exchangeable sodium ions in excess of that found in normal soils, are called alkali soils although the soluble salts may have been leached out. However, there is no sharp line of distinction between a leached alkali soil and a saline soil. Bower et al. (4) believed that the occurrence of calcium and magnesium carbonates prevents accurate determination of exchangeable calcium and magnesium and requires the application of a positive correction factor to values obtained by the usual cation exchange capacity determination.

It has been suggested that one of the possible causes of poor plant growth on soil highly saturated with exchangeable sodium is inability of the plant to obtain an adequate supply of calcium. Thorne (39) grew tomatoes in a mixture of bentonite saturated with various ratios of exchangeable sodium and calcium. He found that the yield and calcium content of the plant decreased markedly as the level of sodium saturation exceeded 50 percent. McGeorge (28) has suggested that the solubility and availability of calcium in alkaline-calcareous soils of high pH is low.

The effect of moisture content on the soluble salts of alkali calcareous and gypsiferous soils has been studied by many investigators (11, 17, 22). In virtually all cases, the alkali and alkaline earth carbonates, bicarbonates, sulfates, phosphates and silicates increased in the soil solution. Reitemeier (33) reported that the soluble cation content of soil varies with the moisture content.

Kelley (20) reported that "white alkali soils" refers to soils which contain an excess of neutral salts, usually chlorides and sulfates. "Black alkali soils" refers to soils which contain injurious amounts of soluble carbonates, either with or without chlorides and sulfate. The former soils may or may not contain absorbed sodium, but the latter always contains absorbed sodium to some extent.

The word "alkali" as used in the English language and in chemistry comes from the Arabic Al Kali. The Arabic origin of this word seems to be Kawi which means to burn, Kalawi which means the burning sensation, Al Kali means that which does the burning or specifically a caustic burning agent such as leachates from wood ashes.

Stewart and William (36) reported the term "alkali" was first applied to the white incrustations on the soils of the arid plains by hunters and trappers of the American Far West before the attention of the soil scientist was directed to it.

Kearney (16) reported that the most common salts which cause soil salinity and alkalinity and hinders or prevents the growth of plants are: Glauber's salt (sodium sulfate), table salt (sodium chloride) and baking soda (sodium bicarbonate). The so called "black alkali" is sal soda, or washing soda (sodium carbonate). Epsom salts (magnesium sulfate) are also an important ingredient of alkalinity in certain localities. Saline soil solutions rising to the surface by capillarity and evaporation, leave salt crusts of various physical characteristics. Sodium chloride, sodium sulfate and magnesium sulfate yield white crusts which are dry at all conditions of atmospheric humidity short of fog and rain. Calcium and magnesium chloride and nitrate crusts are delinquescent and turn to liquid at humidities in excess of about 30 percent. Hence the surface of a soil which contains visible evidence of these salts must be examined at low humidities. With humidities of more than 30 percent these crusts are mixed with the soil and are not recognizable as salt crusts.

Kavda (15) differentiates four types of salinization of soils on the basis of the most conspicuous salts:

1. Salinization by carbonate (soda) and sulfates.
2. Salinization by sulfate with some chlorides.
3. Salinization by chlorides with lesser amounts of sulfates.
4. Salinization overwhelmingly by chlorides.

He states that such an evolution of salinity is determined by the changes in climate toward an increasing aridity with an enhancement of the effectiveness of evaporation.

Saline-Alkali soil is the term applied to soils which have a conductivity of the saturation extract greater than 4 mmhos/centimeter at 25°C. and the exchangeable-sodium percentage is greater than 15 (14). Nonsaline-Alkali soil is the term applied to soils which have an exchangeable sodium-percentage greater than 15 and conductivity of the saturation extract of less than 4 mmhos/centimeter at 25°C. The pH reading of these soils is usually between 8.5 and 10 (14).

The presence of salt in the soil affects plant growth in two ways: first, the increased osmotic pressure of the soil solution restricts water entry; second, certain of the ions present exert a specific toxic action on the activity of the plant cell. Certain plants grow in the presence of salts of high concentration. These plants are classified as resistant while other plants that are easily injured are classified as sensitive. Plants in the resistant class are cultivated plants such as barley, sorghum, and sugar beets, while corn and wheat represent the more sensitive class.

Wadleigh, et al. (43) grew beans, corn, alfalfa, and cotton in containers of soil varying in added salt content with depth from none at the surface to 0.25 percent at the bottom. Observations showed that the relative salt tolerance of four species of plants was the same as that usually observed in the field, that is, bean, corn, alfalfa, and cotton in order of increasing tolerance.

Wadleigh and Gauch (44) grew Guayule plants in sand culture with a control nutrient solution and in cultures with the same solution but with 1, 2, and 3 atmospheres of osmotic pressure due to added salt. Four salts were studied separately, viz. Na_2SO_4, NaCl, $CaCl_2$, and $MgCl_2$. The plants were killed by the lowest concentration of $MgCl_2$ used, therefore, this species is very sensitive to excessive magnesium.. However, the plants made satisfactory growth in the presence of three atmospheres of osmotic pressure due to added $CaCl_2$, therefore, this species is very tolerant to calcium chloride. The plants were all relatively sensitive to sodium salts.

Kelley and Thomas (23) believed that reclamation of alkali soil required the addition of chemical amendments such as gypsum or sulfur or combination of these with manure, followed by heavy leaching. The removal of excess soluble salts by leaching, however, is not enough to restore alkali soils to productivity. Most of the absorbed sodium must be replaced with calcium or magnesium and soil structure must be improved. Chemical amendments for the replacement of absorbed sodium are of two types: soluble calcium salts (calcium chlorides and gypsum); and acid or acid-formers (sulfuric acid, sulfur, and iron and aluminum sulfate). The suitability of the various types of amendments is governed primarily by their solubility, calcium content, and pH of the soil (5).

Kelley (19) applied gypsum at rates of 10, 12, and 15 tons per acre in experiments near Fresno, California. All treatments lowered the exchangeable sodium levels of these soils from 70 percent saturation to 5 percent to a depth of four feet.

Shawarbi and Abdul-Bar (34) added a gypsum (0.4 gm. $CaSO_4$ per litre) solution to 10 gm. samples of air-dry alkaline soil in amounts equivalent to 8, 12, 16, and 20 tons per acre. The mixture was made up to 500 ml., stirred on a water bath for 1 hour, then filtered and the soil washed with alcohol to remove free electrolytes. Exchangeable sodium was decreased by 60 percent with one treatment of gypsum.

Castilla (8) worked on soils from the Cauca Valley Columbia. In pot experiments with soybeans, soil treatments were applied corresponding to 500, 1000, and 2000 kg. of sulfur/ha.; and 1000, 2000, and 4000 kg. of gypsum/ha. Samples were leached with distilled water, and leaching combined with sulfur or gypsum treatment at the medium rate of application. Control pots received only distilled water in moderate amounts. On the basis of dry-matter yields all levels of sulfur and gypsum were highly effective. The first sulfur treatment was most economical for sulfur. The second gypsum level was less effective than the first or third.

The reaction between gypsum and exchangeable sodium is an equilibrium reaction, the extent to which the reaction goes to completion is determined by the interaction of several factors among which are the differences in the replacement energies of calcium and sodium, the exchangeable-sodium-percentage, and the total cation concentration of the soil solution. It is known from many experiments that if the exchangeable-sodium-percentage of the soil exceeds 15 percent that 25-90 percent or more of the calcium supplied by the amendment replaces exchangeable sodium as the soil is leached. The calcium that replaces exchangeable sodium does not become less than 50 percent until the exchangeable-sodium-percentage becomes less than 10 percent (14).

Hilgard (12) calls attention to the fact that the beneficial change brought about by the application of gypsum does not apply to all soils. If soil treatment with gypsum is allowed to become waterlogged by irrigation water or otherwise the salinity problem may become important due to replaced sodium.

Kelley (19) demonstrated with the Fresno and other types of alkali soil that are high in exchangeable sodium that they can be readily changed to calcium saturated soil by leaching with water saturated with carbon dioxide.

Sigh (35) concluded that ammonification was decreased by the application of gypsum, while lime favored ammonification and lime with gypsum showed less effect in general than lime alone. Nitrification was similarly depressed by gypsum alone but the use of gypsum and lime together increased nitrification over lime or gypsum alone.

Kelley and Brown (21) state that the beneficial effect of lime as a treatment for alkali soil is probably limited to acid (the so called degraded) type of alkali soil, for it is obviously unreasonable to expect any important effect from liming, if the soil already contains calcium carbonate.

Mitra and Shanker (29) in pot experiments with air-dry alkali soil treated with 0.2 percent sulfur, 0.5 percent $CaSO_4$ and/or 0.5 percent carbon in the form weed tissue reported that the efficiency of these agents for neutralizing carbonate, increasing exchangeable calcium, and decreasing dispersion was in decreasing order $CaSO_4$ + weeds, $CaSO_4$, sulfur + weeds, sulfur, and weeds.

Kelley and Alexander (24) applied different rates of gypsum, finely ground elemental sulfur, ferrous sulfate, and potassium alum to alkali soils. They concluded that when sulfur is applied to an alkali soil in which the soluble carbonate is largely concentrated near the surface, excessive leaching should be delayed until active oxidation of the sulfur has taken place. In this event the oxidation products will decompose the soluble carbonate, whereas with heavy leaching during the early stages of the oxidation the soluble carbonates will be leached into the subsoil, and capillarity may cause them to rise to the surface at some later time.

There is a sharp line of distinction between "white alkalis" where the salts are present as chlorides and sulfates of sodium and magnesium and the "black alkalis" where the soil contains soluble salts of carbonates and bicarbonates of sodium. The white alkali salts which are deposited by capillarity and evaporation, are readily removed by drainage, while black alkali salts coming from country rock are not readily removed. It is generally known, owing to their wide and general distribution, that the white alkalis are a more serious problem than black alkali, however, locally the black alkali salts are more difficult to cope with.

Harris (10) reported that the net salts removed by drainage due to natural rainfall to a depth of 4 feet, varied from virtually nothing in January to maximum of 0.20 percent in September, while the total for a 25 month period was 1.28 percent per acre.

Powers (32) reports that the maximum accumulation of alkali in heavy loam soils of eastern Oregon occurs where the water table is about 3 .5 feet below the surface. To relieve the alkali and salinity condition he believed drains should be installed 6 to 8 feet below the surfact to tap porous soil layers and to control capillary return of salts to the surface. Spacing of drainage tiles from 440 to 680 feet was most effective.

Kelley and Brown (22) pointed out that a determination of the water-soluble cations, expecially calcium and sodium; replaceable bases; the pH of the soil; and the composition of the irrigation water together make it possible to predict whether leaching alone will bring about successful reclamation.

In Iraq (home of the author) and Egypt (40) three methods of alkali-land reclamation are used. Each of these methods is successful under the reclamation requirement appropriate for its use.

1. Colmatage or warping- This method of reclamation consists simply of flooding land with muddy water long enough to allow the mud to settle, after which the clean water is drawn off and more muddy water run on. Very little attention is paid to drainage, except insofar as surface drains are dug to carry away the clear water. The popular impression prevails that by this method the alkali or salt is covered up with sufficient good soil to permit plant roots to thrive.

2. Flooding with open drains-This is the method in common use in Egypt and Iraq. The land is thoroughly leveled and open ditches to a depth of thirty-two inches are dug at intervals of 150 to 450 feet, and the land is banked up and flooded to a depth of four inches until sufficiently leached to permit plant growth. This method is thoroughly effective for the removal of salt, but it has the objectionable feature of open ditches.

3. Flooding with tile drains-This method has only been tried experimentally in Egypt, but promises to be the most rapid and effective way of reclamation. Tile drains are placed thirty inches deep and thirty-five feet apart.

Thus leaching is the second step after drainage in reclamation of saline soils, to leach salts by adding an excess of water to soil so that much of it goes on through and drains away from the rooting zone. In order to be effective in removing salts, at least 10 percent or more of the water added should be carried away in the drains.

Reclaiming alkali soil is more difficult than reclaiming saline soils, because the former involves not only leaching free of soluble salts, but also neutralizing excess alkalinity, replacing exchangeable sodium with calcium, and improving the physical properties of the soil. A desirable irrigation water for leaching alkali soil is one which has a low sodium percentage. When the irrigation water is not high in calcium or when the soil contains no readily soluble calcium compounds, alkali soil treated with gypsum usually hastens the reclamation procedure. Cropping may also facilitate leaching when roots or incorporated residues make the soil more permeable.

MATERIALS AND METHODS

The soil used in this work was taken in Tillman County from a farm that had been irrigated with saline water for several years. The soil was classified as a Tipton sandy loam (9). It was sampled in the topsoil and subsoil fraction from different locations in the field. Ten inches of the topsoil and 10-20 inches of the subsoil were sampled separately, brought to the laboratory, all the topsoils were mixed together and the subsoils were handled in the same manner. Each sample was then air dried and passed through a 0.25 inch sieve. Results of physical and chemical analysis of the soil is given in Table II.

The soil texture determination was made by the hydrometer method of Bouyoucos (6).

The chemical properties of the soil before and after leaching, and the leachates were made as follows:

The pH was determined by making a soil: salt solution of 1:2 using 0.1 N KCl solution, allowed to stand for 10 minutes and read on the Beckman Zeromatic pH meter. Cation exchange was determined by standard methods (2). Exchangeable cations were determined on 1.0 N ammonium acetate leachate (31) with the Beckman Flame Spectrophotometer with Photomultiplier attachment. Soluble cations in 15 leachates were determined (after the 20 ml. of each sample was passed through a column of anion exchange resin[1] which had been leached with 2 N HCl and washed by distilled water until free from chloride) with the Beckman Flame Spectrophotometer with photomultiplier attachment. Estimation of soluble salts in the soil was accomplished by making water extracts of 1:5 soil: water mixture, and a total dissolved solids or salts were determined by evaporating an aliquot of the sample (14). Conductivity of the leaching water was determined by using a Wheatstone Bridge (7). Soluble sulfate was determined by mixing 20 gr. of air dry soil with 100 ml. extracting solution (which is made of 100 gr. sodium acetate in 500 ml. of water, 30 ml. of 99.5% acetic acid added and made up to one liter with water), and shaken for 30 minutes then filtered, transferred 10 ml. aliquot to a 50 ml. volumetric flask. Two grams of 30-60 mesh $BaCl_2$ crystals were added, then 2 ml. of 0.25% gum acacia, then brought to volume with water and shaken for one minute. The turbidity was read on the Bausch-Lomb photoelectric colorimeter with a blue filter. The ppm of sulfates in the sample was obtained from a standard curve which was prepared with known quantities of sulfate.

The objective of this experiment was to investigate the effect of leaching a saline soil, treated with variable surface applications of gypsum, with saline water approximately equivalent to the salinity of the irrigation water that had caused the soil to become saline. The experiment consisted of cylinders or small lysimeter columns as shown in Figure 1, prepared as follows: The ten to twenty inch subsoil

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[1] Resin used: DOWEX 21K
A strongly basic, anion exchange resin, sphericity greater than 85%
Total exchange capacity (wet volume) 1.4 m.e./ml.
Total exchange capacity (dry basis) 4.1 m.e./gr.
Moisture content 52%

sample was packed into the lower six inches of the cylinder that had been previously plugged with glass wool which served as a soil and filter pad. The surface soil (0-10") layer was then packed into the upper six inches of the cylinder. The same quantity of soil was used in each container for each treatment and replication.

Gypsum treatments equivalent to 0, 1, 3, 5, 7, and 9 tons per acre were applied on the surface of the soil with reagent grade gypsum ($CaSO_4.2H_2O$). The gypsum treatments are designated in the discussion as treatment #1 for check, #2 for one ton of gypsum etc. The cylinders were then arranged in leaching racks in a completely randomized four replication experiment and leached fifteen times with the saline irrigation water equivalent to two acre inches of water per irrigation. The composition of the irrigation (saline) water is shown in Table I.

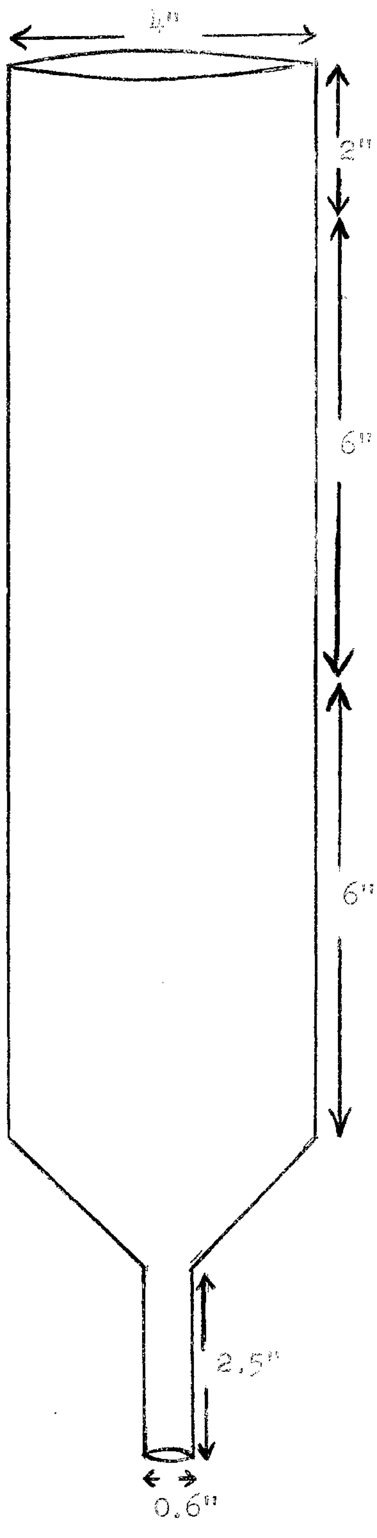

Figure 1. Sketch showing the kind of the cylinder used in this investigation

TABLE I

AVERAGE COMPOSITION OF SALT WATER USED FOR LEACHING

pH.	6.5
Conductivity (micro mhos/cm. at 25°C) .	2959
Total Soluble Salts	2664 ppm
Calcium	590 ppm
Sodium.	545 ppm
Magnesium	350 ppm
Sodium Absorption Ratio	4.37
Percent Sodium.	28.80

RESULTS AND DISCUSSION

This study is an attempt to investigate some of the chemical changes that occur in saline and alkali soils, when treated with gypsum and leached with salt water. At the same time attempts were made to find the gypsum rate most profitable for reclamation of these soils. The results of this study, may throw new light on the chemical reactions that take place during the reclamation of these soils by gypsum and leaching.

The soil used in this study was a sandy loam in the topsoil, and fine sandy loam in subsoil, and high in salt content as shown in Table II. The topsoil was lower than the subsoil in soluble salts. The cation exchange capacity, which was determined after washing the soil with distilled water, was approximately equal for both top and subsoil, however, the exchangeable calcium and potassium were higher in the topsoil than the subsoil and exchangeable sodium and magnesium were reverse of that. Thus exchangeable sodium percentage was higher in the subsoil than the topsoil, but both of them were lower than 15 percent of the exchange capacity and the pH was lower than 8.5, as shown in Table II. Therefore, according to Richards (14) the soil was a saline-nonalkali soil.

The pH, cation exchange capacity and sulfate content of the top and subsoils, after leaching 15 times with salt water for the six

TABLE II

MECHANICAL AND CHEMICAL ANALYSIS OF SOIL USED

	Topsoil	Subsoil
pH	7.75	7.55
Percent Sand	32.75	64.00
Silt	55.50	26.75
Clay	11.75	9.25
Cation Exchange Capacity m.e./100 gr.*	5.25	5.3
Exchangeable Cations m.e./100 gr.*		
Calcium	3.0	2.65
Sodium	0.37	0.52
Magnesium	2.58	2.91
Potassium	0.33	0.20
E.S.P.	7.05	9.81
Sulfate (ppm)	1.0	2.0
Total Soluble Salts (ppm)	1497.5	2037.5

*C.E.C. and Exchangeable cations were determined after washing soil with distilled water until free of chloride (tested with silver nitrate and potassium chromate) treatments with gypsum, is shown in Table III. The pH of the soil decreased with increasing application of gypsum, and was lower in the topsoils than the subsoils in all cases except in the check cylinder, which was free of gypsum. Ames and Schollenberger (1)using the Hopkins potassium nitrate and the vacuum method, found that gypsum applied with manure decreased the acidity of the soil. Lipman (26), however, stated that gypsum is not alkaline and therefore will not significantly change the pH of the soil. Sigh (35) grew plants in pots in soils treated with gypsum. He tested the soil for acidity by the modified Tacke method and found that the acidity was increased by the application of gypsum, with the larger amount giving the greatest increase.

The cation exchange capacity of the topsoil was approximately equal for all treatments. However, it was lower than the cation exchange capacity before treatment. For the subsoil the cation exchange capacity after treatment ranged between 5.21-5.9 m.e./100 gr. The cation exchange capacity for all treatments was lower in the topsoil than the subsoil as shown in Table III. This may have been due to the movement of clay particles from the topsoil to the subsoils during leaching. The quantity of exchangeable cations was higher than the cation exchange capacity of the soil after treatment, however, and the possibility exists of movement of suspended gypsum particles into the part of soil under the surface, Table III.

The sulfates were higher in both topsoils and subsoils after treatments than before. In all treatments sulfate in the topsoil was higher than the subsoil, and increased with increasing application of gypsum as shown in Table III. It was higher than the original soil because the salinized water contained $CaSO_4 \cdot 2H_2O$ and

$MgSO_4.7H_2O$ in addition to the gypsum added to the surface of the soil in the cylinders.

TABLE III

THE pH, CATION EXCHANGE CAPACITY AND SULFATE CONTENT AFTER TREATMENT WITH GYPSUM AND FIFTEEN LEACHINGS

	pH		C.E.C. (m.e./100 gr.)		Sulfate (ppm)	
Treatment	Top	Sub	Top	Sub	Top	Sub
1	6.6	6.6	4.375	5.9	10.5	5.5
2	6.4	6.6	4.762	5.275	12.87	5.75
3	6.3	6.5	4.86	5.21	15.75	6.41
4	6.1	6.4	4.875	5.6	29.86	6.875
5	6.0	6.4	4.9	5.3	49.0	7.06
6	5.8	6.4	4.175	5.575	61.62	8.06

The exchangeable calcium, sodium, magnesium and potassium, after treatment is shown in Table IV. The exchangeable calcium, both for topsoil and subsoil, was higher than before treatment, the exchangeable calcium was also higher in the topsoil than the subsoil, and, in both soils the exchangeable calcium increased with increasing rates of gypsum application. This may support the idea of replacement of sodium by calcium on the clay complex as shown in the equation below:

$$NaX\ (clay) + CaSO_4 = CaX_2 + NaSO_4$$

Sodium sulfate which is the end product, is soluble, and may be lost by leaching.

In the case of treatment #6, the topsoil, which had the highest application rate of gypsum was lower in exchangeable calcium than

TABLE IV

EXCHANGEABLE CATIONS (me./100gr.) AFTER GYPSUM TREATMENT AND 15 LEACHINGS

Treatments	Calcium		Sodium		Magnesium		Potassium	
	Top	Sub	Top	Sub	Top	Sub	Top	Sub
1	3.35	3.35	0.141	0.108	2.25	2.88	0.21	0.24
2	3.4	3.5	0.119	0.152	2.02	2.88	0.19	0.26
3	3.8	3.525	0.092	0.13	1.998	2.29	0.205	0.23
4	4.275	3.36	0.136	0.13	1.55	2.38	0.195	0.248
5	4.66	3.56	0.102	0.125	1.42	2.12	0.195	0.23
6	3.92	3.6	0.065	0.119	1.09	2.42	0.166	0.23

treatment #4 and #5 this may have been due to errors in the method. However, the method was checked in some detail and no appreciable errors were found. The exchangeable sodium decreased with gypsum application and leaching, as shown in Table IV. It was decreased by two thirds in the topsoil, and the exchangeable sodium was decreased in the subsoil by four fifths, or 80%. Exchangeable magnesium decreased with increasing application of gypsum. The effect of gypsum lowered the exchangeable magnesium more in the topsoil than subsoil. Exchangeable potassium was decreased in the topsoil but changed very little in the subsoil.

The Sodium Absorption Ratio was determined in the fifteen leachates. It decreased in all treatments with increasing leaching. Treatments No. 5 and 6 caused the greatest decrease as shown in Figure 2. This indicates that applications of 7 and 9 tons per acre of gypsum with leaching, caused a constant decrease in SAR until the 3500 ml. quantity or nine leachings were reached. However, the SAR value of the check cylinder or treatment #1 decreased more slowly with leaching. The SAR in all treatments was lower than the check cylinder after 6000 ml. (15 leachings). This indicates more rapid replacement of sodium by calcium when gypsum is applied on the surface.

The regression line of the two variables ESP (Exchangeable Sodium Percentage) and ppm of soluble salts of the topsoils is shown in Figure 3 and Table I, Appendix. There was a negative correlation coefficient of -0.71, but was lower than the (r) required for significance at the 5% level which was 0.81. The figure also shows this negative relationship between two variables, that is, the ESP increases as the ppm of soluble salts decreased. This line shows a close relationship between ESP and soluble salts in the soil. Since soluble salts increased with increasing

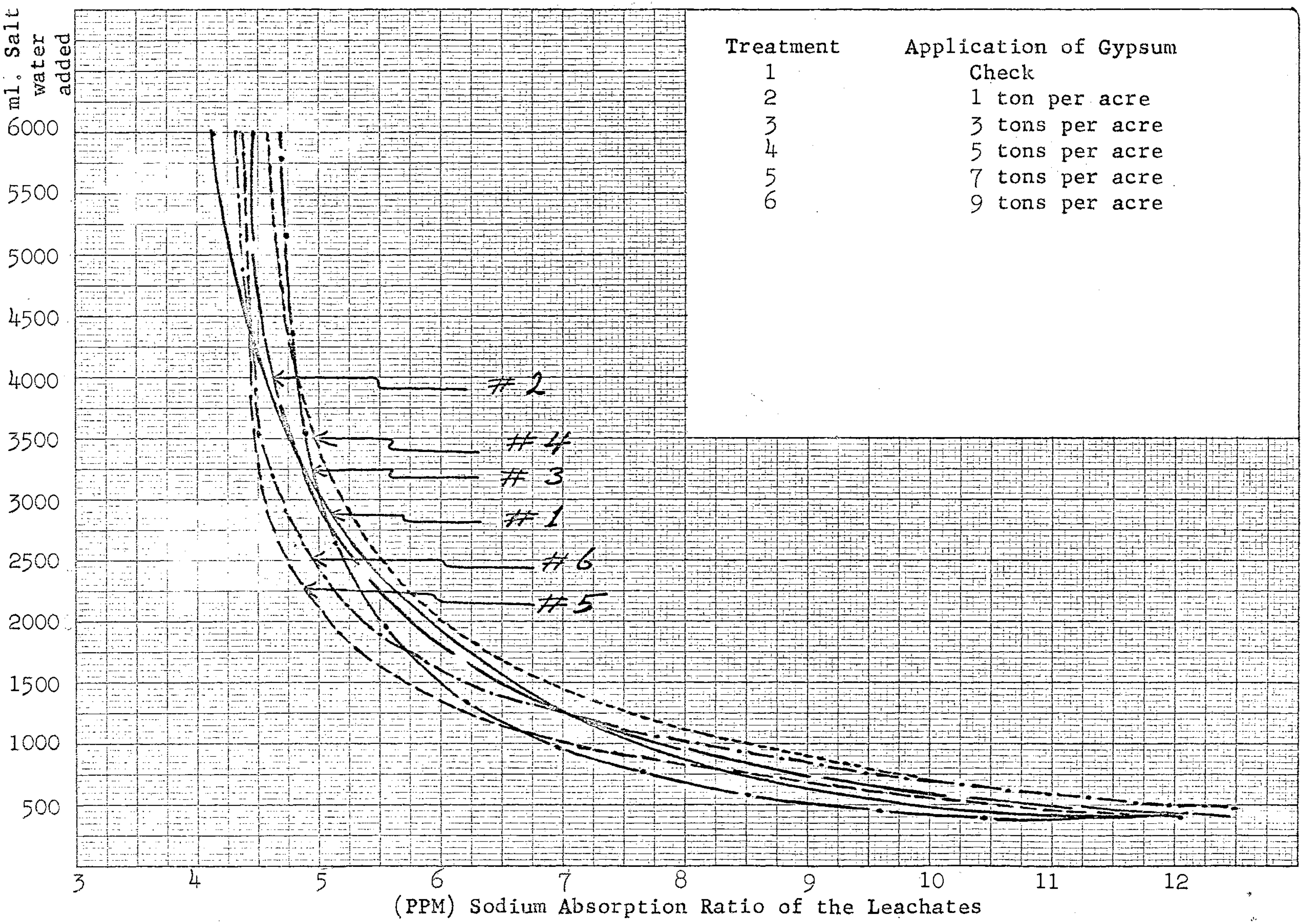

Figure 2. Sodium Absorption ratio in the fifteen leachates for the six treatments

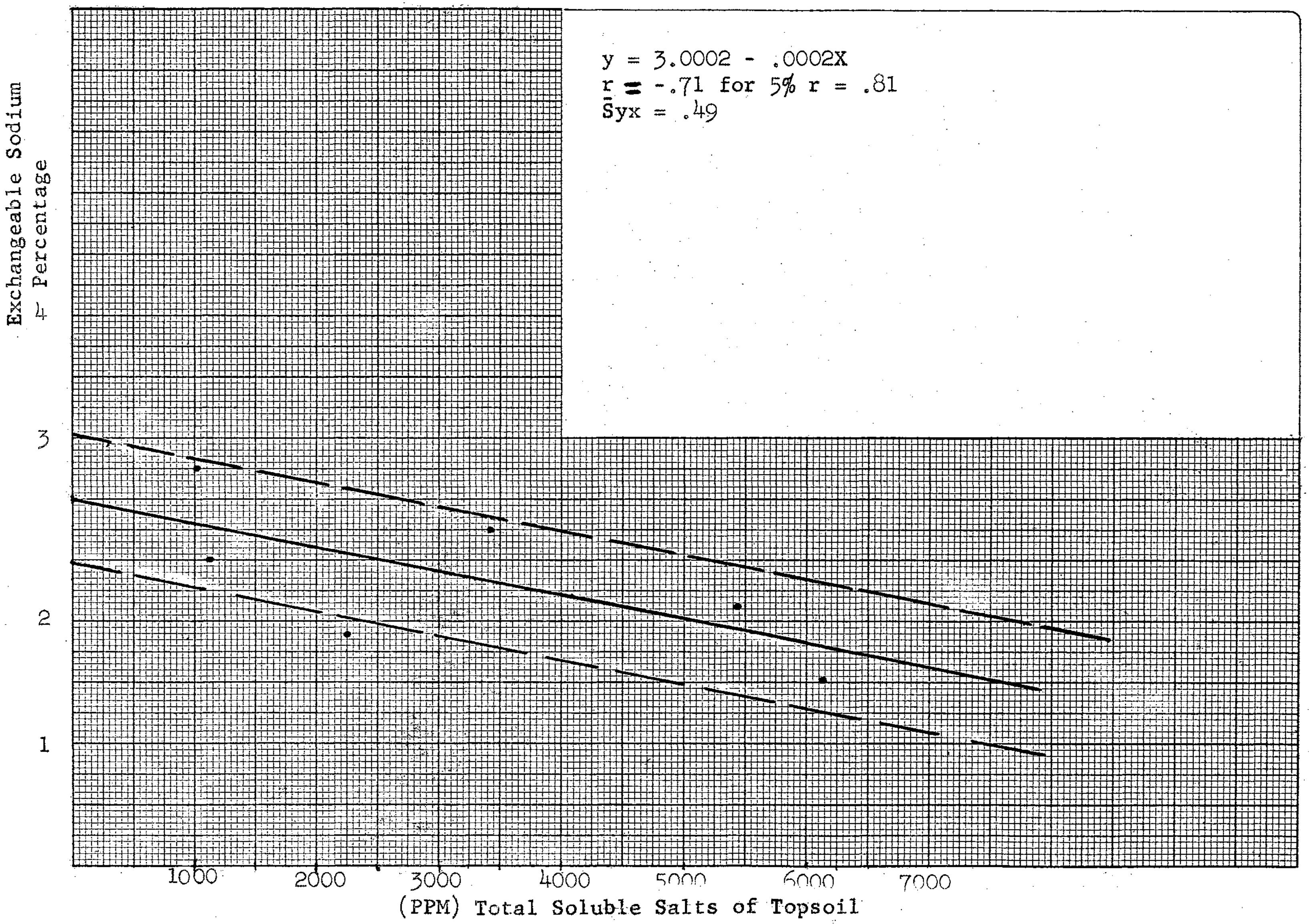

Figure 3. Regression line for the two variables (ESP) and total soluble salts of the topsoil of the six treatments after 15 leachings.

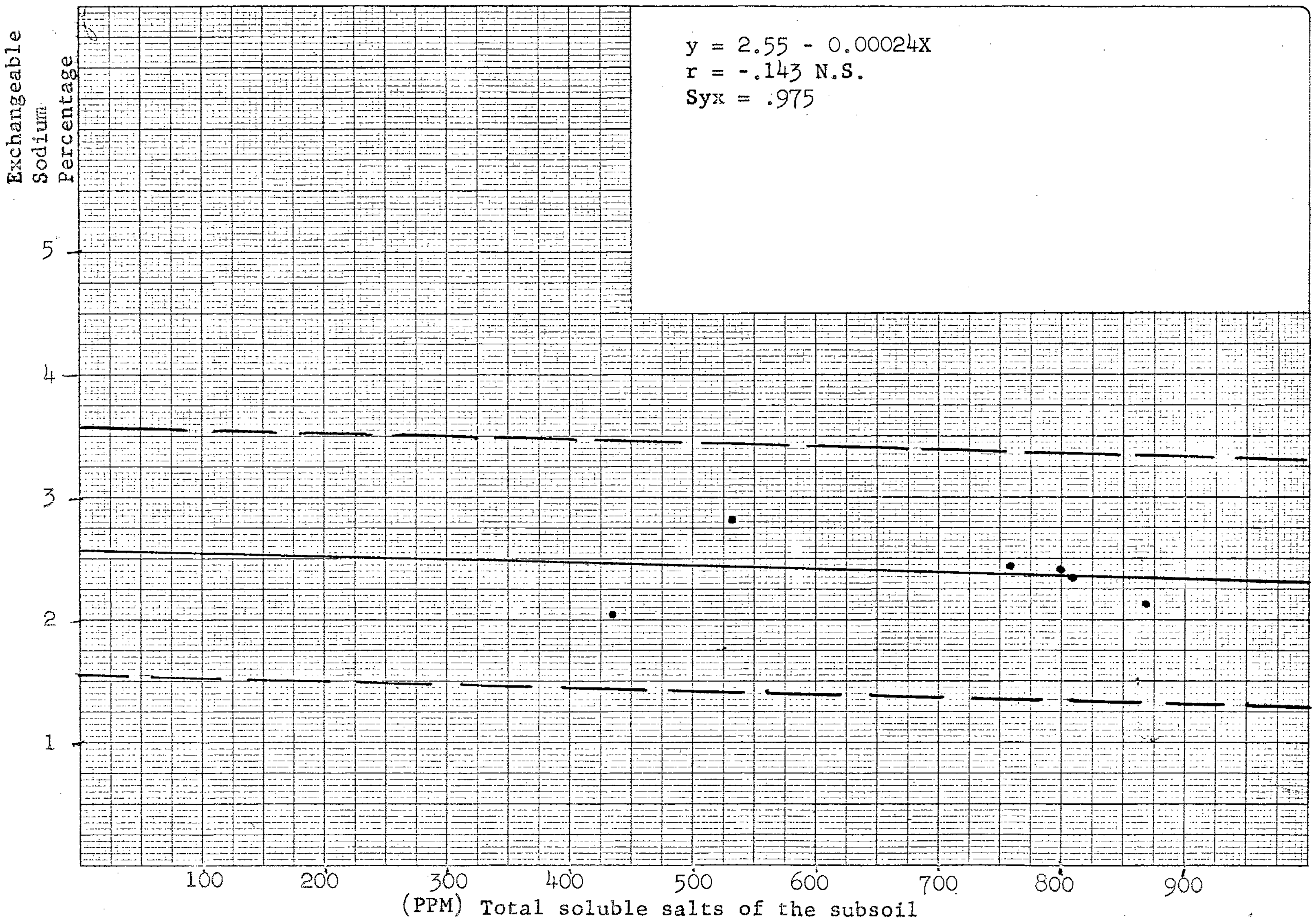

Figure 4. Regression line for the two variables (ESP) and total soluble salts of the subsoil of the six treatments after 15 leachings.

application of gypsum, it seems that the topsoils contained some gypsum before determination of the soluble salts. Although, gypsum has a low solubility in water it may have a marked effect on the total soluble salts.

The regression line for the two variables ESP and total soluble salts of the subsoil is shown in Figure 4 and Table II, Appendix. The correlation coefficient was much lower than the same relation for the topsoil, and the zone of estimate was wider in the subsoil regression line than the topsoil regression line. Gypsum applied on the surface caused an increase in the soluble salts with increasing rate of application, but this increase was lower for the subsoil than the topsoil. In all treatments the soluble salts were lower than the original salts in the subsoil and ESP changed very little in the subsoil with the different treatments. The data for the regression calculation for both topsoil and subsoil regression lines is shown in the Appendix.

A significant difference between treatments as shown by the exchangeable sodium percentage (ESP) of the topsoil is shown in the analysis of variance Table III, Appendix. The highest ESP was, treatment No. 1 (check cylinder), and the lowest was treatment No. 6 (9 tons of gypsum). The rank of the treatments from the lowest ESP to the highest was 6, 3, 5, 2, 4, and 1, and significant difference between treatments was found at the 5% level, the F value found was 3.638.

As shown in Table V of the multiple range test, thate was no significant difference in ESP of the topsoil for treatments No. 6, 3, and 5, and no significant difference between treatments 2, 4, and 1 as shown in multiple range test, Table V. However, there was a significant difference between the members of these two groups of

TABLE V

MULTIPLE RANGE SHOWING ESP DIFFERENCES BETWEEN THE TREATMENTS MEAN (TOPSOIL) AFTER 15 LEACHINGS

A - Standard Error of Treatment Mean: $n_2 = 15$

$$SM = \sqrt{\frac{\text{Mean Square Error}}{\text{DF}}} = 0.295$$

B - Shortest Significant Range

P: (5% P-level)	(2)	(3)	(4)	(5)	(6)
R_p:	0.888	0.93	0.97	0.98	0.99

C-Results

Treatments	T_6	T_3	T_5	T_2	T_4	T_1
Means of ESP	1.53	1.89	2.15	2.49	2.78	3.28

Note: Any two means not underscored by the same line are significantly different. Any two means underscored by the same line are not significantly different.

TABLE VI

MULTIPLE RANGE SHOWING ESP DIFFERENCES BETWEEN THE TREATMENTS MEAN (SUBSOIL) AFTER 15 LEACHINGS

A - Standard Error of treatment mean: $n_2 = 15$

$$S_m = \sqrt{\frac{\text{Mean Square Error}}{\text{DF}}} = 0.135$$

B-Shortest Significant Range

P: (5% P-level)	(2)	(3)	(4)	(5)	(6)
R_p:	0.406	0.427	0.439	0.447	0.454

C-Results

Treatment:	T_1	T_6	T_4	T_5	T_3	T_2
Mean of ESP:	2.04	2.13	2.33	2.35	2.498	2.90

Note: Any two means not underscored by the same line are significantly different. Any two means underscored by the same line are not significantly different.

treatments. These results indicate that application of gypsum decreased the ESP of the soil and this decrease continued with increasing gypsum application. There was no significant difference between replications of different treatments.

A significant difference at the 5% level between treatments for the ESP of the subsoil is shown in the analysis of variance Table IV, Appendix. There was no significant difference between treatments 1, 6, 4, and 5, treatments 2, and 3, and 6, 4, 5, and 3 as shown in the Table VI. However, there was a significant difference between the members of these groups. There was no significant difference in subsoil ESP between treatment 1 (check cylinder) and treatment 6 (9 tons per acre of gypsum) this indicates that gypsum dissolved and moved from the surface to sub-surface soil and caused an increase of exchangeable calcium with subsequent decrease in ESP. In general increasing rates of gypsum application caused a decrease in ESP, which is shown in Table VI.

A significant difference in total soluble salts between treatments of the topsoils is shown in the analysis of variance Table V, Appendix. There was a highly significant difference (1% level) between treatments, and no significant difference between replicates. The F values for the treatments was 16.176 and for replicates 1.5925. As shown in Table VII of the multiple range test, the order of ranking of the results follows the order of gypsum application. These results indicate that gypsum had a significant effect in increasing soluble salts, however, this was probably due to the presence of gypsum in the soil as crystalline gypsum as mentioned before.

A significant difference in total soluble salts between

TABLE VII

MULTIPLE RANGE SHOWING TOTAL SOLUBLE SALTS IN DIFFERENT TREATMENTS MEAN (TOPSOIL) AFTER 15 LEACHINGS

A-Standard Error of Treatment Mean: $n_2 = 15$

$$S_m = \sqrt{\frac{\text{Mean Square Error}}{\text{DF}}} = 482.28$$

B-Shortest Significant Range

P: (1% P-level)	(2)	(3)	(4)	(5)	(6)
R_p:	2011.1	2107.56	2170.26	2208.84	2237.8

C-Results:

Treatment:	T_1	T_2	T_3	T_4	T_5	T_6
Means TSS:	1037.5	1150.0	2268.75	3456.25	5456.25	6137.5

Note: Any two means not underscored by the same line are significantly different. Any two means underscored by the same line are not significantly different.

TABLE VIII

MULTIPLE RANGE SHOWING TOTAL SOLUBLE SALTS IN DIFFERENT TREATMENTS MEAN (SUBSOIL) AFTER 15 LEACHINGS

A-Standard Error of Treatment Mean: $n_2 = 15$

$$S_m = \sqrt{\frac{\text{Mean Square Error}}{\text{DF}}} = 65.81$$

B-Shortest Significant Range:

P: (5% P-level)	(2)	(3)	(4)	(5)	(6)
Rp:	198.09	207.69	213.88	217.83	221.12

C-Results

Treatment:	T_1	T_2	T_3	T_4	T_5	T_6
Means TSS:	462.5	656.25	762.5	800	812.5	868.75

Note: Any two means not underscored by the same line are significantly different. Any two means underscored by the same line are not significantly different.

treatments of the subsoils is shown in the analysis of variance Table VI, Appendix. There was a significant difference (5% level) between treatments, and no significant difference between replicates.

As shown in Table VIII of the multiple range test, the order of ranking of the results, was the same for the subsoil as the topsoil, and followed the order of gypsum application. Thus, gypsum application had a significant effect on the concentration of soluble salts, but the effect on the subsoils was lower than its effect on topsoils.

SUMMARY AND CONCLUSION

This thesis reports the results of a study of a saline soil in the Soils Laboratory of the Agronomy Department of Oklahoma State University in 1959-1960. The objective was to investigate some of the chemical changes which occur in saline and/or alkali soil when treated with different amounts of gypsum and leached with salt water.

The soil used was saline-nonalkali soil (Tipton Sandy Loam).The factor which contributed to the development of the salinity of this soil was use of saline irrigation water with inadequate drainage. In general, it is recognized that the use of saline irrigation water involves the danger of accumulation of soluble salts in the surface soil layer. The artificial drainage of irrigated land has two objectives: (1) The removal of surplus water, whether surface or subsoil accumulation, and (2) The removal of surplus dissolved salts that might otherwise accumulate in the root zone or in the subsoil immediately below the root zone. The effectiveness of a drainage system is to be judged by the condition of crop growth and by field observations made to ascertain, not only whether the surplus water is being removed, but also whether the drainage water is carrying away approximately as much dissolved salts as is being carried to the land by irrigation water.

The soil studied in this investigation was not materially altered in chemical properties after treatment with gypsum and fifteen leachings with salt water.

The analytical data may be summarized as follows:

1. There was a higher accumulation of soluble salts in the subsoil than the topsoil. Sulfate accumulation was minor but increased with increasing application of gypsum.

2. Cation exchange capacity was approximately equal for both topsoil and subsoil, but some decrease in the former and increase in the latter was caused by applying gypsum, and leaching.

3. Exchangeable sodium decreased and exchangeable calcium increased with gypsum application, due to replacement of sodium by calcium on the clay complex.

4. The pH of the soil decreased slightly with increasing gypsum application and leaching. The hydrolysis of absorbed sodium in soil tends to be associated with a decrease in hydroxyl ion activity, that is, pH will be dependent upon the amount of sodium absorbed and the degree of hydrolysis prevailing.

5. Exchangeable sodium percentage decreased with leaching.

6. There was a negative correlation between the ESP and soluble salts of the topsoil.

7. There was a significant difference in ESP between the different applications of gypsum.

8. There was a significant difference in soluble salts between the different treatments.

In prevention and reclamation of saline or alkali soil, it is necessary to treat the soils with an amount of gypsum that can produce sufficient calcium to replace the sodium. The reclamation of these soils can be accomplished by the recommended practice of leaching, drainage and gypsum application.

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APPENDIX

TABLE I

SHOWING CALCULATION OF REGRESSION ESP ON TOTAL SOLUBLE SALTS AFTER 15 LEACHINGS (IN THE TOPSOILS)

Soluble Salts X	ESP Y	X^2	XY	Y^2
1037	3.27			
1150	2.49			
2269	1.89			
3456	2.78			
5456	2.11			
6137	1.54			
Ex 19505	Ey 14.08	Ex^2 86,920,871	Exy 41,113.72	Ey^2 35.02
Mx 3251	My 2.35			
n 6				

$$y = a + bx$$

$$y = 3.0002 - 0.0002X$$

Correlation Coefficient

$$r_{xy} = \frac{E(xy) - nM_xM_y}{\sqrt{[E(X^2) - n(M_x)^2][E(y^2) - n(M_y)^2]}} = -0.71$$

Adjusted Standard Error

$$\bar{S}_{yx} = \sqrt{\frac{E(y^2) - n(M_y)^2}{n-2}(1-(r_{xy})^2)} = 0.49$$

TABLE II

SHOWING CALCULATION OF REGRESSION ESP ON TOTAL SOLUBLE SALTS AFTER 15 LEACHINGS (IN THE SUBSOILS)

Soluble Salts X	ESP Y	X^2	XY	Y^2
437.5	2.04			
533.3	2.87			
762.5	2.46			
800.0	2.42			
812.5	2.35			
806.7	2.13			
Ex 4214.5	Ey 14.27	Ex^2 3,112,017	Exy 9994.5	Ey^2 34.37
Mx 702.4	My 2.38			
n 6				

$$y = a + bx$$

$$y = 2.55 - 0.0024X$$

Correlation Coefficient

$$r_{xy} = \frac{E(xy) - nM_xM_y}{\sqrt{[E(X^2) - n(M_x)^2][E(y^2) - n(M_y)^2]}} = -0.143$$

Adjusted Standard Error

$$\bar{S}_{yx} = \sqrt{\frac{E(y^2) - n(M_y)^2}{n-2} \quad (1 - (r_{xy})^2} = 0.975$$

TABLE III

SHOWING CALCULATIONS OF ANALYSIS OF VARIANCE FOR ESP OF TOPSOILS AFTER 15 LEACHINGS

Source	df	SS	MS	F
Total	23	14.7447	0.641	
Reps.	3	0.37	0.123	0.282
Treatments	5	7.93	1.586	3.638*
Error	15	6.5447	0.436	

	T_1	T_2	T_3	T_4	T_5	T_6	E	
R_1	3.82	3.04	2.20	2.71	2.14	1.04	14.95	
R_2	2.70	2.45	2.06	2.71	2.14	1.02	13.08	
R_3	3.93	2.12	2.37	2.60	1.64	1.05	13.71	
R_4	3.65	2.37	0.92	3.10	2.54	3.06	14.64	
	13.10	9.98	7.55	11.12	8.46	6.17	56.38	56.38

$$\text{Correction Factor} = \frac{E(X_1 + \text{---} + X_n)^2}{n} = 132.45$$

$$\text{Total SS} = X_1^2 + X_2^2 \text{---} + X_n^2 - \text{CF} = 14.7447$$

$$\text{Reps. SS} = \frac{(R_1)^2 + (R_2)^2 + (R_3)^2 + (R_4)^2}{6} - \text{CF} = 0.37$$

$$\text{Treatments SS} = \frac{(T_1)^2 + (T_2)^2 + \text{----}(T_6)^2}{4} - \text{CF} = 7.93$$

*Under 5% Level

TABLE IV

SHOWING CALCULATIONS OF ANALYSIS OF VARIANCE FOR ESP OF SUBSOILS AFTER 15 LEACHINGS

Source	df	SS	MS	F
Total	23	3.61	0.157	
Reps.	3	0.45	0.15	1.67
Treatments	5	1.804	0.361	4.01*
Error	15	1.356	0.09	

	T_1	T_2	T_3	T_4	T_5	T_6	E
R_1	1.59	2.69	2.80	2.02	2.43	1.59	13.12
R_2	2.26	3.06	2.60	2.17	2.41	2.69	15.19
R_3	2.12	3.10	2.45	2.82	2.41	1.88	14.78
R_4	2.12	2.65	2.14	2.30	2.14	2.36	13.71
	8.09	11.5	9.99	9.31	9.39	8.52	56.8 56.8

$$\text{Correction Factor} = \frac{E(X_1 +\text{---}X_n)^2}{n} = 134.43$$

$$\text{Total SS} = X_1^2 + X_2^2 +\text{-----}+ X_n^2 - \text{CF} = 3.61$$

$$\text{Reps. SS} = \frac{(R_1)^2 + (R_2)^2 + (R_3)^2 + (R_4)^2}{6} - \text{CF} = 0.45$$

$$\text{Treatments SS} = \frac{(T_1)^2 + (T_2)^2 +\text{---}+(T_6)^2}{4} - \text{CF} = 1.804$$

*Under 5% Level

TABLE V

SHOWING CALCULATIONS OF ANALYSIS OF VARIANCE FOR SOLUBLE SALTS IN TOPSOILS AFTER 15 LEACHINGS

Source	df	SS	MS	F
Total	23	117,064,349	5089754.3	
Reps.	3	5,556,536	1852178.66	1.5925
Treatments	5	94,062,943	18812588.6	16.176**
Error	15	17,444,870	1162911.33	

	T_1	T_2	T_3	T_4	T_5	T_6	E
R_1	1050	1125	1900	5350	3750	9375	22550
R_2	1125	1350	1500	2525	6225	4100	16825
R_3	925	850	3750	3125	7500	6075	22225
R_4	1050	1275	1925	2825	4350	5000	16425
	4150	4600	9075	13825	21825	24550	78025 78025

$$\text{Correction Factor} = \frac{E(X_1 +---+ X_n)^2}{n} = 253{,}662{,}526$$

$$\text{Total SS} = X_1^2 + X_2^2 + --- X_n^2 - \text{CF} = 117{,}064{,}349$$

$$\text{Reps. SS} = \frac{(R_1)^2 + (R_2)^2 + (R_3)^2 + (R_4)^2}{6} - \text{CF} = 5556536$$

$$\text{Treatments SS} = \frac{(T_1)^2 + (T_2)^2 + --- + (T_6)^2}{4} - \text{CF} = 94062943$$

**Under 1% Level

TABLE VI

SHOWING CALCULATIONS OF ANALYSIS OF VARIANCE FOR SOLUBLE SALTS IN SUBSOILS AFTER 15 LEACHINGS

Source	df	SS	MS	F
Total	23	831146	36136.8	
Reps.	3	15521	5173.7	0.0024
Treatments	5	490833.5	98166.7	4.54*
Error	15	324791.5	21652.8	

	T_1	T_2	T_3	T_4	T_5	T_6	E
R_1	475	550	675	775	875	900	4250
R_2	425	525	675	775	950	875	4225
R_3	400	1025	925	650	700	900	4600
R_4	450	525	775	1000	725	800	4275
							17350
	1750	2625	3050	3200	3250	3475	17350

Correction Factor = $\frac{E(X_1 + X_2 + -- + X_n)^2}{n}$ = 12,542,604

Total SS = $X_1^2 + X_2^2 +---+ X_n^2$ - CF = 8831146

Reps. SS = $\frac{(R_1)^2 + (R_2)^2 + (R_3)^2 + (R_4)^2}{6}$ - CF = 15521

Treatments SS = $\frac{(T_1)^2 + (T_2)^2 + --- + (T_6)^2}{4}$ - CF = 490833.5

*Under 5% Level

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