ACCUMULATION AND TRANSMISSION OF SALT IN SOIL

by

HOOSHANG ASHRAF

Bachelor of Science

Agricultural College University of

Shiraz, Iran

1960

Submitted to the faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
July, 1966

ACCUMULATION AND TRANSMISSION OF

SALT IN SOIL

Thesis Approved:

Lester W. Reed
Thesis Adviser

Wayne W. Huffine

J. K. Boggs
Dean of the Graduate College

ACKNOWLEDGMENT

The writer wishes to express his sincere appreciation to Dr. W. L. Reed, my major adviser, for his encouragement and help in connection with the work throughout the study and the preparation of this thesis.

Also, I would like to express my appreciation to Dr. F. P. Gardner, Head of the Agronomy Department, and the other college staff members and graduate students of the Agronomy Department because of their great friendliness.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

All life depends upon the soil. The quotation, "There can be no life without soil and no soil without life; they have evolved together", from Kellogg (22) shows the importance of soil. Soil, a natural medium for the growth of plants, is a compound of fragments of varied products of weathered or unweathered rocks, organic matter, water and air. Because of the dynamic character of soils, they will undergo change.

One of the very important influential factors in soil characteristics, besides 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 saline accumulation problem in soils.

Soils are influenced by the action of man when he cultivates the land and grazes his herds upon it. On good soils, production can be maintained or improved by proper use; or, it may be decreased through careless use or abuse. When the soil becomes less productive, whether as a result of natural or artificial causes, it is a matter of deep concern to us because upon this depends the prosperity of a nation and the welfare of its society. Someone has rightly said, "The base of the social pyramid rests today where it has always rested -- upon the land". Upon the land, man makes his first application of productive effort -- to extract from it food to sustain his life and give him energy, fiber for clothes to protect his body and conserve its vital warmth, wood to build shelter against the elements and one from which to furnish tools. Therefore, to maintain a high productive capacity in soils, both those which are normally productive and in those which have been impaired for one reason or another are clearly a matter of the highest order of national importance (39).

Among the many harmful and unfavorable soils for plant growth, the saline soils are probably the important ones. Saline soils, despite the fact that they are very harmful for plant production, occupy a vast area of the earth, particularly in arid and irrigated areas. The research reported here is our attempt to define some of the factors affecting movement of saline solutions through soils. Closely associated with irrigation in the arid and semiarid regions of the world is the problem of salt accumulation at and near soil surfaces.

The major salt movement in soils takes place through the medium of water. As water moves upward to the surface from the water table it carries salt with it. Since the proximity of the water table to the soil surface often results in the evaporation of large amounts of water from the soil surface, the salt that remains after such evaporation is concentrated at or near the soil surface. Data shows that the rise of salts has been quite rapid even in those areas where the water table was more than ten feet down from the soil surface (30).

When the water table is $< 3.5 - 5.0$ m. below the surface, accumulation of water soluble salts increases as the depth of the water table decreases. When the water table is lower there is practically no accumulation of water soluble salts.

The influence of a rising water table on the upward capillary flow is analogous to the influence of making a canal grade steeper and steeper, both cause an increase in the velocity of the flowing water. A high water table increases the moisture content of the unsaturated surface soil and thus increases the permeability and the quantity of flow.

The soluble salts are held near the surface of the body of ground water where they may readily be drawn by upward capillary flow to the soil surface and there deposited as the water evaporates.

Some arid-climate soils that were free of excess salts before cultivation have been rendered nonproductive by the use of irrigation water containing excessive quantities. Salts continue to accumulate in soils of irrigated areas where greater amounts are brought in than removed. Irrigation waters contain from 1/10 ton to five tons of salt per acre-foot of water. Some irrigation farmers apply only two feet of water per season, others where the summers are long and hot, apply up to five feet of water or more.

Where drainage is not provided the irrigation water may add as much as one to ten or more tons of salt each year to an acre of land (16). This paper reports research on the effects of salt accumulation and transmission by upward movement and evaporation of water and by irrigation on rate and amount of water moving in the soil and on water lost from the surface.

CHAPTER II

LITERATURE REVIEW

Origin and Occurrence of Saline Soils. During the weathering of rocks and minerals, large quantities of soluble salts are formed. In humid climates these salts are generally carried out of the soil into the ground water and washed to the sea. In arid or semi-arid climates the salt may accumulate in a lower horizon of the soil or be transported to a lower drainage area where the water evaporates and the salt accumulates.

Salt accumulation is most severe in low-lying soils because the factors of position and permeability are intensified. Some of the soluble salts found in dry climates likely originated from secondary deposits. Parent materials high in salt were laid down usually in the bottoms of ancient lakes or seas in early geologic ages. Many shale deposits contain substantial quantities of salts and these contribute to the salt in soils of local areas.

About 25 per cent of the earth's surface is sufficiently arid to make salt accumulation common. In the United States, saline soils occur mainly in the 17 states west of the 100th Meridian. The occurrence is similar in the arid regions of western Canada, in the arid high plains of Mexico and on the western Pacific slopes of South America. Saline soils are also extensive in northern and southwestern Africa, including the Union of South Africa, Rhodesia, Egypt, Algeria, Morocco and Tunis. Only small areas of saline soils occur in Europe.

In Asia, saline soils are most extensive in Turkistan, Pakistan, northern India, parts of Turkey, Russia, China, Iran, Iraq, Syria, Palestine, Tranjordan and Lebanon, and in Asia Minor, all have extensive areas affected by salt. Much of Australia has an arid climate and salt accumulation is extensive (36).

At the present time, salt deposits are accumulating in every continent. They are distributed in two great belts; one in either hemisphere and lying approximately between 15^{o} and 35^{o} from the equator.

The conditions required for their formations are basically that of loss of water by evaporation when it exceeds the sum total of rainfall and surface water. The main factors influencing this balance are latitude, altitude -- both of the area in question and of the surrounding district winds and ocean currents and distance from the sea. The latitude and altitude of an area more or less determine its mean annual temperature. At sea level, this raises from below zero at the poles to about $30^{o}C$ at the equator.

The fall in temperature with height averages $1^{o}C$ for every 180m. The ability of air to accomodate water vapor is determined solely by temperature. At $0^{o}C$, 4.88 gm. of water vapor are required to saturate each cubic meter of air; at $10^{o}C$ this value rises to 9.37 gm.; at $20^{o}C$ to 17.18 gm.; and at $30^{o}C$ to 30.18 gm. At $50^{o}C$ the vapor pressures of water over a saturated sodium chloride solution and a saturated magnesium chloride solution are 93, 70 and 58 m.m. Hg. Hence, the more concentrated the brine, the more slowly it evaporates. For this reason, very soluble salts only precipitate extensively in hot arid regions. But temperature alone is not the critical factor in determining whether evaporites will form. Coasts with a prevailing onshore wind usually receive abundant rainfall but the farther one goes into the heart of continents the drier it becomes. Nearer the equator, eastern shores enjoy a heavier rainfall. For any given area, the rainfall always tends to increase with altitude (temperature falls). Even in the midst of the Sahara and Tibesti ranges there are regular seasonal (summer) rains. If a mountain range is very high, however, the belt of maximum condensation may not extend to its top for the quantity of water vapor remaining in cold air rapidly decreases. In the Himalayas and adjacent ranges, for example, maximum precipitation occurs at between 4,000 and 10,000 feet above sea level. But above that level, temperatures are mostly too low for extensive salt deposits to form. The tendency for evaporites to form then depends primarily on the relationship between temperature and rainfall. Temperature decides whether areas with a low rainfall are hot steepes and deserts, cold snowclad wastes, or grassland. Conversely, evaporites may form in areas with an annual rainfall of more than 25 inches (13).

Wind is another factor influencing evaporite precipitation, for wind affects the rate of evaporation. Moreover, brines may be carried inland for long distances by clouds and then dropped to give rise to cyclic salts. The most famous example of wind transport is provided by the white sands of New Mexico. There gypsum dunes up to 10 m. high cover an area of more than 250 square miles. A similar Australian climate influences the formation of salt deposits indirectly insofar as it controls the nature and amount of vegetation in the area. Apart from influencing the rate of evaporation of surface waters, all plants concentrate salts within themselves to a variable degree. Potash, soda and other salts may be concentrated. The potash content of plant ash varies between three and 34 per cent depending on the species involved. On the other hand, if the plants actually extract their water from the lake, then the salt content of the lake water is reduced and evaporite precipitation may be prevented. Thus, the waters of Lake Chad, a basin of inland drainage in the hot arid zone of the south Sahara remains fresh because of the abundance of reeds in its shallow waters. The salts from plant remains is incorporated into humus and thus not released back into the lake.

In arid areas, ground water may be carried up towards the surface by capillary attraction, evaporate and precipitate its dissolved salts. Usually these salts form a crust a little way below the surface. Such crusts do not form well in exceedingly arid areas where little water is available, but will form in porous surface deposits in moderately arid regions.

The rate of precipitation is also directly proportional to the salt concentration of the inflowing water. Here, the solutions are of marine origin and saline, or where much preliminary concentration has taken place in rivers, salts can accumulate relatively rapidly (13). The most distinct annual banding forms in relatively small basins adjacent to land areas whose rainfall is seasonal and a layer of "Thermophilic" halite may develop in the summer. This layer merges gradually into a winter deposit of "cryophilic" sylvite and primary carnallite. The contact between this winter bed and the overlying clay-dolomite-anhydrite bed is sharply defined and truncated because of an intervening phase of non-deposition and partial resolution.

Clay-marls or argillaceous dolomites denote the influx of water carrying much suspended clay and dissolved bicarbonates of the alkali earths (13). The composition of non-marine evaporites is much more variable than marine evaporites, for it depends to a varying degree upon climate and the nature of the rocks exposed in the catchment area. Nevertheless, carbonates and sulphates predominate. Surface streams carry and deposit mainly calcium sulfates where the climate is more arid. In deserts, ground water drawn up by capillary action precipitates predominantly sodium and potassium chlorides.

As Figure 1 shows, the deposits formed by ground waters vary in the following order:

From the deeply weathered tropic zone to the salt steppes, limestone, limonite gypsum, glaubers salt + halite, and finally more or less pure halite (13).

Table I as Chebotarev (6) reported is reproduced here in somewhat simplified form and provides the best indication of different types of salts which must form under different climatic conditions. Water flowing from humid areas will on concentration give rise first only to limestone or dolomitic limestone. Further evaporation usually produces soda lakes of the type found in shallow depressions. $\overset{++}{Ca}$, $\overset{++}{Mg}$, and $H\,CO_3$ are all less important in arid regions. The sulphate ion now predominates with $Na_2\,SO_4$ as the most common salt component (6).

Formation of Saline Soils. The rate of formation of soluble salts in a soil is decidedly influenced by the nature of the parent material, the total salt content to be dependent mainly upon rainfall (27). In actual accumulation of soluble salts climatic factors are more important than any other, the parent materials having comparatively little influence over the same (32). This had also been previously borne out by the results of experiments of Lipman and Waynick (26) who determined the salt contents of soil blocks brought from one locality and kept them in different localities under different climatic conditions. They observed that soil blocks showed increases in salt contents. Decrease in salt contents of soils under increased rainfall had been found to be due to greater leaching (37). There is close relationship between temperature and many important soil properties (17). Rise in temperature increased the solubilization of soil material and evaporation of moisture while rise in temperature indirectly acted against the leaching out of soluble salts (11). The effect of annual rainfall and temperature on salinity of 43 virgin soil profiles collected from different areas has been determined. The annual rainfall is the predominant factor in determining the salinity of the surface soils. The effect of annual temperature is evident in the case of the profile average salinity, though the effect of rainfall is much more apparent than the effect of temperature.

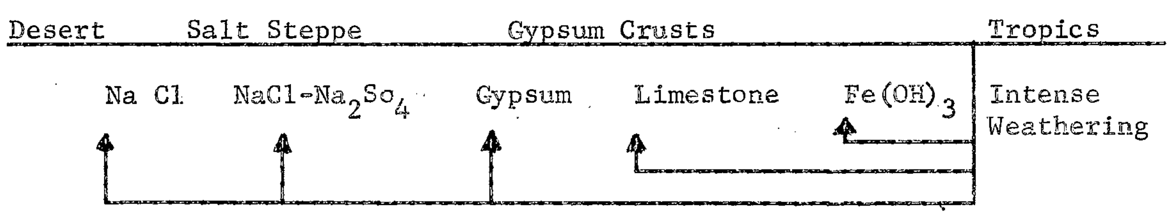

Figure 1. Simplified Scheme of Relationship Between Composition of Ground Water, Precipitation and Climate (13).

The combined effect of annual rainfall and temperature on the surface and profile average (Table II) salinities of soils can be expressed by the equations: $\log_{10} S = 2.935 - 0.4101 \log_{10} R + 0.0031T$ and $\log_{10} Sp = 1.5890 - 0.6412 \log_{10} R + 0.0853T$ respectively, where S and Sp are the surface and profile average salinities of soils in mg. per

100 gm. of soil R, the average annual rainfall in mm. and T the average annual temperature in degree C.

TABLE I

RELATIONSHIP BETWEEN BRINE COMPOSITION AND CLIMATE (6)

Type of Water	Environment	Relative Abundance Cations	Anions	Hydrochemical Factors
River and Lake	Humid-Continental	$Ca > Mg > Na+K$	$HCo_3 > Cl > So_4$	low salinity
		$Na+K > Ca > Mg$	$So_4 > Cl > HCo_3$	high salinity
	Humid-Subtropical	$Na+K > Ca > Mg$	$So_4 > HCo_3 > Cl$	low salinity
			$HCo_3 > Cl > So_4$	high salinity
	Steppe	$Ca > Na > K > Mg$	$HCo_3 So_4 Cl$	low salinity
		$Na+K > Ca > Mg$	$So_4 > Cl > HCo_3$	high salinity
Ground-Water	Desert	$Na+K > Ca > Mg$	$Cl > So_4 > HCo_3$	arid
	Active Circulation	$Na+K > Ca > Mg$	$HCo_3 > Cl > So_4$	low salinity
			$Cl > So_4 > HCo_3$	high salinity
	Restricted Circulation	$Na+K > Ca > Mg$	$Cl > HCo_3 > So_4$	at all salinities
	Stagnant Conditions	$Na+K > Ca+Mg$	$Cl > So_4 + HCo_3$	at all salinities

TABLE II

TOTAL SOLUBLE SALTS OF THE SOILS AT THE SURFACE AND AS AVERAGE OVER THE PROFILE (26)
(Expressed as mg. per cent)

Surface Salinity S	Profile Average Salinity Sp.
46	30
25	24
129	454
110	15
28	24
43	44
39	46
68	93
70	52
68	44

The relationships of surface and profile average salinities with rain factors of soil localities can be expressed in the equations, $\log_{10} S = 2.3832 - 0.3623, \log_{10} F$ (1) and $Sp = 437.8523 - 200.2042 \log_{10} F$ respectively, where S and Sp are surface and profile average salinities in mg. per cent respectively and F is the rain factor. Rainfall seemed to have a more predominant effect in determining the salinity of a soil than temperature (26).

Studies of geological formations show that wherever soluble salts are present in very large amounts they originated from material deposited from concentrated salt waters of some ancient arid climate sea. Some arid-climate soils that are free from excess salts before cultivation have been rendered non-productive by the use of irrigation water containing excessive quantities of salts. Water that comes from the melted snow and rains on mountain areas of salt-bearing rocks contains appreciable amounts of salts.

Salts continue to accumulate in soils of irrigated areas where greater amounts are brought in than are removed. Irrigation waters contain from 1/10 ton to five tons of salt per acre foot of water. Some irrigation farmers apply only two feet of water per season; others, where the summers are long and hot, apply up to five feet of water or more. Where drainage is not provided the irrigation water may add as much as one to ten or more tons of salt each year to an acre of land. The most effective method for the removal of salt from soil is by means of water which passes through the root zone of soil, but if the amount carried away is less than that brought in by irrigation water, salt will accumulate. To prevent salt accumulation and consequent decrease in crop yields, irrigators must remove as much salt as is brought in. In some areas an effort is made to spread limited irrigation water supplies over too many acres with the result that the soil is not wetted below a depth of a few feet. In other areas, the ground-water table is so close to the surface as to retard or prevent the leaching of the salt from the root-zone of soils. In lands having shallow water tables the upward flow of saline ground water results in a continuing accumulation of salt in the surface soil (16).

Clarke (7) has estimated that the average chlorine and sulfur content of the earth's crust is 60.06 and 0.12 per cent respectively, while the cation constituents each occur to the extent of two to three per cent. Water containing carbon dioxide is a particularly active chemical weathering agent which releases appreciable quantities of the cation constituents as the bicarbonate salt constituents are of most importance in saline soils.

Weathering of primary minerals is the indirect source of nearly all of soluble salts. Saline soils usually occur only in those areas which receive salt from other areas and water is a primary carrier (8).

The ocean is also the source of the salts in the saline soils which are found along the margin of the sea coasts. More commonly, however, the direct source of salts is salt-bearing surface and ground waters. All of these waters contain dissolved salts, the concentration depending upon the salt content of the soil and geological materials with which they come in contact. These waters act as sources of salt when used for irrigation (34).

Salinization of soils occurs under conditions which favor the accumulation of the soluble salts, and take place through the medium of water. Owing to their solubility in water, salt constituents are readily transported by its movement and are deposited in the soil or on its surface when the water evaporates. The drainage of salt-bearing waters away from high areas of the basin may raise the water table near to the surface on the lower flat areas or may even cause temporary flooding from permanent salty lakes.

Upward movement of the saline ground water or evaporation and concentration of surface waters result in the formation of saline soils. Low soil permeability causes poor drainage by impeding the downward movement of water. Low permeability may be due to an unfavorable soil texture or structure or to the presence of indurated layers. The latter may consist of a clay pan, a caliche layer or a silica hard pan.

Although saline soils occur extensively under natural conditions, it appears that the salinity problem of principal economic importance arises when previously non-saline soil becomes saline as the result of irrigation. Irrigated lands are often located on the low lying alluvial soils which occur in the valleys adjacent to streams.

When bringing new lands under irrigation, settlers have frequently failed to recognize the need for establishing artificial drains to care for the additional water and soluble salt. As a result, the ground water table may rise from a considerable depth to within a few feet of the soil surface within a short span of years.

While the water table is still at a considerable depth, the excessive use of water keeps the plant root zone essentially free of soluble salts; but, when the water table rises within five or six feet of the soil surface, ground water moves upward into the root zone and the soil surface. Under such conditions, ground water as well as irrigation water contribute to the salinization of the soil (8).

Saline soils are those where the conductivity of the saturation extract is more than four millimhos/c.m. and exchangeable sodium percentage is less than 15, ordinarily, the pH is less than 8.5. These soils correspond to Hilgard's "white alkali" soils and to the "solonchaks" of the Russians. When adequate drainage is established and the soluble salts are removed by leaching, they again become normal soils (14).

Relation of Conductivity to Salt Content and Osmotic Pressure of Solutions. The relation between conductivity and salt content for various solutions change the relation of conductivity to m.e./l for solutions of salts which commonly occur in soils. It is seen that the curves for the chloride salts and NA_2SO_4 almost coincide, but M_gSo_4, Ca So_4 and $NaHCo_3$ have much lower conductivity than the other salts at the same equivalent.

When the concentration is given in per cent salt or ppm, the curves as shown in Figure 2 are more widely scattered.

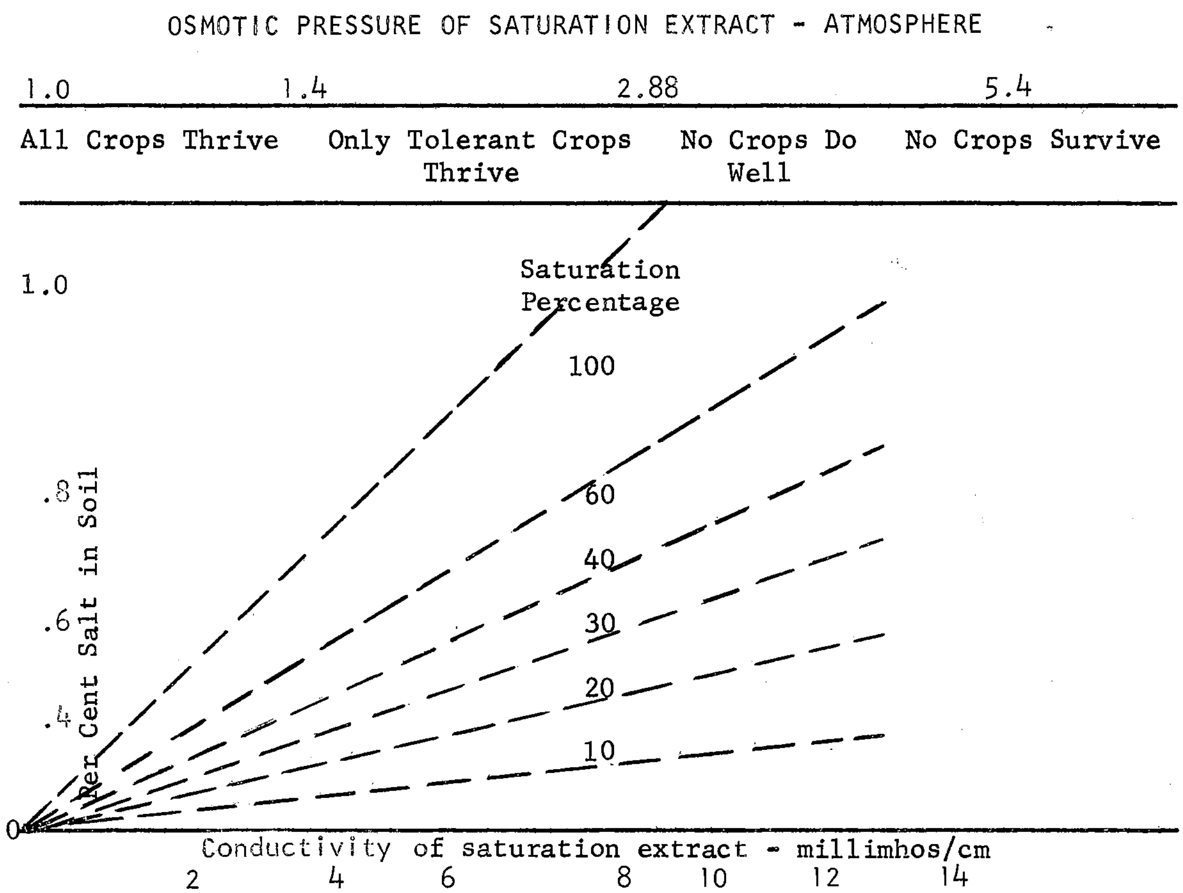

Figure 2. Representation of the Relation of Crop Growth to the Conductivity and Osmotic Pressure of the Saturation Extract and to the Per Cent Salt in Saline Soils (36).

Figure 2 shows the relation of conductivity to concentration in m.e./1 for surface stream and well water from widely separated sources. It seems that the concentration in m.e./1 is approximately ten times conductivity when the latter is expressed in millimhose/cm.

Experimental work conducted shows that the osmotic pressure of the soil solution is closely related to the rates of water uptake and plant growth in saline soils (8).

Movement of Salt in Soils. If it were possible to maintain a moisture distribution in irrigated soils such that water flow would be continuously downward there would be relatively little trouble from salinity on irrigated farms. A continuous downward flow of water with adequate drainage would gradually decrease the soluble salts in the upper few feet of soil in which plants obtain most of their moisture and nutrient elements. However, in the absence of adequate drainage, downward percolating waters fill the lower soil spaces and cause the water table to rise. During periods between irrigations, a high water table favors the upward capillary flow of water to the land surface where it evaporates (16).

The soluble salts carried by the upward moving water cannot be evaporated, hence, they are deposited on or near the soil surface. Salts so deposited may come from soil horizons well below the surface that contain high percentage of salts. The mere concentration on the surface of the salts that normally occur distributed through the upper few feet of soil may cause serious salinity.

The influence of a rising water table on the upward capillary flow is analogous to the influence of making a canal grade steeper and steeper, both cause an increase in the velocity of the flowing water.

The position of the water table influences the hydraulic slope and hence the upward flow of soil water. A high water table increases the moisture content of the unsaturated surface soil and thus increases the moisture permeability and the quantity of flow. The soluble salts are held near the surface of the body of ground water where they may readily be drawn by upward capillary flow to the soil surface and there deposited as the water evaporates. As the water lowers, some of the salts in the free water are retained by the soil so that the free water gradually becomes less saline. The kind and quantity of salts in the soil solution usually differ from those found in the free ground water or from the alkali incrustrations on top of the soil. Because of differences in solubility certain of the soluble salt ions are absorbed by the soil, while others move somewhat more freely. Calcium sulfate may be abundant in the soil solution with magnesium sulfate second, while sodium sulfate forms much of the surface salts and the salts next to the surface. Sodium chloride does not separate as readily as some of the other salts. Irrigation farmers sometimes urge the advantages of keeping the water table within a few feet of the soil surface because of the high crop yields obtained during the early years after it has risen from great depths. The favorable moisture supply from a water table near the soil surface may cause high crop yields, but as a rule, in areas where alkali salts occur, the temporary favorable condition of the high water table is followed by serious decrease in yields, if not by complete nonproductivity due to salt concentration (10).

Reducing Evaporation. The most important single step in reducing evaporation from irrigation soils is to keep the water table well below the land surface either by efficient application of irrigation water or by drainage, or both. However, certain additional factors tend to favor excessive evaporation, of which the following are noteworthy:

1. Unduly frequent irrigation, thus keeping the surface wet during a proportionately long time.

2. Direct exposure of the land surface to sunlight by lack of cropping. As a rule on all irrigation farms the irrigator should fully moisten the soil to the depth from which plant roots have taken the moisture previously in the soil.

This depth ranges from two to six feet approximately, depending on the crop and the texture, structure and depth of the soil. In the management of saline and alkali soil it is important to moisten the soil at each irrigation to the full depth that it needs additional moisture, in order to reduce the frequency of irrigation and thus reduce the upward flow and evaporation of water (16).

The soluble Na percentage of water is important because a high proportion of Na in irrigation water results in a high proportion of Na in the soil solution. If the soluble sodium percentage is less than 60, trouble from excess sodium on the soil will not usually occur. But, if soil naturally has good structure and permeability, it may not give any trouble even if its sodium percentage is as high as 75, in the irrigation water. This is providing the total salt content is low (38).

Salt accumulation on the soil surface and in the root zone is the result of capillary flow of water upward from a saline shallow ground water zone. Salt deposition and concentration of the soil solution occur when this water evaporates or is transpired by plants to the atmosphere. The saline nature of this ground water may be due to the dissolution of salts from lower soil zones. In most cases, salts are dissolved and transported in the course of ground water flow from higher land to lower areas and deposited to points where conditions for discharge to the soil surface are favorable. The source of this ground water may be influent seepage from canals, irrigation or natural precipitation (1).

TABLE III

PRELIMINARY MEASUREMENTS (38)

Nature of Soil	Conductivity of Sat. Ext. millmhos/cm.	Exchangeable Sodium %	pH
Saline	4 or higher	less than 15	usually less than 8.5
Saline-Alkali	4 or higher	15 or higher	usually greater than 8.5
Non-Saline-Alkali	Less than 4	15 or higher	- - - - - - -

The principle governing the flow of ground water was expressed by Darcy (Darcy H. Paris, 1856) (1). It specifies the relationship between ground water velocity, soil permeability and hydraulic gradient.

V = KI where v = velocity of flow L/T

K = permeability L^3/L^2T

I = hydraulic gradient (no dimension)

For quantitative evaluation of ground water flow may be made in the form Q = KIA, which is a derivation of the basic hydraulic formula

Q = VA, where Q = rate of flow (L^3/T), A = area through which flow occurs (L^3) (1).

<u>Movement of Water and Salts Solutes in Unsaturated Soils</u>. Recent studies of soil-water relations in saline and alkali soils include the investigations of hydraulic head and soil moisture tension. Evaporation causes an accumulation of salt at the surface of saline soils following irrigation or leaching operations.

To study the hydraulics of this process, a multiple tensiometer has been developed so that hydraulic head values can be conveniently read at five equally spaced soil depth intervals down a soil tube hole in a soil profile. The vertical component of the hydraulic gradient and the direction of flow of soil water is thereby directly indicated by the manometer scale readings. Following flood irrigation, it is found that there is a "static zone", that is, a zone more or less parallel to the soil surface and in which hydraulic gradient is zero and the soil water is at rest under gravity.

Above the static zone, water movement is upward because the tension gradient force that is established by surface evaporation exceeds the gravity forces.

Below the static zone, flow is downward. Moisture supply to plants on saline soil involves intensity and extensity aspects. Intensity is evaluated in terms of the sum of soil moisture tension and osmotic pressure. The extensity aspect involves the capacity of a soil profile to retain water that is available for plant use, which can be expressed in terms of "depth percentage". The equivalent depth of free water/100 units of depth of soil.

The available water, which is the difference between the upper and lower limits, can thus be expressed in term of depth percentage at each measuring depth.

The depth of available water in each textural zone in a profile is obtained by multiplying the available range expressed in depth percentage by the thickness of the zone and dividing by 100. The available depth percentage for a fine sandy loam may be 25, for a silty clay may be 15, 15 cm. depth of available water for 100 cm. depth of soil. A sand with an available depth percentage of seven requires very frequent irrigation and soils for which the average value of this number over the root zone interval is less than five or six cannot be profitably irrigated by ordinary field methods (28).

Effect of Salinity on Soils. The evidence thus far indicates that the continued injury to plant growth in soils by sodium chloride is to a large extent due to the physical condition of the soil caused by the salt. Laboratory work in the present connection indicates that any salt which raises the alkalinity of a soil about two units or more above normal causes almost instant puddling of the soil. The carbonate and bicarbonate of sodium produced a pH of 9.8 each and the greatest initial degree of puddling. When these soils were leached well with distilled water, their pH dropped to 8.7 and the degree of puddling did not increase (29).

The initial pH of the sodium chloride treated soil was lowered a tenth pH unit by the salt with a degree of puddling considerably less than that caused by the alkaline salts.

A salt puddled soil assumes a porous condition as it dries and becomes hard; it is then very permeable to air. However, as soon as such a porous piece of soil is wetted, it disintegrates into single grain soil, or nearly so, almost at once. Such soil disperses most completely when the soluble sodium becomes all but absent from the soil and the exchange sodium is high.

In addition to the loss of the usual exchangeable elements, potassium is lost in large amounts and sodium liberates silica and also organic matter.

Some soils are known which have excellent physical conditions and at the same time contain more exchangeable sodium than do some soils of the same types in the same area which have poor physical conditions. This situation is quite prevalent in some long established oil fields.

Salt peptizes organic matter which is lost by leaching (29). Consequently, the volume weight of the soil is increased. Organic matter which coats individual soil particles acts as a lubricant, increases friability and decreases the volume weight of soil. Further, salt mobilizes extra silica as amorphous or non-crystaline silicic acid in the soil. This substance is believed to act as a cementing material in salt affected soil. The injury that salt does to soil seems to be mainly the peptization of dispersal of the soil particles, such that puddling and induration take place. The theory that the friability of saline soils is closely related to the ratio of calcium to sodium ions is well known, particularly in sub-humid climates.

Large amounts of soluble salts are continually being introduced into the soils of the semi-arid region either as constituents of irrigation water or by capillary rise from the subsoil. The chemical reactions involved are of special interest. The reactions taking place and the specific cations replaced by a given salt seem to depend mainly on the nature and amount of the silicates present and the state of subdivision of the soil (23).

Lemberg (9), Eichhorn (25) and Sullivan (33) showed that salt solutions containing monovalent bases readily react with certain silicates. Salts of divalent bases react with others while neither of these classes of salts reacts with still other silicates. The reactions appear to be of the nature of exchange of bases and are usually reversible although the reaction does not necessarily take place with equal facility in both directions. It is probable that calcium is more easily replaced from the soils than some monovalent bases.

Experiments were conducted with two kinds of soils (light sandy loam and a clay loam) where each was treated with solutions of different salts in ratio of one part soil to five parts solution. Extracts with water were obtained by shaking the soil with carbon dioxide free distilled water in a ratio of 1.5 and the results were reported as in the case of the salt solutions in parts per million of the extracts.

Each of these soils had been cropped with grain for many years without irrigation or the application of fertilizer. As the data show, the solubility of each cation is low (23).

TABLE IV

COMPOSITION OF WATER EXTRACTS OF SOILS (23)
(p.p.m. of solutions)

		Light Sandy Loam Soil No. 1	Clay Loam Soil No. 2
Ca	Calcium	4	6
mg	Magnesium	2	3
k	Potassium	3	6
Na	Sodium	4	4
Cl	Chlorine	2	4
Co_3	Carbonate	0	0
HCo_3	Bicuronate	12	17
So_4	Sulfate	4	7
No_3	Nitrate	1	5
Po_4	Phosphate	3	1
Sio_2	Silica	5	5
Total Soluble Solids		48	93
Ph		7.0	7.1

<u>Effect of Natural Salt Solutions</u>. The effects of 0.01N solutions of sodium, potassium, ammonium, calcium and magnesium chlorides are shown in Tables V and VI (23).

TABLE V

EFFECT OF CHLORIDES ON SOIL NO. 1
(p.p.m. of solution)

	0.01N Solutions				
	NaCl	KCl	NH_4Cl	$CaCl_2$	$MgCl_2$
Calcium (Ca)	18	41	38	175	62
Magnesium (Mg)	6	11	9	16	83
Potassium (K)	10	290	20	13	16
Sodium (Na)	210	5	2	6	8
Chlorine (Cl)	356	350	358	355	356
Ammonia (NH_4)			130		

TABLE VI

EFFECT OF CHLORIDES ON SOIL NO. 2
(p.p.m. of solution)

	0.01N Solutions				
	NaCl	KCl	NH_4Cl	$CaCl_2$	$MgCl_2$
Calcium (Ca)	45	84	80	153	134
Magnesium (Mg)	12	21	19	29	45
Potassium (K)	18	178	34	19	23
Sodium (Na)	174	7	5	14	10
Chlorine (Cl)	360	360	360	359	360
Ammonia (NH_4)			72		

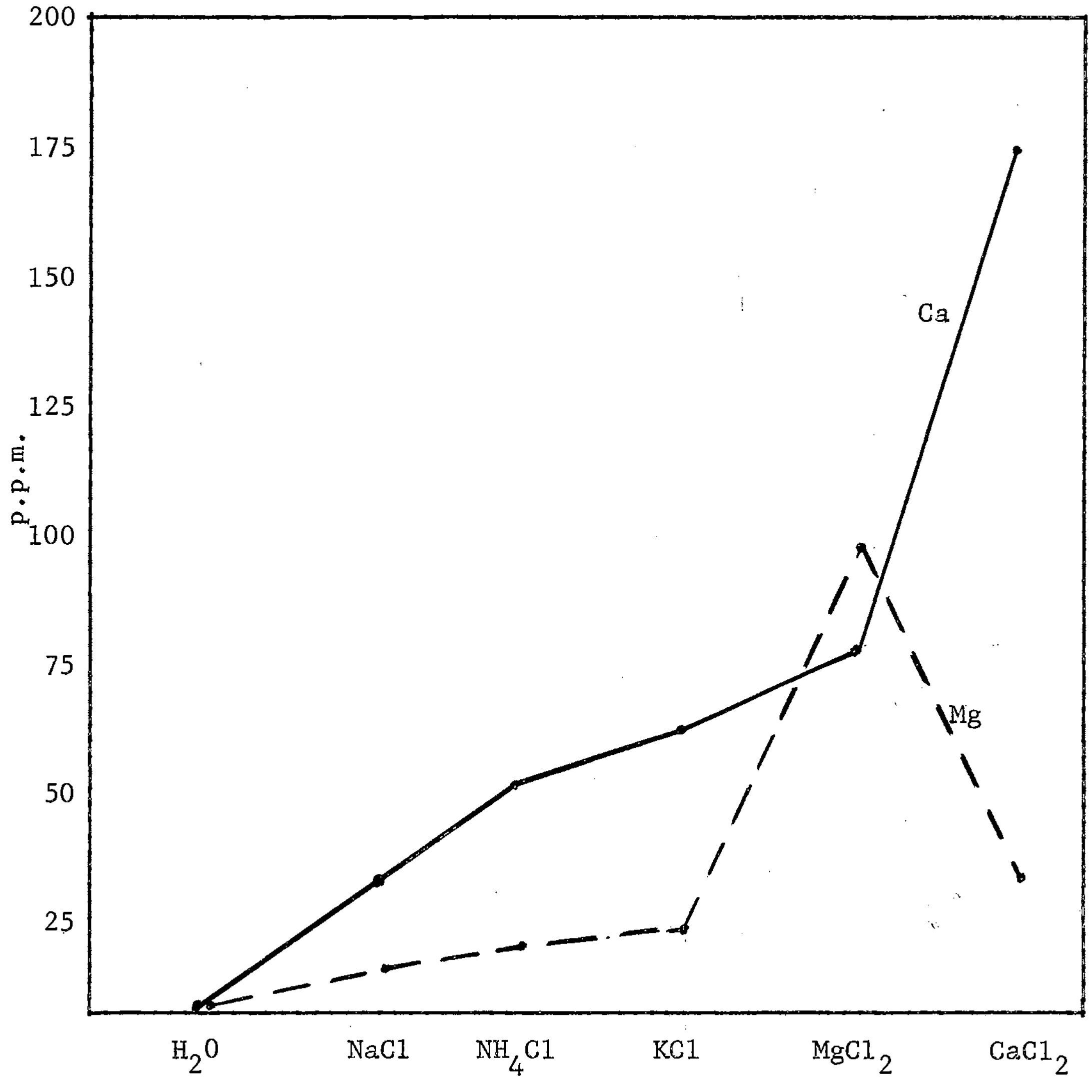

Figure 3. Graphs for Soil No. 1 Showing Ca and Mg Soluble in Water and in 0.01N Solutions of Various Chlorides (23)

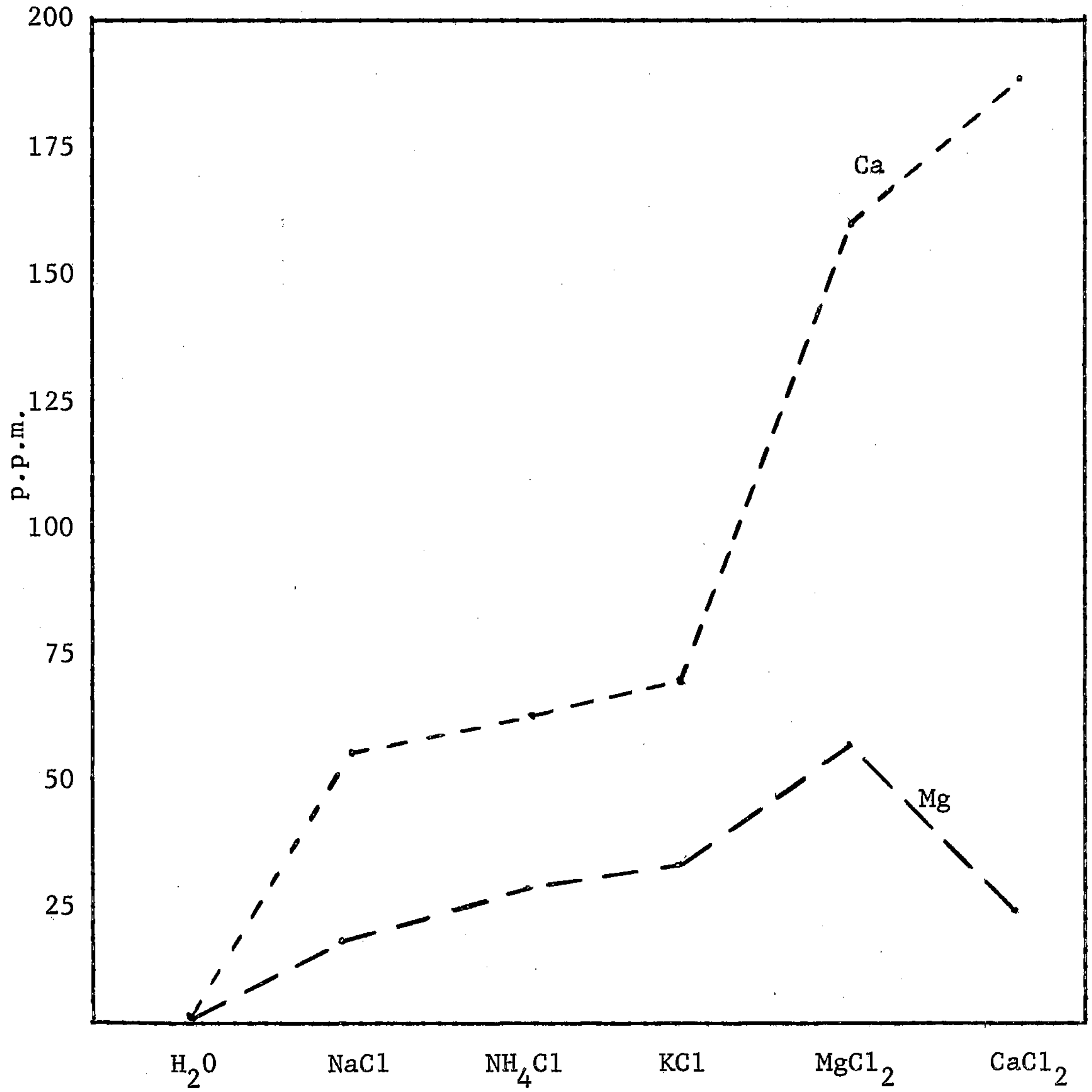

Figure 4. Graphs for Soil No. 2 Showing Ca and Mg Soluble in Water and in 0.01N Solutions of Various Chlorides (23)

The amount of the exchange reactions were considerable with sodium salts the least exchangeable and magnesium salts were the greatest. Calcium is the base most readily replaced in these soils, while small increases in the solubility of potassium and magnesium also were produced by each of the exchange salts.

The effects of potassiu, ammonium, calcium and magnesium salts on the solubility of sodium were variable and in no case very great. The effects of the different salts are especially striking in the case of soil no. 2. Sodium, potassium, ammonium and magnesium salts all replaced substantial amounts of calcium from the soil.

With the use of ammonium salts the extracts were found to contain greater amounts of calcium than ammonia remaining in solution, while with the use of magnesium salts the extracts contained more than twice as much calcium as magnesium. The data obtained by the use of magnesium salts show the extreme importance of considering the reactions in the soil. While magnesium salts in simple solutions are highly toxic, the presence of soluble calcium decreases the toxicity of magnesium.

The data shows that with the use of 0.01N magnesium salts plant roots in soil no. 2 would be in contact with a solution containing an even greater molecular concentration of calcium than magnesium. In this case, it would be more nearly correct to consider the nutrient solution as a calcium solution than as a magnesium solution. In the light of these data, it is self evident that different physiological effects may be expected to result from the use of the same salt on different soils.

It was noted that the more concentrated solutions replaced greater amounts of calcium, magnesium and potassium than the weaker solutions with both soils 0.1N NaCl replaced fully as much magnesium as 0.2N solution, whereas the 0.04N solutions replaced the maximum amounts of potassium. The amount of calcium set free increased with the strength of the solution.

The composition of the soluble salts in soil moisture solutions following the addition of NaCl of varying strengths will differ, not only quantitatively, but qualitatively as well. In other words, the roots of plants under such conditions must come in contact with solutions containing varying amounts of other ions as well as sodium.

It is reasonable to infer, therefore, that treating a soil with a salt solution not only brings about changes in the liquid components of the system represented by the soil. If a soil be subjected to prolonged contact with sodium or magnesium salts and provision at the same time be made for removing the soluble products of the reactions, such as afforded by leaching or by the growth of crops, the reaction will continue until ultimately a greatly changed chemical system will result.

Effects of Total Salt on Soil. In soil studies, it has been customary to report salt concentration on a weight basis, or in terms of parts per million parts soil. Salt characteristics affecting osmotic pressure also affect the capacity of solutions to carry electric current. Consequently, measurement of conductivity of soil solutions is a better guide to crop yields than is a determination of the weight of salt per cent. Direct measurement of osmotic pressure of soil solutions are too laborious for use in routine soil testing.

Since so much published data on salt toxicity are expressed as percentage or as parts per million (ppm), conversion to equivalent (36) weight values may be of some aid in interpretation. This is done by dividing the ppm for any salt by the equivalent weight (e.w.) of the salt to give the equivalent per million.

$$epm = \frac{ppm}{ew}$$

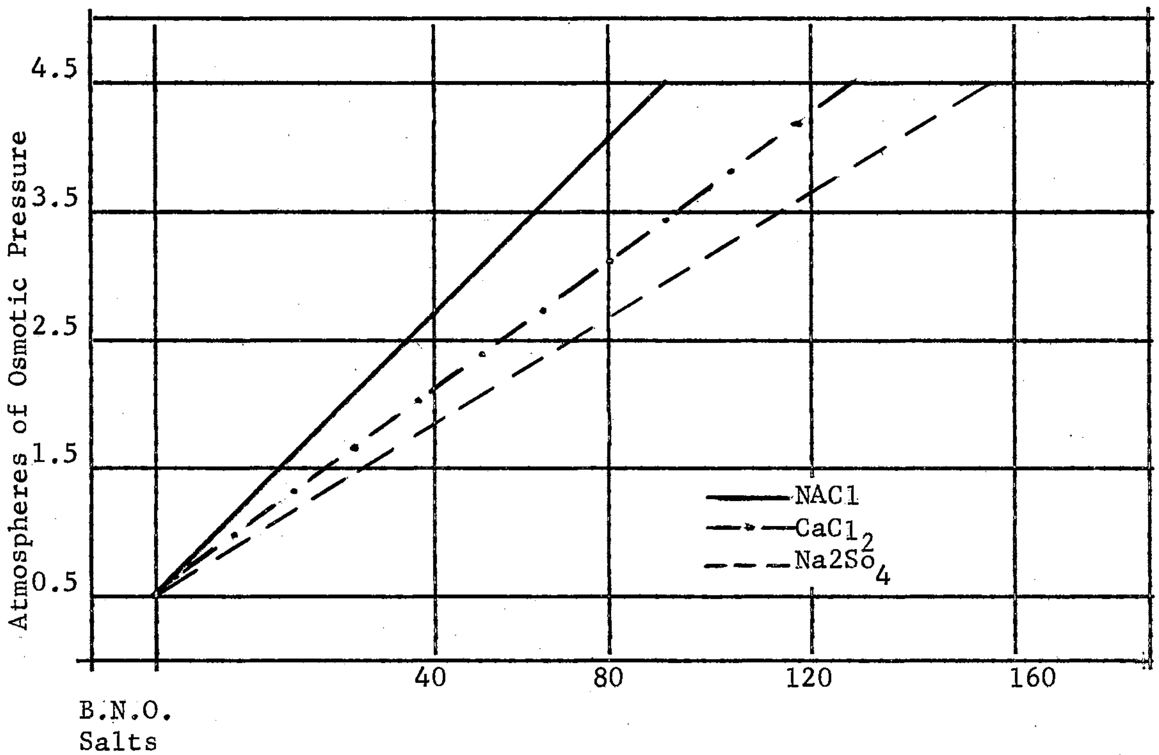

Figure 5. M.E. Per Liter of Salt Added to Base Nutrient (36)

The relation between salt expressed on a weight basis in soils and that in the soil solution can be calculated as epm in the soil solution $= \frac{100 \times \text{epm in soil}}{\text{per cent water in soil}}$. A large quantity of salts seems to keep the soil colloids flocculated so that the soil may appear to be in a desirable granular condition. As the excess salts are leached out and the soil approaches an alkaline condition the effect of salt becomes apparent.

With the removal of excess salts some of the exchangeable sodium hydrolyzes raising the soil pH, the clay swells and becomes deflocculated, and drainage and aeration are impeded.

Degrees of Salinity. Degrees of salinity of soils where salt troubles have developed may be expressed as percentage of soluble salts in the root zones (15). Some authorities consider soils as non-saline when they contain less than 0-2 per cent of soluble salts. In as much as one acre foot of soil weighs about four million pounds. A 0-2 per cent salt content would mean the presence of about four tons of soluble salts in each acre foot of soil.

Kearney and Scofield (21) used the following terms and percentages to designate different degrees of salinity in root zones:

Salinity designation	Salt content per cent
Excessive	More than 1.5
Very strong	1.0 - 1.5
Strong	0.8 - 1.0
Medium strong	0.6 - 0.8
Medium	0.4 - 0.6
Weak	0.1 - 0.4
Negligible	Less than 0.1

The majority of soils have a low salt content in the upper part of the profile and if salts occur they are in the lower horizons. Most of the A horizon sampled contained less than 0.1 per cent. The mode distribution of soluble salts in the B horizon is between 0.01 and 0.1 per cent. The frequency distribution of soluble salts is plotted for the upper C horizon and for C horizon below five feet.

As gypsum is one of the principle salts present the limit of its solubility in the 1:5 soil:water suspensions is about one per cent of the gypsum in the soil. About 0.2 - 0.5 per cent sodium chloride is present in most of soils high in salts and so the 0.9 per cent mode should be significant. Typical soluble salt profiles for various soil types, will show a zone of soluble salt accumulation at a depth of 15 - 20 inches for the red-brown earths and in the marginal red-brown earths it is fairly regularly present at about 27 - 30 inches. The soluble salt profiles of gray and brown soils of heavy texture show the zone of maximum soluble salt accumulation in the vicinity of 30 - 40 inches (19).

Moisture equivalent and permanent wilting percentage or wilting coefficient as preferred by some are two moisture values that are used extensively in irrigated agriculture, particularly in semi-arid regions. Each of these values represents degree of wetness that is comparable for each of variable texture (5).

For example the wilting percentage may be as low as two per cent in a sandy soil and as high as 30 per cent in a clay soil, but in both soils the percentages represent a moisture content at which moisture absorption by the plant falls behind transpiration to such a degree that the plant becomes permanently wilted.

The moisture equivalent is an arbitrary soil moisture percentage at which all soils are equally wet, and it can be rapidly and accurately determined. The wilting percentage is closely related to a soil moisture stress of 15 atmospheres, to Schofield's pF 4.2 for water in soil, and to the freezing point of soil moisture. If a quantity of salt is present in the soil solution, the increased osmotic force will restrain water absorption by plants and salinity should influence wilting.

Salinity affects pF of soil moisture at the wilting point but to a much smaller degree than at the moisture equivalent. With addition of increasing amounts of soluble salts to a soil a total soil moisture stress of 15 atmospheres will occur at increasing soil moisture percentages. The amount of moisture available between field capacity and total soil moisture stress of 15 atmospheres will decrease with increasing salinity.

Use of the freezing point method to study moisture stress in relation to wilting for a group of soils in which the conductivity of the saturation extract varied between 0.65 and 5.40 mmho/cm. Kearney (21) used wheat plants to compare the wilting percentage of soil by the direct plant method and by the indirect method as calculated from the moisture equivalent. The wheat seedlings were planted in glasses of soil. The moisture equivalent of soil was 25 per cent. The salinities were all within the range of 0.18 and 0.76 per cent soluble salt.

In a sunflower test the plant is grown in 600 g of soil and when it shows evidence of wilt it is placed in a darkened moist chamber to test its ability to revive. This is repeated until permanent wilt is obtained. The wilting percentage of the soil is largely governed by the thickness of the moisture film around the particles in close proximity to the roots and it must be recognized that the absorbing zone of the root does not include the entire length of the root. When the root is drawing water from the soil particles with which it is in contact, the water used must be replaced from the surrounding soil with sufficient rapidity to meet the transpiration rate.

The importance of root population, root distribution and soil structure and their relation to moisture stress that the plant exhibits is self evident. Wilting symptoms appear to depend so greatly on these and other factors that severe crop injury can occur at moisture percentage well above the wilting percentage. Under field conditions it is more practical to recognize a wilting range rather than a wilting percentage and under such conditions a calculation of wilting percentage from the moisture equivalent should be satisfactory for many purposes.

Presence of salt in soils causes a reduction in microbiological activity particularly in reducing ammonification and nitrification. The effects of salts on microbial processes are highly variable or are highly dependent upon experimental procedures. A "toxic level" of salts on the nitrification process as determined by various workers shows that Na_2So_4 is either the least or the most toxic of salts listed.

It appears probable that the inconsistencies lie in the moisture regime of the sample during incubation and the failure to relate concentration data to osmotic values (20).

TABLE VII

INFLUENCE OF VARIOUS SALTS ON NITRIFICATION (20)

Investigator	Compound	Toxic Level, % Salt in Soil on a Dry Weight Basis
Lipman	Na_2Co_3	0.025
	Nacl	0.10
	Na_2So_4	0.35
Greaver et al	Nacl	0.152
	Na_2So_4	0.0095
Brown and Hitchcock	Nacl	0.01
	Na_2So_4	4.14
	$MgSo_4$	0.30
Greaves and Lund	Nacl	0.023
	Na_2So_4	0.00016

Even so, the low concentration of Na_2So_4 claimed to be toxic are difficult to explain since they do not approach levels where salinity effects should appear. The influence of osmotic tension on nitrification of added ammonium as a function of time in Fig. 6 and data shown in calcareous systems respectively that a decrease in nitrification as a function of osmotic tension and the influence of the three salt systems after three weeks of incubation.

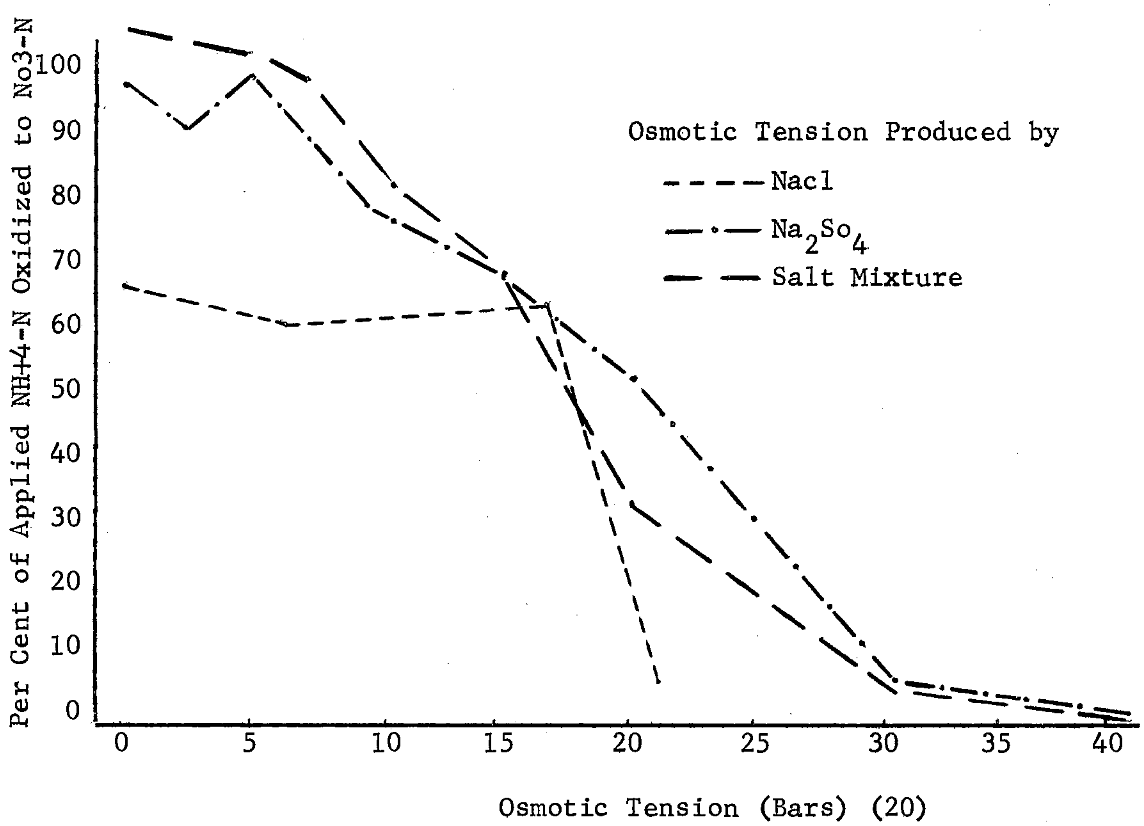

Figure 6. Ammonium Oxidation in 21 Days as a Function of Osmotic Tension in Fort Collins Calcareous Soil

There is an effect due to molecular species. Sodium chloride has a greater depressive effect than Na_2SO_4 in soils, while the salt mixture has an intermediate effect.

In the calcareous systems are less steep or there is a higher degree of tolerance for added salts as shown in Figure 9. At high levels of osmotic tension (20 to 25 bars) the response is similar in both soils and nitrification proceeds at a very slow rate. This indicates a high, but variable degree of sensitivity of the nitrification organism to salts. A difference in the effect of Na_2SO_4 or Nacl on nitrification, that the salt mixture reduced nitrification significantly more in the noncalcareous soil.

Carbon dioxide evolution is often taken as a measure of overall metabolic activity in soil and to represent the activity of the generalized microflora rather than that of specialized organisms such as those which carry out nitrification (20).

The influence of osmotic tension on this process is shown in Figure 7.

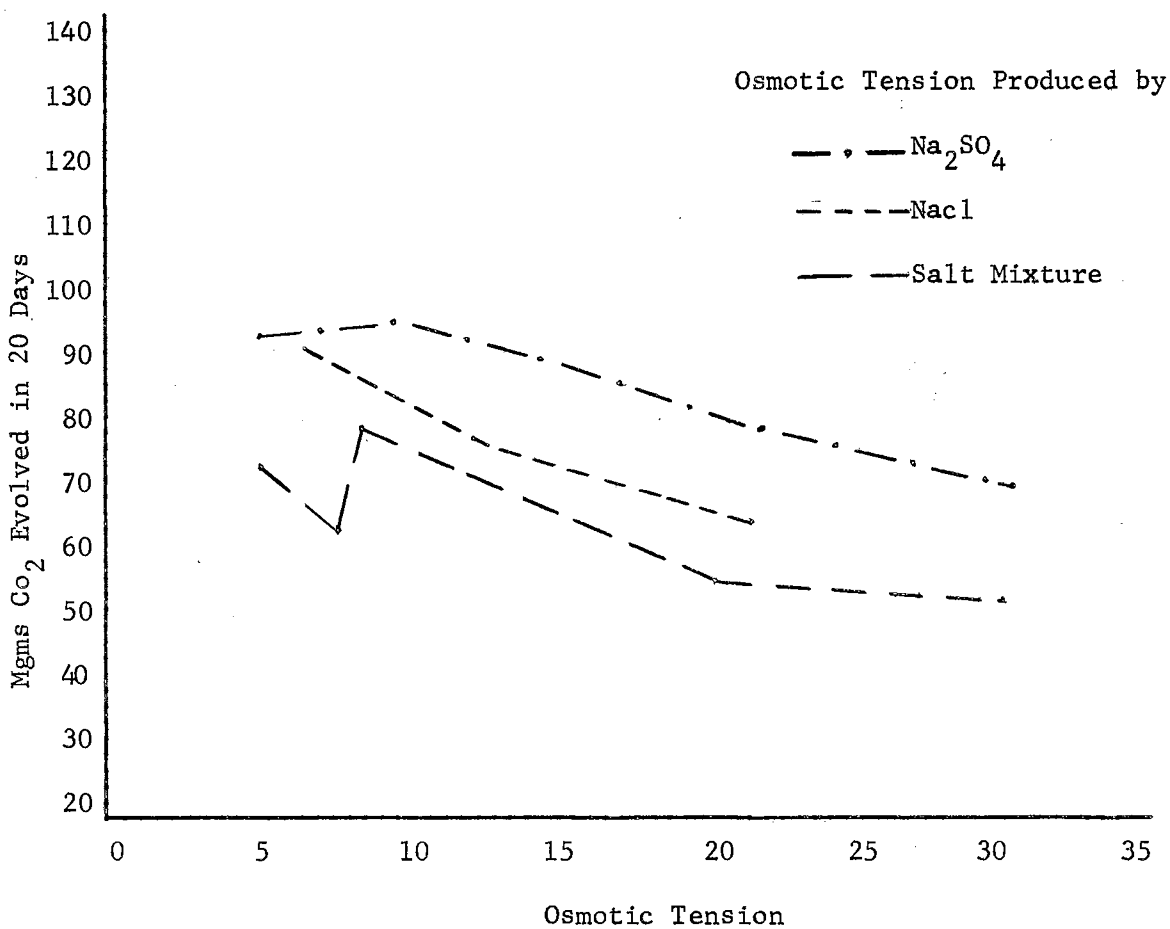

Figure 7. Carbon Dioxide Evolution from the Fort Collins Noncalcareous Soil in Twenty Days as a Function of Osmotic Tension (20)

Carbon dioxide evolution was higher in the noncalcareous soil due no doubt to its higher organic carbon content. There is a less definite influence of the individual salt treatment than in ammonium oxidation.

In summary, osmotic tension reduces nitrate production and Co_2 evolution in a linear manner as the salt concentration of the soil increases.

Effect of Salinity on Plants. In arid and semi-arid regions it is generally recognized that an excessive salt concentration in the soil is detrimental to plant growth (36). It is also commonly accepted that some salts are more toxic than others and that certain plants are able to tolerate higher concentrations. Salts in solutions around roots would reduce or prevent water absorption by plants. A general understanding of plant relations to saline soils must be based on a difference in soil characteristics. Saline soils characterized only by the presence of excess salts in the soil solution differ fundamentally from the alkali soils with high exchangeable sodium, poor physical conditions and frequent high alkalinity in addition to the varying amounts of soluble salts. Sodium chloride has been reported to injure the growth of some crops at about 0.2 per cent concentration in the soil. Under similar conditions sodium sulfate required a concentration of nearly 0.4 per cent for similar toxic effects. In all cases, however, the relative toxicity of one salt alone, or any constant combination of salts has been almost directly proportional to the concentration in the soil solution (36).

Water absorption by plants is a function of the difference between the osmotic pressure of the plant root cells and the sum of the osmotic pressure of the soil solution and the physical tension on it.

Any drastic fluctuation in osmotic pressure in the soil solution would greatly influence water availability.

A general suppression of growth is probably the most common plant response to salinity (excess soluble salt in the root medium). Sodium and chloride ions are among the more common ions found in excess in saline soils and some plant species are quite sensitive to one or both of these ions. With many species, however, the ionic composition seems to be less important than the total amount of salt.

Crop plants differ greatly in their tolerance of salinity. Spinach and the garden beet are highly tolerant and often show a stimulation of growth by levels of NaCl that would be lethal for the pea. The majority of crop plants fall between these two extremes. The physiological basis for such pronounced differences in salt tolerance is not known. Actually very little is known about the effect of salinity on plant metabolism. In suppressing growth salinity must decrease the rate of photosynthate in growth or both of these. It is concluded that in the case of barley, salinity affected the utilization of photosynthate rather than photosynthesis itself. Data on alfalfa and the tomato indicate that the rate of photosynthesis per unit leaf area may actually be increased in salt tolerance in association with a high rate of photosynthesis and a low rate of respiration.

The same effects of salinity on growth and on the rate of photosynthesis and respiration, as indicated by tissue samples, were examined with twelve crop species covering a wide range of salt tolerance (31). Nacl was the salt present in excess in the saline cultures, and plant species were selected which were not specifically sensitive to either ion. Replication was sacrificed in order to include as many different species as possible, growth at the same time and the same conditions. In the absence of replication, only large and consistent effects of salinity have been considered as shown in Table VIII.

TABLE VIII

EFFECT OF NaCl ON RATE OF PHOTOSYNTHESIS BY LEAF DISKS

O_2 production (ml/SQ CM/HR)[1/]

Species	0 atm OP	1 atm OP	2 atm OP	3 atm OP	4 atm OP
Beet	45.7	42.2	45.4	---	45.9
Spinach	63.6	53.6	62.0	56.8	61.0
Turnip	58.4	54.5	57.2	59.2	60.0
Cabbage	58.0	50.2	55.0	60.6	63.4
Tomato	54.4	54.2	53.0	54.2	57.8
Mustard	48.3	47.3	46.1	50.1[2/]	43.3
Lettuce	24.8	33.6	32.4	37.4	35.4
Radish	56.2	60.0	60.8	56.1	56.6
Pepper	47.5	47.5	58.4	57.4	53.6
Bean	24.8	45.1	48.4	41.3	41.9
Onion	34.2	31.6	35.6	33.0	32.8
Pea	44.5	38.3	30.4	---	---

1/ Each value is average 02 production, corrected for uptake of two composite samples containing tissue from four leaves.

2/ Single sample only containing tissue from two leaves (31).

Nacl increased the succulence of leaves (water content per unit area) of all species except onion. It also increased the ratio of water to dry matter in the leaves of most species, the greatest increase occurred in beet and spinach the two most tolerant species.

There was no correlation between salt tolerance and photosynthetic activity per unit area of leaf samples. The activity per unit of chlorophyll, however, tended to be higher in the more tolerant species.

CHAPTER III

MATERIALS AND METHODS

The study was carried out in a constant temperature room. The temperature was maintained at $25^{o} \pm 2^{o}C$. The Norge soil was compacted in columns with an inside diameter of 6.6 cm. Two same soils were compacted in two cylinders to depth of 48 cm. The soil texture used in this experiment (2, 24) was determined by mechanical analysis (Table IX).

The Norge soil was taken from an area that has been used for several years for production of wheat on the Oklahoma State University Experimental Farm at Perkins, Oklahoma.

The Perkins Farm lies in the tension zone between the cross timbers and reddish prairies of Oklahoma. Prairie grasses have developed on the loamy materials. The series soils on this station are representative of those soils developed on mantles within a few miles of the major rivers through central Oklahoma.

The soil has a brown loam surface 15 to 20 inches deep over a brown clay loam subsoil that grades to a strong brown or reddish-yellow sandy clay loam substratum. The substratum becomes more sandy below 36 to 48 inches. This granular well drained unit is inherently fertile responsive to management and highly productive.

Profile:

A_1P 0' - 8" - Brown loam or coarse, silt loam weak medium granular friable soft and crumbly, permeable, PH about 6.0 many pores and pin holes rests with a shear face on the layer below.

Variation:

In areas where wind erosion has removed some of the finer materials, surface textures are fine sandy loams. Locally surface colors are grayish brown. The moisture content of the soil was determined from the oven dried samples of air dried soil (24 hours at 105°C). The pH values of soil was determined by the glass electrode method and the organic matter and exchangeable magnesium, potassium and sodium Mg.K and Na were determined according to Jackson (17), (4) is shown in Table X.

TABLE IX

RESULTS OF MECHANICAL ANALYSIS OF NORGE SANDY LOAM SOIL (PER CENT)

Soil	Clay	Silt	Sand
A_1P (0 - 8")	14%	22%	64%

The experiment was divided into two parts. Part one concerned the effect of water table and evaporation on salt accumulation and transmission. Air dried soil was placed in the cylinder as indicated previously and the 6 mm. sieved sample was compacted in cylinders to a depth of 48 cm. and the moisture content was 1.2 per cent. The surface area of the soil column was 34.2 sq. cm. and the volume of soil was 1640^3 cubic cm.

The soil column was supported in the lucite tube by a perforated

TABLE X

CHEMICAL CHARACTERISTICS OF NORGE SANDY LOAM SOIL

Soil Sample	pH Value	Moisture Per Cent	O.M %	C.E.C. m.e./100 gm.	Exchangeable Cation m.e./100 gm. Mg	k	Na	P.P.M. Soluble Salts	P.P.M. Cl	P.P.M. mg	$E.C X 10^6$ Micromhos/cm.
Perkins											
A_1P 0 - 8"	5.8	1.2	1.2	5.24	1.58	0.037	0.12	176	142	8	82.4

lucite plate and a screen. The bottom of the lucite tube was sealed and a salt solution was used to fill the compartment below the soil. This compartment was attached to a mariotte siphon, which maintained the water table (contain magnesium chloride ($Mg\ cl_2$) 0.4N) 0.5 cm. above the bottom of the soil column and facilitated the measurement of daily water loss. The compacted column was placed on the table. After sixty days the amount of evaporation of soluble salt through the soil to the soil surface was as follows:

1. Amount of water evaporation through soil column . . 1540 ml.
2. Length of soil column . . . . 48 cm.
3. Surface area of soil column . . . . 34.2 sq.cm.
4. Soil volume . . . . 1640 $cm.^3$
5. Amount of evaporation (at 25^{o}C) . . . . 25.6 ml/24 hrs.
6. Rate of water through soil column (capillary) ml. 0.018/min.

Part two was concerned with the effect of irrigated water soluble salt on salt accumulation and transmission. Air dried soil was sieved through a 6 mm. sieve and was compacted in a 6.6 cm. diameter cylinder to a depth of 48 cm.

Soil column was supported in the lucite tube by a perforated lucite plate and a screen. The bottom of the lucite tube was held in a flask and the salt solution was added to the surface of the irrigated soil column. The affluent was collected in the flask and after sixty days the amount of irrigation water and the soluble salt passing through the soil were found to be as follows:

1. Amount of water added to the irrigated soil column . . . . 7345 ml.
2. Length of soil column . . . . 48 cm.
3. Surface area of soil column . . . . 34.2 sq. cm.

4. Soil volume . . . . 1640 $cm.^3$

5. Movement of water through soil column . . . . . 122.4 mL/24 hrs.

6. Rate of water movement through column . . . . . 0.085 mL/min.

Experimental Data. After nine weeks from the start of experiments when steady state conditions could be assumed to have been achieved the columns were cut up into four cm. thick sections and analyzed for soluble salts in sections. The results are shown in Tables XI, XII, XIII, XIV, XV and XVI. Experiment No. 1 shows affect of perched water table on movement of saline water (Tables XI, XII and XIII).

TABLE XI

THE pH VALUE AND ELECTRICAL CONDUCTIVITY OF SOIL IRRIGATED FROM THE WATER TABLE

No.	Depth cm.	pH Value of Evaporated Soil	$E.C X 10^6$ - Micromhos/cm.
1	4	5.2	520
2	8	5.0	824
3	12	5.1	900
4	16	5.0	990
5	20	4.6	1545
6	24	5.0	1238
7	28	5.1	1335
8	32	5.1	2150
9	36	5.7	3800
10	40	5.4	2600
11	44	5.4	2645
12	48	5.6	6180

TABLE XII

TOTAL SOLUBLE SALTS PER 100g OF SOIL AND P.P.M. IN THE DIFFERENT DEPTHS OF THE SOIL COLUMN WITH EVAPORATION OF WATER SOLUBLE SALT FROM THE SURFACE

No.	Depth cm.	Total Soluble Salts/100g of Soil	P.P.M.
1	4	0.82	820
2	8	0.140	1400
3	12	0.184	1840
4	16	0.142	1420
5	20	0.240	2400
6	24	0.186	1860
7	28	0.268	2680
8	32	0.400	4000
9	36	0.476	4760
10	40	0.330	3300
11	44	0.420	4200
12	48	0.682	6820

TABLE XIII

P.P.M. OF Cl AND Mg IN THE DIFFERENT AT DEPTHS EVAPORATION OF WATER CONTAINING SOLUBLE SALT ($Mg\ Cl_2$) AT THE WATERTABLE

No.	Depth Cm	P.P.M. of Cl	P.P.M. of Mg.
1	4	354	12
2	8	709	48
3	12	780	64
4	16	780	60
5	20	1205	106
6	24	1134	94
7	28	1247	224
8	32	2127	660
9	36	2481	552
10	40	2056	588
11	44	2197	800
12	48	3828	508

TABLE XIV

THE pH VALUE AND ELECTRICAL CONDUCTIVITY
OF IRRIGATED SOIL

No.	Depth cm.	pH Value of the Irrigated Soil	$E.C X 10^{6}$ = Micromhos/cm.
1	4	5.6	3882
2	8	5.9	3040
3	12	5.1	3300
4	16	5.1	3805
5	20	5.5	3738
6	24	5.6	3960
7	28	5.8	3600
8	32	5.7	3530
9	36	6.0	3805
10	40	5.9	3530
11	44	5.9	3530
12	48	5.9	3475

TABLE XV

TOTAL SOLUBLE SALTS PER 100g OF SOIL AND P.P.M. AT DIFFERENT DEPTHS IN THE SOIL COLUMN IRRIGATED WITH WATER HIGH IN SOLUBLE SALT

No.	Depth cm.	Total Soluble Salt in gms/100g of Soil	P.P.M.
1	4	0.1204	12040
2	8	0.592	5920
3	12	0.742	7420
4	16	0.818	8180
5	20	0.780	7800
6	24	0.906	9060
7	28	0.782	7820
8	32	0.416	4160
9	36	0.828	8280
10	40	0.764	7640
11	44	0.806	8060
12	48	0.892	8920

TABLE XVI

AMOUNT OF CHLORIDE AND MAGNESIUM AT DIFFERENT DEPTHS IN A SOIL COLUMN IRRIGATED WITH WATER CONTAINING SOLUBLE SALT ($MgCl_2$)

No.	Depth cm.	P.P.M. of Cl.	P.P.M. of Mg.
1	4 cm	4395	1392
2	8 cm	2268	732
3	12 cm	2552	776
4	16 cm	2762	920
5	20 cm	2623	872
6	24 cm	3408	992
7	28 cm	3190	872
8	32 cm	3048	848
9	36 cm	3261	1016
10	40 cm	3190	960
11	44 cm	3190	872
12	48 cm	3421	1050

CHAPTER IV

RESULTS AND DISCUSSION

The results of the first run are shown in Figures 8, 9 and 10 in which the evaporated soil (or perched water table) moisture moved toward the surface shows that the salt contents are different with depths and with increased distance from the water table the amount of accumulation and transmission of salt is decreased.

The movement of water toward the surface and of the salt into the soil was increased with time. Salt is moved up into the soil rapidly from a perched water table when the salts had become more or less uniformly distributed throughout the column and water tended to move toward the surface and become more uniformly distributed. In general, there was more accumulation in the depths of between 32 and 48 cm. of the column although the accumulation was low.

The results of salt accumulation on the irrigated soil are shown in Figures 11, 12 and 13. Here the salt, decreased from the surface downward, increases.

In soils with high moisture contents, high salt concentrations in the top of the column resulted in an accumulation of water at the bottom. After the salt that had diffused downward was more equally distributed throughout the column, more uniform distribution of water through the column was found. An increase in salt content decreases the swelling pressures of a clay and thereby decreases its moisture contents at a given tension.

Thus, high salt contents at the top of the column would reduce the swelling pressure of the soil, the particles would come closer together at the prevailing tension, and the water which lay between them would be pulled to the lower end of the column by the gravitation and the greater swelling (or imbibing) pressure in the lower salt-free soil.

Later the salt content would decrease at the top of the column and increase at the bottom until it would be almost uniform throughout the column (Figures 8, 9 and 10). Under these conditions, swelling (or imbibing) pressures are approximately the same throughout the column and some water would be expected to return to the top of the column.

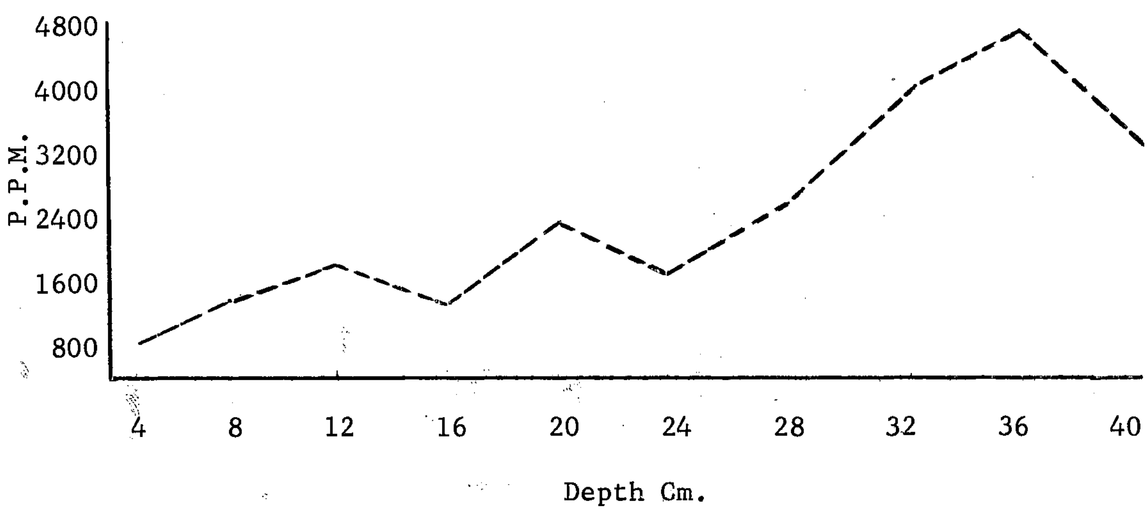

Figure 8. P.P.M. of Soluble Salt in the Different Depths of Soil Irrigated from Water Table

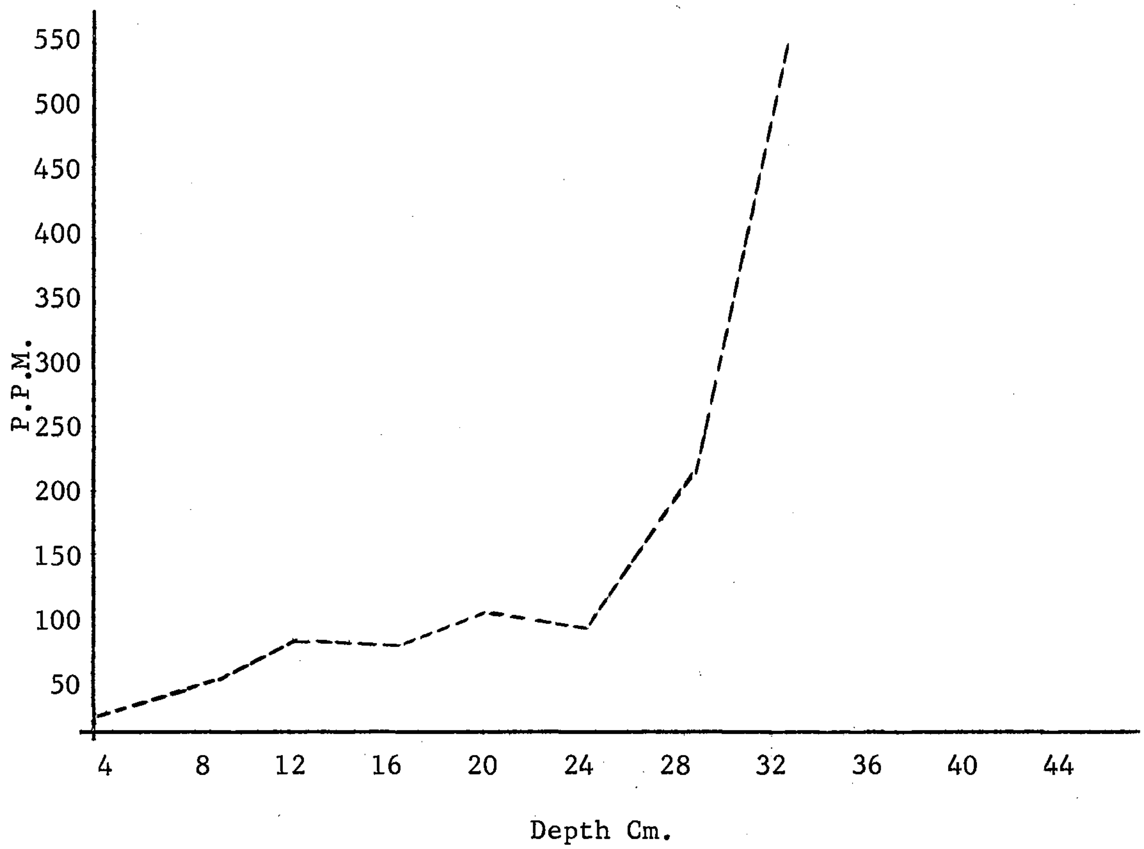

Figure 9. P.P.M. of Magnesium in the Different Depths of Soil Irrigated from Water Table

When the perched water table column was analyzed it was found that there was more salt in the top 36 cm. of soil than at other depths. This difference appears to be explainable in terms of the moisture and salt transmission, and with movement of water through the soil the salt probably accumulated to very high levels in the soil near the surface. Thus reducing the swelling pressure between the clay platelets and consequently reducing the moisture content.

This reduction in moisture content would cause a decrease in the unsaturated, hydraulic conductivity. As the rate of supply of water to the surface was reduced to a level lower than the rate of evaporation the surface soil would begin to dry.

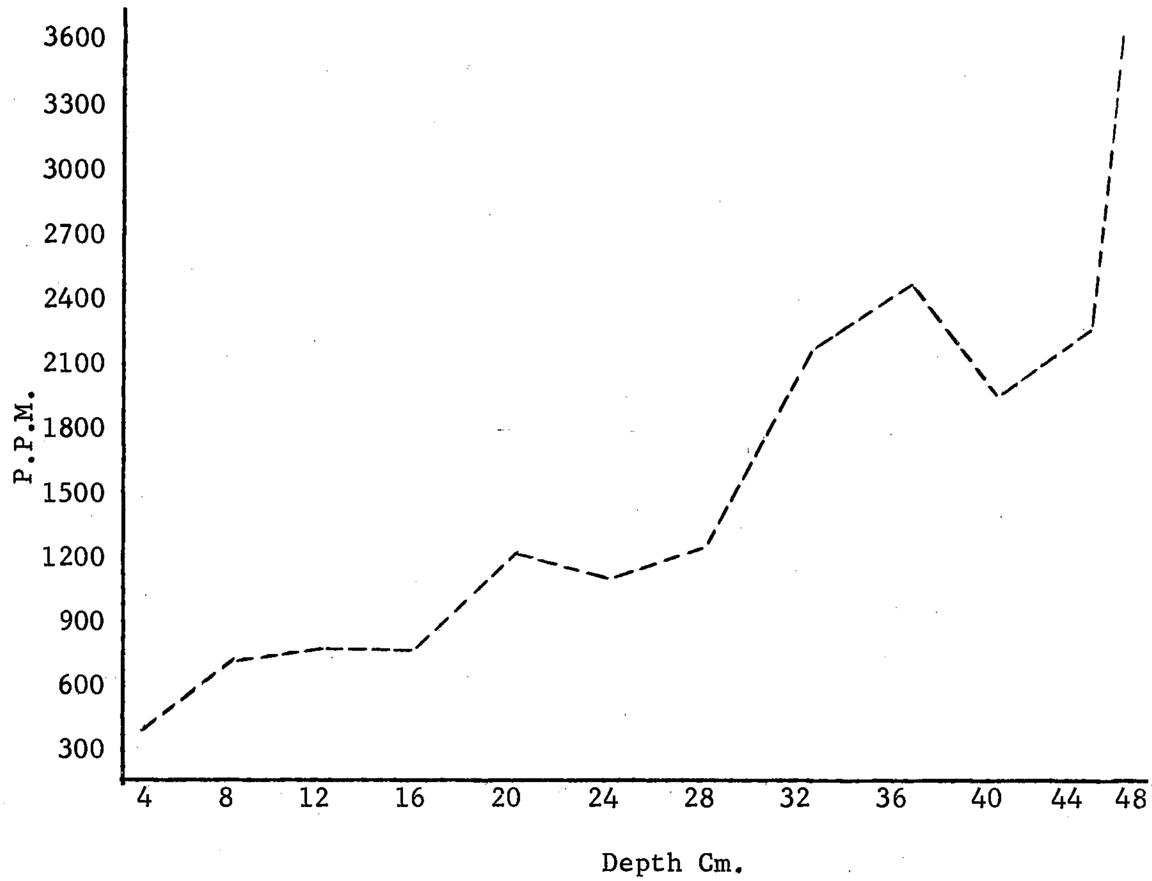

Figure 10. P.P.M. of Chloride in the Different Depths of Soil Irrigated from Water Table

In the 12 and 20 cm. depth salt accumulated rapidly. The increased salt content at these depths was sufficient to help move water to the surface by a diffusive process.

The data obtained for columns with high salt contents are chiefly of academic interest because soil with such high salt content is seldom, if ever, used agronomically.

It is clear that with an increase in the height of the water table and loss of water by evaporation there is an increased accumulation of salt at different depths in soil. The movement of water upward (capillary) is one of the most prevalent causes of saline soils. Where irrigation has been practiced for a long time there is usually a problem of removing soluble salts that have accumulated.

Good drainage for this land implies:

1. A relatively permeable soil through which water moves readily.
2. The absence of a water table within a depth where it would greatly influence the water retained in the root zone.

Some soils are so impermeable that water will evaporate from the surface faster than it will enter the soil. So natural drainage requires a permeable soil for the removal of ground water at a rate that will maintain the water table at an adequate depth. Under most conditions the water table should be at least six to ten feet below the surface, but where salinity is low a water table near the surface may not be harmful.

In the second experiment with soil irrigated with a soluble salt solution the results show that movement of water downward changes the amount of soluble salt at different depths (Figures 11, 12, 13).

The salt balance of an irrigated area is commonly defined as the difference between the total solids carried away annually by the drainage water. When the input of salts is less than the output the salt balance is unfavorable. When the salt input is definitely less than the salt output undesirable salts probably do not accumulate in the root zone.

When the salt input is definitely greater than the salt output, undesirable salts accumulate in the root zone (Figures 11, 12, and 13). Measurements of discharge and chemical analysis of samples at different depths supply data for calculating approximate values of salt balance in the column under consideration for both irrigation and drainage water soluble salt (Tables VII and VIII and Figures 11, 12 and 13). In the experiment the highest accumulation has been on the surface, Figure 11. In Figures 12 and 13 also the highest Magnesium and chloride have been accumulated on the surface and then at the depth of 8 cm. and these accumulations have been changed, but in the depths of 12, 16, 20, 24, 28, 32, 36, 40, 44 and 48 cm. the accumulation has been gradual.

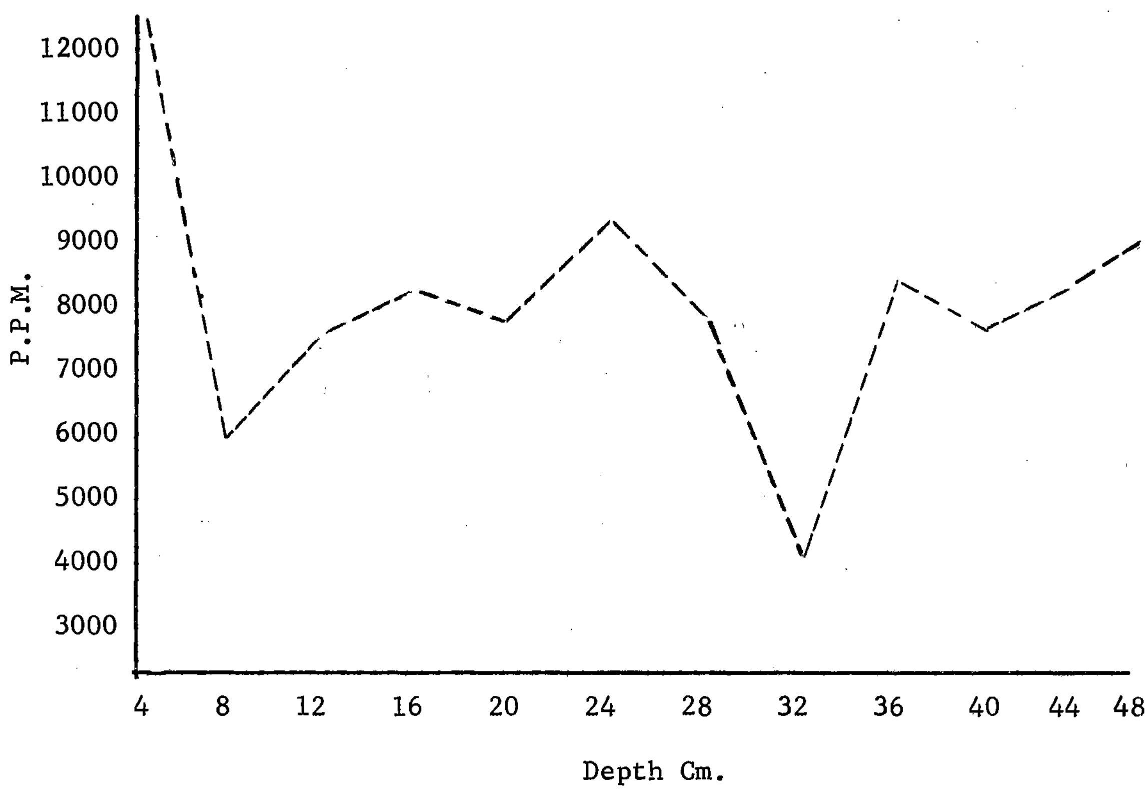

Figure 11. P.P.M. of Soluble Salt in Soil Irrigated from the Surface.

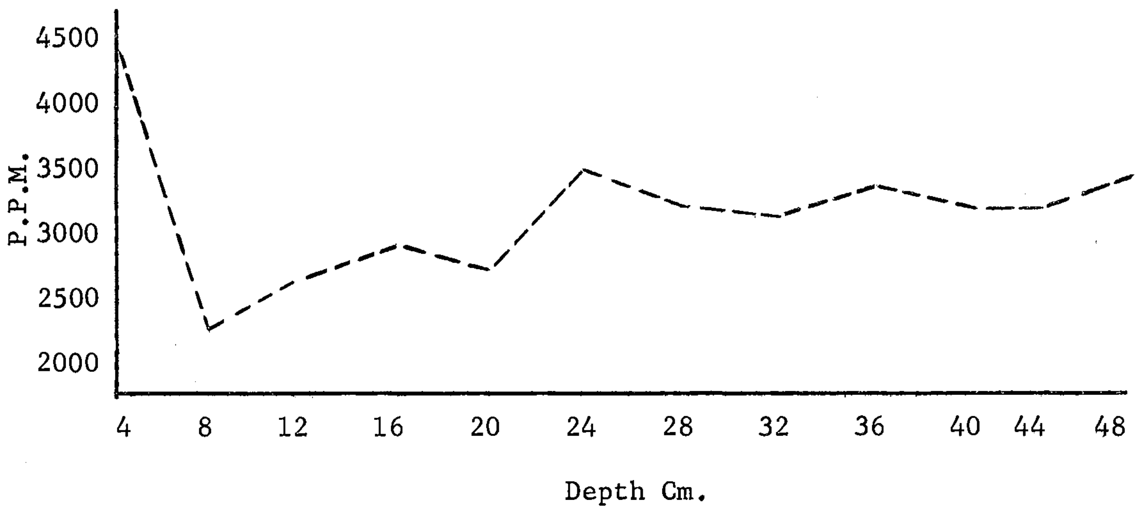

Figure 12. P.P.M. of Chloride in Different Depths of Soil Irrigated from the Surface

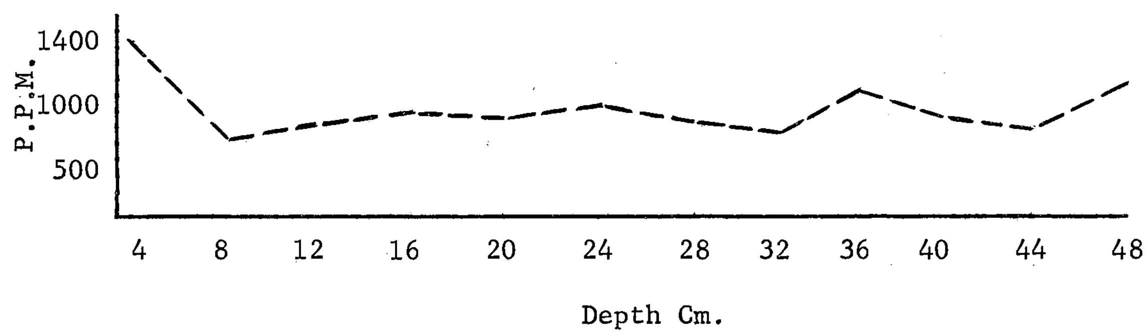

Figure 13. P.P.M. of Magnesium in Different Depths of Soil Irrigated from the Surface.

When the irrigation water contains moderate amounts of salt, sufficient water must be applied to prevent salt accumulation in the soil and to leach out excess salts in soil where they have already accumulated.

The P.P.M. of soluble salts on the surface 4 cm. is 12040 and in certain tests soils were unable to support plant growth when the concentration of salt exceeded approximately 10,000 P.P.M. Some irrigation water contains from 1/10 ton to five tons of salt per acre-foot of water, if irrigation apply only two feet of water per season. When the drainage is not provided the irrigation water may add as much as ten or more tons of salt each year to an acre of land.

The results obtained from the experiment are: (12, 35)

1. Chemical and physical factors affecting soil permeability -- Good drainage is the heart of the problem of maintaining production on irrigated lands and good soil permeability is the key to the drainage problem.
2. Selection and improvement of drainage methods by study of local conditions.
3. Reclamation of alkali and saline lands -- especially on the quantitative of water and alternative soil amendments such as sulphur, sulfuric acid and aluminum sulfate may become more feasible.
4. Survey and diagnosis of saline and alkali areas.
5. Plant tolerance to saline soils.
6. Germination and early growth.
7. Reducing evaporation by using mulching. A good mulch is a well and deep-tilled surface soil which is kept so constantly stirred that a crust is never allowed to form.
8. Leaching - This is accomplished by first providing adequate under drainage and following this with copious irrigation keeping the surface layers of soil saturated with water for protracted periods so that there is a continuous downward movement of gravity water which escapes through the drains.

CHAPTER V

SUMMARY AND CONCLUSION

Salt injures soil by exchanging desirable cation from the soil and replacing them with sodium. The maximum physical injury done to soils seems to occur at the time the soil has about the same amount of total salt it originally had or even less. In high concentrations of slat five tons per acre and more, plants and germinating seeds are injured by plasmolysis. However, salt leaches out of a soil rapidly and most subsequent damage is a result of bad physical condition of the soil. Plants can take many times their normal salt contents without seeming injury.

The influence of a rising water table on the upward capillary flow is analogous to the influence of making a canal grade steeper. Both cause an increase in the velocity of flowing water. The water table influences the hydraulic slope and hence the upward flow of soil water. A high water table increases the moisture content of the unsaturated surface soil and thus increases the permeability and the quantity of flow. The soluble salts are held near the surface of the body of ground water where they may readily be drawn by upward capillary flow to the soil surface and there deposited as the water evaporates.

Salt accumulation on the soil surface and in the root zone is the result of capillary flow of water upward from a saline shallow ground water zone. Salt deposition and concentration of the soil solution occur when this water evaporates or is transpired by plants to the atmosphere.

A study to determine the effect of salt accumulation and transmission by irrigation water soluble salts and by rise of water table and evaporation within a soil profile and evaporation from soil surface. Salt ($MgCl_2$) was used and the soil column sealed in lucite cylinders.

After definite time periods the columns were cut up and analyzed for salt accumulation and transmission. The data indicate a definite movement of the salt-bearing surface as diffusive flow at moisture contents. To determine the effects of evaporation on salts accumulation a soil column 48 cm. in length was placed over a water table containing 0.4 N $MgCl_2$ which maintained at a constant level near the bottom of the column.

The column was wetted and the rate of evaporation measured. When it could be assumed that steady-state conditions existed, the column was sectioned and analyzed for accumulation and distribution of $MgCl_2$. There was greater evaporation from the soil and greater accumulation of salt with a white crust at the top of the column. And it showed the effect of rise in the water table with evaporation and subsequent accumulation and transmission of salts to different depths in the soil profile.

Another experiment in the irrigated column with water soluble salts, the results of which are shown with the movement of water downward, the amount of accumulation and transmission of soluble salt in the different depths has been changed.

Measurements of discharge and chemical analysis of samples at different depth for both irrigation and drainage water soluble salt supply data for calculating approximate values of salt balance in column under consideration. In this experiment the highest accumulation has been on the surface or the first 4 cm. section. Also Mg and Cl have been accumulated on surface and then on the depth of 8 cm. and these accumulations have been changed, but on the depths of 12, 16, 20, 24, 28, 32, 36, 40, 44, and 48 cm. the accumulation has been gradual.

In conclusion, the water soluble salt from a free water table moved into the soil by diffusion. At higher moisture contents due to applying saline water at the surface comparative rapidity of flow compared to diffusive flow caused high salt accumulation in the lower part of the soil column.

In the soil columns where saline water moved downward and high salt accumulation gathered at the bottom. After the salt had been transmitted downward and was distributed throughout the columns, nonuniform distribution of water was found. Thus, high salt content in the soil probably reduced the swelling pressure of the soil and the particles came closer together at the prevailing tension. The water which was between the particles would be pulled to the lower end of the column by gravitation and by the reduction of swelling pressure in the salt-free soil at the lower end of the column. Thus rate of flow and other factors that may have reduced swelling pressure between clay particles were apparently the major factors in determining salt accumulation and transmission and distribution. Salt concentration gradients and the resulting diffusive flow of water with a rising water table and with evaporation from soils surface became important factors in the accumulation of salt in the soils.

LITERATURE CITED

(1) Ayers, H. D. "Soil Permability as a Factor in the Translocation of Salts on Irrigation Land." Scientific Agri. Vol. 31. pp. 383-388, (1951).

(2) Bouyoucos, G. J. "A Recalibration of the Hydrometer Method for Making Mechanical Analysis of Soils." Agro. Jour. Vol. 43 (1951) pp. 434-438.

(3) Branson, E. B. "Original of Thick Gypsum and Salt Deposits." Bul. Geol. Soc. Am. Vol. 26 (1915) p. 235.

(4) Bower, C. A., R. F. Reitemeier and M. Fireman "Exchangeable Cations Analysis of Saline and Alkaline Soils." Soil Sci. Vol. 73 (1957) pp. 251-261.

(5) Breazle, E. L. and W. T. McGeorge "Effect of Salinity on the Wilting Percentage of Soil." Soil Sci. Vol. 80, (1955) pp. 443-446.

(6) Chebatareu "Geochemical Metabolism in Natural Waters." XX Int. Geol. Congr. Mexico Resumenes Trab. Present. pp. 210 (1956)

(7) Clarke, F. W. "The data of Geochemistry." U. S. Geol. Sur. Bul. 770 5th ed., (1924).

(8) "Diagnosis and Improvement of Saline and Alkaline Soils." Agr. Handbook 60 U.S.D.A. (1954).

(9) Eichhorn, H. "Ueber die Einwirkung Verdunnter SalZosungen auf silicate." In Pogg. Ann. Phy. Chem. Bd. 705, (1858) pp. 120-133.

(10) Fireman, Milton and G. B. Bodman "The Effect of Saline on Irrigation Water Upon the Permeability and Base Status of Soils." Proc. Soil Sci. Soc. Am. Vol. 4 (1939) pp. 71-77.

(11) Gustafson, A. F. "The Effect of Drying Soils on their Water Soluble Constituents" Soil Sci. Vol. 13 (1922) pp. 173-195.

(12) Herbert M. Wilson, C. E. "Irrigation Engineering." pp. 7-14, (1919). John Wiley & Sons, Inc., London.

(13) Hermann Borchert and Richard O. Muir "Salt Deposits." pp. 10-203 (1964). D. Van Nostrand Co., LTD. London.

(14) Hilgard, E. W. "Soils Their Formation Properties, Composition, and Relations to Climate and Plant Growth." Illus. New York and London (1906) p. 593. John Wiley & Sons, Inc.

(15) Houk, Ivan E. "Irrigation Engineering." Vol. 1 (1951) pp. 475-487. John Wiley & Sons, Inc., New York.

(16) Israelsen, Orson W. "Irrigation Principles and Practices." (1953) pp. 246-267. John Wiley & Sons, Inc., New York.

(17) Jackson, M. L. "Soil Chemical Analysis." (1958)

(18) Jenny, H. "Factors of Soil Formation." McGraw-Hill Book Co., Inc. New York and Longdon.

(19) Johnston "Total Soluble Salts." Australia C. S. I. R. O. Publication Nos. 1-13. (1953) pp. 36-49.

(20) Johnson, D. D. and W. D. Guenzi "Influence of Salts on Ammonium Oxidation and . . . ." Soil Sci. Soc. Am. Vol. 27, (1963) pp. 663-665.

(21) Kearney, T. H. and C. S. Scofield "The Choice of Crops for Saline Land." U. S. Dept. Agr. Cir. 404 (1936).

(22) Kellogg, Charles E. "Soil and Landscape." Soils and Men U. S. Agr. Yearbook (1938) pp. 863-896.

(23) Kelly, W. P. and A. B. Cummins "Chemical Effect of Salts on Soils." Soil Sci. Vol. 11 (1921) pp. 139-158.

(24) Kilmar, V. J. and L. T. Alexander "Methods of Making Mechanical Analysis of Soils." Soil Sci. Vol. 68 (1949) pp. 15-24.

(25) Lemberg, J. "Ueber Einige Umwandlungen findlondischer Feldspathe." In Ztschr . Deut. Geol. Gesell, Bd. 22 (1870) pp. 335-372.

(26) Lipman, C. B. and D. D. Waynick "A Detailed Study of the Effect of Climate on Important Properties of Soils." Soil Sci. Vol. 1 (1916) pp. 15-49.

(27) McCool, M. M. and C. E. Miller "The Formation of Soluble Substances in Soils Taken from Widely Separated Regions." Soil Sci. Vol. 10 (1920) pp. 219-235.

(28) "Movement of Water and Solutes in Unsaturated Soil." Semi-annual Progress Report, U. S. Salinity Lab. (1958).

(29) Plice, M. J. "Some Effects of Salt Water on Soil Fertility." Soil Sci. Am. Pro. Vol. 14 (1949) pp. 275-278.

(30) Qayyum, Mohammad A. and W. D. Kemper "Salt Concentration Gradients in Soils and their Effects on Moisture Movement and Evaporation." Soil Sci. Vol. 93 (1962) pp. 333-342.

(31) Nieman, Richard H. "Some Effects of Sodium Chloride on Growth, Photosynthesis and Respiration of Twelve Crop Plants." Botanical Gazette Vol. 123 (1961, 1962) pp. 279-284.

(32) Sen Abhiswar "Influence of Climatic Factors on Salinity." Indian Jou. of Agr. Sci. Vol. 28 (1958) pp. 61-71.

(33) Sullivan, Eugene C. "The Interaction Between Minerals and Water Solutions with Special Reference to Geologic Phenomena." U. S. Geol. Survey Bul. 312 (1907)

(34) Teakle, L. J. H. "The Salt Content of Rain Water." West. Austral. Dep. Agr. Jour. Ser. 2, 14 (1937) pp. 115-125.

(35) "The Salt Problem in Irrigation Agriculture." Publication No. 607 U. S. Dep. of Agriculture.

(36) Thorne, D. W. and H. B. Peterson "Irrigated Soils." (1954) pp. 58-68. The Blakeston Co., Philadelphia and Toronto.

(37) Upson, F. W. and J. W. Calvin "The Loose Soils of the Nebraska Portion of the Transition Region, the Water Soluble Constituents." Soil Sci. Vol. 1 (1916) pp. 377-386.

(38) Vilenskii "Pochvevedenie"(Soil Sci) Univeristy of Moscow (1957).

(39) Way, J. T. "On the Power of Soils to Absorb Manure." J. Royal Agr. Soc. Vol. 11 (1850) pp. 313-379.

VITA

Hooshang Ashraf

Candidate for the Degree of

Master of Science

Thesis: ACCUMULATION AND TRANSMISSION OF SALT IN SOIL

Major Field: Agronomy (Soils)

Biographical:

Personal Data: Born March 20, 1933 in Shiraz, Iran the son of Mohammad Hassan Ashraf

Education: Graduate from NemaZy High School in 1956. Received the Bachelor of Science degree from the Agricultural College University of Shiraz, Iran with a major in Agricultural Engineering in October, 1960. Completed requirements for the Master of Science degree in July, 1966.

Professional Experience: Head of Irrigations Department of Shiraz, management and distribution of water for irrigation. Head of Statistical Land Distribution of city of Fassa.

Experiences: General agricultural practices and irrigation engineering.