MINERALOGY AND CHEMISTRY OF AN IRRIGATED TILLMAN-HOLLISTER SOIL

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CHAPTER I

INTRODUCTION

About twenty-five percent of the earth's surface is sufficiently arid for salt accumulation in the soil. In the United States a large area, especially in the Western states may contain soil areas classified as saline soils. Near Altus, Oklahoma, there is a large area of irrigated soils known as the Tillman-Hollister Complex. Small acreages of these soils are beginning to show significant accumulation of soluble salts. These saline soils appear to be growing in areal extent and the need for leaching and subsurface drainage appears to be increasing. There are two hypotheses to explain the origin of soluble salts in these soils. Irrigation water from the Altus-Lugert Reservoir has a soluble salt burden in excess of 1500 ppm soluble salts and if these salts accumulate in the soil excess salinity is possible. A second source of soluble salts may be found in the soil itself, that is, these soils were developed from Permian Redbed parent material and old alluvium and most Permian geological formations in Oklahoma contain some soluble salts, therefore soluble salts in these soils may be inherited from the parent material. In addition to these two possible sources of soluble salts in these soils there may be other sources of minor nature such as municipal refuse, etc. These other sources are considered to be minor.

The research reported here is an attempt to study the mineralogy and the chemistry of irrigated Tillman-Hollister soil to provide some information concerning the extent of the salinity problem and to make some estimate of the change in soluble salt content of a saline or potentially saline area.

CHAPTER II

LITERATURE REVIEW

In arid and semiarid areas the vertical and horizontal expansion of cultivated soils meet some difficulties as a result of soil salinity.

Among the soil formation factors which affect soil salinity are: (1) the parent material, igneous rocks and sedimentary parent rock; (2) the climate, arid and semiarid weather including the amount of precipitation and the temperature daily and annually; and (3) the vegetation, as a result of non-vegetation, humus content is low.

Some salts more or less soluble in water are the result of the weathering processes on rocks. The predominant salts are chlorides, sulphates, and carbonates of calcium, magnesium and sodium, while the minor salts are nitrates.

These salts are classified according to their water solubility to: (1) salts of low solubility, calcium and magnesium carbonates; (2) salts of medium solubility, calcium sulphate; and (3) salts of high solubility, sodium carbonate, sodium and magnesium sulphate, and calcium, magnesium and sodium chloride.

The U.S. Salinity Laboratory (1953) proposed a simple classification separating the salted soils into three groups: (1) Saline soils: These soils contain a relatively high concentration of soluble salts. The sodium makes up more than one-half of the soluble cations. The pH value is 8.5 or less, and the exchangeable sodium percent is less than 15. These soils were designated as Solonchak in the Russian classification; (2) Saline-alkali soils: These soils are distinguished by a high concentration of soluble salts, but the exchangeable sodium percent is greater than 15. The pH value exceeds 8.5. It is the Solonetz in the Russian classification; and (3) Non-saline-alkali soils: These soils contain a low concentration of soluble salts, but they have a larger amount of adsorbed sodium, the exchangeable sodium percent exceeds 15. The pH values range between 8.5 and 10. These soils are the Solod in the Russian classification.

The presence of large amounts of exchangeable sodium and soluble salts leads to the lack of structure and swelling of material when moist, to retarded development of soil in drying, to limited mobility of moisture, low rate of air exchange, and to strong compression of the soil and its resistance to tillage. Harris (1931) studied the relation between soil permeability and replaceable Na and concluded that the permeability decreases exponentially as the Na concentration increases.

Sources of saline salts are: (1) from the sedimentary parent material during the process of rock's deposition at the bottom of a sea or a salt lake where the salts are accumulated; (2) translocation of salts by wind or by precipitation as may happen around coastal maritime areas where a continuous evaporation of sea water results in precipitated salts that may be carried by wind to other areas; (3) the saline ground water as a result of igneous rocks weathering accompanied by soluble salt formation; and (4) irrigation water can bring salts to the soil especially when river water is strongly mineralized in arid areas.

Formation of Saline Soils Concepts

The formation of saline soils is associated with the introduction of salts by the mineralized groundwater and their accumulation in the superficial horizons of the soil due to the evaporation of groundwater at the surface. The nature of the salt accumulation and saline formation is determined by the vegetation and the depth and the composition of groundwater.

Polynov introduced the concept of the critical depth of groundwater, meaning the maximal water table depth for which salinization of the superficial soil horizon is possible. The critical depth for soils and subsoils of various mechanical composition is within the limits of 1.5 to 3.5 m. It is less on heavy clay and sand, and greater on loamy and loess subsoil.

The degree of salt accumulation, for equal depth of groundwater, increases with the increase in their mineralization, primarily associated with aridity of the climate. When mineralization is small, bicarbonates and carbonates of alkalis predominate in the salt composition. When the degree of mineralization increases, an accumulation of sulphates occurs, mostly in the form of gypsum and due to this, sodium carbonate disappears.

$$Na_2CO_3 + CaSO_4 \longrightarrow Na_2SO_4 + CaCO_3$$

The soil is characterized by the accumulation of sodium sulphate (Na_2SO_4), and at the same time by the deposition of gypsum ($CaSO_4$) and calcium carbonate ($CaCO_3$).

Sodium chloride begins to predominate over all the other salts in very high mineralization of groundwater.

Due to the great differences in salt solubilities in the groundwater and soil solution, maximum accumulations of individual salts occur in different horizons of salt profile of the saline soil. The most readily soluble salts, particularly chlorides, accumulate on the surface. The less soluble gypsum, lying below, and calcium carbonate, still lower.

The processes which lead to the formation of saline soils have been summarized by Magistad (1945) as follows: (1) Salinization: the process of salt accumulation in soils and concentration by water evaporation. Sodium salts usually predominate in the early stages of salinization. Calcium carbonate and calcium sulphate are less soluble, so they accumulate more slowly and precipitate as the process of evaporation and concentration proceed; (2) Alkalization: as salts accumulate in soils there is an equilibrium established between the positively charged ions in solution, and those adsorbed on the colloid. As sodium salts become more concentrated in the soil solution, greater quantities are adsorbed. As the percentage of exchangeable sodium is increased, the soil becomes more alkaline in reaction, and for this reason the process is termed alkalization; (3) Desalinization: this is the process of leaching away soluble salts from soils which have had large accumulation. When the salts are largely removed, the colloids tend to disperse and permeability decreases; and (4) Degradation: if a soil undergoing desalinization does not contain gypsum or calcium carbonate, there are few bases to replace sodium after the soluble salts have been removed. Exchangeable sodium then tends to hydrolize and form sodium hydroxide with hydrogen being added to the clay. The NaOH results in a dispersion of organic matter, sometimes called a "black alkali" condition. The sodium hydroxide reacts readily with carbon dioxide from the soil air to form sodium carbonate.

$$\begin{matrix} & Na & \\ Ca & Clay & Na \\ & Na & \end{matrix} + H_2O \rightleftharpoons NaOH + H \begin{matrix} Na & \\ Clay & Ca \\ Na & \end{matrix}$$

$$CO_2 + H_2O \longrightarrow H_2CO_3 + 2NaOH \longrightarrow Na_2CO_3 + 2H_2O$$

With extensive leaching, the sodium carbonate is gradually removed, and the hydrogen exchange for sodium is brought to near completion with a resulting drop in the soil pH.

Effect of Saline Irrigation Water on Soil Characteristics

Kelley _et al_. (1940) reported that the soluble salts of irrigation water are very important due to its effect on the concentration and composition of the soil solution, and their effect on the absorbed bases of the soil. With a given irrigation water, the former is greatly influenced, and the latter to some extent, by the inherent properties of the soil, its permeability and profile characteristics, the climatic conditions, and the amount of the water applied. They added that sodium salt solutions react with soils by base exchange with resulting absorption of Na by the soil. This effect increases with increasing concentration of solution and also as the ratio of Na:Ca increases. The presence of absorbed Na soils tends to affect their physical properties adversely.

Although agricultural science has shown that saline water can be used, within limits, for the successful cultivation of certain salt-resistant plants, as described by Kearney and Scofield (1936) and by Foaden (1897), two factors must be considered; namely, the direct effect of saline water on the soil, which in turn will affect the growth of plants. Puffeles (1939) investigated the effect of saline water on the loess soils of the Beersheba area (southern Palestine). This type of soil is highly permeable to air and water and possesses good physical properties but the soil is poor in nutrients. He found that if the very saline water that is available is used for irrigation, under favorable climatic and drainage conditions, such as obtained in this area, the salts will not accumulate, but instead an alkaline salt will, in time, be formed by base exchange and this will lead the soil to be useless for agricultural purposes.

Doneen (1954, p. 944) states:

> When nonsaline soils, irrigated for some years, gradually develop a high salt concentration, it is usually due to the accumulation of soluble salts brought in with the irrigation water. Under high water-table conditions, the concentration of salts occasionally may be due to soluble salts from the deep subsoils coming to or near the soil surface with the rise of the water table, and some salts may be dissolved from the soil by the water table. This dissolving of the soil minerals is probably a minor source in salt accumulation for a short period of time, and most of the salt increase may be directly attributed to the irrigation water. In the absence of a high water table, the irrigation water would be the main source of salts in the development of a saline soil.

Some investigators show that the soil solution in well-drained soil to be more concentrated than the irrigation water used. Under this condition Scofield (1935) found that the soil solution in heavily leached soil may be twice as concentrated as the irrigation water; and under less severe leaching where the water is used sparingly, the difference is much greater, often eight times or more the concentration of the irrigation water. This concentration of salts in the soil is due to two factors, evaporation from the soil surface and water used by the plants in transpiration. Plants usually remove only a small percentage of the total salt occurring in the irrigation water.

Harper and Stout (1950) studied the effect of ten years of irrigation of cotton with water which had a Ca:Na ratio of 1:2 from the S.W. Oklahoma Cotton Station at Tipton. They showed that the pH of an irrigated soil rose as compared with nonirrigated soil. Exchangeable Na was higher in the irrigated soil, but exchangeable K was similar for both soils. Very little soluble K was found in either soil. Exchangeable calcium was much lower in the irrigated soil.

McGeorge *et al*. (1952) found that two years of irrigation with a water containing a conductance of 6 millimhos and a sodium percentage of about 83 increased the exchangeable sodium percentage of soil on the Arizona Safford Experiment Farm from about 10 to near the equilibrium value of 25. These results indicate that many effects of irrigation water are established in relatively short periods of time.

Thorne and Thorne (1954) found that the salt content of the soils was closely related to the salt content of the irrigation waters. They also found that the percentages of exchangeable sodium in the soils had significant regressions on sodium percentages, weighted sodium percentages, sodium adsorption ratios and the theoretical exchangeable sodium percentages for the irrigation waters in their study.

Plice (1949, p. 278) states:

> Salt (sodium chloride) injures soil by dispersing it, at the time causing organic matter and exchangeable material to be lost. The extent of the damage it does is not entirely proportional to the amount of salt present. The maximum physical injury done to soils seems to occur at the time the soil again has about the same amount of total sodium it originally had, or even less.

The movement of water through the soil profile is an important mechanism in soil development. During irrigation, additional waters with chemical compositions different from that of rainfall are applied to the soil. River and ground waters often acquire significant quantities of mineral salts between the time the water falls as rain and the time it is intercepted for irrigation. Under intensive irrigation these dissolved salts have certain influences on the soil.

In irrigated areas, some soil problems such as decreased soil permeability, development of saline or alkali soils, and increased requirements for specific soil amendments, are traceable to the influence of irrigation water.

Chapman and Kelley (1930), Kelley et al. (1949), Bushnell (1949), and Hosking (1948) have shown that relatively insoluble constituents, such as the carbonates and sulfates of calcium and the soils' minerals themselves, have a great influence on chemical equilibriums established in soils.

Irrigation waters containing an excess of carbonates and bicarbonates may precipitate much of the calcium and magnesium and thus cause sodium to become the predominant cation in the soil solution. This theory has been postulated by Eaton (1950), and corrective measures have been suggested (Eaton, 1954). In a study of this high bicarbonate factor, Wilcox et al. (1954) concluded that bicarbonate would have to exceed a concentration of 1.25 me per liter of water before it could be considered important.

Lewis and Juve (1956) studied the effects of irrigation water quality on soil characteristics in Idaho soils. They found that: (1) soluble salts were evenly distributed throughout the profiles of the irrigated soils; (2) the soluble calcium content of the soil was reduced in general, with increasing depth in the profile; (3) there was a correlation between the sodium-adsorption ratio of the irrigation water and that of the saturation extract of the soil; (4) there was a good correlation between the sodium-adsorption ratio of the saturation extract and the exchangeable sodium percentage of soil; (5) saturation extracts from soils approach the chemical composition of irrigation water applied to them; and (6) the calcium carbonate content of the soil showed an increase when irrigation water high in calcium and bicarbonate ions are used.

Influence of Exchangeable Cations on Soil Properties

Among the important cations which can affect the physical and chemical properties of soils are sodium (Na), calcium (Ca), potassium (K), and magnesium (Mg).

The dispersion of soil colloids and resultant breakdown of aggregation as a result of the adsorption of high percentages of Na ions by the soil exchange complex is widely noted (Gedroix, 1931; Chang and Dregne, 1955; and DeSigmond, 1927).

Gedroix (1931) by artificially saturating Chernozems with various cations reports increasing deflocculation with increasing degree of Na saturation of the exchange complex. Also noted was the fact that Mg reacts in a manner similar to Na when the exchange complex is completely saturated with either cation. The work of Veihmeyer and Hendrickson (1937) is in agreement with Gedroix's results as pertaining to the rate of Na in deflocculation.

The effects of exchangeable calcium on the physical properties of soils are better understood than the effects of exchangeable potassium and magnesium. Most of the literature indicates that the role of exchangeable potassium and magnesium is controversial.

Shawrguin (1935), Joffe and Zimmerman (1945) and others have concluded that exchangeable magnesium has an effect similar to that of exchangeable sodium. Others believe that magnesium has an effect similar to that of calcium. Few, if any, investigators have given satisfactory reasons for the poor soil physical conditions sometimes associated with the high exchangeable magnesium. Baver and Hall (1937, p. 18) pointed out that "the low flocculating power of the magnesium ion with respect to organic matter suggests a possible explanation of the formation of magnesium solonetz soils." Gill and Sherman (1952) have associated the poor physical properties of some Hawaiian soils with their high contents of exchangeable magnesium. They suspected that the reason for the low permeability and high plasticity was that the hydration of the exchangeable magnesium ion is greater in the presence of certain humates and that this hydration results in a dispersion of the clay and organic matter.

CHAPTER III

METHODS AND MATERIALS

All soil samples for this study were collected from the Altus Irrigation Station, (Oklahoma Agricultural Experiment Station), Altus, Oklahoma. The soil studied was the Tillman-Hollister clay loam (fine mixed, thermic Typic-Pachic Paleustoll). The soil samples were air-dried in the laboratory and ground and screened to pass through 20-mesh sieve, for physical, chemical, and mineralogical analyses.

Physical Analyses

Particle size distribution analyses (mechanical analyses) were determined by the Hydrometer Method (Day, 1956). The method used was as follows: weigh out 50.0 grams of soil for analyses and add 50 ml of distilled water, shake for one hour, centrifuge, decant and the extraction solution was kept for chemical analyses, the remaining soil was transfered to 1000 ml sedimentation cylinder. Add 10 ml of sodium carbonate solution, and bring to the 1000 ml mark with distilled water. Move cylinder into constant temperature room.

When the suspension has reached constant temperature, insert the plunger and move it up and down to mix the contents thoroughly. Material trapped at the bottom will require strong upward strokes of the plunger to lift them into suspension. When the suspension has been thoroughly mixed, note the time and remove the plunger, tipping it slightly to remove adhering drops of suspension.

Lower the hydrometer carefully into the suspension and, at the end of 30 seconds, read the scale at the top of the meniscus. Without removing, read again at the end of one minute. Remove carefully, wipe clean with a soft towel, and be ready to repeat at the end of three minutes.

Subsequent hydrometer measurements should be made at three minutes, 10 minutes, 30 minutes, 90 minutes, 4 hours, 8 hours, and 12 hours, or at other conveniently spaced intervals. Each time a measurement is to be made, the hydrometer should be lowered carefully into the suspension 20 seconds before the desired time and removed carefully after reading.

Chemical Analyses

The chemical analyses consisted of the determination of the total soluble salts, the electric conductivity (EC), the chlorine (Cl), and the extractable sodium, calcium and magnesium. The extractable cations were determined with the atomic absorption spectrophotometer as described in U.S.D.A. Handbook No. 60 (1954).

Mineralogical Analyses

The total clay suspension was saved for x-ray diffraction analyses. After 24 hours the clay suspension (at depth of 30 cm) was siphoned off and saved. The hydrometer cylinder was refilled to 1000 ml with distilled water, shaken, allowed to stand for 24 hours, and then siphoned off again. Siphoning was repeated until the suspension (after setting 24 hours) was essentially clear. All horizons for profile No. 1

were analyzed by x-ray. In these analyses, coarse clay and fine clay were the only fractions analyzed.

The preparation and x-ray examination of samples were described by Black *et al*. (1965). A dilute suspension of clay, containing approximately 25 mg clay, was added to the surface of a porous ceramic plate after Ca-saturation, ethylene glycole, and K-saturation. The samples were air-dried and x-rayed. The K-saturated samples were heated to 550 C for four hours and then x-rayed again.

CHAPTER IV

RESULTS AND DISCUSSION

Physical Analyses

The particle size distribution in the nine profiles of Altus irrigated soil studied are reported in Tables I to IX. The sand and silt were subfractioned to coarse, fine, and very fine sand for the sand group, and coarse silt and fine silt for the silt group. The relative percentage of fine to coarse sand, generally decreased by depth except in profiles 4, 5, and 7, where the decrease was in the B horizon then the percentage increased, while in profile 9, the percentage of fine to coarse sand increased with depth (Table IX). The percentage of fine to coarse sand in all profiles ranged between 13 and 50. Profile 9 contains the lowest percentage (19) of f/c sand in the A horizon, while profile 8 contains the highest percentage in the same layer (31%).

The percentage of very fine sand generally decreased with depth in all profiles and its values were generally less than that of the fine to coarse sand ratio. The relative percentages of the silt group where the ratio of coarse silt to fine silt were less than sand and clay percentages in all profiles. The percentage of coarse silt was double or more than the fine silt, however, the coarse silt generally decreased with depth. The silt is distributed through the profiles with very little change from horizon to horizon.

TABLE I

PARTICLE SIZE DISTRIBUTION IN PROFILE #1
OBSERVATION WELL, OKLA. AGRIC. EXPT.
STA., ALTUS, OKLA., SOUTH SIDE OF
STATION, IRRIGATED TILLMAN-
HOLLISTER SI.CL.L.

Depth (cm)	Fine-Coarse Sand %	Very Fine Sand %	Coarse Silt %	Fine Silt %	Clay %
0-15	24	18	17	6	34
15-30	26	16	15	7	36
30-45	26	16	16	5	37
45-60	22	17	19	7	35
60-75	23	18	18	6	35
75-90	26	17	15	5	37
90-105	27	13	17	4	39
105-120	25	16	15	4	40
120-135	21	16	14	5	44
135-150	26	17	15	4	38
150-165	16	16	16	6	41
165-180	18	19	20	7	36
180-195	19	17	19	7	38
195-210	23	15	16	5	41
210-225	21	15	15	6	43
225-240	19	15	17	5	44
240-255	19	16	16	5	44
255-270	24	13	12	4	47
270-285	23	16	16	5	40
285+	20	15	15	5	45

TABLE II

PARTICLE SIZE DISTRIBUTION IN PROFILE #2 OBSERVATION WELL, OKLA. AGRI. EXPT. STA., ALTUS, OKLA., NORTH SIDE OF STATION, IRRIGATED TILLMAN-HOLLISTER SI.CL.L.

Depth (cm)	Fine-Coarse Sand %	Very Fine Sand %	Coarse Silt %	Fine Silt %	Clay %
0-15	29	16	18	7	30
15-30	25	18	20	7	30
30-45	21	18	20	7	34
45-60	23	19	19	6	33
60-75	20	20	22	7	31
75-90	25	20	20	6	29
90-105	23	19	20	6	32
105-120	23	18	21	5	32
120-135	21	19	18	7	35
135-150	24	16	18	5	37
150-165	23	18	17	5	37
165-180	22	15	16	6	41
180-195	22	17	16	5	40
195-210	20	16	18	4	42
210-225	18	17	18	3	44
225-240	18	19	19	6	38
240-255	19	20	18	6	37

TABLE III

PARTICLE SIZE DISTRIBUTION IN PROFILE #3
OBSERVATION WELL #14, OKLA. AGRI.
IRRIGATION EXPT. STA., ALTUS,
OKLA., TILLMAN-HOLLISTER
SI.CL.L.

Depth (cm)	Fine-Coarse Sand %	Very Fine Sand %	Coarse Silt %	Fine Silt %	Clay %
0-15	28	22	22	6	22
15-30	24	21	21	6	28
30-45	24	22	21	7	26
45-60	24	22	22	8	24
60-75	20	23	24	7	26
75-90	24	22	22	7	25
90-105	26	20	19	7	28
105-120	24	22	21	7	26
120-135	24	19	20	7	30
135-150	27	19	19	6	29
150-165	21	18	18	6	37
165-180	23	18	17	5	37
180-195	19	17	16	6	42
195-210	26	14	15	5	40
210-225	22	16	15	5	42
225-240	13	22	20	7	38
240-255	23	17	17	6	37

TABLE IV

PARTICLE SIZE DISTRIBUTION IN PROFILE #4 OBSERVATION WELL #13, OKLA. AGRI. IRRIGATION EXPT. STA., ALTUS, OKLA., TILLMAN-HOLLISTER SI.CL.L.

Depth (cm)	Fine-Coarse Sand %	Very Fine Sand %	Coarse Silt %	Fine Silt %	Clay %
15-30	26	18	18	6	32
30-45	22	21	21	7	29
60-75	19	22	22	7	30
75-90	17	23	22	7	31
105-120	18	19	19	6	38
120-135	21	17	17	6	39
135-150	26	16	16	5	37
150-165	26	15	15	5	39

TABLE V

PARTICLE SIZE DISTRIBUTION IN PROFILE #5 OBSERVATION WELL #15, OKLA. AGRI. IRRIGATION EXPT. STA., ALTUS, OKLA., TILLMAN-HOLLISTER SI.CL.L.

Depth (cm)	Fine-Coarse Sand %	Very Fine Sand %	Coarse Silt %	Fine Silt %	Clay %
0-15	23	25	26	8	18
15-30	27	20	20	7	26
30-45	22	21	20	7	30
45-60	22	21	21	7	29
75-90	22	21	20	7	30
90-105	21	23	22	8	26
105-120	17	23	23	7	30
120-135	17	24	24	8	29
135-150	18	20	21	7	34
150-165	23	16	16	5	40
165-180	19	22	22	8	29
180-195	18	16	17	5	44
195-210	23	20	21	7	36
210-225	22	18	18	7	35

TABLE VI

PARTICLE SIZE DISTRIBUTION IN PROFILE #6 OBSERVATION WELL #12, OKLA. AGRI. EXPT. STA., ALTUS, OKLA. (ADJACENT TO DRAINAGE CANAL) TILLMAN-HOLLISTER SI.CL.L.

Depth (cm)	Fine-Coarse Sand %	Very Fine Sand %	Coarse Silt %	Fine Silt %	Clay %
0-15	27	19	19	7	28
15-30	19	23	22	8	28
30-45	19	22	22	7	28
45-60	22	20	21	7	30
60-75	21	20	21	6	32
75-90	22	19	19	6	34
90-105	16	16	16	6	41
105-120	24	13	14	5	44
120-135	28	15	15	4	38
135-150	25	12	12	4	47
150-165	26	11	12	4	47
165-180	21	18	17	6	38

TABLE VII

PARTICLE SIZE DISTRIBUTION IN PROFILE #7
ROBINSON FARM, NE¼,NE¼,NE¼ SECTION 6
T1NR20W, TILLMAN-HOLLISTER
SI.CL.L.

Depth (cm)	Fine-Coarse Sand %	Very Fine Sand %	Coarse Silt %	Fine Silt %	Clay %
0-15	23	23	23	7	24
15-30	24	20	21	7	28
30-45	25	24	22	8	21
45-60	24	22	21	7	26
60-75	24	21	20	7	28
75-90	19	23	22	8	28
90-105	17	22	22	7	32
105-120	17	22	22	7	32
120-135	14	23	23	8	32
135-150	14	23	23	8	32
150-165	20	21	21	6	32
165-180	15	22	20	7	36
180-195	23	18	18	6	35
195-210	13	22	22	7	36
210-225	18	18	19	7	38
225-240	19	15	15	5	46
240-255	21	17	15	6	41
255-270	21	17	16	5	41

TABLE VIII

PARTICLE SIZE DISTRIBUTION IN PROFILE #8
ROBBINS FARM 0.4 MILE WEST OF N.E.
CORNER OF SE¼ SECTION 13-R2WT21N
TILLMAN-HOLLISTER SI.CL.L.

Depth (cm)	Fine-Coarse Sand %	Very Fine Sand %	Coarse Silt %	Fine Silt %	Clay %
0-1.25	31	24	25	8	12
0-15	30	22	22	8	18
15-30	31	21	20	6	22
30-45	22	22	21	8	27
45-60	17	23	22	8	30
60-75	20	21	21	6	32
75-90	20	21	20	7	32
90-105	23	18	17	6	36
105-120	17	20	20	7	36
120-135	19	18	18	5	40
135-150	24	13	14	5	44
150-165	26	13	14	4	43
165-180	26	12	13	4	45
180-195	20	16	16	6	42
195-210	20	22	22	6	30

TABLE IX

PARTICLE SIZE DISTRIBUTION IN PROFILE #9
ROBBINS FARM 0.25 MILE S. AND 0.25 MILE
WEST OF N.E. CORNER OF SE¼ SECTION 13
R21WT2N, TREADWAY CLAY

Depth (cm)	Fine-Coarse Sand %	Very Fine Sand %	Coarse Silt %	Fine Silt %	Clay %
0-15	19	18	18	7	38
15-30	22	16	17	5	40
30-45	22	19	18	6	35
60-75	22	16	15	6	41
75-90	23	18	16	6	37
90-105	21	18	18	6	37
105-120	28	15	15	5	37
120-135	25	17	16	6	36
135-150	25	17	17	5	36
150-165	41	11	11	3	34
165-180	50	11	10	4	25
180-195	30	17	15	5	33

The percentage of clay in all profiles increased substantially in the B horizon and then decreased in the C horizon. The dominance of clay in the B horizon is probably due to illuviation.

Mineralogical Analyses

Profile No. 1 was studied by x-ray diffraction for identification and differentiation of clay minerals.

K-saturated Air-dried Samples

This treatment allowed the separation of vermiculite from hydrous micas (illite) where hydrous mica was observed as the $10A^{o}$ diffraction peak, and vermiculite did not tend to collapse.

K-saturation and then Heating of Samples to 550C

This treatment aids in identification of clay minerals. First, it causes the collapse of vermiculite and other 2:1 micaceous minerals which may contain non-exchangeable interlayer aluminum hydroxy complexes. Second, it destroys the kaolin minerals. When chlorite is present in the sample, it normally yields a second-order peak maximum at nearly the same position as the first-order maximum of kaolinite (7.15A). If a 7.15A spacing is obtained from an unheated sample, or disappears or is decreased in intensity after heating to 550C, the presence of kaolinite is confirmed.

Ca-saturated Air-dried Samples

A diffraction spacing of approximately 14A obtained from Ca-saturated preparations indicates the following clay minerals:

vermiculite, chlorite, montmorillonite (smutite), or a mixture of these species.

Ca-saturated and Ethylene Glycol-solvated Samples

These treatments give a diffraction spacing of 17-18A which may indicate the presence of montmorillonite which expands from 14 to 17 or 18A upon ethylene glycol solvation of Ca-saturated samples.

The results of the x-ray mineralogical analyses for the fine and coarse clay are presented in Table X.

Fine Clay

Mica, kaolinite and quartz were dominant in all horizons of these profiles. Montmorillonite, vermiculite and chlorite were present to a lesser extent in the surface layer where more of the total clay of the A horizon may be in the coarse fraction (2.0 - 0.2μ). Jackson (1956) noted that the coarse clay (<2μ) may be abundant in hydrous mica (illite) and that large amounts of poorly crystallized hydrous micas with poorly resolved basal spacings may not be detected in the presence of large amounts of montmorillonite or kaolinite. In the B and C horizons where the fine clay was abundant, montmorillonite, vermiculite, chlorite, mica, kaolinite and quartz all gave strong diffraction patterns. The presence of quartz in all profiles may have been enhanced by quartz in the ceramic slides used as mounts for the clay samples. The presence of kaolinite in the fine clay was not completely understood. Some small crystals of calcite were also found in the fine clay. Calcite was found in the fine clay at depth of 180-225 cm.

TABLE X

MINERALOGICAL DATA OF PROFILE #1

Depth (cm)	Clay Minerals	
	Fine Clay	Coarse Clay
0-15	m, v, cl, Mi, K, Q	Mi, Q
30-45	m, v, cl, Mi, K, Q	m, v, cl, Mi, Q, Ca
60-75	M, V, Cl, Mi, K, Q	m, v, cl, Mi, Q, Ca
90-105	M, V, Cl, Mi, K, Q	m, v, cl, Mi, Q, Ca
120-135	M, V, Cl, Mi, K, Q	Mi, Q, Ca
150-165	M, V, Cl, Mi, K, Q	m, v, cl, Mi, Q, Ca
180-195	M, V, Cl, Mi, K, Q, Ca	Mi, Q, Ca
210-225	M, V, Cl, Mi, K, Q, Ca	Mi, Q
240-255	M, V, Cl, Mi, K, Q	M, V, Cl, Mi, Q
270-285	M, V, Cl, Mi, K, Q	M, V, Cl, Mi, Q, Ca
285 +	M, V, Cl, Mi, K, Q	M, V, Cl, Mi, Q, Ca

Weak = m, v, cl, Mi, K, Q

Strong = M, V, Cl, Ca

M = montmorillonite

V = vermiculite

Cl = chlorite

Ca = calcite

K = kaolin

Q = quartz

Mi = hydrous mica

Coarse Clay

Mica, quartz and calcite were dominant in the A, B and C horizons. Montmorillonite, vermiculite and chlorite gave weak diffraction patterns in the A and B horizons which may have been due to the dominance of quartz and mica in the coarse clay. With depth, all these minerals gave strong diffraction patterns. As mentioned in the discussion of the x-ray mineralogy of the fine clay, kaolinite was usually present. However, in some of the coarse clay samples, kaoline was not present which was unexpected and no explanation can be given at this time for a satisfactory explanation of the absence of kaolinite.

Chemical Analyses

The soluble salts composition of all soils are reported in Tables XI to XIX.

Electrical Conductivity (EC)

The salt content of the soil can be estimated roughly from an electrical conductivity measurement on a saturated soil paste or in a 1:1 water extract of the soil. The $EC_{25^{o}C}$/cm of soil samples, generally, increased with depth. This increase of $EC_{25^{o}C}$/cm by depth may be due to the leaching process of the irrigation water. While the majority of the profiles showed an increase of EC with depth and then a decrease in the C horizon, profile No. 1 showed a gradual increase in the EC until the C horizon, while it showed a decrease in the B horizon. Most of the profiles showed a negligible salinity effect in the A horizon, except profile 1 and 8 where the EC ranged from 4700 to

TABLE XI

SOLUBLE SALT COMPOSITION OF PROFILE #1, OBSERVATION WELL, OKLA. AGRIC. EXPT. STA., ALTUS, OKLA. SOUTH SIDE OF STATION, IRRIGATED TILLMAN-HOLLISTER SI.CL.L.

Depth (cm)	E.C. μmho/cm	PPM					SAR	ESP
		Soluble Solids	Cl	Na	Ca	Mg		
0-15	4700	230	28	50	66	8	1.56	1.00
15-30	5076	1140	28	68	151	30	1.30	.64
30-45	5358	3440	77	363	444	140	3.84	4.12
45-60	5640	3570	224	490	388	155	5.30	6.00
60-75	2961	2670	434	636	278	139	7.60	7.98
75-90	3290	1850	623	375	176	84	5.82	6.67
90-105	3337	1820	665	368	174	94	5.57	6.35
105-120	3243	1530	602	345	139	79	5.77	6.60
120-135	7520	1150	473	300	110	60	5.68	6.50
135-150	2820	1320	245	206	219	68	3.11	3.15
150-165	5546	780	315	245	85	35	5.60	6.40
165-180	5405	750	298	255	71	53	5.57	6.30
180-195	2914	420	245	218	69	23	5.78	6.63
195-210	5640	520	228	215	65	23	5.81	6.60
210-225	7050	650	280	224	80	30	5.40	7.30
225-240	5076	1030	245	275	118	48	5.39	6.13
240-255	5170	400	105	74	54	23	2.12	1.79
255-270	4700	480	193	185	50	20	5.58	6.37
270-285	5217	350	193	194	43	20	6.09	7.00
285 +	5640	1940	665	352	158	63	5.98	6.87

TABLE XII

SOLUBLE SALT COMPOSITION OF PROFILE #2, OBSERVATION WELL, OKLA. AGRI. EXPT. STA., ALTUS, OKLA. NORTH SIDE OF STATION, IRRIGATED TILLMAN-HOLLISTER SI.CL.L.

Depth (cm)	E.C. μmho/cm	PPM					SAR	ESP
		Soluble Solids	Cl	Na	Ca	Mg		
0-15	1000	1030	140	85	90	40	1.86	1.40
15-30	955	1650	438	178	143	50	3.25	3.30
30-45	3900	3720	823	360	580	130	3.51	3.60
45-60	4800	4950	1190	460	710	215	3.86	4.15
60-75	5000	4960	1260	470	700	230	3.90	4.20
75-90	4346	3700	980	380	500	165	3.75	4.00
90-105	4400	4070	1155	500	450	200	4.92	5.53
105-120	3800	3300	910	480	345	160	5.33	6.05
120-135	3200	2670	770	455	230	120	6.03	6.90
135-150	3100	2520	805	420	240	115	5.57	6.35
150-165	3000	2320	735	445	190	85	6.72	7.78
165-180	2700	2170	665	420	175	80	6.57	7.60
180-195	4600	5120	718	555	625	230	4.83	5.41
195-210	4600	5280	700	550	595	210	4.92	5.54
210-225	4400	4930	613	505	625	215	4.68	5.22
225-240	3100	2680	595	405	255	85	5.59	6.38
240-255	3100	2690	665	475	240	90	6.62	7.66

TABLE XIII

SOLUBLE SALT COMPOSITION OF PROFILE #3, OBSERVATION WELL #14, OKLA. AGRI. IRRIGATION EXPT. STA., ALTUS, OKLA., TILLMAN-HOLLISTER SI.CL.L.

Depth (cm)	E.C. μmho/cm	PPM					SAR	ESP
		Soluble Solids	Cl	Na	Ca	Mg		
0-15	720	250	70	71	68	19	1.96	1.57
15-30	660	230	53	79	45	15	2.60	2.45
30-45	2910	2670	70	244	300	158	2.83	2.77
45-60	3200	3120	105	326	296	195	3.60	3.80
60-75	4160	4140	280	431	274	274	4.39	4.84
75-90	3120	2220	525	379	203	153	4.88	5.47
90-105	2800	1800	648	353	143	113	5.33	6.05
105-120	3330	2330	875	405	188	150	5.32	6.04
120-135	4410	3370	1243	521	281	214	5.66	6.47
135-150	2500	1720	613	285	161	101	4.32	4.75
150-165	4090	3120	1155	529	255	176	6.22	7.17
165-180	3250	2250	822	383	206	120	6.00	6.89
180-195	3370	2280	858	446	191	124	6.16	7.09
195-210	3600	2490	945	435	221	131	5.71	6.52
210-225	3880	2810	1068	473	278	150	5.67	6.48
225-240	3390	2470	875	416	229	135	5.37	6.10
240-255	2900	1970	735	323	218	79	4.74	5.29

TABLE XIV

SOLUBLE SALT COMPOSITION OF PROFILE #4, OBSERVATION WELL #13, OKLA. AGRI. IRRIGATION EXPT. STA., ALTUS, OKLA., TILLMAN-HOLLISTER SI.CL.L.

Depth (cm)	E.C. µmho/cm	PPM					SAR	ESP
		Soluble Solids	Cl	Na	Ca	Mg		
15-30	1000	720	88	146	71	19	3.97	4.29
30-45	2980	860	140	311	304	124	3.79	4.05
60-75	3120	2340	770	330	259	143	4.07	4.42
75-90	3600	2830	998	341	311	188	3.75	4.00
105-120	4310	4360	1295	514	349	263	5.00	5.63
120-135	4200	3160	1208	439	327	210	4.64	5.17
135-150	3710	2820	1103	413	293	180	6.32	7.29
150-165	3440	2560	963	409	263	146	5.00	5.63

TABLE XV

SOLUBLE SALT COMPOSITION OF PROFILE #5, OBSERVATION WELL #15, OKLA. AGRI. IRRIGATION EXPT. STA., ALTUS, OKLA., TILLMAN-HOLLISTER SI.CL.L.

Depth (cm)	E.C. µmho/cm	PPM					SAR	ESP
		Soluble Solids	Cl	Na	Ca	Mg		
0-15	890	440	105	71	86	23	1.76	1.29
15-30	670	260	88	79	56	11	2.52	2.34
30-45	1000	620	53	128	83	26	3.13	3.17
45-60	2190	1840	70	289	210	86	4.23	4.63
75-90	3500	3120	368	409	274	180	4.69	5.23
90-105	3690	2910	578	461	251	169	6.32	7.29
105-120	3900	2770	910	469	240	161	5.73	6.56
120-135	5990	5700	1190	656	476	349	5.55	6.33
135-150	5950	5730	1120	619	469	330	5.33	6.05
150-165	3910	2790	1050	548	229	139	7.00	8.12
165-180	2580	1680	560	311	184	79	4.83	5.41
180-220	3880	2760	980	503	255	139	6.25	7.20
220-250	4400	3310	1208	495	326	158	5.60	6.39
250-280	3490	2530	963	409	233	113	5.47	6.23

TABLE XVI

SOLUBLE SALT COMPOSITION OF PROFILE #6, OBSERVATION WELL #12, OKLA. AGRI. EXPT. STA., ALTUS, OKLA. (ADJACENT TO DRAINAGE CANAL) TILLMAN-HOLLISTER SI.CL.L.

Depth (cm)	E.C. μmho/cm	PPM					SAR	ESP
		Soluble Solids	Cl	Na	Ca	Mg		
0-15	800	520	53	101	64	23	2.74	2.64
15-30	1900	1720	88	240	173	75	3.82	4.09
30-45	3900	4140	193	431	270	251	4.52	5.00
45-60	3580	3260	403	514	206	199	6.09	7.00
60-75	3720	3070	665	551	210	191	6.60	7.64
75-90	3880	3150	805	529	233	206	6.05	6.96
90-105	3900	3230	735	536	243	210	6.05	6.96
105-120	4840	5100	578	574	334	326	5.34	6.06
120-135	3340	2990	403	428	240	169	5.15	5.82
135-150	2150	1690	368	338	113	75	6.02	6.92
150-165	1830	1360	315	278	94	56	5.60	6.39
165-220	1800	1220	315	266	90	53	5.48	6.24

TABLE XVII

SOLUBLE SALT COMPOSITION OF PROFILE #7, ROBINSON FARM, NE¼,NE¼,NE¼ SECTION 6, T1NR20W TILLMAN-HOLLISTER SI.CL.L.

Depth (cm)	E.C. µmho/cm	PPM					SAR	ESP
		Soluble Solids	Cl	Na	Ca	Mg		
0-15	1100	780	140	30	26	8	1.31	.65
15-30	1000	740	140	28	25	8	1.25	.57
30-45	810	560	123	26	19	5	1.36	.72
45-60	1100	850	158	36	26	7	1.62	1.09
60-75	2000	1680	210	50	67	19	1.38	.75
75-90	2200	1940	368	51	66	28	1.32	.67
90-105	2100	1700	490	58	40	29	1.69	1.19
105-120	2000	1610	403	61	37	27	1.85	1.41
120-135	2200	1740	560	74	33	26	2.33	2.08
135-150	2300	1800	595	82	36	28	2.34	2.09
150-165	2000	1660	507	68	37	23	2.17	1.86
165-180	2700	2310	718	97	50	34	2.59	2.44
180-195	2900	2300	735	101	52	33	2.68	2.56
195-210	3200	2530	875	116	55	33	3.04	3.05
210-225	5000	5050	840	142	126	76	2.46	2.26
225-240	5000	5080	910	138	129	71	2.40	2.18
240-255	3200	2570	910	116	63	35	2.90	2.86
255-270	3100	2300	823	104	58	31	2.72	2.61

TABLE XVIII

SOLUBLE SALT COMPOSITION OF PROFILE #8, ROBBINS FARM
0.4 MILE WEST OF N.E. CORNER OF SE¼ SECTION 13-
R2WT21N TILLMAN-HOLLISTER SI.CL.L.

Depth (cm)	E.C. µmho/cm	PPM					SAR	ESP
		Soluble Solids	Cl	Na	Ca	Mg		
0-1.25	35000	46730	10937	2516	4773	834	8.81	10.27
0-15	6200	6970	1523	894	875	275	6.74	7.81
15-30	4730	5420	1068	625	644	206	5.47	6.23
30-45	4900	5740	1085	465	728	158	4.06	4.41
45-60	2800	3520	158	360	203	143	4.71	5.26
60-75	4500	4910	720	548	383	150	5.87	6.73
75-90	4800	5940	595	596	341	300	5.64	6.44
90-105	3800	4410	403	529	233	195	6.17	7.10
105-120	1500	2060	245	270	68	26	7.03	8.16
120-135	1600	2050	228	266	64	38	6.50	7.51
135-150	1630	2110	263	259	86	45	5.63	6.43
150-165	1500	1920	228	218	83	34	5.07	5.72
165-180	1000	1610	123	154	60	11	4.79	5.36
180-195	1500	1950	245	236	79	30	5.70	6.52
195-210	940	1550	123	143	60	11	4.44	4.91

TABLE XIX

SOLUBLE SALT COMPOSITION OF PROFILE #9, ROBBINS FARM
0.25 MILE S. AND 0.25 MILE WEST OF N.E. CORNER
OF SE¼ SECTION 13 R21WT2N,
TREADWAY CLAY

Depth (cm)	E.C. µmho/cm	PPM					SAR	ESP
		Soluble Solids	Cl	Na	Ca	Mg		
0-15	490	1330	18	23	53	11	.75	-0.15
15-30	410	1300	53	30	45	8	1.08	.32
30-45	400	1310	53	34	41	8	1.26	.58
45-75	1330	2530	228	53	150	60	.92	.09
75-90	1750	2600	403	75	169	86	1.17	.45
90-105	1540	2320	298	90	158	83	1.43	.82
105-120	1660	2356	368	109	124	86	1.40	.78
120-135	1500	2120	350	116	101	79	2.10	1.76
135-150	1380	1940	263	120	83	71	2.33	2.08
150-165	1200	1820	158	165	68	41	3.88	4.17
165-180	1400	1940	210	202	75	38	4.72	5.27
180-210	1430	1990	228	233	75	38	5.48	6.24

35000 μmho/cm. This high value of EC in these profiles could restrict the yield of many crops. Profile 8 shows a decrease of EC with depth and this can be attributed to the accumulation of soluble salts on the soil surface as shown in Table XVIII where the EC was 35000 μmho/cm in the layer 0 - 1.25 cm, and the TDS (Total Dissolved Solids) were 46730 ppm in the same layer.

Total Dissolved Solids (TDS)

The amount of soluble salts (TDS) showed a large variation in the increase or decrease in each profile. Generally the soluble salts increased in the B horizon and then decreased in the C horizon, except in profile 1 where the soluble salts increased from the surface down to the C horizon. Profile 8 was an exception for all of the profiles, due to an accumulation of soluble salts on the soil surface as in the 0 - 125 cm layer as shown in Table XVIII.

Soluble Cations and Anions

The soluble cations determined were sodium (Na), calcium (Ca), and magnesium (Mg). The chlorine (Cl) was the only anion determined and both cations and chlorine are reported in Tables XI to XIX.

The chlorine (Cl) ion, generally increased with depth and then decreased in the C horizon except in profiles 1, 2, and 9. In profile 8 the surface layer (0 - 1.25 cm) contained a very high amount of Cl (10937.00 ppm) and this was mentioned previously in the discussion and was due to an accumulation of soluble salts on the soil surface.

The dominant cation was sodium (Na) and it usually increased with depth in the B horizon and then decreased in the C horizon except in profile 9 where it increased with depth into the profile.

Calcium (Ca) showed less tendency to increase with depth probably due to lower solubility and accumulation at the upper layers of the profile.

Magnesium (Mg) increased with depth through the B horizon and then decreased in the C horizon.

Exchangeable Sodium Percentage (ESP)

The ESP for the soils studied ranged between 0.15 to 10.27 as is shown in Tables XI to XIX. It is known that the structural deterioration of soil results only indirectly from the use of high Sodium Absorption Ratio (SAR) irrigation water. The ESP, a function of SAR, may be used as an indication of the extent of structural breakdown in irrigated soils. While 15% exchangeable Na is generally considered to be the point at which structural breakdown begins, it is logical to assume that soils of low clay content may tolerate higher exchangeable Na percentages than do fine textured soils.

The Sodium Absorption Ratio (SAR) did not exceed 8.81 in any of these soil samples. The SAR of these soils was very well correlated with the ESP with an "r" of .96. Both SAR and ESP increased with depth except for profile 8 where the surface layer (0 - 1.25 cm) had an SAR of 8.81 and an ESP of 10.27 and these results were probably due to the accumulation of soluble salts on the soil surface. The increase of ESP by depth can be explained by the role of irrigation water in leaching soluble salts downward into the soil profile. It is suggested that the irrigation water should be analyzed to determine the principal source of salinity. Another explanation for the increase of SAR and ESP with depth may be due to the local soluble salts from the parent material in the profile.

CHAPTER V

SUMMARY AND CONCLUSIONS

Nine profiles from an irrigated Tillman-Hollister soil were investigated for their mineralogical, physical, and chemical characteristics.

The percentage of fine to coarse sand generally decreased with depth. The percentage of very fine sand also decreased with depth. The percentage coarse and fine silt were present in lowere percentages than sand and clay, and both the coarse and fine silt decreased with depth. The percentage of clay increased substantially into the B horizon and then decreased in the C horizon. The dominance of clay in the B horizon may be due to illuviation.

Mineralogical determinations by x-ray diffraction of these profiles showed that mica, kaolinite and quartz were dominant in the fine clay fraction of all profiles, whereas mica, quartz and calcite were dominant in the coarse clay fractions. Montmorillonite, vermiculite and chlorite were present to a lesser extent in the fine clay fraction from the surface layers. Weak diffraction patterns for these minerals were observed in the A and B horizons for the coarse clay fractions. It was found that kaolinite was present in the fine clay fraction but did not exist in the coarse clay fraction. This phenomenon was not completely understood. Small crystals of calcite were found in the fine clay at depths of 185 - 225 cm.

The chemical analyses of these soils showed that the EC increased with depth and decreased in the C horizon. All profiles showed low EC values except profile No. 8 where the EC varied from 4700-35000 μmho/cm but it decreased with depth. The total soluble salts generally showed an increase in the B horizon and then decreased in the C horizon.

The chlorine content increased with depth but decreased in the C horizon except for profile No. 8 where the accumulation of soluble salts was very high in the surface area.

The dominant cation was sodium which increased with depth and decreased in the C horizon except for profile No. 9 where it increased with depth through all the profile. Magnesium concentration was similar to sodium, while the calcium decreased with depth.

The ESP and SAR showed an increase with depth and this was probably due to the role of irrigation water in leaching the soluble salts downward into the soil profile.

It is suggested that the irrigation water may be one of the causes of salinity in these soils plus the effect of the local salts in the parent material.

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