

MOVEMENT AND REDISTRIBUTION OF CERTAIN SALT
CONSTITUENTS IN A CLAY LOAM SOIL IRRIGATED
WITH HIGH-SALT LOW-SODIUM WATER

By

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"He who is not thankful to the people through whom Allah (God) has granted him His tidings is actually not thankful to Allah Himself."

(Prophet Mohammed). Therefore, I am deeply indebted to each and every one who might have given the minutest contribution to this work.

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CHAPTER I

INTRODUCTION

Among other things, water quality and availability for irrigation is a prominent limiting factor to soils that otherwise could have been productive or cultivable year-round. This is especially true in areas of the world where feeding people is a problem that becomes more acute each day with the population explosion. Numerous literature citations are available on investigations of quality of irrigation water and classification of crop tolerance.

Studies have also been and are being conducted to evaluate the use of saline water in irrigation.

The objective of this work was to study the movement and redistribution of certain salt constituents in the soil profile above the water table in a clay loam soil irrigated for eighteen years with high salt--low sodium water.

CHAPTER II

LITERATURE REVIEW

Kelley (9) in a comprehensive monograph states that salts in soils probably originate in the weathering of igneous rocks. In humid climates natural precipitation is usually sufficient to leach out the soluble salts as fast as they are formed. The salts of the ocean have probably originated in this fashion and the ocean is gradually increasing in salinity. In dry regions a substantially greater percentage of the natural precipitation evaporates than in humid regions.

Surface and ground water of arid regions will be high in soluble salts and if this water is used for irrigation a salinity hazard may exist.

Kelley points out that salts in soils and irrigation water in the arid zone are present due to evaporation either from high water tables or from some previous oceanic inundation or from secondary or sedimentary deposits. Saline irrigation waters may be high in soluble salts and the saline composition will tend to change dependent on soil conditions. For example, calcium and magnesium will tend to precipitate as carbonates and sulfates while sodium will remain in soluble form usually as the chloride. Whether or not the sodium salts accumulate in the root zone will be due to at least five factors:

1. Composition and concentration of the salts in the water.
2. The amount of water applied per irrigation and the method of

application.

3. The rainfall.
4. The permeability and method of irrigation water application.
5. The depth of the water table.

The chemical effects of soluble salts on soils were reviewed by Kelley. Divalent cations are held by soil clay colloids much more firmly than the monovalent alkali metal cations. Only where high soluble sodium salts accumulate in soils or where soils are in contact with high sodium water is the soil-exchange-complex excessively high in exchangeable sodium. When soils are high in exchangeable sodium the soils are usually not favorable media for plant growth.

The concentration of soluble salts according to Kelley also affects the cation exchange which takes place. The amounts of divalent cations displaced increase steadily as the volume or concentration of sodium salts in a soil increase. The most noticeable effect of sodium salts on soil is on the physical condition of the soil. As the salts are removed in an attempt at reclamation the soil tends to disperse and drainage becomes very slow for fine textured soils. The amount and type of dispersion is dependent on the clay type.

Kelley (10) reported on the distribution of salinity in "alkali" soils of California. These soils were found to contain the salt distribution shown in Figure 1. This distribution of salt is typical in a saline-alkali soil where evaporation exceeds leaching and where a high water table, temporary or permanent, exists close to the surface.

These results as reported by Kelley are the conditions found in naturally saline-alkali soils and the distribution of soluble salts in irrigated soils should be different from that reported here. The data

reported in the present report bears out this conclusion.

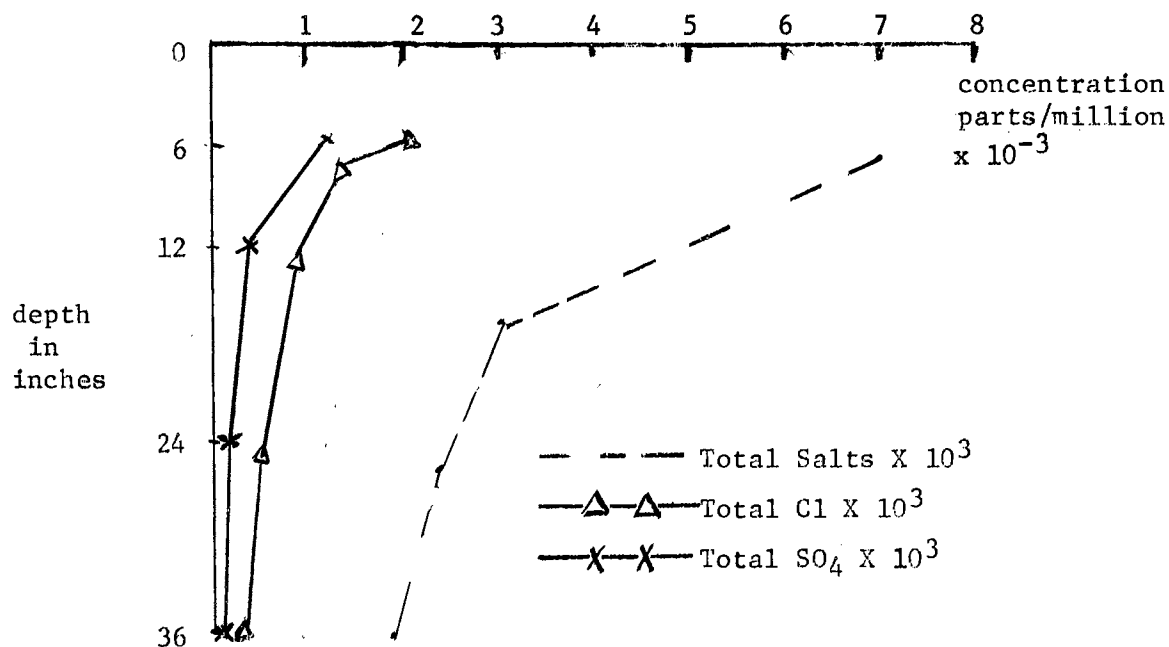


Figure 1. Soluble Salt Composition of Fresno Soil (California) from Kelley (10).

Wilcox (17) found that salt is brought to the land in irrigation water. Thus, an equal quantity of salt must be removed in the drainage water to prevent the accumulation of salt in soil. Scofield (14) was one of the first investigators to observe that crop plants do not absorb water and dissolved substances from the soil solution in the same proportions that these constituents occur together. Thus, the residual solutions become definitely more concentrated than the original. He thought that if saline water must be used for irrigation it should be applied in sufficient quantities not only to supply crop needs and to

meet evaporation losses, but to leach the root zone and thus carry away the salts that are left from the water that is evaporated from the soil and absorbed by plants. Campbell et al. (3) found that salt accumulation in irrigated areas is generally associated with an upward movement of the ground water. Thus, if water high in soluble salts moves upward from the water table by capillarity and the water is removed by plant roots, an accumulation of salts might be expected at the point where the water was removed.

For a number of years, however, as well as at present, much of the literature found on ion movement and distribution in soils is frequently in the area of soil physics where the soluble salts are used as indicators of water flow. Dyer's work (4,5) is an example of this observation.

Of the recent findings that are thought to have a somewhat direct bearing on this study are those by Thorne and Thorne (16), Miller et al. (11), and Dyer (5). Thorne and Thorne (16) in an experiment to investigate changes in composition of irrigated soils as related to the quality of irrigation water, found that the salt content of the soil was closely related to the salt content of the irrigation water. Miller et al. (6) used chloride salts as a single indicator in an experiment to find possible water management practices that may allow a greater control of solute behavior under field conditions. They found that chloride movement results from a dynamic process that may be controlled by the method of water application. Dyer (5) traced Cl^- and NO_3^- in irrigated and non-irrigated profiles; he found that deep percolating irrigation water leached the Cl^- and NO_3^- to considerable depths. Cl^- and NO_3^- reached a greater maximum concentration in the irrigated profiles with a

close parallel between leachings.

CHAPTER III

MATERIALS AND METHODS

The soil used in this research is from the Altus, Oklahoma Irrigation Experiment Station and is classified as a Hollister-Tillman silty clay loam complex. (See Appendix for detailed soil description.) The soil samples used in this report were from an area that had been irrigated with the high salinity--low sodium Lugert Lake irrigation water for nearly 20 years. The field has been planted to cotton each year and on the average received four acre inches of water per irrigation. The soil has probably received on the average five irrigations per cotton crop.

Each year the soil is fertilized with 200 pounds of 16-20-0 or 16-48-0 fertilizer after the crop has been planted to a satisfactory "stand." No records of fertilizer applied previous to 1950 are available and from a knowledge of general practices in this area no fertilizer was probably used prior to this time.

Twelve profiles from the irrigated area were taken in a regular grid pattern over the field in 6 inch depths until a water table was reached. Samples of water from the sample hole were also taken after the hole filled with water.

Soil samples were also taken in the same manner from a non-irrigated area. This location was sufficiently far removed from irrigation canals to assure no influence from underground seepage. Water table water samples were also taken from this area.

All soil samples were placed in "Kraft" paper or plastic (polyethylene) bags and removed to the laboratory. The samples were air dried and then ground to pass a 2 mm. mesh sieve.

Laboratory procedures include soil-water mixtures of 1:1 which approximates the saturation extract procedure of Richards (13) for soluble constituents. After allowing the samples (1:1) to stand for 24 hours with intermittent shaking, the samples were filtered on "#30 Whatman" filter paper and the clear extract used in the determinations. However, profiles 22, 23, 30, 31, 32 and 33 were extracted with a 2:1 water-soil mixture. This ratio was used for these profiles because the clay content was so high that a sufficient quantity of extract could not be obtained.

The extracts were analyzed for the various constituents by the procedures recommended by Jackson (7) and Richards (13) unless otherwise indicated. The pH of the soil paste and water extract was determined with the glass electrode "Beckman Zeromatic" pH meter (12). Total dissolved solids and conductivity were determined in the usual manner (7). Calcium and magnesium were determined by the ethylene--diaminetetra acetic acid titration procedure (7). Chloride was determined by the "Mohr" titration (13) and sulfate by a turbidimetric procedure developed by C. C. Schaller of the Oklahoma Agricultural Experiment Station Soils Laboratory.¹ Nitrate was determined by the brucine sulfate method (2,8,12,15) and is given in detail in the Appendix. This procedure is not subject to errors due to excess chloride as found in the phenoldisul-

¹Private communication.

fonic procedure as recommended by Harper (6). See Appendix for detailed procedure.

CHAPTER IV

RESULTS AND DISCUSSION

The raw data collected in this research is found in the Appendix. Interpretative data as tables and figures are derived from this data. All data collected were reduced from parts per million (ppm) to $\text{ppm} \times 10^{-2}$. The data collected from similar profiles was combined and presented as graphs of concentrations of $\text{ppm} \times 10^{-2}$. The total dissolved solids versus soil profile depth and other dissolved constituents were grouped together after inspection of the data and three categories of soil profile are presented.

1. Data from non-irrigated soil profiles #1 and #2 are referred to as Control or "C". Since these two profiles were sampled at different depths and some distance apart an average value was obtained by graphing the data and taking an average at each depth which corresponds with the same depth of the irrigated soil profiles.

2. The irrigated soil profiles 10, 11, 12, 13, 20 and 31 were grouped together and designated as Group I or "G-I". All of the data presented in this section designated as G-I is an average of these six profiles.

3. The irrigated soil profiles 21, 22, 23, 30, 32 and 33 were grouped together and designated Group II or "G-II". All of the data presented in this section designated as G-II is an average of these six profiles.

The data collected and the systematic method of collecting soil samples precludes a statistical interpretation of the data. Although statistical interpretation may be desirable in many instances the data presented here are almost statements of fact and the averages of several samples would appear to be equally as satisfactory as a statistical interpretation.

Some of the chemical properties of a non-irrigated soil sample taken on the Altus Station in 1961 are shown in Table I. These data are quite similar to the data presented here and indicates that the composition of the check soil has probably not changed in 20 years.

TABLE I
CHEMICAL PROPERTIES OF HOLLISTER-TILLMAN COMPLEX SOIL.
IRRIGATION EXPERIMENT STATION ALTUS OKLAHOMA.
UNPUBLISHED DATA BY
L. W. REED 7/11/61.

Number	Inches Depth	Horizon	pH	CEC	Exchange Cations Me/100			
					Ca	Mg	K	Na
61-S-73	0-5	Ap	6.4	16.4	8.05	8.00	1.18	0.87
74	5-11	A ₁	6.2	23.7	8.05	8.00	1.13	0.83
75	11-23	B ₂	6.8	23.6	11.70	15.00	0.92	1.35
76	23-31	B ₃	7.4	20.5	13.10	14.50	0.74	1.22
77	31-44	Cca	7.7	19.2	17.0	17.5	0.74	1.57
78	44-50	C	7.6	17.4	17.5	18.9	0.74	2.83

	Soluble Salts						Conductivity micromhos
	ppm Soluble Constituents						
	Solids	Ca	Mg	Na	Cl	SO ₄	
61-S-73	510	30	23	70	38	90	676
74	340	18	17	78	28	110	456
75	880	92	43	105	96	450	1210
76	1310	155	68	117	160	650	1690
77	1620	165	91	176	310	650	2110
78	1790	138	93	264	600	430	2670

The distribution of total dissolved solids (TDS) in the Control (C), Group I (G-I) and Group II (G-II) soil profiles is shown in Table II and Figure 2. The Control (C) soil profiles (non-irrigated) show little salt accumulation in the upper layers of the profile with a gradual increase in salt accumulation with depth. A salt accumulation peak was reached at the 69 inch depth with a reading of 3500. Relative to the control, G-I and G-II showed an opposite trend in soluble salt in the profile. Soluble salts in the irrigated soils were higher in the 3-35 inch layers with a peak of soluble salt (TDS) deposition at 21 inches.

TABLE II
VALUES IN PPM X 10^{-2} OF TDS IN C, G-I AND G-II
SOIL PROFILES OF HOLLISTER CLAY LOAM SOIL
ALTUS, OKLAHOMA.

Depth/inches	Control	G-I	G-II
0 - 6		6.0	32.0
6 - 12	2.0	14.0	41.0
12 - 18	3.0	23.0	28.0
18 - 24	6.0	25.0	37.0
24 - 30	10.0	24.0	36.0
30 - 36	16.0	20.0	31.0
36 - 42	24.0	19.0	24.0
42 - 48	24.0	19.0	29.0
48 - 54	28.0	22.0	61.0
54 - 60	30.0	23.0	43.0
60 - 66	32.0	21.0	43.0
66 - 72	35.0	21.0	59.0
72 - 78	30.0	25.0	42.0
78 - 84	17.0	27.0	70.0
84 - 90	15.0	27.0	61.0
90 - 96		24.0	

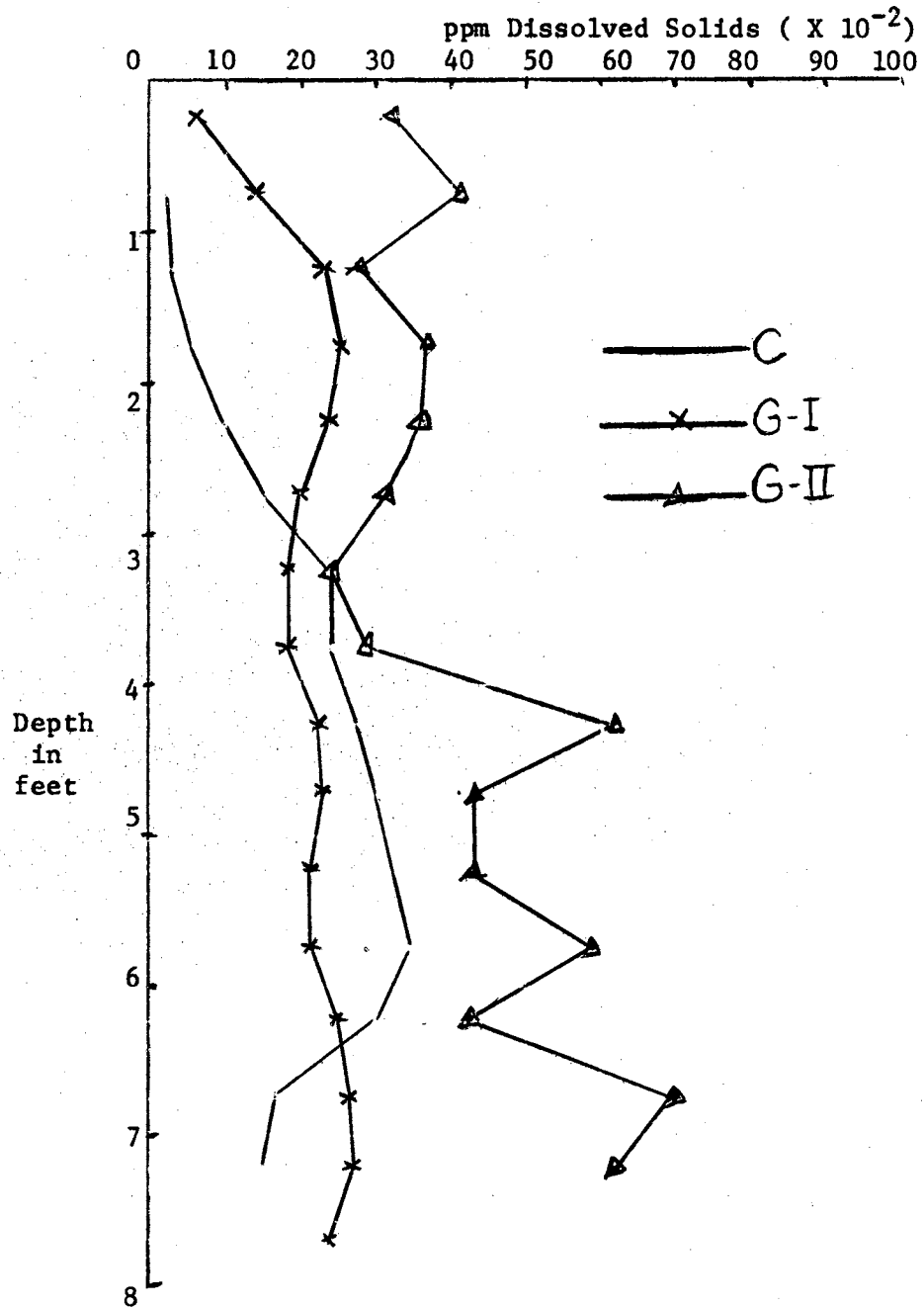


Figure 2. PPM of Total Dissolved Solids (TDS) in Hollister Clay Loam Soil, Altus, Oklahoma.

G-II, on the other hand, showed marked accumulation in two distinctive regions in the profile that coincided with one of the regions in G-I. Accumulation in the lower region is almost twice as much that in the upper one. Two accumulation peaks are observed in the upper region, one at the 9-inch depth with a value of 41.5×10^2 ppm and a second at the 21-inch depth with the deposition of 37×10^2 ppm. The lower accumulation resulted in three peaks:

1. Deposition increased at the 51 inch depth with TDS of 61×10^2 ppm.
2. Deposition increased at the 69 inch depth with a TDS of 59×10^2 ppm.
3. Deposition increased at the 81 inch depth with a TDS of 70×10^2 ppm.

The change of calcium concentration with depth is shown in Table III and Figure 3. The pattern of calcium distribution in the control (C), Group I (G-I) and Group II (G-II) profiles is very similar to the distribution of total dissolved solids (TDS) as shown in Table II and Figure 2. The rate of accumulation is different from the TDS pattern but the relative distribution is nearly the same.

The change in magnesium concentration with depth is shown in Table IV and Figure 4. The pattern of magnesium distribution is different from those of calcium and TDS and the G-I and G-II distribution patterns are also different. The accumulation pattern of magnesium in the G-II profiles shows a strong zone of deposition at 57 inch depth. The G-II profiles showed an increase in soluble magnesium over the G-I profiles with some indication of magnesium accumulation in the G-II profile.

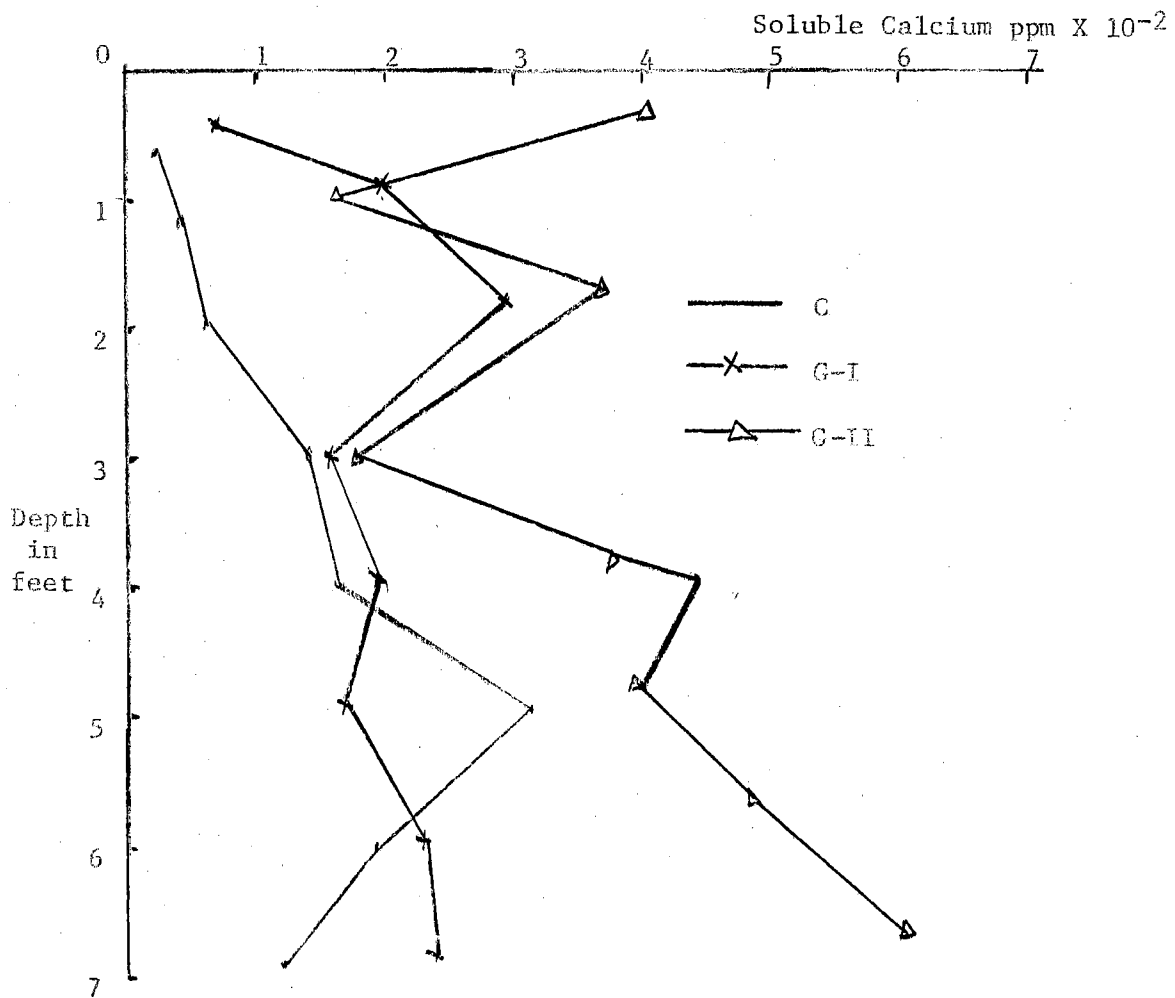


Figure 3. PPM of Soluble Calcium in Hollister Clay Loam Soil, Altus, Oklahoma.

TABLE III
 VALUES IN PPM X 10^{-2} OF SOLUBLE CALCIUM IN C, G-I, AND G-II
 SOIL PROFILES OF HOLLISTER CLAY LOAM SOIL
 ALTUS, OKLAHOMA.

Depth/inches	Control	G-I	G-II
0 - 6		0.80	4.00
6 - 12	0.20	1.16	1.30
12 - 18	0.25	2.86	2.83
18 - 24	0.50	3.05	3.92
24 - 30	0.70	2.59	2.95
30 - 36	1.30	1.90	2.50
36 - 42	1.90	1.79	1.75
42 - 48	1.20	1.42	2.57
48 - 54	1.50	1.66	4.97
54 - 60	3.10	1.71	3.98
60 - 66	3.20	1.87	4.22
66 - 72	2.10	1.91	4.18
72 - 78	1.30	2.56	5.21
78 - 84	1.35	2.52	7.04
84 - 90	1.00	2.21	6.94
90 - 96		2.13	

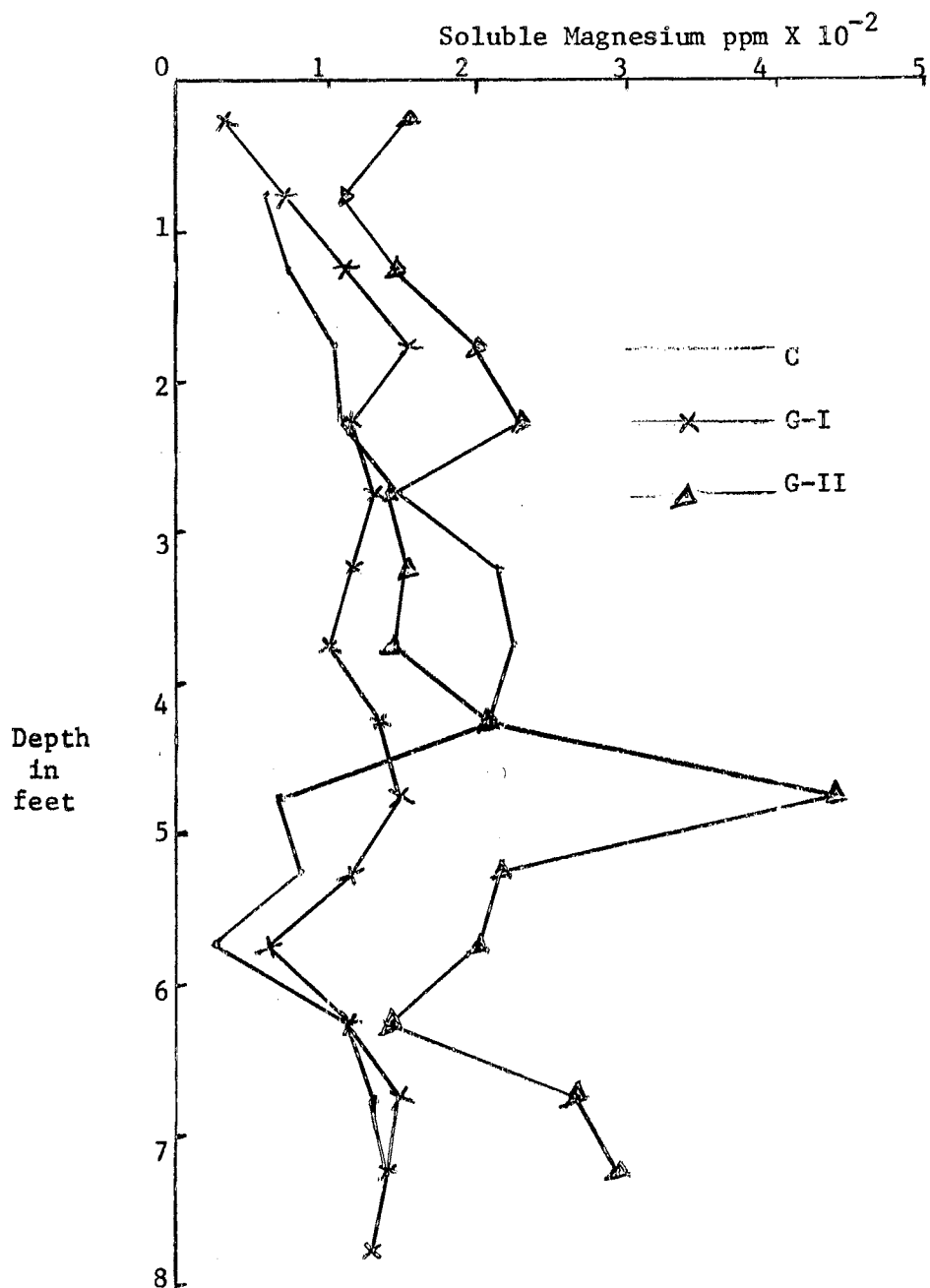


Figure 4. PPM of Soluble Magnesium in Hollister Clay Loam Soil, Altus, Oklahoma.

TABLE IV
 VALUES IN PPM X 10^{-2} OF SOLUBLE MAGNESIUM IN C, G-I, AND G-II
 SOIL PROFILES OF HOLLISTER CLAY LOAM SOIL
 ALTUS, OKLAHOMA.

Depth/inches	Control	G-I	G-II
0 - 6		0.30	1.55
6 - 12	0.61	0.46	1.19
12 - 18	0.74	1.06	1.45
18 - 24	1.03	1.53	1.99
24 - 30	1.08	1.26	2.13
30 - 36	1.51	1.30	1.46
36 - 42	2.16	1.13	1.55
42 - 48	2.24	1.00	1.44
48 - 54	2.08	1.37	2.06
54 - 60	0.70	1.49	4.35
60 - 66	0.82	1.13	2.14
66 - 72	0.46	0.98	1.98
72 - 78	1.16	1.15	1.41
78 - 84	1.30	1.47	2.65
84 - 90	1.40	1.41	2.96
90 - 96		1.31	

Sodium increased in the profiles studied with depth in an almost linear fashion. However, the G-II profiles were higher in soluble sodium than the G-I profiles as shown in Table V and Figure 5. The two series of irrigated profiles show an accumulation of sodium in the deeper layers. Note that the sodium concentration at the surface for the three sets of soil profiles is nearly the same with an increase for G-II from 4.5 to 9×10^2 at 87 inches.

TABLE V
VALUES IN PPM $\times 10^{-2}$ OF SOLUBLE SODIUM IN C, G-I, AND G-II
SOIL PROFILES OF HOLLISTER CLAY LOAM SOIL
ALTUS, OKLAHOMA.

Depth/inches	Control	G-I	G-II
0 - 6		1.51	4.21
6 - 12	2.54	2.83	2.65
12 - 18	1.57	3.15	3.72
18 - 24	2.88	3.42	3.81
24 - 30	4.60	3.55	4.88
30 - 36	4.28	3.43	4.61
36 - 42	3.75	4.08	4.86
42 - 48	3.70	3.74	5.56
48 - 54	3.80	4.57	6.29
54 - 60	3.80	4.75	6.73
60 - 66	3.70	4.74	6.77
66 - 72	3.35	4.53	6.39
72 - 78	3.20	4.76	7.40
78 - 84	4.85	4.68	9.05
84 - 90	4.65	4.68	9.02
90 - 96			

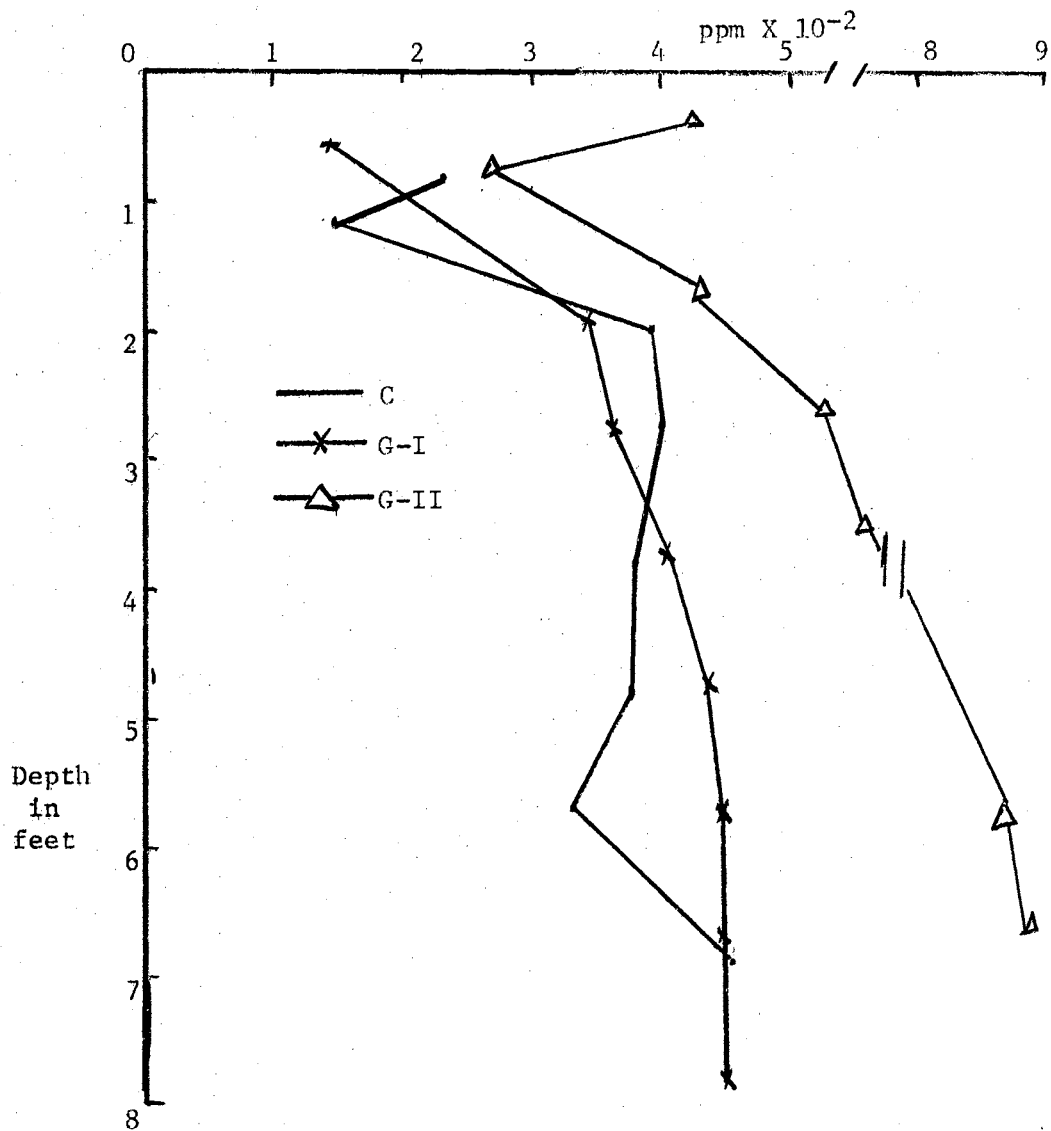


Figure 5. PPM of Soluble Sodium in Hollister Clay Loam Soil, Altus, Oklahoma.

The chloride content of the control (C) profiles is high from the surface to the deepest depths sampled as shown in Table VI and Figure 6. However, the G-I and G-II profiles are much higher in chloride in the bottom layers of the profile which indicates chloride removal from the surface soil and deposition in the lower depths. This deposition pattern is somewhat similar to the patterns shown for sodium and magnesium. The accumulation of chloride in the region close to the water table is higher for the G-II profiles than the G-I profiles. The reasons for these differences are obscure and could not be determined during the course of this study.

TABLE VI
VALUES IN PPM X 10^{-2} OF CHLORIDE IN C, G-I, AND G-II
SOIL PROFILES OF HOLLISTER CLAY LOAM SOIL
ALTUS, OKLAHOMA.

Depth/inches	Control	G-I	G-II
0 - 6		2.01	6.26
6 - 12	0.70	3.75	1.87
12 - 18	1.10	2.80	2.16
18 - 24	1.40	3.58	3.58
24 - 30	3.90	4.88	5.33
30 - 36	6.65	6.46	6.66
36 - 42	10.10	8.13	7.58
42 - 48	9.40	7.83	8.35
48 - 54	8.20	8.36	9.54
54 - 60	6.15	7.71	12.92
60 - 66	6.35	8.02	10.26
66 - 72	5.85	8.16	9.77
72 - 78	6.15	7.96	11.51
78 - 84	4.75	8.33	11.46
84 - 90	4.80	8.54	10.31
90 - 96		8.79	

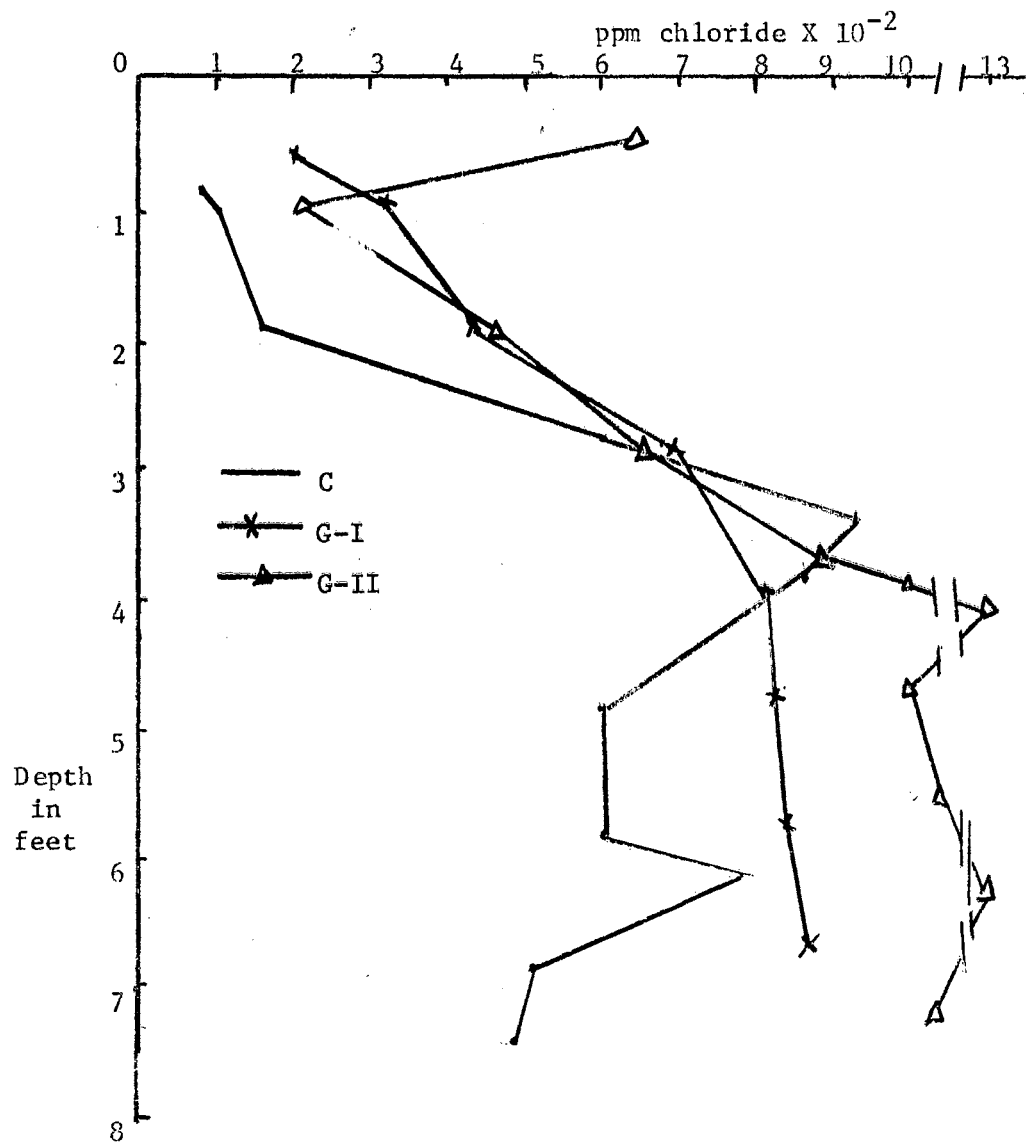


Figure 6. PPM of Soluble Chloride in Hollister Clay Loam Soil, Altus, Oklahoma.

The deposition of sulfate in these profiles is most interesting as shown in Table VII and Figure 7. The sulfate content of the "C" profile steadily increases down to the water table and then declines. However, the sulfate content of the two sets of irrigated profiles shows a very large increase in the surface layers followed by a decline with depth and then a continual increase down to the water table. Both the G-I and G-II sulfate accumulation data are almost parallel with G-II showing a higher quantity of sulfate at each depth. The accumulation of sulfate in the surface layers is probably due to lower solubility of the sulfate salts as compared to chlorides and nitrates; however, there is a continual downward movement of sulfate salts also.

TABLE VII
VALUES IN PPM X 10^{-2} OF SOLUBLE SULFATE IN C, G-I, AND G-II
SOIL PROFILES OF HOLLISTER CLAY LOAM SOIL
ALTUS, OKLAHOMA.

Depth/inches	Control	G-I	G-II
0 - 6		1.25	10.6
6 - 12		3.77	5.87
12 - 18	1.00	10.48	14.88
18 - 24	1.50	19.28	21.60
24 - 30	1.70	14.74	23.2
30 - 36	4.70	5.21	6.32
36 - 42	9.00	4.48	4.82
42 - 48	9.00	4.08	8.33
48 - 54	7.50	7.72	9.17
54 - 60	6.00	8.89	13.65
60 - 66	7.30	7.48	14.50
66 - 72	12.00	7.77	19.70
72 - 78	17.70	7.85	9.09
78 - 84	10.50	15.93	20.87
84 - 90	6.50	14.25	21.55
90 - 96		13.03	

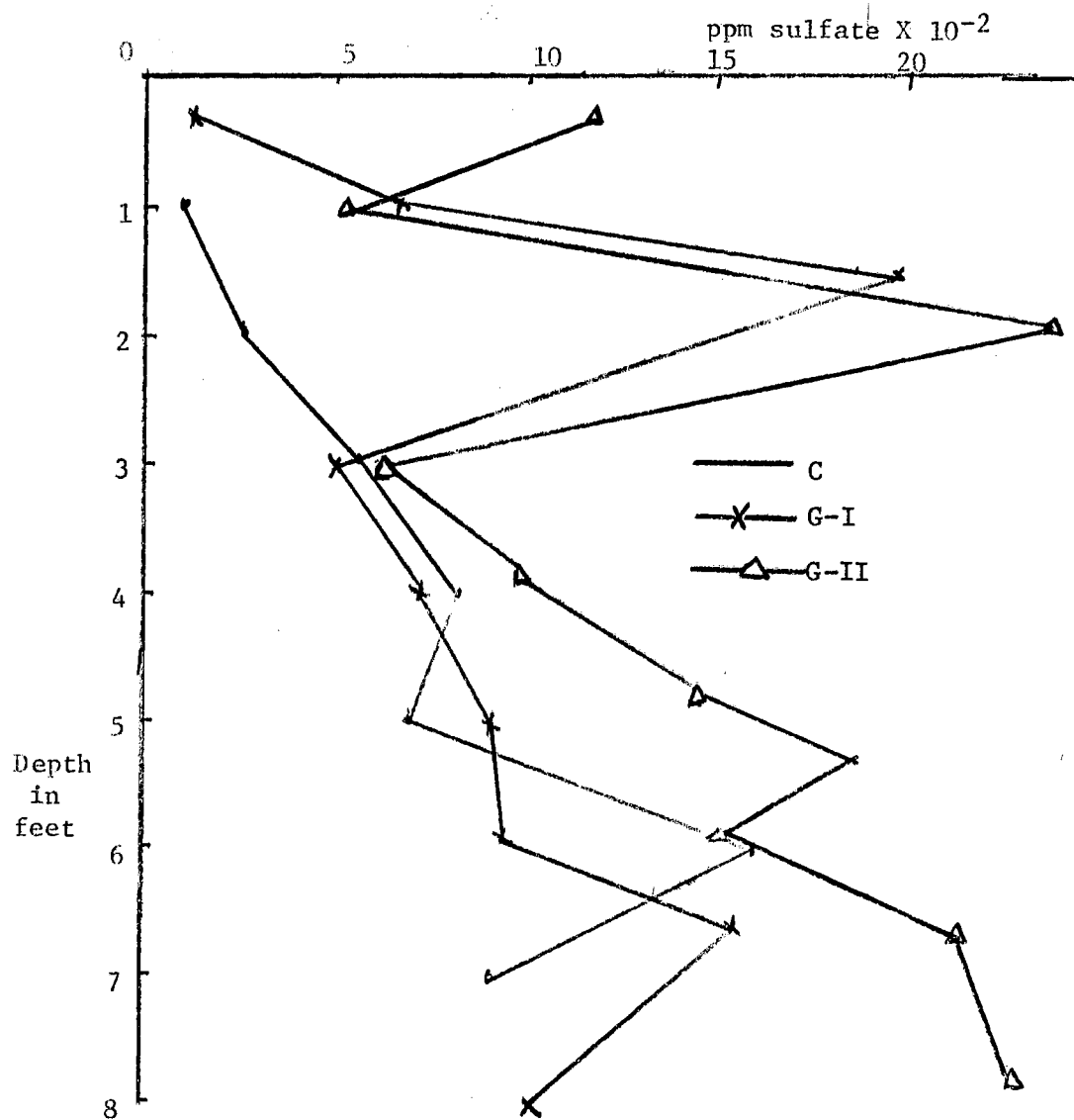


Figure 7. PPM of Soluble Sulfate in Hollister Clay Loam Soil Altus, Oklahoma.

The behavior of nitrate leaching is remarkably different from all of the previously observed patterns as shown by the data from Table VIII and Figure 8. It is interesting to speculate why the difference between C, G-I and G-II exists. In all previous ions examined the G-II profiles were higher than G-I in soluble constituents. The nitrates were determined to be present in relatively low concentration at all depths but were consistently higher in the irrigated as compared to the non-irrigated profiles.

TABLE VIII

VALUES IN PPM OF NITRATE IN C, G-I, AND G-II
SOIL PROFILES OF HOLLISTER CLAY LOAM SOIL
ALTUS, OKLAHOMA.

Depth/inches	Control	G-I	G-II
0 - 6		23.83	12.50
6 - 12	2.20	12.33	6.67
12 - 18	0.85	5.50	4.60
18 - 24	0.70	6.18	3.00
24 - 30	0.55	3.33	1.83
30 - 36	0.65	11.00	1.33
36 - 42	0.95	4.18	2.33
42 - 48	1.27	4.52	2.00
48 - 54	2.10	6.33	4.00
54 - 60	3.60	6.67	3.83
60 - 66	3.60	11.17	7.33
66 - 72	4.15	9.33	8.50
72 - 78	3.85	7.67	6.20
78 - 84	2.70	6.85	5.50
84 - 90		10.50	4.50
90 - 96			

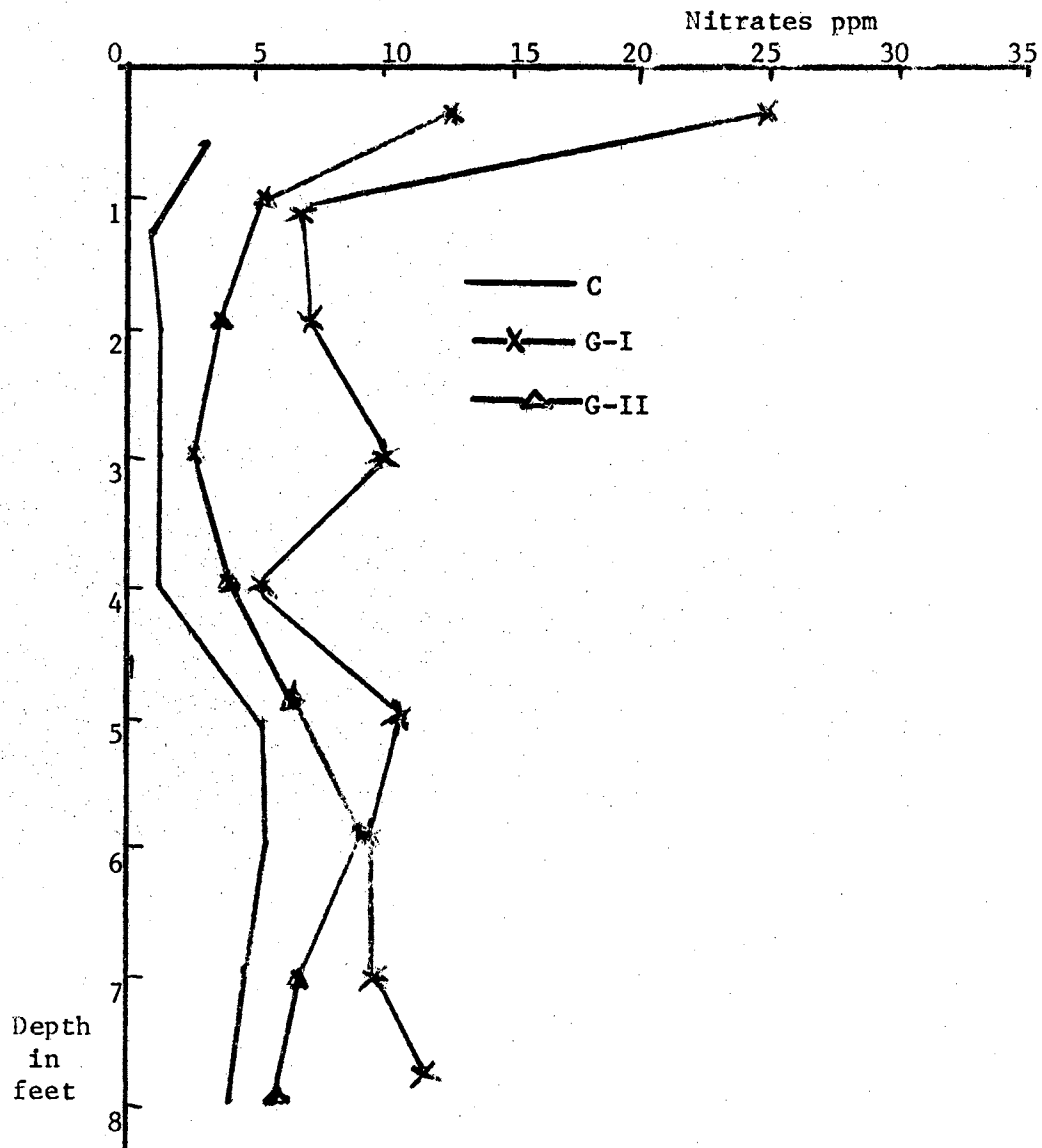


Figure 8. PPM of Soluble Nitrate in Hollister Clay Loam Soil, Altus, Oklahoma.

An overall examination of the data of individual samples with respect to pH in both extract and paste shows a persistent trend in the soil of all profiles in all depths to stay slightly above or below neutrality. This is primarily due to the fact that the irrigation water was low in sodium despite its high salinity. The electrical conductivity in terms of micromhos/cm of the extracts indicate medium and high salinity, being over 750 $\mu\text{mhos/cm}$ and 2250 $\mu\text{mhos/cm}$ respectively (1).

The graphs illustrating the distribution and accumulation patterns of TDS and other salt constituents, reveal highly significant zones of salt accumulation and leaching of salts to the water table as shown by data presented in Table IX.

TABLE IX
VALUES IN PPM X 10^{-2} OF SOLUBLE CONSTITUENTS IN THE
FREE WATER OF THE WATER-TABLE IN
HOLLISTER CLAY LOAM SOIL
ALTUS, OKLAHOMA.

Analysis	G-I	G-II
TDS	136.68	141.38
Ca ⁺⁺	11.56	12.54
Mg ⁺⁺	5.06	7.92
Na ⁺	26.85	22.85
Cl ⁻	59.63	57.18
SO ₄ ⁻⁻	9.12	7.84
NO ₃ ⁻	5.29	3.87

This salt accumulation is primarily brought about by the high salinity of the irrigation water. A factor enhancing accumulation is the occurrence of a water table at about 8-9 feet. The excessive salt content in irrigation water increases the salt concentration of the soil solution leading to the precipitation and accumulation of the less soluble salts in the soil profile and the movement of the more soluble salts to the water table. This may be explained through the evapotranspiration mechanisms that cause the salt content to increase in the first few inches of the profile and at the root zone area. The water table builds salt accumulation through the downward movement of water from the surface into the deeper layers of the profile with eventual deposition at the water table. The water from the water table has a very high salt content as shown by the data in Table IX due to the salt movement into the water table with irrigation water. The salt from the water table increases the concentration in soil solution resulting in the precipitation and accumulation of salt in the soil above the water table.

The different patterns of salt accumulation developed by different salt constituents reveal that certain ions are more susceptible to precipitation in the profile than others due to solubility and mobility and/or complementary or hindering reactions with other ions. In this case Ca^{++} , Mg^{++} , Cl^- and SO_4^{--} seem to be responsible to a larger extent for the composition of the salt accumulated. The nitrate ion, on the other hand, while showing very little precipitation tendency, seems to have been leached away with a concomitant increase in the nitrate content of the water samples taken from the water table in all irrigated profiles.

Since layers at some locations in the profile as well as in the

water table are to some extent favorable to denitrification; and since denitrification is a relatively rapid process, it is suggested that there is reason to think that the nitrate content could have been higher in the profile and in the water table; it is thought that it could have been even much higher in the profile if denitrification had not reduced the total.

It could nevertheless be argued that even with no appreciable denitrification, the water table content of nitrate probably could not have been much higher because of the lateral water flow through which nitrate and other constituents can be easily lost. The denitrification process is thus thought to be responsible for greater reduction of the nitrate content in the profile since this soil is highly fertilized. Plants cannot take all of the nitrate and it is rather difficult to assume that the leaching-away process coupled with the high solubility and mobility of the nitrate ion can exhaust the nitrate content to so low a level as a fraction of a ppm or even nil in some cases.

It can then be reasoned that high salinity irrigation water with low sodium may not be harmful to the soil as such but the definite increase in salt concentration and its eventual accumulation, especially in the area of the root zone, can be highly critical to crop production. Uptake of water and nutrients by the roots can be highly affected through increased osmotic pressure of the soil solution. Certain salt constituents can also cause some elements essential to plant growth to become unavailable; such as phosphorus. A study on the productivity of these soils can therefore reveal interesting and important findings.

Though this soil is regarded as uniform, the irrigated profiles did not exhibit high behavioral similarity in distribution and accumulation

of salts. Thus, significant non-uniform distribution and accumulation are found. This in a sense means that no matter what degree of uniformity in topography, soil texture, and other characteristics; an area of a soil shows, it is still essentially a heterogeneous body in a highly complex fashion in terms of components and dynamic conditions. Thus, even if soil profiles could be in some respect grouped together for a certain purpose, each profile in every inch of it still possesses certain characteristics and dynamic conditions which make every inch different from each other and each profile different from one another. Therefore, the revealed different patterns of distribution and accumulation should not be unexpected.

CHAPTER V

SUMMARY AND CONCLUSIONS

Irrigation with high salinity--low sodium water for 18 years on a clay loam soil with a water table developed significant patterns of salt distribution and accumulation. Much of the accumulation has taken place mostly in the root zone and above the water table. Nitrate content was extremely low in the profile, probably due to leaching away and denitrification. Nitrate was relatively very high in the water table. The sodium content though high, its effect was offset by a higher content of Ca^{++} and Mg^{++} . Salt accumulation is critical to good productivity which points out that one must use great caution if saline water--low in sodium should be used in irrigation, especially in the presence of a water table. The above findings are in agreement with some previous work.¹

¹Personal communication with Lester W. Reed and James M. Davidson, Professor and Associate Professor of Agronomy respectively, Oklahoma State University, 1968.

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APPENDIX

TABLE X

DETERMINATION OF pH, CONDUCTIVITY, TDS AND CERTAIN
SALT CONSTITUENTS IN THE NON-IRRIGATED PROFILE NO. 1
HOLLISTER CLAY LOAM SOIL
ALTUS, OKLAHOMA.

Depth inches	pH in extract	pH in paste	E.C. µmhos /cm	Ca ⁺⁺ ppm	Mg ⁺⁺ ppm	Na ⁺ ppm	Cl ⁻ ppm	SO ₄ ⁻⁻ ppm	NO ₃ ⁻ ppm	TDS ppm	Sam- ple
0 - 8	7.85	7.00	339	60	36	445	71	nil	0.1	200	764
8 - 11	8.10	7.25	359	20	72	450	36	50	4.0	240	765
11 - 20	7.70	7.10	360	20	48	295	71	100	1.0	200	766
20 - 27	7.90	7.50	988	60	72	605	250	100	0.1	500	767
27 - 36	7.90	7.55	1593	80	108	1525	426	100	0.1	860	768
36 - 44	7.80	7.60	4490	180	240	2350	1142	400	1.0	2350	769
44 - 53	7.70	7.60	5220	200	276	3250	1392	500	2.0	2850	770
53 - 60	7.70	7.65	3952	180	144	3500	928	400	6.0	2250	771
60 - 70	7.40	7.60	4704	220	180	2860	1000	1100	5.0	2830	772
70 - 79	7.30	7.60	6175	140	132	3000	785	3800	6.0	4500	773
79 - 88	7.70	7.55	3952	220	168	651	714	1600	4.0	2510	774
88 - 96	7.70	7.50	3528	100	156	580	821	500	0.1	1840	775
96 - 106	7.70	7.70	3528	140	132	590	857	400	2.0	1890	776

TABLE XI

DETERMINATION OF pH, CONDUCTIVITY, TDS AND CERTAIN
SALT CONSTITUENTS IN THE NON-IRRIGATED PROFILE NO. 2
HOLLISTER CLAY LOAM SOIL
ALTUS, OKLAHOMA.

Depth inches	pH in extract	pH in paste	E.C. μ mhos /cm	Ca ⁺⁺ ppm	Mg ⁺⁺ ppm	Na ⁺ ppm	Cl ⁻ ppm	SO ₄ ⁻⁻ ppm	NO ₃ ⁻ ppm	TDS ppm	Sam- ple
0 - 9	8.0	6.80	367	20	48	30	107	nil	2.0	160	777
9 - 15	7.8	6.95	457	20	36	25	107	100	nil	210	778
15 - 22	8.0	7.20	968	40	144	5	214	150	1.0	480	779
22 - 33	7.9	7.58	2195	80	132	250	464	250	1.0	1260	780
33 - 42	7.9	7.60	4940	240	204	505	1035	1150	1.0	2790	781
42 - 50	7.8	7.60	3293	120	180	450	535	1350	1.0	2010	782
50 - 59	7.7	7.40	4490	440	180	415	286	370	1.0	3630	783
59 - 66	7.5	7.40	4940	440	216	425	286	460	2.0	3860	784
66 - 74	7.7	7.40	3087	200	132	360	250	180	3.0	2270	785
74 - 85	8.1	7.45	1829	60	96	245	250	450	1.0	1090	786
85 - 95	7.8	7.70	1431	40	132	205	178	250	2.0	850	787

TABLE XII

DETERMINATION OF pH, CONDUCTIVITY, TDS AND CERTAIN
SALT CONSTITUENTS IN THE IRRIGATED PROFILE NO. 10
HOLLISTER CLAY LOAM SOIL
ALTUS, OKLAHOMA

Depth inches	pH in extract	pH in paste	E.C. µmhos /cm	Ca ⁺⁺ ppm	Mg ⁺⁺ ppm	Na ⁺ ppm	Cl ⁻ ppm	SO ₄ ⁻⁻ ppm	NO ₃ ⁻ ppm	TDS ppm	Sam- ple
0 - 6	7.0	7.3	874	80	39	93	179	180	27.	500	556
6 - 12	7.0	7.4	1219	110	44	140	321	300	3.	690	557
12 - 18	7.0	7.4	3293	392	85	256	142	1625	4.	2390	558
18 - 24	6.9	7.7	3293	348	45	272	142	1375	4.	2320	559
24 - 30	7.0	7.6	3293	292	42	282	249	1125	4.	2150	560
30 - 36	7.0	7.6	2905	202	147	282	536	800	7.	1630	561
36 - 42	6.9	7.6	2905	368	99	600	607	575	6.	1620	562
42 - 48	7.0	7.6	2905	164	99	326	678	380	7.	1620	563
48 - 54	7.0	7.6	2905	176	119	344	714	374	6.	1680	564
54 - 60	7.0	7.7	3087	176	119	372	714	374	10.	2530	565
60 - 66	7.0	7.65	3293	176	77	400	821	880	10.	1770	566
66 - 72	6.9	7.6	3087	164	53	390	785	380	14.	1760	567
72 - 78	7.0	7.6	3528	220	79	422	821	374	7.	2020	568
78 - 84	7.0	7.9	3800	220	97	380	928	330	0.1	2200	569
84 - 90	6.8	7.6	3952	220	59	464	1000	388	22.	2320	570
90 - 96	7.0	7.7	3528	220	59	454	893	388	19.0	1930	571
96 -102	7.0	7.7	3528	202	53	400	928	310	18.0	2000	572

TABLE XIII

DETERMINATION OF pH, CONDUCTIVITY, TDS AND CERTAIN
SALT CONSTITUENTS IN THE IRRIGATED PROFILE NO. 11
HOLLISTER CLAY LOAM SOIL
ALTUS, OKLAHOMA.

Depth inches	pH in extract	pH in paste	E.C. μ hos /cm	Ca ⁺⁺ ppm	Mg ⁺⁺ ppm	Na ⁺ ppm	Cl ⁻ ppm	SO ₄ ⁻⁻ ppm	NO ₃ ⁻ ppm	TDS ppm	Sam- ple
0 - 6	7.2	7.5	1029	56	31	113	179	100	34	560	573
6 - 12	7.0	7.5	1764	126	43	565	179	750	13	1080	574
12 - 18	6.9	7.6	3528	314	134	305	321	2500	3	2580	575
18 - 24	6.9	7.65	3528	264	132	305	393	2050	3	2470	576
24 - 30	7.4	7.7	3659	218	152	325	535	1400	2	2450	577
30 - 36	6.7	7.75	3293	114	136	325	608	650	2	2080	578
36 - 42	7.85	7.7	3097	110	152	315	714	450	6	1910	579
42 - 48	6.85	7.8	2993	82	90	345	643	450	10	1910	580
48 - 54	7.5	7.75	2993	26	125	470	607	400	11	1730	581
54 - 60	6.7	7.7	2993	96	78	425	714	400	20	1770	582
60 - 66	6.85	7.7	2993	88	60	450	643	250	18	1790	583
66 - 72	7.65	7.8	2600	61	64	360	535	200	20	1460	584
72 - 78	7.55	7.85	2905	74	73	390	643	700	23	1680	585
78 - 84	7.60	7.7	2670	108	58	350	607	1100	23	1530	586
84 - 90	7.65	7.8	2533	76	68	305	535	150	22	1460	587
90 - 96	7.75	7.75	2670	112	176	325	571	100	23	1620	588

TABLE XIV

DETERMINATION OF pH, CONDUCTIVITY, TDS AND CERTAIN
SALT CONSTITUENTS IN THE IRRIGATED PROFILE NO. 12
HOLLISTER CLAY LOAM SOIL
ALTUS, OKLAHOMA.

Depth inches	pH in extract	pH in paste	E.C. µmhos /cm	Ca ⁺⁺ ppm	Mg ⁺⁺ ppm	Na ⁺ ppm	Cl ⁻ ppm	SO ₄ ⁻⁻ ppm	NO ₃ ⁻ ppm	TDS ppm	Sam- ple
0 - 6	7.95	7.20	754	56	14	80	143	150	26.	470	589
6 - 12	6.85	7.70	2993	140	86	325	678	300	8.	1940	590
12 - 18	6.90	7.30	1122	52	26	125	143	100	16.	750	591
18 - 24	7.35	7.25	2744	222	92	260	219	1450	14.	2090	592
24 - 30	6.75	7.40	3406	322	104	305	357	2250	nil	2650	593
30 - 36	7.75	7.60	3952	308	132	325	500	195	34.	2820	594
36 - 42	6.75	7.65	3582	156	113	345	464	400	0.1	2220	595
42 - 48	6.70	7.7	3952	156	116	300	928	450	0.1	2250	596
48 - 54	6.85	7.65	4295	184	142	440	1000	750	4.	2600	597
54 - 60	6.8	7.55	5811	282	227	510	928	2300	3.	3750	598
60 - 66	6.7	7.65	5200	338	132	485	892	1950	8.	3230	599
66 - 72	7.75	7.55	4704	260	108	485	928	1200	4.	2880	600
72 - 78	7.05	7.45	6586	446	0.	1605	1000	3800	6.	4320	601
78 - 84	7.	7.50	7057	426	272	590	1000	3850	7.	4380	602
84 - 90	6.85	7.45	6586	508	211	590	1000	3800	4.	4330	603
90 - 96	7.55	7.35	6586	518	217	565	928	3400	3.	4310	604
96 -102	6.95	7.50	5811	134	448	590	1071	1400	3.	3370	605

TABLE XV
 DETERMINATION OF pH, CONDUCTIVITY, TDS AND CERTAIN
 SALT CONSTITUENTS IN THE IRRIGATED PROFILE NO. 13
 HOLLISTER CLAY LOAM SOIL
 ALTUS, OKLAHOMA.

Depth inches	pH in extract	pH in paste	E.C. µmhos /cm	Ca ⁺⁺ ppm	Mg ⁺⁺ ppm	Na ⁺ ppm	Cl ⁻ ppm	SO ₄ ⁻⁻⁻ ppm	NO ₃ ⁻ ppm	TDS ppm	Sam- ple
0 - 6	7.7	7.0	178	58	13	205	348	100	29.	560	606
6 - 12	7.6	7.3	178	102	35	140	717	350	17.	1000	607
12 - 18	7.75	7.35	286	246	116	260	469	200	16	2270	608
18 - 24	6.6	7.6	428	284	226	315	611	2250	16	2650	609
24 - 30	7.65	7.65	643	232	149	360	833	1350	11	2480	610
30 - 36	7.15	7.65	714	128	127	335	987	400	17	7480	611
36 - 42	6.8	7.65	892	142	131	370	1811	500	2	2150	612
42 - 48	7.65	7.7	892	160	108	450	1235	500	2	2190	613
48 - 54	7.1	7.6	892	348	216	530	1250	2400	2	3620	614
54 - 60	7.6	7.65	892	244	190	555	880	1650	2	3200	615
60 - 66	7.65	7.45	1035	244	94	485	994	1050	10	2760	616
66 - 72	7.5	7.50	1428	248	79	485	1221	500	3	2550	617
72 - 78	7.	7.50	1071	148	103	475	1207	500	2	2440	618
78 - 84	6.6	7.40	1035	446	216	520	1179	3400	3	4250	619
84 - 90	7.15	7.40	964	452	161	520	1093	3500	2	4080	620
90 - 96	6.85	7.35	1142	180	120	360	1278	3450	3	2460	621
96 - 102	6.85	7.50	1178	200	84	450	1292	400	3	2370	622
102 - 108	6.80	7.50	1142	200	96	450	1363	250	nil	2390	623
108 - 114	6.95	7.30	1142	120	132	460	1335	200	3	2420	624
114 - 120	6.8	7.30	964	140	96	415	1150	100	2	2040	625

TABLE XVI

DETERMINATION OF pH, CONDUCTIVITY, TDS AND CERTAIN
SALT CONSTITUENTS IN THE IRRIGATED PROFILE NO. 20
HOLLISTER CLAY LOAM SOIL
ALTUS, OKLAHOMA.

Depth inches	pH in extract	pH in paste	E.C. µmhos /cm	Ca ⁺⁺ ppm	Mg ⁺⁺ ppm	Na ⁺ ppm	Cl ⁻ ppm	SO ₄ ⁻⁻ ppm	NO ₃ ⁻ ppm	TDS ppm	Sam- ple
0 - 6	6.75	7.35	1018	80	36	105	178	100	26	630	626
6 - 12	6.85	7.60	1703	120	36	160	178	400	6	1050	627
12 - 18	6.50	7.7	4490	380	180	360	357	300	3	3160	628
18 - 24	6.85	7.7	4295	300	228	370	464	2200	0.1	2870	629
24 - 30	6.65	7.75	3800	220	180	360	572	1400	2.	2450	630
30 - 36	6.55	7.65	3293	180	144	335	607	700	1	1980	631
36 - 42	7.7	7.65	2993	120	96	345	643	300	6	1720	632
42 - 48	6.7	7.6	3293	140	108	380	714	350	3	1830	633
48 - 54	6.8	7.6	3659	100	120	430	803	350	4	2030	634
54 - 60	6.9	7.6	3800	60	180	440	785	300	5	1940	635
60 - 66	7.1	7.55	4490	120	240	500	892	500	9	2540	636
66 - 72	7.	7.60	2800	180	192	450	857	300	9	2110	637
72 - 78	7.35	7.5	2600	140	96	325	571	200	6	1370	638
78 - 84	7.45	7.6	2670	140	168	305	607	200	5	1380	639
84 - 90	7.35	7.6	3087	180	216	360	750	250	6	1640	640
90 - 96	7.20	7.55	3528	180	120	370	857	200	5	1790	641
96 -102	7.30	7.55	3952	260	60	450	964	300	9	1930	642

TABLE XVII

DETERMINATION OF pH, CONDUCTIVITY, TDS AND CERTAIN
SALT CONSTITUENTS IN THE IRRIGATED PROFILE NO. 21
HOLLISTER CLAY LOAM SOIL,
ALTUS, OKLAHOMA.

Depth inches	pH in extract	pH in paste	E.C. umhos /cm	Ca ⁺⁺ ppm	Mg ⁺⁺ ppm	Na ⁺ ppm	Cl ⁻ ppm	SO ₄ ⁼⁼ ppm	NO ₃ ⁻ ppm	TDS ppm	Sam- ple
0 - 6	7.10	7.4	1204	120	36	110	214	150	21	690	643
6 - 12	6.7	7.15	1733	140	168	140	143	500	7	1130	644
12 - 18	6.8	7.25	2470	80	240	205	214	1000	4	1600	645
18 - 24	7.8	7.3	3087	200	156	230	357	1200	3	2020	646
24 - 30	7.9	7.5	2993	140	240	245	535	1000	3	2020	647
30 - 36	7.7	7.6	2993	100	168	275	643	250	1	1550	648
36 - 42	7.8	7.7	3087	100	240	295	678	250	6	1750	649
42 - 48	7.9	7.7	2533	100	144	260	607	200	4	1060	650
48 - 54	6.6	7.6	4117	1392	390	363	1136	4000	13	7800	651
54 - 60	7.0	7.55	3349	510	1650	375	994	1750	13	5320	652
60 - 66	6.7	7.5	3467	650	390	367	1136	2000	18	5780	653
66 - 72	6.6	7.6	2267	186	139	333	1065	2500	27	2760	654
72 - 78	6.6	7.6	3349	603	306	350	923	1700	16	3020	655
78 - 84	6.8	7.6	2352	325	111	312	852	400	13	5760	656
84 - 90	7.5	7.65	2058	93	139	300	923	150	11	2360	657
90 - 96	6.8	7.7	2058	186	111	275	994	100	11	2380	658
96 -102	7.3	7.7	1647	139	111	245	923	nil	11	2000	659

TABLE XVIII

DETERMINATION OF pH, CONDUCTIVITY, TDS AND CERTAIN
SALT CONSTITUENTS IN THE IRRIGATED PROFILE NO. 22
HOLLISTER CLAY LOAM SOIL
ALTUS, OKLAHOMA.

Depth inches	pH in extract	pH in paste	E.C. µmhos /cm	Ca ⁺⁺ ppm	Mg ⁺⁺ ppm	Na ⁺ ppm	Cl ⁻ ppm	SO ₄ ⁼⁼ ppm	NO ₃ ⁻ ppm	TDS ppm	Sam- ple
0 - 6	7.45	7.00	1200	200	96	225	284	500	29	2600	660
6 - 12	7.10	7.68	1228	180	252	275	178	980	9	1540	661
12 - 18	7.10	7.50	1159	460	120	400	178	2620	3	3980	662
18 - 24	6.95	7.60	1960	460	252	465	249	3020	1	4380	663
24 - 30	7.20	7.60	2157	340	180	460	355	2000	1	3520	664
30 - 36	7.10	7.65	1578	140	108	440	497	640	2	1920	665
36 - 42	6.90	7.60	1727	120	156	460	604	540	2	2780	666
42 - 48	7.85	7.65	2533	240	180	460	817	1120	1	3680	667
48 - 54	7.70	7.50	2655	380	204	610	817	1560	4	4280	668
54 - 60	7.60	7.50	2655	240	156	640	1172	780	1	3560	669
60 - 66	7.90	7.40	2147	200	132	700	852	440	13	2960	670
66 - 72	7.20	7.40	4082	740	348	540	497	3640	2	7120	671
72 - 78											*672
78 - 84	6.50	7.35	4333	960	384	820	1207	4600	4	8300	673
84 - 90	7.00	7.30	4638	1020	408	820	1633	4200	1	8980	674
90 - 96	7.05	7.30	4450	940	360	820	1314	1700	4	8180	675
96 - 102	7.05	6.90	3322	500	240	840	1314	920	6	4270	676
102 - 108	7.30	6.90	2975	360	144	680	1278	640	4	4820	677
108 - 114	7.50	7.64	2600	280	144	650	1207	400	1	3260	678
114 - 116	7.40	7.72	2600	240	132	650	1278	---	4	2920	679

*Sample 672 was not taken.

TABLE XIX

DETERMINATION OF pH, CONDUCTIVITY, TDS AND CERTAIN
SALT CONSTITUENTS IN THE IRRIGATED PROFILE NO. 23
HOLLISTER CLAY LOAM SOIL
ALTUS, OKLAHOMA.

Depth inches	pH in extract	pH in paste	E.C. μ hos /cm	Ca ⁺⁺ ppm	Mg ⁺⁺ ppm	Na ⁺ ppm	Cl ⁻ ppm	SO ₄ ⁻⁻ ppm	NO ₃ ⁻ ppm	TDS ppm	Sam- ple
0 - 6	7.00	7.00	658	400	155	155	142	20	13	980	680
6 - 12	6.45	6.70	932	100	36	255	178	320	9	1260	681
12 - 18	7.05	7.25	2120	350	144	400	337	1240	13	3300	682
18 - 24	6.90	7.55	2470	440	198	500	497	1880	10	4160	683
24 - 30	7.05	7.64	2470	360	186	480	692	1400	4	3580	684
30 - 36	6.80	7.65	1960	210	120	400	763	480	2	2440	685
36 - 42	6.70	7.6	1976	200	114	460	905	260	3	2240	686
42 - 48	6.75	7.6	2245	330	120	515	1065	420	3	2440	687
48 - 54	6.85	7.6	2352	330	126	565	1136	340	3	2620	688
54 - 60	7.05	7.6	2445	220	132	580	1172	320	4	3440	689
60 - 66	6.95	7.5	249 ^a	240	126	535	1207	520	4	3540	690
66 - 72	6.87	7.5	2482	240	126	525	1260	440	6	3700	691
72 - 78	6.80	7.5	2482	220	138	650	1296	340	6	3880	692
78 - 84	7.10	7.48	4532	1050	276	740	1314	3280	5	10480	693
84 - 90	6.60	7.4	4410	950	354	750	1314	3280	6	8160	694
90 - 96	6.60	7.4	4416	830	318	745	1225	2620	5	7300	695
96 - 102	6.50	7.5	3874	650	318	765	1296	2480	6	6540	696

TABLE XX

DETERMINATION OF pH, CONDUCTIVITY, TDS AND CERTAIN
SALT CONSTITUENTS IN THE IRRIGATED PROFILE NO. 30
HOLLISTER CLAY LOAM SOIL
ALTUS, OKLAHOMA.

Depth inches	pH in extract	pH in paste	E.C. μ hos /cm	Ca ⁺⁺ ppm	Mg ⁺⁺ ppm	Na ⁺ ppm	Cl ⁻ ppm	SO ₄ ⁻⁻ ppm	NO ₃ ⁻ ppm	TDS ppm	Sam- ple
0 - 6	6.4	7.45	3126	450	180	710	1456	1000	4	4660	697
6 - 12	6.8	7.25	914	140	48	220	160	280	4	1400	698
12 - 18	7.2	7.20	1735	266	145	372	267	1488	5	2840	699
18 - 24	6.6	7.20	2940	570	282	570	426	3360	2	5280	700
24 - 30	6.5	7.58	2905	530	276	565	604	2880	1	5060	701
30 - 36	6.7	7.60	2375	300	204	525	746	1400	1	3640	702
36 - 42	6.5	7.62	2111	200	168	495	781	520	1	3020	703
42 - 48	7.0	7.65	1914	150	132	500	799	400	1	2760	704
48 - 54	6.3	7.70	3087	430	282	620	905	2120	1	16560	705
54 - 60	6.9	7.65	3952	880	414	695	888	4600	nil	7280	706
60 - 66	6.5	7.70	4116	970	420	690	852	4600	2	8040	707
66 - 72	6.3	7.70	3874	870	348	670	817	4280	2	15040	708
72 - 78	6.6	7.70	2600	350	78	700	1278	320	4	3140	709
78 - 84	6.9	7.85	2000	100	132	530	1172	280	6	2440	710
84 - 90	7.0	7.70	1871	160	84	520	959	200	4	2180	711

TABLE XXI

DETERMINATION OF pH, CONDUCTIVITY, TDS AND CERTAIN
SALT CONSTITUENTS IN THE IRRIGATED PROFILE NO. 31
HOLLISTER CLAY LOAM SOIL
ALTUS, OKLAHOMA.

Depth inches	pH in extract	pH in paste	E.C. μ hos /cm	Ca ⁺⁺ ppm	Mg ⁺⁺ ppm	Na ⁺ ppm	Cl ⁻ ppm	SO ₄ ⁻⁻ ppm	NO ₃ ⁻ ppm	TDS ppm	Sam- ple
0 - 6	8.10	7.45	1148	150	48	410	178	120	1	700	712
6 - 12	7.95	7.48	760	100	30	370	178	160	nil	700	713
12 - 18	7.00	7.40	1829	330	96	580	249	1560	1	2400	714
18 - 24	7.00	7.55	2245	410	192	525	320	2240	1	2800	715
24 - 30	7.30	7.70	1871	270	126	500	426	1320	1	2300	716
30 - 36	6.90	7.80	1703	210	96	460	639	380	1	1900	717
36 - 42	6.90	7.70	1619	180	84	470	639	460	1	1600	718
42 - 48	7.70	7.68	1452	150	78	445	497	320	4	1400	719
48 - 54	7.10	7.55	1588	160	102	525	639	360	2	1700	720
54 - 60	7.20	7.60	1588	170	108	550	604	360	2	900	721
60 - 66	7.4	7.68	1593	160	72	525	568	360	2	600	722
66 - 72	7.60	7.65	1900	230	90	550	568	1040	3	1900	723
72 - 78	6.40	7.65	2684	510	222	620	533	2560	2	3200	724
78 - 84	7.40	7.70	1802	170	90	575	675	620	4	2400	725
84 - 90	7.50	7.70	1789	160	90	570	746	460	6	2200	726
90 - 96	6.80	7.75	1776	150	96	625	746	360	5	2400	727
96 -102	7.50	7.70	1857	190	60	580	817	400	5	1800	728
102 -106	6.70	7.75	1273	210	78	325	320	320	36	1500	729

TABLE XXII

DETERMINATION OF pH, CONDUCTIVITY, TDS AND CERTAIN
SALT CONSTITUENTS IN THE IRRIGATED PROFILE NO. 32
HOLLISTER CLAY LOAM SOIL
ALTUS, OKLAHOMA.

Depth inches	pH in extract	pH in paste	E.C. µmhos /cm	Ca ⁺⁺ ppm	Mg ⁺⁺ ppm	Na ⁺ ppm	Cl ⁻ ppm	SO ₄ ⁻⁻ ppm	NO ₃ ⁻ ppm	TDS ppm	Sam- ple
0 - 6	7.7	6.95	1646	290	84	455	302	520	5	2440	730
6 - 12	7.0	7.25	1900	280	126	525	337	1380	2	2760	731
12 - 18	7.5	7.40	2494	490	180	570	426	2500	1	4400	732
18 - 24	7.2	7.50	2677	450	192	560	408	2440	1	4140	733
24 - 30	6.8	7.60	2439	360	168	605	550	2080	1	3700	734
30 - 36	7.25	7.60	2058	300	108	630	674	860	1	4960	735
36 - 42	7.40	7.60	1976	140	114	660	799	440	1	2480	736
42 - 48	7.30	7.50	3087	510	210	735	870	2460	1	4840	737
48 - 54	7.20	7.45	2166	240	102	640	852	400	1	3040	738
54 - 60	7.20	7.30	2409	260	108	725	976	740	3	3280	739
60 - 66	6.70	7.40	2501	250	114	725	1082	640	6	2500	740
66 - 72	6.60	7.45	2572	250	120	760	1172	560	2	3500	741
72 - 78	7.00	7.38	2822	300	144	840	1278	820	3	3860	742
78 - 84	6.90	7.38	4032	740	300	900	1296	3280	3	6940	743
84 - 90	7.00	7.25	4595	1020	390	925	1296	4600	3	8220	744
90 - 96	6.60	7.20	4682	1380	150	950	1331	4600	2	746	745

TABLE XXIII

DETERMINATION OF pH, CONDUCTIVITY, TDS AND CERTAIN
SALT CONSTITUENTS IN THE IRRIGATED PROFILE NO. 33
HOLLISTER CLAY LOAM SOIL
ALTUS, OKLAHOMA.

Depth inches	pH in extract	pH in paste	E.C. μ mhos /cm	Ca ⁺⁺ ppm	Mg ⁺⁺ ppm	Na ⁺ ppm	Cl ⁻ ppm	SO ₄ ⁻⁻ ppm	NO ₃ ⁻ ppm	TDS ppm	Sam- ple
0 - 6	7.25	7.34	4430	940	378	870	1367	4200	3	7680	746
6 - 12	7.6	7.08	511	50	36	205	124	60	9	16900	747
12 - 18	7.6	7.10	633	50	36	285	142	80	2	860	748
18 - 24	7.5	7.18	1543	230	114	460	213	1060	1	2080	749
24 - 30	7.6	7.25	2445	42	228	570	391	2440	1	3580	750
30 - 36	7.35	7.55	2533	450	180	610	533	1960	1	3980	751
36 - 42	7.2	7.65	1914	180	138	545	621	880	1	2380	752
42 - 48	7.2	7.68	1843	210	78	570	781	400	2	2300	753
48 - 54	7.4	7.6	2166	210	132	615	834	680	2	2780	754
54 - 60	7.	7.5	2225	280	114	650	2521	680	2	3000	755
60 - 66	7.3	7.5	2102	220	102	675	976	500	1	2860	756
66 - 72	7.3	7.5	2147	220	108	675	1012	400	2	2920	757
72 - 78	7.2	7.3	4186	1070	360	810	1012	4600	2	7640	758
78 - 84	7.4	7.2	4204	1050	384	815	1047	4600	2	7820	759
84 - 90	6.95	7.2	4032	920	402	800	1047	4120	2	7160	760

TABLE XXIV
 ANALYSIS OF WATER SAMPLES FROM THE WATER TABLE
 OF IRRIGATED SOIL PROFILES OF
 HOLLISTER CLAY LOAM SOIL
 ALTUS, OKLAHOMA

Sample from pro- file no.	pH	E.C. µmhos /cm	TDS ppm	Ca ⁺⁺ ppm	Mg ⁺⁺ ppm	Na ⁺ ppm	Cl ⁻ ppm	SO ₄ ⁻⁻ ppm	NO ₃ ⁻ ppm
10*									
11	7.7	15833	14230	1160	912	2950	5751	640	1335
12	7.2	13608	17220	1210	1140	2850	6958	980	380
13	6.8	9592	17520	1410	954	3125	7206	780	170
20	6.7	14746	3370	900	792	2250	4952	940	380
21	6.9	16735	13495	990	693	2250	5751	785	332
22	7.55	16917	18320	1120	1086	2500	7988	1060	425
23*									
30	6.90	18095	12180	1250	1014	2700	6656	890	320
31	7.90	14969	16000	1100	792	2250	4952	1220	280
32	6.70	19760	16580	1670	1002	3000	7491	920	468
33	7.13	3393	10115	1240	165	975	707	265	398

*was not taken

HOLLISTER CLAY LOAM

Soil Profile described by Professor Roy Smith, Assistant Professor of Agronomy, July 1963.

Location: 550 feet east and 55 feet north of SW corner of SW $\frac{1}{4}$ of section 32, T2N; R20W, Jackson County, Oklahoma.

Hollister clay loam, 0-1% slopes

Sample S63-OK-33-1-1

Ap 0-8" Very dark grayish brown (10 YR 3/2) clay loam, dark yellowish brown (10 YR 4/4) dry; weak medium granular; friable moist, slightly hard dry; pH 8.0; clear boundary.

Sample S63-OK-33-1-2

B₁ 8-13" Dark brown (7.5 YR 3/2) light clay, brown (7.5 YR 4/2) dry; moderate medium blocky; very firm moist, hard dry; small lime concretions; weakly calcareous; pH 8.0; gradual boundary.

Sample S63-OK-33-1-3

B_{2t-1} 13-28" Dark brown (7.5 YR 3/2) clay, brown (7.5 YR 4/2) dry; weak medium and coarse blocky; very firm moist, hard when dry; calcareous; pH 8.0; gradual boundary.

Sample S63-OK-3-1-1-4

B_{2t-2} 28-34" Dark reddish brown (5 YR 3/3) clay, reddish brown (5 YR 4/3) dry; weak medium and coarse blocky, few pink granite pebbles and lime concretions present;

calcareous in mass; pH 8.0: gradual boundary.

Sample S63-OK-33-1-5

B₃ 34-54" Dark reddish brown (5 YR 3/3) clay loam, reddish
brown (5 YR 4/3) dry; massive; calcareous; pH 8.0.

BRUCINE SULFATE—MODIFICATION METHOD FOR
NITRATE DETERMINATION IN SALINE AND
ESTUARINE WATERS

Brucine Modification Method

Nitrate reacts with brucine sulfate to form a yellow colored brucine nitrate. The amount of brucine nitrate formed is dependent upon nitrate concentration and temperature. The temperature control is critical. Samples and standards must be maintained at identical temperature and time. This is easily accomplished by placing standards and samples in a boiling water bath for 20 minutes.

The chloride effect is minimized by the addition of a large amount of sodium chloride to all samples and standards. Nitrite interference is eliminated by the use of sulfanilic acid.

I. Reagents

1. Brucine-sulfanilic acid reagent. Dissolve 1 gram of brucine sulfate and 0.1 gram of sulfanilic acid in approximately 70 ml of hot distilled water. Add 3 ml concentrated HCl, cool, and make up to 100 ml. Store in refrigerator. This solution is stable for several months when kept refrigerated.
2. Sulfuric acid solution. Carefully add 500 ml of concentrated H_2SO_4 to 125 ml of distilled water. Cool and keep stoppered to prevent absorption of moisture.
3. 30% sodium chloride solution. Dissolve 300 grams sodium chloride in distilled water and dilute to 1 liter.
4. Standard nitrate solution. Dissolve 0.7218 grams anhydrous

KNO_3 in distilled water and dilute to 1 liter. One ml of this solution contains 0.10 mg. $\text{NO}_3\text{-N}$.

5. Working nitrate standard. Dilute 100 ml of the nitrate stock solution to 1 liter. 1 ml contains 0.01 mg $\text{NO}_3\text{-N}$.

II. Procedure

1. Pipette 10.0 ml sample into 2.5 cm test tubes. Add 10.0 ml distilled water to a similar tube for a reagent blank.
2. Add 2 ml 30% NaCl solution to samples and reagent blank in test tubes.
3. Mix well by swirling and place in cool water bath (15° to 25° C.).
4. Pipette 10.0 ml H_2SO_4 solution into each tube. Carefully mix by swirling. Keep in cool water bath at 15 to 25° C. until thermal equilibrium is reached (about 15 minutes).
5. Add 0.5 ml of brucine-sulfanilic acid solution to each tube. Carefully mix by swirling.
6. Place the tubes in boiling water for exactly 20 minutes.
7. Remove from boiling water and place in cool water bath to bring temperature to $15\text{-}25^\circ$ C.
8. Read the absorbance at 410 millimicrons in a spectrophotometer. Zero the instrument with the reagent blank.
9. When samples have visible turbidity and color, correct the absorbance for turbidity and color by treating the turbid sample according to the above procedure, with omission of the brucine-sulfanilic acid reagent.
Brucine nitrate absorbance - turbidity absorbance = corrected absorbance.

10. To prepare a standard curve, pipette 0.00, 20.0, 40.0, 60.0, 80.0 and 100.0 ml of working nitrate standard into 1000 ml volumetric flasks. Dilute to mark with distilled water. These standards are 0.0, 0.2, 0.4, 0.6, 0.8 and 1.0 mg/l NO_3^- -N. Treat 10.0 ml of each standard according to the above procedure. Plot mg/l NO_3^- -N versus absorbance.

VITA

Moustafa Ibrahim Katta

Candidate for the Degree of

Doctor of Philosophy

Thesis: MOVEMENT AND REDISTRIBUTION OF CERTAIN SALT CONSTITUENTS IN A
CLAY LOAM SOIL IRRIGATED WITH HIGH-SALT LOW-SODIUM WATER

Major Field: Soil Science

Biographical:

Personal Data: Born in Benha, Egypt, UAR, August 28th, 1933.
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Education: Attended elementary and high school in Cairo and Benha, Egypt. Graduated from high school in June, 1952. Received a Bachelor of Science degree with honors in soils from Ain-Shams University, Cairo, Egypt, UAR in 1956. In junior and senior years of college received distinction awards. Received a UAR scholarship for graduate studies in 1960. Studied in the University of California, Berkeley, in 1960-1962. Graduate study at Oklahoma State University from 1962 to present.

Professional Experience: Employed as Agricultural Officer in Ministry of Agriculture for high quality cotton seed production in July 1956. In November 1956, was appointed research worker at the Soil Department of the Desert Institution of Mattareia, Cairo, Egypt. In December 1957, was appointed teacher-assistant in the Soil Dept. of the College of Agriculture, Ain-Shams University.