# THE
# EFFECT OF MOISTURE CONTENT, TEMPERATURE AND COMPACTION UPON THE MOVEMENT OF SOLUBLE SALTS IN SOILS

Thesis for the Degree of M. S.

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1917

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# THE EFFECT OF MOISTURE CONTENT, TEMPERATURE, AND COMPACTION UPON THE MOVEMENT OF SOLUBLE SALTS IN SOILS.

THESIS

Submitted to the Faculty of the Michigan Agricultural College
in Partial Fulfillment of the Requirements for the Degree of
Master of Science.

Lawrence Clifford Wheeting.
October 1917.

# CONTENTS.

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## Introduction.

A review of the available literature concerning the movement of soluble salts in soils, brings forth, for the most part, only meagre and somewhat contradictory ideas, and it was, therefore, considered of sufficient importance to investigate some points with regard to salt movements, which might tend to clear up the doubts surrounding the subject. Certain definite statements are sometimes made concerning salt movements as,the tendency of nitrates to rise and of phosphatic salts to become fixed in soils. It is believed that the lateral movement of fertilizer salts in plot experiments is open to discussion. The questions as - do nitrates always move upward, or sidewise and downward as well; are phosphate salts movable; and do salts move equally in all directions,- are important. It seems also highly desirable to know what effect different salts, varying moisture contents, changes of temperature, and compaction have upon these movements. Indeed, there seems to be a large field of research surrounding the addition of a salt to the soil and what ultimately becomes of it. Absorption, water movements, texture of the medium, chemical reactions seem to be concerned and as a result a very complex set of conditions arise. Hence, there is difficulty in explaining many of the phenomena found.

After showing (1) that salts actually move when added to a soil it seemed advisable to investigate in this thesis the following phases. (1) The effect of different moisture contents upon the rate and distance of the salt movements.

(2) The effect of temperature upon the rate and distance of movement. (3) The effect of different degrees of compaction upon the rate and distance of movement.

## Historical Resumé

Muntz, A. and Gaudechon, H. (2) using a field soil, which in an air dry condition contained 3.2% moisture, and placing at four points in a box about 0.5 gm. of crystalline $NaNO_3$ in a place, found a moist area 10 M.m. in diameter formed around the crystals which at the end of eight days had reached 31-40 m.m in diameter. The water content at the middle of the spot was found to be 7.3%. Upon setting up a garden soil in a similar manner, analyses made for salt after two months showed no movement, but a movement of moisture was found as before. With a similar soil containing 17.5% moisture no movement could be detected after three days with either KCl or $NaNO_3$ respectively. At 15.6% moisture, after six days, no salt was detected 2.5 m.m. away from the deposit. Other experiments show only extremely slow or no movement either vertically or horizontally.

Seeds placed in these boxes did not grow, due to the high salt content in the moist area and to lack of moisture surrounding the salt spots. At higher moisture contents, the water movement toward the salt is not marked, and no salt movement occurs.

The authors believe that under field conditions salts will remain localized for long periods. The same authors, two years later(3) reported results which substantiate their previous investigations. They maintain that when a salt is added to a

homogeneous mass of soil, two systems result inasmuch as the salt solution has a high vapor pressure. Consequently a distillation of vapor results, which explains the collecting of the water around the salt deposit. This concentration of the soil solution around a salt deposit may be harmful to germination.

Demolon and Brouet (4) reported no difference other than a displacement of salt by movement of water, as the result of rainfall. These authors used KCl and $NaNO_3$ respectively in their work.

Malpeaux, L., and Defort, A., (5) investigated the movement of nitrates in boxes of soil, and under field conditions. In boxes a very unequal distribution was found at 5 c.m., 10 c.m. - 15 c.m. from the original deposit. Vertical diffusion did not appear more rapid than horizontal movement.

In the field, $NaNO_3$ was buried at a depth of 25,50, 75 and 100 c.m., and after a suitable time samples were taken eight c.m. down and five c.m. out from the deposit. At eleven days portions of the 25 c.m. deposit had reached the surface, at 31 days some of the 50 c.m. deposit was detected, at 43 days the 75 c.m. deposit was noticed, while at this time the 100 c.m. deposit showed only a trace. In cultivated plots, rain had washed the nitrate down 20-30 c.m. and for every depth of deposit, there was a zone of maximum nitrate concentration. On the whole, the nitrate was nearer to the surface at the end of the season than at the beginning.

The same investigators (6), the following year, reported further results, showing that if nitrates are caught in the evaporation current, they may be brought up long distances and at a comparatively rapid rate. Even in wet seasons the nitrate will rise enough to be within the reach of plant roots. They show

that after one month of wet weather, the zone of maximum nitrate content is 20 - 40 c.m. deep, while a month of dry weather, causes them to collect near the surface. The total amount of nitrate in the 40 c.m. of soil remained nearly constant for the season. On cropped plots the upper layers were removed by the crops and hence the tendency in all cases was to produce a uniform distribution. The crop showed beneficial effects of nitrate. These men, then, report a vigorous vertical movement of nitrates.

According to Frear, W. (7) there are two processes which tend to lift dissolved materials from the subsoil, namely, capillarity and diffusion. King is cited by Frear as saying that nitrates, chlorides and sulphates tend to accumulate in the surface soil. Calcium and magnesium rise more slowly. Potassium rises very slowly, and phosphorus scarcely at all. Pellet also cited by Frear in this bulletin says that the soluble salts of the soil are of two classes. 1. Those that tend to rise to the surface. 2. Those that tend to sink to the subsoil. Most salts tend to rise, but especially deliquescent ones such as $K_2CO_3$ and $CaCl_2$, sink. Lime in combination with strong mineral acids will rise but since it is usually found as a silicate or chloride its movement is very slight.

Frear further states that diffusion is the tendency of soluble materials to make a homoganous solution. In soil, this adjustment is slow, due to the discontinuity of the film water or to colloids. Under systems of irrigation many salts move rapidly but this is more of a translocation than movement by diffusion.

Sharp (8), in 1916, reported effects brought about by the addition of sodium salts to a clay loam soil in cylinders and the subsequent washing by water. He found a diffusion of soil colloids and a marked retardation of the rate of percolation. Increased amounts of calcium and magnesium in the percolate led him to believe that chemical processes and substitution of bases were concerned in the changes resulting from additions of the salts. He also believes that an actual movement of soil particles occurs, but the greater factor in the diffusion he explains on chemical grounds. Water movements by surface tension or otherwise influence salt movement.

## Experimental Results

The work reported in the following pages is not completed in many respects, and should be considered rather as an investigation to obtain ideas, which will open up new fields of thought and research. Some divisions are more complete than others but it is believed that enough work has been done with each phase, to either establish a principle, or to provide a sound basis for further study.

With these things in mind, the examination of the experimental results may be more intelligently accomplished.

### I. a. Effects of Varying Moisture Conditions upon the Movements of Salts and Water in Soils.

Method.- Glass cylinders, 8 inches long and 1 7/8 inches in diameter were employed in this series. The cylinders were filled about one-half full of soil which had been made up to the desired moisture content; then 2 grams of chemically pure crystalline potassium chloride and sodium carbonate respectively were put in and uniformally spread over the surface. The tube was then filled with the soil and finally sealed at both ends with melted paraffin. In order to eliminate variations in compaction all tubes received equal weights of soil, and the compaction necessary to place this definite weight into the cylinders, was practically the same throughout the series. Precautions were taken to prevent undue losses of moisture by evaporation during the process of filling. The filled cylinders then had about four inches of soil on each side of the 2 gm. deposit of salt; the soil weighing 500 grams in the case of sand and 450 grams when silt loam was used. These cylinders were set away at a nearly constant temperature of 18°C for suitable lengths of time, in this series for periods of ten and twenty days, after which, they were opened, and one inch layers of the soil removed, placed in weighed aluminum cans and dried, at 103° for about forty-eight hours. They were then cooled and weighed, and the moisture calculated in percent, for each section.

The salt movement itself was detected by means of the freezing point apparatus described by Bouyoucos (9). The reading obtained subtracted from the freezing point of distilled water, gives the depression of the soil solution. When this depression exceeds the depression of a control soil, that is, one which has no salt content, then it is an indication of a salt in the solution. For salts in solution cause a lowering of the freezing point, in proportion to the amount of salt present. Faint traces may be detected, since depressions of 0.002°C, can be read. The Freezing Point Lowerings expressed in the tables are obtained by the subtraction of the standard or check depression, from that of each section. For instance the sand used, freezes with a depression of .015°C, with 25% water. Then .015 is subtracted from all depressions of the sections frozen at the same moisture content and the true lowering, below the check is thus obtained.

The first series of moisture experiments were run with air dry medium sand, and silt loam, over 10 and 20 day periods. The results of the work are given in Table 1. It will be noticed

that no movement or salt or moisture resulted. It appears, then that soils with only the so-called hygroscopic moisture content are inactive with respect to salt and moisture movements. This is probably due to unvailability of this form of soil moisture as well as to the lack of continuous contact in the column. Since diffusion of salt, as well as movement of water depends upon the continuity of the system it can be readily understood why no movements have taken place.

The Moveme

| Inches from Salt Layer | Si | |
|---|---|---|
| | After 10 days | |
| | Freezing Point Lowering | Mois Con |
| 4 | | 1.5 |
| 3 | | 1.7 |
| 2 | | 1.6 |
| 1 | | 1.6 |
| 1 | | 1.5 |
| 2 | | 1.5 |
| 3 | | 1.4 |
| 4 | | 1.6 |
| | | |
| 4 | | 1.4 |
| 3 | | 1.4 |
| 2 | | 1.4 |
| 1 | none | 1.5 |
| 1 | | 1.6 |
| 2 | | 1.5 |
| 3 | | 1.6 |
| 4 | | 1.7 |

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The second series of experiments were carried on with medium sand at a moisture content of 0.5%, and with silt silt loam at 2.0% moisture. Some difficulty was encountered in obtaining a homogeneous mixture with such small quantities of water, but fairly uniform columns were obtained. The results for petiods of 10 and 20 days are shown in table II. In contrast with the results of Table I., these data, show both salt and moisture movements. The appearance of a dark ring around the zone where the salt was placed, was plainly due to the increase in the moisture content which collected there at the expense of the outward layers. The salts moved only as far as this dark zone proceeded, as is shown by the data in the table. This zone was most marked in the case of potassium chloride and sand, but showed well with silt loam. The sodium carbonate was less active under these conditions of moisture in case of sand and was inactive with silt loam. When potassium chloride was added to the silt loam, the salt was detected one inch away after 10 days and had proceeded three inches at the end of 20 days. Sodium carbonate moved but one inch in 20 days and a lower concentration only is shown at the end of the 10 day period. In sand, the potassium chloride moved but one inch in 20 days although the concentration of this layer increased throughout the period. The sodium carbonate moved one inch in 10 days and showed traces two inches away at the end of 20 days. Hence, salts vary in their action in different media, but all tend to set up two systems in the column. One system is the result of the movement of moisture toward the salt deposit and the other is brought about by the movement of the salt into the surrounding medium. This water movement, if rapid, must retard somewhat the movement of the salt. On the other hand, the increase of moisture in any zone, tends to increase the rate of salt translocation. It seems to be difficult to determine just what effect the moisture movements have upon the salt movements, in this case, at least.

The Movements (

and

| Inches from Salt Layer | Silt |  |
|---|---|---|
|  | After 10 days |  |
|  | Freezing Point Lowering | Moisture Content |
| 4 | 0.000 | 2.39 |
| 3 | .000 | 2.45 |
| 2 | .000 | 2.32 |
| 1 | .150 | 3.46 |
| 1 | .840 | 3.86 |
| 2 | .000 | 2.33 |
| 3 | .000 | 2.60 |
| 4 | .000 | 2.62 |
|  |  |  |
| 4 | 0.000 | 2.68 |
| 3 | .000 | 2.90 |
| 2 | .000 | 2.75 |
| 1 | .050 | 3.17 |
| 1 | .070 | 2.78 |
| 2 | .000 | 2.68 |
| 3 | .000 | 2.78 |
| 4 | .000 | 2.70 |

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In Table III, is given the data from the treatment of silt loam at 4% moisture, and medium sand at 1% moisture with Potassium chloride and sodium carbonate respectively. These data show very clearly in all cases the movement of water towards the salt deposits, and in comparing these movements with those in Table II, it seems evident that the increased moisture present accompanies greater salt and water movements. This is perhaps due to the greater number of contacts, and the greater continuity of the films around the particles of the column. The salt solution in the vicinity of the deposit is doubtless a very concentrated one, and its surface tension is then markedly increased. The solution surrounding the soil in the outer layers is less concentrated, and therefore, has a much lower surface tension. Then if there is a continuous contact between these solutions the one with salt and the greater surface tension will withdraw moisture from the other. This no doubt explains why the water collects around the salt deposits. At the same time the salt solutions are diffusing into the soil moisture, true to the law concerning them, which states that all solutions tend to become homogeneous throughout, if left in contact long enough. Experiments run over long periods of time result in a uniform concentration of the soil solution for all sections of the column. The data of Table III show that in silt loam at this moisture content, potassium chloride has the greatest water pulling power but in sand, the sodium carbonate leads, at least at the 10 day period. The potassium chloride shows greater activity throughout the series, and seems less influenced by the movement of the water against it, since it has often moved out three inches, while only the first inch from the salt deposit shows any increase in moisture content.

The sodium carbonate seems to be more localized and remains in the zone of high moisture content. It seems difficult to determine the cause of these variations unless they can be explained by relative solubilities on differences in the mobility of ions.

The Movements c

| Inches from Salt Layer | Silt I |  |
|---|---|---|
|  | After 10 days |  |
|  | Freezing Point Lowering | Moisture Content |
| 4 | 0.000 | 4.59 |
| 3 | .005 | 4.38 |
| 2 | .030 | 3.56 |
| 1 | 1.260 | 7.12 |
| 2 | .020 | 3.51 |
| 3 | .000 | 4.19 |
| 4 | .000 | 4.31 |
|  |  |  |
| 4 | 0.000 | 4.91 |
| 3 | .000 | 4.84 |
| 2 | .000 | 4.28 |
| 1 | .160 | 6.58 |
| 1 | .210 | 5.48 |
| 2 | .000 | 4.09 |
| 3 | .000 | 4.57 |
| 4 | .000 | 4.59 |

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When potassium chloride was placed in contact with silt loam at 6% moisture and with medium sand at 2% moisture the water pulling capacity of the salt, which was very noticeable from the results given in Table III, seemed to be changed. The zone immediately surrounding the salt deposit did not hold very much more water than the other sections of the column, and in sand the layers throughout were almost uniform in moisture content. A very marked movement of salt occurred, however, probably because of the better contact between all parts, and the fact that there was undoubtedly a faster rate of solution of the salt resulting from more water being present. The sodium carbonate still showed power to pull water in both soils, but its movement was very limited, and confined to the zone of high moisture content as before. A consideration of the data given in Table V is interesting. It was found that no appreciable variation in the moisture contents of the different sections could be detected for either salt in silt loam at 10% moisture. In sand with 3% moisture the potassium chloride gave analogous results, but the sodium carbonate still increased the water content in the first inch. There was this change, however, the sodium carbonate moved three inches in 20 days, which is a notable increase over other series run. The potassium chloride was again more active than it was under the conditions noted in Table IV, and has been detected at the end of the tubes after 20 days, and three inches out at the end of 10 days. Both salts have moved farther with these moisture contents than with the lower ones, preceding.

The Movements o

| Inches from Salt Layer | Silt Loam | | |
|---|---|---|---|
| | After 10 days | | Aft |
| | Freezing Point Lowering | Moisture Content | Fr Po Lo |
| 4 | 0.000 | 6.69 | 0. |
| 3 | .015 | 6.91 | . |
| 2 | .190 | 6.93 | . |
| 1 | .980 | 7.64 | . |
| 1 | 1.185 | 7.50 | . |
| 2 | .330 | 6.89 | . |
| 3 | .015 | 6.51 | . |
| 4 | .010 | 6.36 | . |
| | | | |
| 4 | 0.000 | 6.19 | 0. |
| 3 | .000 | 6.20 | . |
| 2 | .000 | 5.79 | . |
| 1 | .105 | 8.30 | . |
| 1 | .300 | 8.75 | . |
| 2 | .000 | 5.77 | . |
| 3 | .000 | 6.16 | . |
| 4 | .000 | 6.19 | . |

The Movements

| Inches from Salt Layer | Silt Lo | |
|---|---|---|
| | After 10 | days A |
| | Freezing Point Lowering | Moistur Content |
| 4 | 0.000 | 8.72 |
| 3 | .020 | 8.81 |
| 2 | .165 | 8.92 |
| 1 | .480 | 8.64 |
| 1 | .620 | 8.71 |
| 2 | .216 | 8.80 |
| 3 | .030 | 8.68 |
| 4 | .000 | 8.73 |
| | | |
| 4 | 0.000 | 8.90 |
| 3 | .000 | 8.92 |
| 2 | .020 | 8.88 |
| 1 | .020 | 8.96 |
| 1 | .810 | 8.70 |
| 2 | .018 | 8.84 |
| 3 | .000 | 8.78 |
| 4 | .000 | 8.80 |

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As a final series, the soils were made up to high moisture contents and run at 9% in sand, and 20% in silt loam. The data are given in Table VI, and when compared with Table V, show but little if any increase in the amount or distance that the salt has moved. It may be safely said then, that at 3% moisture in sand, and at 10% moisture in silt loam, the maximum activity has been reached, and further additions of moisture have but a slight effect in hastening the movements. At 9% moisture in sand, the sodium carbonate did not increase the moisture immediately around the deposit.

An examination of the data from the entire series presented in the six tables shows that the amount and speed of salt translocation increases with the increase of moisture content up to a certain point after which other additions have little effect; that there is a moisture condition where the maximum amount of moisture is drawn around the salt and at all higher moisture contents this property becomes lost; that the texture of the medium has but little effect in causing wide variations in salt and water movements; and that salts vary in their moving power, in this case, potassium chloride being a much more mobile salt than sodium carbonate.

Theoretical considerations of these facts lead one to believe that the reasons underlying the increase in the amount and speed of movement up to a certain maximum point, are to be found in the solubilities of the salts. It is a generally recognized fact that soluble salts will go into solution fast at first, but as the concentration of the solution increases, the rate of solution decreases. Then in the soil containing but 0.5% of water the total amount of salt really in solution is small, as compared with the

The Movements

| Inches from Salt Layer | Silt Loa | |
|---|---|---|
| | After 10 | days Af |
| | Freezing Point Lowering | Moisture Content |
| 4 | 0.000 | 17.24 |
| 3 | .050 | 17.30 |
| 2 | .180 | 17.48 |
| 1 | .840 | 17.22 |
| 1 | .750 | 17.34 |
| 2 | .220 | 17.30 |
| 3 | .102 | 17.41 |
| 4 | .000 | 17.08 |
| | | |
| 4 | 0.000 | 18.02 |
| 3 | .000 | 17.96 |
| 2 | .008 | 17.84 |
| 1 | .529 | 17.60 |
| 1 | .642 | 17.71 |
| 2 | .010 | 17.86 |
| 3 | .000 | 17.91 |
| 4 | .000 | 17.89 |

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total amount in solution with the soil at 3% moisture. And so, in the latter case, more salt being active, a greater potential is created, and the relation follows the law of mass action. Greater movement s of salt consequently take place. Now, further additions of moisture, do not increase the total movement, because probably the lower percent was sufficient to completely dissolve the salt, and really all the added water does is to dilute the diffusing solution so that its rate is slowed down even when more contacts have been provided. This is tenable from the fact that the movement of salt from a strong concentration to water is greater than the same movement from a weak concentration. Thus it seems reasonable to assume that the whole phenomenon may be explained upon the basis of solubilities.

A corresponding line of reasoning may be employed in the explanation of the water pulling capacities . At law moisture contents, the concentration around the salt deposit becomes great since undoubtedly a saturated solution is produced. This has a strong attractive force, due to its increased surface tension, and draws more moisture from the surrounding layers. This water, in the adjacent layers, is however, held with considerable tenacity and the saturated solution can obtain only a part of what it requires. But, upon the use of more water more becomes available and movable while the solution of salt is still saturated. Hence, a greater amount will be withdrawn in the second case. Additions of water tend to increase the ease with which the water moves around the soil particles, while it still produces a saturated solution for the tractive agent. Finally when past the maximum the salt becomes entirely dissolved and only a weak solution results. Its pulling power is thus reduced. Since sodium carbonate is somewhat less soluble than potassium chloride, it continues to produce a saturated solution for a longer length of time and exerts its pulling power longer which seems in accord with the facts.

The influence of texture seems negligible, in most cases. The moistures used and compared are roughly, multiples of the original hygroscopic moisure found. For example, the air dry sand held about 0.25% of water, while air dry silt loam had about 1.5% moisture. The next table gives sand with an average of 0.58% or roughly two times the air dry water content. In Table II, silt loam has about 2.9% moisture on the average, which is again approximately two times the first moisture content. This may be carried on with other tables, but briefly it shows that proportional amounts of free water were supplied in nearly every case. This may explain why proportional salt movements were obtained.

The greater activity of potassium chloride is probably due to two properties in which it surpasses sodium carbonate. It is more readily soluble in water, and has a greater solubility product. Also its ions possess greater mobility. The solubiltity of potassium chloride in water is 25.4 grams in 100 grams of solution at 20°C, while under the same conditions sodium carbonate solution contains only 17.7 grams per 100 grams of solution. The mobility of the potassium ion is given by Kohlraush as 2.05 while the mobility of the sodium ion is 1.26 at 18°C The mobility of the chlorine ion is 2.12, while that of the carbonate ion is 1.89. Total molecular mobility for potassium chloride is then 4.17, while for sodium carbonate it is only 3.15.

I. b. The Effect of an already present salt upon the rate and amount of movement of 1% potassium chloride.

Method.- Brass tubes 1½ inches in diameter were employed in this series and were made in three sections. The center portion was about two inches long and joined at both ends to sections each eight inches long, by means of couplings. These were set up as follows: The center or short division was filled with the soil made up with a salt solution to the desired moisture content. Solutions were used, so that 1 gram of salt was present in every 100 grams of salt treated soil. One long section of tubing was then screwed on, and filled with soil moistened with distilled water to the same moisture content as the salt layer. The third portion was then fastened on to the opposite end of the salt layer and also filled with moist soil. Rubber stoppers were used to close each end, and the couplings in the center were paraffined to prevent loss of moisture. Some of the soil, into which the salt was to diffuse, was treated with 1% calcium carbonate, which is equivalent to 10 tons of limestone per acre six inches. The complete series then contained a tube with limed and one with unlimed soil otherwise but received, the same treatment.

After allowing these tubes to stand for 10 and 20 day periods respectively at a constant temperature of 18°C, samples were taken in a similar manner as described in the first section of this paper. Both moisture contents and freezing point lowerings were determined for two soils, a medium sand and silt loam.

The data obtained from the addition of 1% potassium chloride are contained in Tables VII and VIII. In silt loam there were no moisture movements from one region to the other, but striking differences may be seen in the salt translocation. After 10 days an increase in the concentration was detected in the fourth inch from the salt layer, in limed soil, while, movement only to the second inch could be found in the unlimed soil. At the end of twenty days, the salt was at the end in both tubes but a greater concentration was noted in the case of the limed soil. These effects are nearly negligible in the case of sand, and no increase worthy of consideration was obtained from the use of limed soil. We must conclude then that with potassium chloride, liming increases the rate of translocation in this particular fine textured soil, but has little effect in the coarse textured one.

If one considers the "substitution of bases" theory in this connection, some light is thrown upon the problem. For, when a salt solution is placed in contact with a soil reactions take place and if the resulting solution be analyzed it would probably not be the same as the one added. Then, when a salt is detected three inches away in a column of soil, it is not the original salt. Change of bases and absorption make it impossible to determine what the salt solution is, and all that can be said is that an increased concentration was found. In the present instance, the potassium ion is probably absorbed, and calcium liberated to take its place. And so, in a soil with an abundant supply of calcium compounds it seems that a much greater ease of substitution would be possible, and the greater activity resulting would explain why limed soil shows higher concentrations at greater distances from the salt deposit.

of

The Effect of

| Inches from Salt Layer | Original Water Content | Freez Point Lower |
|---|---|---|
| 5 | | 0.00 |
| 4 | | .00 |
| 3 | - 17.48 | .02 |
| 2 | | .03 |
| 1 | | .20 |
| 0 | - 17.35 | .44 |
| 1 | | .25 |
| 2 | | .02 |
| 3 | 17.48 | .01 |
| 4 | | .01 |
| 5 | | .00 |

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| Inches from Salt Layer | Original Water | |
|---|---|---|
| | Content | Freez Point Lower |
| 5 | | 0.00 |
| 4 | | .00 |
| 3 | - 8.20 | .00 |
| 2 | | .02 |
| 1 | | .11 |
| 0 | - 8.21 | .37 |
| 1 | | .16 |
| 2 | | .01 |
| 3 | 8.20 | .00 |
| 4 | | .00 |

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I. c. The effects of air spaces in soil upon the movement of moisture from water treated to salt treated soils.

Method.- Brass tubes of two portions, only, were used in this series, a short two inch section for salt treated soil, and a longer eight inch section for water moistened soil. The salt treated soil contained 1% potassium chloride and was made up to the same moisture content as the soil with water alone. For each water content there was provided a tube with the salt treated and water treated soils in contact, and another tube, in which the two components of the system were separated by about a ½ inch air space. After storing at 18°C for intervals of 5, 10, and 25 days, the tubes were taken down in one inch sections, and dried. Moisture determinations were made on all sections and freezing point determinations run in a few instances as a check. There were no salt movements of course in the tubes with air spaces, but the usual movement took place in the contact tubes. The moisture contents alone have been given and are found in Table IX.

There was a fairly rapid distillation of vapor across the air space in sand, at both moisture contents, and the amount that passed across increased with the time which the tubes were allowed to stand. But at the end of 25 days, the maximum amount of vapor that could pass over had not done so, and it is probable that the water would continue to collect in the salt layer until free water is formed, which would then flow back as a stream.

In tubes with the salt in contact with the soil, there was no movement of water which could be detected. It might be suggested however, that a movement of vapor took place between the two components, as before, but the increase in the salt layer, due to the condensation of the vapor, was taken care of by the continuity of the capillary water, which would allow a readjustment as soon as one part of the system held more water than another. As a consequence then there was probably a stream of vapor passing from the water solution to the salt solution with its high surface tension, in both cases. But with an air space, in one case, there was no chance for a readjustment of the film, and so a steady increase was recorded. In the other case, as was explained above, the readjustment thru the entire column was possible. This in fact may explain the phenomena.

It is worthy of note, that in the work of Bouyoucos(10) upon the effect of temperature in causing moisture to pass across this air space, there were only insignificant movements recorded even between amplitudes of temperature of 40°C. It is then primarily due, in the present instance, to the pressure of a salt solution in one component of the system, which provides for a higher surface tension, and a lower vapor pressure. This inequality then starts the movement of vapor from a point of high pressure to one of low pressure.

The Movemen

1½ I

| Inches from Salt Layer | Sand |  | H |
|---|---|---|---|
|  | Original | After 5 days |  |
| 6 | 8.46 | 7.86 |  |
| 5 | 8.46 | 7.79 |  |
| 4 | 8.46 | 7.91 |  |
| 3 | 8.46 | 7.83 |  |
| 2 | 8.46 | 8.08 |  |
| 1 | 8.46 | 7.99 |  |
| 0 | break<br>7.85 | 9.12 |  |
| 0 | 7.85 | 8.80 |  |
|  |  |  |  |
| 6 | 8.46 | 8.01 |  |
| 5 | 8.46 | 8.16 |  |
| 4 | 8.46 | 7.99 |  |
| 3 | 8.46 | 8.17 |  |
| 2 | 8.46 | 8.04 |  |
| 1 | 8.46 | 7.61 |  |
| 0 | solid<br>7.85 | 7.92 |  |
| 0 | 7.85 | 7.69 |  |

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| Inches from Salt Layer | Sand |  | H |
|---|---|---|---|
|  | Original | After 5 days |  |
| 6 | 8.46 | 7.86 |  |
| 5 | 8.46 | 7.79 |  |
| 4 | 8.46 | 7.91 |  |
| 3 | 8.46 | 7.83 |  |
| 2 | 8.46 | 8.08 |  |
| 1 | 8.46 | 7.99 |  |
|  | break |  |  |
| 0 | 7.85 | 9.12 |  |
| 0 | 7.85 | 8.80 |  |
|  |  |  |  |
| 6 | 8.46 | 8.01 |  |
| 5 | 8.46 | 8.16 |  |
| 4 | 8.46 | 7.99 |  |
| 3 | 8.46 | 8.17 |  |
| 2 | 8.46 | 8.04 |  |
| 1 | 8.46 | 7.61 |  |
|  | solid |  |  |
| 0 | 7.85 | 7.92 |  |
| 0 | 7.85 | 7.69 |  |

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## II. The Effect of Temperature upon the rate of movement of salt in soil.

Method- Brass tubes of two sections, similar to those described in part three of the first section of this thesis, were used to make the temperature studies. The short section contained soil with 1% potassium chloride in solution, and was at the same moisture content as the soil placed in the long section which was moistened with water alone. The tubes were sealed with rubber stoppers at each end, and kept at temperatures of 0°, 15° and 65°C respectively, for ten days. Sampling was performed as usual and both moisture and freezing point determinations, made. The temperature of 0°C, was maintained by packing the tubes in a bath of melting ice. A thermograph attached, showed that very small fluctuations occured. Another series of tubes were immersed in a water bath, which remained more nearly at 15°C, than could have been possible in the case of an air chamber. The high temperature of 65°C, was maintained in an electric drying oven, with a part of the heating coils removed. Two tubes, of each moisture content were employed, to guard against loss from leaks or otherwise.

The data given in Table X are regular in their trend, and establish the fact that higher temperatures increase the activity of salt movement. There were no noteworthy movements of moisture. At the temperature of melting ice, the movement of salt was very slight, and in no case, was detected more than one inch from the deposit. In com-

The Effect of Tem

induced by the ad

| Inches from Salt Layer | Silt Lo | | |
|---|---|---|---|
| | At Low Moisture | | At Hi |
| | Freezing Point Lowering | Moisture Content | Free Poin Lowe |
| 5 | 0.000 | 11.38 | 0.0 |
| 4 | .000 | 11.49 | .0 |
| 3 | .000 | 11.68 | .0 |
| 2 | .000 | 11.65 | .0 |
| 1 | .115 | 12.02 | .1 |
| 0 | .560 | 11.62 | .5 |
| | | | |
| 5 | 0.000 | 10.30 | 0.0 |
| 4 | .000 | 10.48 | .0 |
| 3 | .000 | 10.55 | .0 |
| 2 | .075 | 10.93 | .1 |
| 1 | .350 | 10.88 | .2 |
| 0 | .560 | 11.62 | .5 |
| | | | |
| 5 | 0.025 | 9.52 | 0.0 |
| 4 | .035 | 9.76 | .0 |
| 3 | .050 | 9.95 | .0 |
| 2 | .090 | 9.49 | .1 |
| 1 | .280 | 9.46 | .2 |
| 0 | .570 | 9.80 | .4 |

parison with this, the salt moved two and often three inches outward at the temperature of 15°C. Moreover, a larger quantity of salt was distributed at this temperature since greater depressions were obtained. At 65°C, a temperature about four times as high as the preceding, a great increase in rate and amount of salt moved, was observed. Under these conditions of temperature the potassium chloride moved the entire length of the columns. There were small differences in concentration of corresponding layers of silt loam and sand. However, sand showed a tendency to move a greater amount of soluble material. It was believed possible then to almost eliminate factors of texture and moisture content, by the use of comparatively high temperatures.

A consideration of these facts, with relation to physical chemistry has led to these hypotheses. - (1) Since the speed of a chemical reaction is increased by the application of heat, and increases in activity have occurred in soils treated with salt solutions, when higher temperatures were used, it appears reasonable to believe that the movement of salts thru soil may have been due in part to chemical processes. (2) Increases in the rate of physical diffusion are also obtained under increased temperatures, hence there may have been increases in rates of salt translocations, as a direct effect of physical processes.

Due, then, to a lack of available data concerning relative rates of action of the chemical and physical processes respectively, definite theories cannot be advanced at this time. The difficulty in obtaining these data is made greater by the fact that such a large number of reactions may be in progress at one time which produce a resultant of reactions, not easily resolved into its components. For instance, while potassium is being replaced in the solution by calcium there is undoubtedly also a replacement of potassium by magnesium as well, occurring at the same time. The rate of reaction between potassium and calcium, being different the velocity of the action between potassium and magnesium, makes the determination of the amount of the original element active in each case, impossible.

Therefore, the explanation of the movements was left as a general idea of physico-chemical relationships.

## III. The effect of different degrees of Compaction upon the movement of a Soluble Salt, as Potassium chloride.

Method- Glass cylinders, similar to those used in the first series of moisture experiments, were filled with silt loam at 10% and 20% moisture respectively and with sand at 3 and 9% water contents. In each tube near the center was placed a 50 gram portion of soil treated with 1% potassium chloride. The tubes which were compacted held 500 grams of sand, the apparent specific gravity being 1.37 and 450 grams of silt loam with apparent specific gravity of 1.23 respectively, while the tubes which were not compacted held 450 grams of sand, the apparent specific gravity being, 1.23 and 400 grams of silt loam, with apparent specific gravity of 1.40 in each respective case. The compaction required in the first instance was appreciable while scarcely more than spreading about, was necessary in the loosely filled tubes. After sealing, with paraffin, the series was placed away at constant temperature of 18°C for ten days. Samples were then procured in the usual manner, and moisture contents and freezing point lowerings determined.

The results are given in table XI.

The Effect c

of 1% Potass

| Inches from Salt Layer | Si | |
|---|---|---|
| | At High Moisture | |
| | Freezing Point Lowering | Moisture Content |
| 3 | 0.015 | 17.84 |
| 2 | .070 | 17.10 |
| 1 | .180 | 17.00 |
| 0 | .240 | 17.00 |
| 1 | .160 | 16.96 |
| 2 | .110 | 17.21 |
| 3 | .054 | 17.40 |
| 4 | .040 | 17.50 |

| | | |
|---|---|---|
| 3 | 0.040 | 17.20 |
| 2 | .080 | 17.41 |
| 1 | .200 | 17.30 |
| 0 | .290 | 17.95 |
| 1 | .170 | 17.35 |
| 2 | .080 | 17.50 |
| 3 | .020 | 17.50 |
| 4 | .010 | 17.48 |

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It is very noticeable in the case of silt loam, that there were no moisture movements in any tubes. The data show in contrast a tendency on the part of the sand to allow its moisture to collect in the lower layers of soil in all but one set of tubes. This tendency can scarcely be explained since the preceding results in many cases show that there is no free water at these moisture contents. Inasmuch, as the salt movements in these instances were stronger upward, suspicions pointed to an escape of moisture from the top, rather than translocation of water downward. However, the variations were small.

The comparison of the distance and the amount of salt withdrawn to the outer layers in loose and compact soil, showed small differences. There were no appreciable advantages shown in any instances by the compact soil. The results were especially uniform when high moisture contents were used, and the trend of the data as a whole, would not permit drawing conclusions in favor of compacting the soil to facilitate salt movements.

It was thought probable that under conditions of low moisture, the differences in movement might be more clearly seen, since the difficulties for contact in a loose soil would surely be greater than those in a compact one. This lack of contact was probably not a limiting factor at the moisture contents used. Further investigation of this phase seems desirable.

## Additional Remarks

It as stated at the beginning of the paper, the results of this investigation are incomplete in many respects, and merely are a means of opening up new fields of thought and research. During the progress of the work, several thoughts, with regard to salt movements, have occured, which seem important. The relation of temperature to the rate of salt translocation under different conditions of moisture and texture and with various salts involves much study and research for its solution.

Further study of the vapor movements into salt treated soils could be made, and might find practical application in the arid, alkali sections of the West and southwest. Field studies of the behavior of many salts under varied conditions of moisture, climate and texture would be extremely interesting, and would be an excellent correlation to laboratory data. The relation between an already present salt, and the moving salt is not fully worked out. Qualitative determinations concerning rates of chemical and physical reactions between soil and salt solutions, might prove a means of explaining the translocations observed in the work. As the work progresses, more ideas occur, and it seems almost impossible to investigate many interesting phases.

## Summary and Conclusions

The results and conclusions of the work as far as completed, may be summarized as follows:-

1. Soils with only the so-called hygroscopic moisture content are inactive with regard to salt and moisture movements.

2. The rate of both salt and water translocations increases with greater moisture contents to a certain maximum point, after which other additions of moisture have little effect. The point of maximum movement under the conditions of this experiment for sand is at about 3% water, and for silt loam approximately 10%.

3. The influence of texture was not found important in this series.

4. Differences in mobility of two salts, namely, potassium chloride and sodium carbonate, were found, the former being more active in all cases. This was thought to be mainly due to variations in solubilities and mobility of ions.

5. A substance such as limestone, was found to enhance the movement of potassium chloride thru soil. The explanation of this probably lies in the increased ease of substitution made possible by an excess of soluble calcium, available for the reaction.

6. There was a marked movement of vapor across an air space between a moist salt treated soil, and a moist soil, with no treatment. This distillation of moisture is made possible by the lowered vapor pressure of the salt treated component.

7. Pulling power of a salt treated soil for water in a solid column may be explained by the increased surface tension of a saturated salt solution.

8. Greater salt movements are obtained under rising temperatures. At $0^{\circ}C$ negligible movement occurred while at $65^{\circ}C$ vigorous activity was observed. This phenomenon was probably caused by either physical or chemical agencies or a combination of the two.

9. Variations of 10% to 15% in compaction had little effect upon movements of salt or moisture under the conditions of these experiments. The comparatively high moistures employed probably minimize the variations.

10. Solid salts become dissolved and move with as much readiness as solutions of the salts added directly.

11. It is believed that, substitution of bases, absorption, reaction, and vapor pressure are vitally concerned in the movements studied.

# Acknowledgments.

The writer is greatly indebted to Dr. M. M. McCool for supervision of the work, helpful suggestions, and valuable criticism of technique and phraseology.

The helpful cooperation of all members of the department has been highly appreciated, as well.

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