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SALINITY STATUS OF SOME SELECTED HAWAIIAN SOILS

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INTRODUCTION

Salinity is saltiness (Bernstein et al 1955). Soils containing excessive amounts of dissolved salts are called saline soils. The salt-affected soils are classified into three different groups: (1) Saline soils, (2) Sodic soils, and (3) Saline-Sodic soils.

Saline soils contain sufficiently high contents of soluble salts to depress plant growth, while sodic soils (U. S. Salinity Laboratory Board of Collaborators 1958) formerly known as "alkali soils" (U. S. Salinity Laboratory Staff 1954) contain sufficient amounts of adsorbed sodium to affect growth adversely. Saline-sodic soils have both excessive soluble salts and high adsorbed sodium.

Salts may be a natural constituent of the soil or may be added to the soil by man in the form of fertilizers and dissolved salts in irrigation waters. Salt accumulation occurs, and often to harmful levels, when addition to the soil exceeds the removal from the solum. Such conditions are commonly encountered in arid and semi-arid regions of the world where high temperature favors evapotranspiration and rainfall is inadequate to leach salts beyond the rooting zone.

These regions are widespread in both the northern and southern hemispheres (see Figure 1). Dickson (1957) showed that about one-tenth of

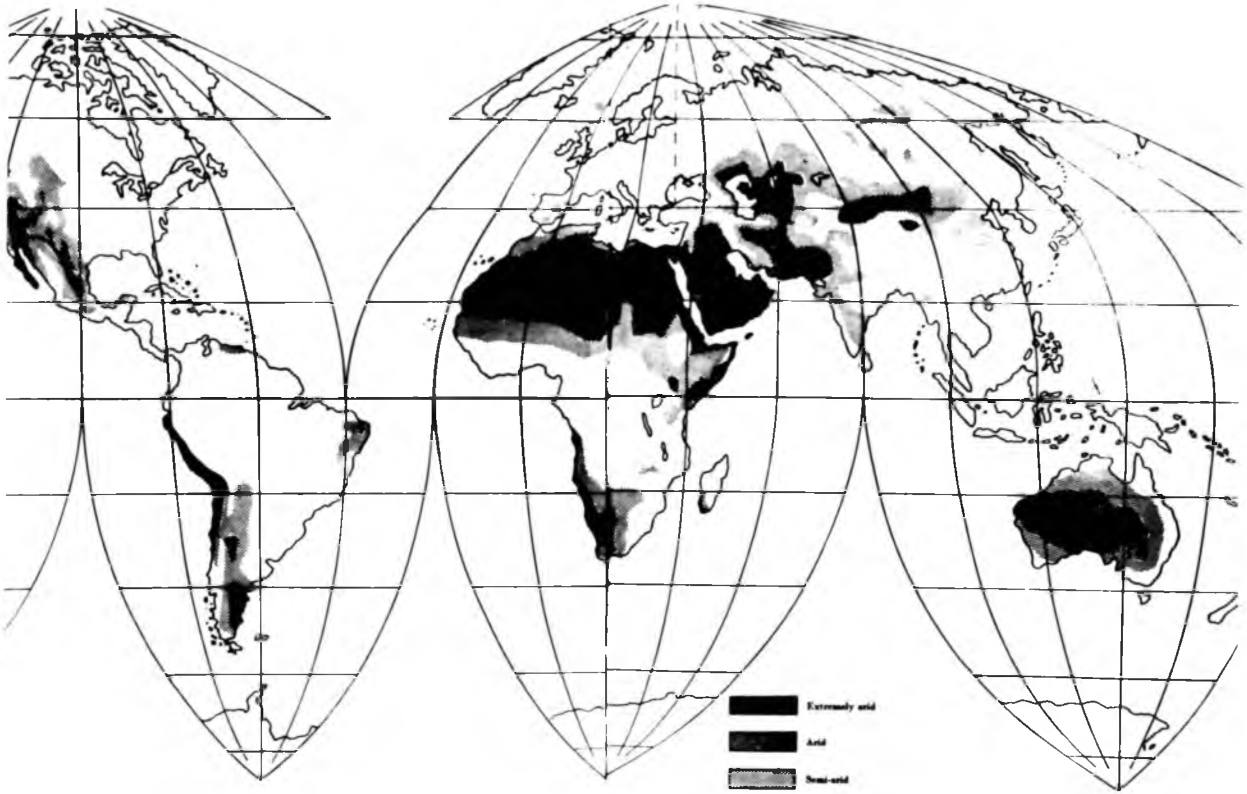

FIGURE 1. WORLD DISTRIBUTION OF ARID AND SEMI-ARID REGIONS.

the 57 million square miles of the land mass is under some sort of cultivation. One-tenth of a million square miles of land is not favored with adequate rainfall and receives less than ten inches in any given year. Thus, the agricultural productivity of these regions depends upon the establishment of a permanent irrigation system and the efficient use of the water resources.

Poor agricultural management has, in many cases, brought land under saline conditions. The previously existing saline areas were found to expand rapidly when poor quality irrigation water was applied. In Pakistan and other countries of the Middle East like Egypt, man has contributed more toward the spread of salinity than nature itself.

In Pakistan alone, more than 5 million acres of land suffer from salinity, while in about 11 million acres of land saline patches are common (Tipton 1959). Szabolez, (1956a) estimated that salt-affected land in Hungary occupies over half a million hectares. Solonetz (sodic) and Solonchak (saline) soils account for more than 75 million hectares in the U.S.S.R. (Popazov 1956). Syun (1956) states that 20 million hectares in China have chloride-sulphate type salinity. Yugoslavia has more than half a million acres of salt-affected land (Miljkovic et al 1959). Buehrer and Hanna, (1956) reported the occurrence of saline soils in Iraq. Saline and sodic soils occur in Egypt on regularly irrigated land (Schoonover et al 1957).

Reference to saline soils occurring in North Africa (Berger-Landefeldt 1957), North Cameroon (Pias and Guichard, 1956), the lower valley of the

Guadalquirvir in Spain (Garcia et al 1956), their geographical extent and the nature of salinity has been made by UNESCO.

In some humid zones of India, salinity due to magnesium salts has been reported by Banerjee (1959a, 1959b). Similar cases of magnesium salinity have been cited for many low lying coastal areas of Holland (Hissink 1932), where the sea had encroached land during geologic times. In the Philippines, Alicante (1933) reported soils having twice as much magnesium as calcium in the water extract. Ellis and Caldwell (1935) reported magnesium salinity in certain Manitoba soils. Kudrin and Rosanov (1938) characterized serozems with high content of adsorbed magnesium. In the Red River Valley, Rost and Chang (1941) separated soils having magnesium salinity from those with high exchangeable calcium. Several workers have reported magnesium salinity in Hawaii (McGeorge 1930, Hance and Stewart 1927, and Ewart, unpublished data of American Factors, Limited).

Windblown sea spray or "cyclic salt" has also contributed towards the salinity hazard in Australia (Teakle 1937). In Hawaii the windblown deposits have been reported by Sideris (1955) who showed that amounts as much as 13.8 lbs/A per month was collected over a two year period within a distance of 1000 feet from the sea. The amount of salt deposited decreased as the distance increased.

The principal cations present in the soil solution of saline and sodic soils are calcium, magnesium, sodium and potassium, while the principal anions are chloride, sulphate, carbonate and bicarbonate. Some ions act as nutrient elements, but excessive accumulation of a single ion may be detrimental and injurious to plants. Salt accumulation affects plant growth in several ways. Increase in salt content is accompanied with an increase in osmotic pressure of the soil solution in the root medium which acts against the intake of water by plants, hence causes an undesirable condition similar to drought.

Specific ion effects (toxicities and nutritional disturbances) may be superimposed on the general osmotic effect (Hayward and Wadleigh 1949), Grillot 1956, Bernstein and Hayward 1958, Bernstein 1962).

The effect of excessive salt accumulation on the chemical and physical properties of the soil indirectly affects plant growth. Prolonged evaporation from a saline soil produces characteristic changes in the composition of its soluble salts. The relative amount of sodium in solution is increased by precipitation of carbonates and sulphates of calcium and magnesium. When this occurs, sodium replaces calcium and magnesium from the exchange complex and gives rise to sodic soils (Kellley 1951). Large amounts of sodium adsorbed on the exchange complex produce special undesirable physical and chemical changes in the soil. Sodium favors dispersion of the soil and reduces its permeability to water and gases. Furthermore, due to specific effect of the sodium ion, plants with high calcium requirement may actually suffer the sodium induced calcium deficiency.

Since the effect of excessive soluble salts on plants and crops is of considerable economic importance, and extensive study of salinity problems in areas concerned is vital for the successful eradication of the menace.

The purpose of this research was to evaluate the salinity status of some selected Hawaiian soils. The applicability of electrode measurement of sodium ion activity was also included as part of this research work.

REVIEW OF LITERATURE

EARLY INVESTIGATIONS

It was not too long ago that agriculturalists began to appreciate the agronomic potentialities of soils in arid and semi-arid regions. Hilgard in California was perhaps among the first workers to give attention to the systematic study of the soils of low rainfall areas. The high salt content of soils was attributed to either the presence of large amounts of natural salt or to use of irrigation water having high salt contents.

Early thoughts and observations concerning spread of soluble salts in various parts of Southern California were recorded. Hilgard (1890) as cited by Kelley (1951) pointed out the heavy accumulation of soluble salts in San Joaquin Valley, California, and later Hilgard et al (1902) reported two soils in Imperial Valley where the spread of salinity was very common. From his investigations (1906) a fairly comprehensive understanding of saline and alkali soils was made possible. Gedroiz et al (1912), (1926) and (1928) in Russia, de'Sigmond (1927a, b, c) and (1932) in Hungary and Hissink (1933) in Holland and Kelley (1922), and other workers in other parts of the world have contributed a great deal to our present knowledge of saline and alkali soils.

PRESENT INVESTIGATIONS

Salt-affected soils are classified according to either a chemical or morphological basis. Following the lead of de'Sigmond, the United States Salinity Laboratory Staff (U.S.S.L. 1954) developed the chemical classification of the soil with arbitrary limits. This classification is based upon plant tolerance to various salt levels.

Saline soil contain high enough concentration of soluble salts to depress plant growth, while sodic soils (U.S.S. L. Board of Collaborators 1958) formerly known as "alkali soils" contain sufficient exchangeable sodium to affect growth adversely. As practical definitions, the lower limit for saline soil was set at 4 millimhos per centimeter electrical conductivity of the saturation extract at 25° C (EC_e), and for sodic soils at 15 exchangeable sodium percentage (ESP).

Saline-sodic soils contain sufficient quantities of soluble salts and adsorbed sodium to reduce the yield of most plants. Their ESP is equal to or greater than 15 and the EC_e is greater than 4 mmhos/cm. The pH of the saturated paste is usually less than 8.5, but if gypsum is present in appreciable quantities, the pH may be as low as 8.2. Saline soils correspond to the "white alkali" of Hilgard and Solonchak of Russian workers, and sodic soils correspond to the "black alkali" of Hilgard, and in many cases to "Solonetz" as used by the Russians.

Soviet scientists attach considerable importance to the composition of the salts in soil in relation to plant growth, but the emphasis is on the anion composition (Bower *et al* 1962). Thus, chloride-salinity and sulphate-salinity are terms frequently used.

Bower (1962) has further emphasized the difference in basic approach towards the salinity investigation in Russia and the United States, saying that soil particles being negatively charged undergo cation exchange reactions and influence the chemical and physical properties of the soil markedly, while the negative adsorption plays an insignificant part on the soil systems.

STUDIES CONCERNING THE EFFECT OF SALINITY ON PLANT GROWTH

Plant growth responses on saline soils have been discussed by Hayward and Wadleigh (1949), Hayward (1953), Grillot (1946), Hayward and Bernstein (1958), Lagerwarft and Ogata (1960), Bernstein and Hayward (1958) and Bernstein (1962). More often the total concentration of the soluble salts in the soil solution, rather than their chemical nature, is mainly responsible for the injurious effect on the growth of plant crops. The causes are associated with increase in osmotic pressure of the root medium. This situation decreases the water availability due to a decrease in the diffusion pressure gradiant between the soil solution and the plant. Eaton (1942) has questioned the actuality of this effect on the basis that the osmotic pressure of leaves or above ground parts of plants increases as the salinity increases. The osmotic adjustment in many plants has been reported to a marked extent and hence the physiology of the plant is not too much affected unless the concentration of the soluble salt increases to critical levels (McKay 1935, Bonner 1959, Epstein 1960 and Scholander _et al_ 1962, Bernstein _et al_ 1961, 1963). However, the qualitative aspects of plant growth on saline media are not insignificant. Progressive stunting of plants and the attendant smaller, darker green leaves and tip burns which, in most cases, resemble drought symptoms have been noticed. The prevailing view held by most workers is that water deficit induced by high osmotic pressure is the factor restricting plant growth (Gardner 1960).

ROLE OF SODIUM

In salt-affected soils sodium exists in two phases, soluble sodium and exchangeable sodium. There is no strict boundary between the two phases as such, and an ion on the exchange complex can migrate into the soluble phase, and vice versa under certain conditions. Further, the layer of cations adsorbed on the clay surface diffuses rather indistinctly into the electrically neutral dissolved salt phase. The role played by sodium in saline and sodic soils can be divided in the following:

A. The Effect of Soluble Sodium on Plant and Soil

Although sodium is not considered as an essential plant nutrient, its presence in relatively small quantities may stimulate the productivity of certain truck crops. Harmer and Benne (1941) have attributed the increase in the yield of beets, celery and turnips to the small amount of sodium. Many plant species, however, tend to accumulate large amounts of sodium in their tissues and leaves (Peterson 1958). Bernstein and Pearson as late as (1956) have shown that moderate levels of sodium accumulation were reached in beans, clover and alfalfa, but vary high levels were attained in beets.

In spite of this selectivity for sodium accumulation by plants, few well-defined instances of sodium toxicity have been reported.

Lilleland *et al* (1945) described a tip burn of almond leaves related to sodium concentration. Ayers and his associates (1951) described a sodium-scorch of avocado leaves. Ayers (1950) and Brown *et al* (1959) growing avocado and stone fruit in water culture salinized by sodium salts observed a similar leaf injury. El-Gabably (1958) studying salt tolerance of barley, wheat, clover and horse beans showed that barley failed to grow when the soluble sodium percentage (SSP) exceeded 65, but reported fair growth at SSP values less than 50. Wheat did not grow at all at a SSP of 82 and there was no growth of clover at SSP of 70. Wahab (1958) studied the effect of increasing the amount of sodium chloride (NaCl) on wheat, corn, barley, rice and cotton, and showed that the germination of wheat was adversely affected when the NaCl concentration was above 0.2% at moisture levels equivalent to 15% of the water holding capacity. Corn did not germinate beyond 0.2% concentration of NaCl at 30% of the water holding capacity. Similar results were obtained for other crops.

The effect of soluble sodium upon the soil system has not been cited in the generally available literature.

B. The Effect of Exchangeable Sodium on Plants and Soil

Exchangeable sodium is that portion of the soil sodium adsorbed by the soil and may be replaced by, or exchanged with, other cations (Pearson 1960). It is expressed as me/100 gm of soil.

The adverse effect of exchangeable sodium (ES) to plants is indirect. The immediate effect of exchangeable sodium is to cause the soil particles to disperse, thus resulting in smaller pores. Problems related to aeration, water movement and root development are associated with the charges in the physical condition of the soil (Chang and Dregne 1955, McGeorge and Brezeale 1958).

In addition to growth problems related to physical conditions, the exchangeable sodium produces nutritional problems (Ratner 1935, Bower and Wadleigh 1948, and Thorne 1945). Ratner (1944) stated that under such conditions the exchange complex actually extracts calcium from the root tissues, and death may follow because of calcium deficiency. Laboratory experiments show that addition of calcium and magnesium oftentimes improves plant growth (Bower and Turk 1946).

Bernstein and Pearson (1956), Wadleigh and Bower (1948) have tried to relate the direct effect of exchangeable sodium percentage on plant growth as distinguished from indirect effect related to changes in the physical condition of the soil.

MEASUREMENT OF SODIUM BY THE SPECIFIC ION ELECTRODE

Although Lengyell and Blum (1934) observed that sodium silicate glass electrodes containing Al_2O_3 or B_2O_3 were sensitive to several metallic cations as well as hydrogen, attempts to develop and utilize such electrodes for the measurement of sodium ion activity have been made only recently. (Aleshin and Gorb 1958, Eiseman *et al* 1957, Goremykin and Kryukov 1957, and Leonard 1962).

Following the lead of all these scientists, Beckman Instruments Incorporated manufactured electrodes with catalog number 78137V and later 78187V. The latter is sensitive only to Na+ in the pH range between 7 to 11 and does not respond to calcium and magnesium (Bower 1959). Bower (1961) determined the amount of soluble and exchangeable sodium with the help of the electrode and compared the results with the flame photometer. He obtained results which were in good agreement.

The absolute concentration is not entirely responsible for chemical changes, but rather there is a fraction of the total concentration which is effective in producing chemical reactions. Thus, the use of the electrode provides better estimates of the active or effective concentration in a system. Furthermore, the use of electrodes has been found to be more rapid, accurate and economical.

It was with this background that the present work was carried out. In the absence of any previous work of this sort on Hawaiian soil, ideas and techniques were freely applied.

The author has found the applicability of this electrode quite satisfactory, and fully agrees with the following statement made by L. Bernstein of U.S.D.A. ARS-USSL at the Paris Symposium on Arid Zone Research in 1962:

> Although Na and K determination by flame photometry have now replaced the more tedious chemical methods, another facile method has been proposed. Glass electrodes have been produced which are sensitive to Na, K and H^+. The method promises even greater convenience than flame photometry, with less specialized equipment required.

SALINITY INVESTIGATIONS IN HAWAII

Cline (1955) has reported the occurrence of solonchak and, to a lesser extent, that of solonetz in Hawaii. Kalani clay, a solonetz soils occupies a small area in the Kau section on the Big Island. In the poorly drained area of Maui, soils were found with high base-saturation. These soils were high in exchangeable magnesium (Sherman et al 1947). A high proportion of the bases was magnesium.

The high magnesium content of Hawaiian lavas results in soils high in magnesium. This is especially true in soil occurring in the low lands. The sodium concentration has been found to be lower than the other cations. McGeorge (1930) studying the effects of irrigation water from artesian wells on the physics and chemistry of soils at Ewa Plantation, reported an increase in exchangeable magnesium when high magnesium water was used.

Sherman et al (1947) concluded that a high soluble magnesium content was essential for the process of dolomitization to take place. The soils of the Lualualei, Makaha and Waianae Valleys were found to be rich in magnesium. Gill and Sherman (1952) attributed the dispersed character of the gray hydromorphic soils to high exchangeable magnesium, especially where the ratio of the exchangeable magnesium to exchangeable calcium was equal to or greater than one.

Some work in the area of salt tolerance of plants showed that irrigation water as high as 2.56 $EC \times 10^3$ can be successfully used for the production of many truck crops (Nightingale and Yoshida 1954). In the same area, grasses and legumes showed excellent growth when water of 4.43 $EC \times 10^3$ was used for irrigation purposes.

Ahmed (1965) working with artificially prepared saline and sodic soils of the Molokai and Lualualei series, concluded that the dispersive effect of magnesium in soils may be due to the formation uni-valent magnesium ion complex.

In Kekaha Plantation, Ewart (personal communication) found that in all cases magnesium was higher than calcium and sodium.

MATERIALS AND METHODS

DESCRIPTION OF THE SOILS USED

Five soils and four drainage water samples from Kekaha Plantation on the island of Kauai were used for the present study.[1]

This study was conducted to ascertain the presence of salt in soils, its effect on plants and its removal from soils.[2] Samples were taken from various portions of furrows. At least one sample in each field was taken from the furrow ridge where salt accumulation is usually high. Where visual examination of cane showed effects of salinity, samples were collected from at least three depths. For purposes of comparison, areas of high, medium and low levels of salinity were sampled.

A brief description of the soils from different cane fields is given below. Their locations are shown in Figure 2.

Field 260 was among the newest fields and is located on recently reclaimed land. The soil was formerly classified as the catano series, sand dune phase and

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[1] Thanks are due to Mr. George Schattenburg, Agriculture Engineer of the Kekaha Plantation for his cooperation and interest in sampling for the present work.

[2] Unfortunately a heavy rainfall of 3.5" was recorded by plantation management in that area only a day before the samples were taken, and much of the soluble salt was either flushed away or leached down to greater depths.

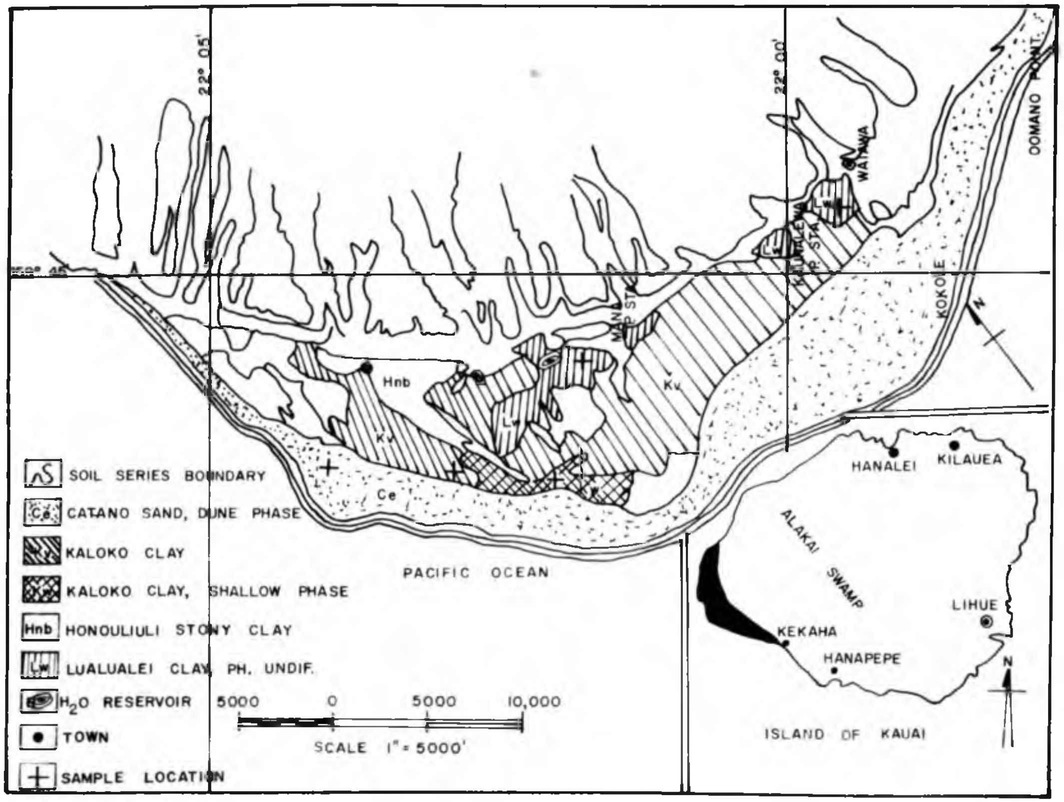

FIGURE 2. LOCATION OF SAMPLING SITES.

essentially consisted of beach sand. The sub-surface material is weakly consolidated and pale in color. The soil was reclaimed by mixing large amounts of bagasse and mill waste with the surface of 12 inches. Crystals of gypsum and other salts were common on the surface. Since the field had been only recently placed under cultivation, only two samples were taken to the following depths.

Furrow Ridge	0 - 10"
Furrow Bottom	0 - 12"

The soils of fields 242 and 237 are classified as the Kaloko series. They are characterized by marl-like material probably derived from alluvium and coral sand. The average rainfall in this area is about 25". The surface 10" is reported by Cline et al (1955) as dark reddish-brown clay; weak medium crumb structure, firm when dry and moderately plastic when wet. The pH ranges between 7.5 and 7.8. Cation exchange capacities for this soil are generally 50 me/100 gm and is about 90% base saturated (Kanehiro 1956). Samples were collected from the following depths.

Field 242		Field 237		
	0 - 2"		Furrow Ridge	0 - 10"
	2 - 10"		Furrow Bottom	0 - 6"
	10 - 22"			6 - 12"
	22 - 30"			12 - 20"

The soils of fields A-1 and 11-5 are classified as Lualualei clay, phase undifferentiated (0-3% slope). They are plastic hard clays derived from deep alluvium deposits on coastal flats or talus slopes. They occur at elevations of less than 250 feet, and receive an annual rainfall of about 25 inches. They are dark brownish-gray and have a moderately developed medium granular structure. The pH ranges between 7.0 and 8.0. Their cation exchange capacity is about 50 me/100 gm of soil and is around 100% base saturated (Kanehiro 1956). The following depths were samples.

Field A-1	Furrow Ridge	0 - 8"	Field 11-5	Furrow Ridge	0 - 10"
	Furrow Bottom	0 - 8"		Furrow Bottom	0 - 8"
	Furrow Bottom	8 - 20"		Furrow Bottom	8 - 16"

Three drainage water samples, 1000 ml of each, were collected in polyethylene bottles from various subsidiary drainage ditches around the fields. One sample was taken from the main drainage canal of the plantation. Care was taken to obtain a representative sample from running water in the ditches. Sample No. 242 was collected from a drainage ditch adjacent to field 242. This field showed the severest salt burns. Sample No. A-1 was collected from a drainage ditch near field A-1. Sample No. 260 was collected from a "bucket" drainage ditch in the middle of field 260. This drain did not have adequate flow. The excavated soil had visible gypsum crystals on its surface. The field was recently reclaimed and the seedling crop of sugarcane was less than 6 months old. A sample was collected from the primary drainage canal which drains water to the sea. It is a composite sample for all drainage waters throughout the plantation.

HISTORY OF THE AREA

As reported by Ewart (office records) a large portion of Kekaha Flats now occupied by the Kekaha Plantation on the island of Kauai was swampland up to the early days of 1921. It was fed by a high water table, seeps, springs, sea encroachment and periodic run-offs from the adjacent hills. The rains washed the hill slopes and deposited their loads in the form of alluvial fans.

Since much of the reclaimed area is about 4 feet above sea level, drainage was essential for sugar production. A major program of drainage was started in 1925 consisting of a closely spaced network of smaller "bucket" drains put into operation wherever isolated low-lying patches of water saturated land was observed.

After establishing the drainage system, large scale grading was done to improve water distribution. A program was initiated to keep the main canals and other vital drains free from limu (aquatic weeds). Tilapia mossambica and Tilapia melanopleura, mouth breeders noted for their voracious appetite for weeds, were introduced in 1955 (Sherburn 1961). Their efficiency in weed control can be seen in Figure 3. Weed control was a major factor in maintaining good drainage.

In isolated areas where drainage and salt content were unfavorable for sugar production, bagasse was incorporated into the soil. Mixing the bagasse resulted in better aggregation and lower bulk density, resulting in improved permeability and aeration. Heavy machinery was used to spread the bagasse, which in later

FIGURE 3. WEED CONTROL BELOW THE WATER LINE BY *TILAPIA* SP. IN DRAINAGE CANAL.

years, was mixed with the soil with the help of a turnover plow. The fields were then criss-crossed and chiseled or sub-soiled to a depth of approximately 14" to 18" (see Figure 4). The usefulness of bagasse also resulted in better emergence, weed control and uniformity of stand.

In some "bucket" drains where caving of the sides was a problem, ditches were filled with bagasse and covered with soil. Drains of this type were successful in reclaiming areas with this type of problem (Figure 5).

Until some years ago, there were scattered patches of saline within the fields. Although the soluble salt content of the presently used irrigation water ranged from 0.75 EC x 10^3 to 6.5 EC x 10^3 (office records), with chloride ion concentration ranging from 120 parts per million to 1590 parts per million, the vigorous growth of sugarcane in almost all fields attest to the success of saline soil reclamation.

METHODS OF ANALYSIS

The soil samples were air dried and then freed of coarse organic matter by hand picking. The soil was first ground to pass a 8 mesh (2mm) sieve, then further ground to pass a 32 mesh (0.5 mm) sieve. All samples were thoroughly mixed and stored in wide mouthed glass bottles for subsequent analysis.

Methods of soil characterization for the purpose of salinity studies were adapted from U.S.D.A. Handbook #60 (USSL 1954). Moisture ratios $\frac{OD}{AD}$, i.e., oven dry weight over air dry weight, and moisture factor (Pw) was calculated for all soils, on a weight basis.

FIGURE 4. RECLAMATION OF CALCAREOUS SOIL (CATANO SAND). NOTE INCORPORATION OF BAGASSE AND USE OF TILES.

FIGURE 5. "BUCKET" TRENCH UTILIZED FOR DRAINAGE.

Because of the high clay content of these soils, the paste was allowed to stand overnight to assure complete saturation. The pH of the saturation paste was measured with a Beckman Zeromatic pH meter.

The saturation extract was obtained by filtering the paste under vacuum through Whatman filter paper No. 541 on a Buechner funnel. To prevent precipitation of carbonates and bicarbonates, a few drops of 1000 ppm sodium hexametaphosphate solution was added to the extract, after sodium concentration had been measured.

Electrical conductivity of the saturation extract was determined by the conductivity bridge Model RC 16B2, using dip-and-fill type conductivity cell.

The conductivity of irrigation water and saturation extract was expressed in millimhos/cm at 25° C.

Soluble cations and anions were determined by the following methods described in Handbook #60.

Calcium and Magnesium	Method No. 7
Sodium	Method No. 10a
Carbonate and Bicarbonate	Method No. 12
Chloride	Method No. 13
Sulphate	Method No. 14

METHODS USED FOR DETERMINATION OF SODIUM

The determination of sodium in saline and sodic media involves the measurement of the concentration of soluble sodium ions in the saturation extract, and the exchangeable sodium percent (ESP). The determination of soluble sodium leads to calculation of the sodium adsorption ratio (SAR). For the purpose of calculating the ESP the cation exchange capacity (CEC) of the soil was determined. The following methods were used for the various determinations.

A. Determination of Sodium in the Saturation Extract

A 10 ml aliquot of the extract was pipetted into a 50 ml beaker and 10 ml of 2N magnesium acetate was added to the extract and mixed thoroughly. A Beckman No. 39278 sodium ion electrode in combination with a saturated KCl calomel reference electrode was inserted in the solution. Readings in millivolts were noted on the scale previously calibrated to standard Na OAc solution. A Beckman Model 76 pH Meter,[3] provided with an expanded scale was used for EMF measurement. The sodium concentration of the saturation extracts and irrigation waters was found by comparison with the calibration curve.

B. Determination of Exchangeable Sodium in the Soil

About 5 gm of soil of known moisture content was placed in a 100 ml polyethylene centrifuge tube and 33 ml 1N magnesium acetate solution was added to the soil and shaken in a reciprocating shaker for 10 minutes. The suspension

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[3] Thanks are due to Dr. Yokoyama and Dr. Winnik of the Pacific Biomedical Research Center and Department of Biochemistry of the University of Hawaii, respectively, for allowing the author to use their laboratory facilities.

was centrifuged for 5 minutes in the International Centrifuge Universal Model UV, operating at a speed of 1500 rmp's. The clear supernatant liquid was carefully decanted into a 100 ml volumetric flask. This procedure was repeated 3 times to ensure complete removal of exchangeable and soluble ions.

The contents of the flask was made up to volume and the sodium concentration in the 1N MgOAc extract was measured by employing the sodium electrode.

The amount of sodium was expressed in milliequivalents of Na extracted per 100 gm of oven dried soil. The amount of soluble sodium in the saturation extract was subtracted from that in the MgOAc extract to obtain the exchangeable sodium in me/100 gm of soil.

C. Determination of Cation Exchange Capacity

About 5 gm of soil of known moisture content were placed in a 100 ml polyethylene centrifuge tube. The soil was suspended in 33 ml of 1N NaOAc solution of pH 8.2 and shaken in a reciprocating shaker for 10 minutes. The contents were centrifuged until the supernatant liquid was clear. This took about 5 minutes. The supernatant liquid was discarded. The sample was treated in this manner for a total of 4 times, discarding the supernatant liquid each time.

The sodium saturated soil was again suspended in a 33 ml portion of 95% ethanol and agitated for 10 minutes in the reciprocating shaker. The suspension was centrifuged and the clear supernatant liquid discarded. The sample was washed in this manner for a total of 5 times. The adsorbed sodium was replaced with three 33 ml portions of 1N MgOAc solution, and collected in a 100 ml volumetric flask and made up to volume. Sodium concentration was determined with the electrode in the manner described earlier. The sodium concentration expressed in milliequivalents per 100 gm of oven dry soil was recorded as cation exchange capacity.

For purposes of comparison, another set of 16 samples was analyzed for CEC according to method No. 19 U.S.D.A. Handbook # 60. A set of 7 samples was run for CEC by the standard NH_4OAc method.[4]

D. Preparation of the Standard Curve

The sodium electrode was preconditioned in 0.1N sodium chloride solution for one hour before use. A saturated potassium chloride calomel electrode with fiber junction was used in the circuit.

Sodium chloride solutions of 0.1N, 0.01N, 0.001N and 0.0001N were prepared in 1N MgOAc. Another set using NaOAc instead of NaCl was prepared. A straight line was obtained with a slope of 59-61 millivolt per tenfold difference in concentration. Since the scale is capable of accommodating 140 mv, only 3 orders of magnitude of concentration difference were measurable (Figure 6).

The concentration of sodium in ethanol was measured with the same electrode arrangement. The sensitivity of these cationic electrodes have been shown to be solvent independent. (Rechnitz and Zamochmick, 1964).

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[4] Samples analyzed by Annie Chang.

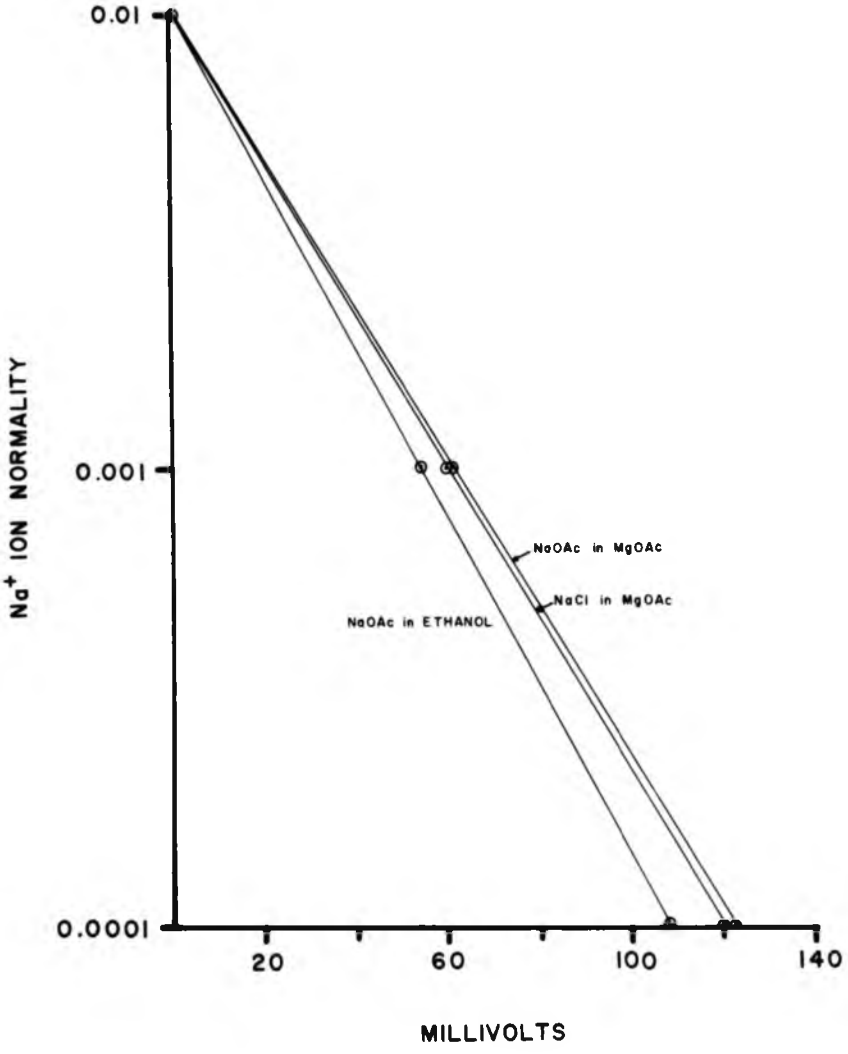

FIGURE 6. RELATION BETWEEN SODIUM CONCENTRATION AND MILLIVOLT READING FOR TWO SALTS IN WATER AND 95% ETHANOL.

RESULTS AND DISCUSSION

The saturation percentage of the 16 samples are shown in Table 1. The values range from 66 to 127 percent. The measurement is rapid, fairly reproduceable and tells the analyst something about the soil.

It is indicative of the texture of the soil. Low values indicate a comparatively coarse textured soil. In temperate zones, soils are generally lower in clay content and hence, as a rule, the saturation percentage is around 30 for coarse, 60 for medium, and 80 for fine-grained soils. In this study the lowest saturation percentage (66%) was obtained from field 260, a recently reclaimed parcel of land where much of the soil is composed of corals and mixed with soil brought from other sources, and incorporated with bagasse.

Measurements by several workers have shown that over a wide textural range the saturation percentage is approximately equal to 4 times the 15-atmospheres percentage, and is about twice the field capacity. Soluble salt concentration in the saturation extract therefore, tends to be about one-half of the concentration at the upper end of the field moisture range, and about one-fourth the concentration of the permanent wilting percentage. In the same way, the osmotic pressure of the saturation extract is about one-half that of the soil solution extract near field capacity and is about one-fourth that of the permanent wilting percentage.

In the case of fine-textured and high organic matter soils, the ratio is smaller (Campbell and Richards 1950).

For field 242 (22-30") the ratios of saturation percentage to the moisture equivalent and to the 15 bar were 1.79 and 2.62 respectively. Similarly, the above mentioned ratios were 1.54 and 2.73 for field A-1 (0-8"). For Lualualei series the ratio of SP/PWP was found to be 3.03.

The ratios between moisture equivalent and 15 bar for fields 242 and A-1, for the above mentioned depths were found to be 1.48 and 1.78.

Ahmed (1965) reported on a value for me/15 bar of 1.47 and 1.46 for the Molokai and Lualualei series. The values for the magnesium saturated Molokai and Lualualei were 1.36 and 1.46 respectively. Raymundo (1965) reported ratios ranging between 1.41 and 1.46 for three profiles of Lualualei series from Lualualei Valley. Thorne (1950) reported average values of 1.53, 1.43 and 1.41 for the Molokai, Lahaina and Wahiawa families respectively.

Shaw and Swezey (1937) reported a ratio of 1.14 for the coastal plain soils of Wailua, Oahu.

It seems that for the Hawaiian soils which are high in clay content the ratios of SP/ME and me/15 bar are always lower than temperate region soils. Latosols are able to hold more water at field capacity and permanent wilting percentage and hence, the affective salt concentration at these two levels of moisture is always lower. For sils of most tropical regions and especially the ones under study, the equivalent salt concentrations at field capacity and permanent wilting percentage are higher than the SP by a factor of 1.6 and 2.8 - 3.0 respectively for water contents at field capacity, and wilting percentage and not 2.0 and 4.0 reported for temperate region soils.

An extract of a sample at field capacity would appear to be more meaningful, but the difficulties in obtaining a sufficient volume of extract at this moisture level hinders this practice. Salt dilution during preparation of the saturation paste changes the true equilibrium concentration of the system, and results are not well correlated to actual field conditions.

The salt concentration of the saturation extract depends upon the total salt present in a given amount of soil. In the case of sandy soils the moisture content at SP is always higher relative to its field moisture range than that of other soils; hence, the conductivity measurement of the extract gives a lower value of salinity (Wilcox 1951).

A sandy and clayey soil may have the same percentage of soluble salt expressed on a dry weight basis, but the salt concentration of the soil solution when near the wilting percentage may be 10 times higher for the sand than for the clay soil.

The high saturation percentages noted in the sample coincide with the high clay and montmorillonitic nature of the Dark Magnesium clays and Gray Hydromorphic soils.

pH MEASUREMENT OF THE SATURATION PASTE AND EXTRACT

The soil reaction of the paste ranged from 7.10 to 7.95 and from 8.00

to 8.60 in the saturation extract. (Table I).

The measured pH depends upon various factors such as the influence of total salt, effects due to individual cations and anions, presence and absence of carbonates and bicarbonates, presence or absence of gypsum and relation of the soil pH to the so-called iso-hydric pH. The soil characteristics known to influence pH readings include the type and amount of soil colloids and proportion of different sized particles (McGeorge 1944).

The pH range in the saturation paste and the extract indicates that the soils were not high in exchangeable sodium. Also, these values predict the absence of any significant amount of alkaline earth carbonates (Fireman and Wadleigh 1951).

ELECTRICAL CONDUCTIVITY AND SALT CONTENTS

One basis for the classification of salt-affected soil is its electrical conductivity. The values for 16 samples are shown in Table I. Soils with an electrical conductivity value above 4 mmhos/cm are known as saline soils. Such soils invariably have a pH lower than 8.5. The highest soluble salt contents were found in field 242. For this field all depths below 2 inches have excessive amounts of salt. In general, however, the salt contents of the test soils were not particularly high, and only 25 percent of the samples can be considered saline.

As mentioned before, 3.5 inches of rain was recorded just prior to

TABLE I. SALINITY STATUS OF THE SOILS

				Saturation Extracts				
Field No.	Depth	SP	pH	EC x 10^3	pH	Cations me/1 Ca	Mg	Na
242	0- 2"	78	7.95	1.58	8.5	3.24	6.91	0.68
	2-10"	85	7.80	4.40	8.1	9.28	19.22	1.38
	10-20"	100	7.85	4.74	8.3	9.28	22.03	1.64
	22-30"	86	7.85	7.48	8.4	12.31	38.88	2.90
237	0-10"FR	93	7.60	1.95	8.6	6.04	12.96	0.36
	0- 6"	100	7.70	1.40	8.5	3.34	8.10	0.40
	6-12"	111	7.80	2.16	8.3	3.45	10.15	0.76
	12-20"	127	7.90	3.29	8.5	2.80	12.00	1.64
11-5	0-10" FR	69	7.65	1.02	8.5	3.56	7.45	0.20
	0- 8"	70	7.60	0.49	8.4	2.80	2.91	0.20
	8-16"	78	7.35	0.50	8.4	2.37	3.99	0.20
A-1	0-8"FR	79	7.50	2.21	8.5	5.29	11.88	0.38
	0-8"	85	7.55	2.22	8.0	5.72	11.77	0.46
	8-20"	77	7.60	2.01	8.3	5.40	10.04	0.48
260	0-10"FR	66	7.30	4.44	8.2	27.54	34.23	0.44
	0-12"	72	7.10	3.76	8.3	21.70	25.27	0.40

SP - Saturation Percentage

EC_e x 10^3 - Electrical conductivity of the
Saturation extract in mmho/cm at 25°C.

sampling and this may have contributed to the low EC values.

From well proven empirical relationships the salt content of the soil can be calculated from the EC data. Similarly, the osmotic pressure of the solution can be calculated. Recall that the osmotic pressure of the soil solution at field capacity and the wilting point is twice and 4 times that of the saturation extract. These are presented in Table II.

Hayward and Spurr (1944), Wadleigh and Ayers (1945) have shown that osmotic pressure of soil solutions is closely related to the rate of water uptake and growth of the plants in saline soils. The extent to which these values will affect sugarcane growth will be discussed later.

SOLUBLE CATIONS

Cations most commonly present in saline and sodic soils are Ca, Mg, Na, and K. Cations such as Si, Al and Fe have not been reported in many temperate zone soils except from a few places such as Arizona (McGeorge 1941) where high soil pH dissolves some of the sesquioxides. Since K is seldom found in saline and sodic soils, it is determined when the sum of the cations is considerably lower than the milliequivalent per liter estimated from the electrical conductivity measurement.

Table I shows that in all saturation extracts the dominant cations were Ca, and Mg. It is interesting to note that the concentration of magnesium is always higher than calcium and sodium combined.

TABLE II: THE ELECTRICAL CONDUCTIVITIES OF SATURATION EXTRACT, CALCULATED EQUIVALENT OSMOTIC PRESSURE AND % SALT IN THE SOIL

Field No.	Depth	SP	% Salt Calc.*	ECx10^3	OP (atm) Calc.**
242	0-2"	78	0.07	1.58	0.57
	2-10"	85	0.24	4.40	1.58
	10-20"	100	0.30	4.74	1.70
	22-30"	86	0.41	7.48	2.70
237	0-10"**FR	93	0.11	1.95	0.70
	0-6"	100	0.09	1.40	0.50
	6-12"	111	0.15	2.16	0.77
	12-20"	127	0.26	3.29	1.18
11-5	0-10"FR	69	0.04	1.02	0.36
	0-8"	70	0.02	0.49	0.17
	8-16"	78	0.02	0.50	0.18
A-1	0-8"FR	79	0.11	2.21	0.79
	0-8"	85	0.12	2.22	0.79
	8-20"	77	0.09	2.01	0.79
260	0-10"FR	66	0.18	4.44	1.60
	0-12"	72	0.17	3.76	1.35

*% Salt in Soil = $0.064 \times EC \times 10^3 \times \frac{SP}{100}$

** OP = Osmotic pressure = $0.36 \times EC \times 10^3$

Electrical conductivity of the saturation extract

++ FR = Furrow Ridge

Similar results were obtained in the analysis of the drainage waters. The concentration of Mg ions in the irrigation water has been reported to be consistently higher than Ca and Na (Ewart, personal communication). Similar results have been cited by workers on magnesium solonetz elsewhere. Another thing which is common in areas where magnesium salinity is reported is that these areas were at some time covered by sea water.

In the case of the Kekaha area where soils developed from the parent material high in magnesium, and further reclaimed and irrigated with high magnesium waters, the magnesium content is most likely related to both factors. Higher solubility of gypsum in water containing sodium chloride than in pure water, probably accounts for the lower calcium content.

Page and Williams (1926) and Hissink (1932) found that soils known to have been submerged in sea water contained substantially greater proportions of exchangeable magnesium. This finding was further supported by the experiment conducted by Kelley and Liebig (1934) in which they leached both soil and bentonitic clay with oceanic water and found similar results. The sea water on an average contains approximately 1 equivalent of magnesium to 4.3 equivalents of sodium; and further the higher replacing power of magnesium may cause a situation indicated by the analysis (Table I).

Another explanation which is less generally accepted was put forward by Reitmeier (1946). He studied the Regan loam, and concluded that the calcium ion brought into solution by dilution, effects the equilibrium in favor of its concentration, and hence, strike out Mg, Na and K from the exchange complex.

SOLUBLE ANIONS

The composition and the concentration of the soluble anions is given in Table III. It is evident from the data that the bulk of anions consists of chloride, and to a lesser extent, the bicarbonates. The concentration of bicarbonates is higher than chlorides in only one sample. The sulphate anion is present only intraces except in field 242. The high concentration of calcium sulphate in field 260 was mentioned earlier. Low solubility of gypsum in water accounts for low sulphate concentration in other fields.

The saturation extract of field 242 and 260 have considerable amounts of dissolved salts. The solubility of gypsum in these media is more than in pure water

Hoagland *et al* (1920) emphasized the limitation of estimating the salt concentrations in the soil-water phase. They argued that the soil solution is a different medium, and its composition changes with time. Such "solvent" would easily dissolve appreciable amounts of gypsum which is recorded in the present analysis. Conversely, the amount of carbonate is practically absent in the same samples.

Similar anionic composition was reported by Kelley (1934b) from the soils of western San Joaquin Valley where SO_4 and Cl were abundant and CO_3 was low.

TABLE III: THE ELECTRICAL CONDUCTIVITY AND THE ANION COMPOSITION OF THE SATURATION EXTRACT

Field No.	Depth		Saturation Extract Anion me/l		
		$EC\times10^3$*	$CO_3 + HCO_3$	Cl	SO_4
242	0-2"	1.58	6.10	7.50	1.99
	2-10"	4.40	4.69	45.00	Trace
	10-22"	4.47	3.67	47.50	Trace
	22-30"	7.48	2.44	77.50	2.99
237 FR	0-10"	1.95	5.71	16.20	Trace
	0-6"	1.40	5.50	12.50	Trace
	6-12"	2.16	4.08	21.20	Trace
	12-20"	3.29	3.87	28.70	Trace
11-5 FR	0-10"	1.02	6.12	5.00	Trace
	0-8"	0.49	4.48	5.00	Trace
	8-16"	0.50	4.89	8.70	Trace
A-1 FR	0-8"	2.21	3.87	17.50	Trace
	0-8"	2.22	4.08	21.20	Trace
	8-20"	2.01	3.46	20.00	Trace
260 FR	0-10"	4.44	2.65	16.25	38.99
	0-12"	3.76	3.46	18.75	26.99

* Conductivity values are given for comparison.

In the area surrounding the Great Salt Lake, Utah, Cl^- and SO_4^{--} were especially highly concentrated. Many of the soils of Imperial Valley were high in Cl^- and SO_4^- as compared to CO_3^-. This is particularly true around the Salton Sea.

In Russia, Kovda (1939) showed that in the northeastern regions around the Caspian Sea, Cl was predominant.

Since the Kekaha area too was inundated by sea water, the presence of large amounts of Cl, and to a lesser extent, sulphate is in agreement with results obtained from areas of similar geologic history.

SODIUM STATUS OF THE SOILS

The details of the sodium status of the soils studied are shown in Table IV. A glance over the result shows that while the soils have high cation exchange capacity ranging from 36 to 61 me/100 gm, the exchangeable sodium percentage is rather low. The sodium adsorption ration which is directly related to exchangeable sodium percentage is also low.

The large amounts of Ca and Mg counteract the detrimental effect of sodium in the soil system. It appears that the concentration of the calcium and magnesium is higher than the carbonates and bicarbonates together, and hence, there is no danger of residual sodium carbonate to impair the physical condition of the soil.

TABLE IV: SODIUM STATUS OF THE SOIL

Field No.	Depth	Sodium me/100 gm. Total	Sol	Exch.	CEC	ESP	SAR++	Residual Na_2CO_3
242	0-2"	0.20	0.05	0.15	43.40	0.35	0.30	Nil
	20-10"	0.28	0.12	0.16	41.00	0.39	0.36	Nil
	10-22"	0.35	0.16	0.19	43.80	0.43	0.41	Nil
	22-30"	0.38	0.25	0.13	36.80	0.35	0.57	Nil
237 FR	0-10"	0.11	0.03	0.07	53.10	0.14	0.11	Nil
	0-6"	0.15	0.04	0.11	50.20	0.23	0.16	Nil
	6-12"	0.31	0.08	0.22	49.70	0.46	0.29	Nil
	12-20"	0.47	0.21	0.26	52.70	0.50	0.60	Nil
11-5 FR	0-10"	0.04	0.01	0.03	43.40	0.07	0.06	Nil
	0-8"	0.30	0.01	0.01	39.90	0.03	0.08	Nil
	8-16"	0.30	0.01	0.01	42.70	0.03	0.08	Nil
A-1 FR	0-8"	0.10	0.03	0.07	61.00	0.12	0.13	Nil
	0-8"	0.15	0.04	0.11	55.80	0.20	0.15	Nil
	8-20"	0.13	0.03	0.09	56.40	0.17	0.17	Nil
260 FR	0-10"	0.06	0.03	0.03	33.30	0.10	0.08	Nil
	0-12"	0.06	0.03	0.03	36.70	0.08	0.08	Nil

++ Sodium Adsorption Ratio

EXCHANGEABLE AND SOLUBLE CATIONS

The values for exchangeable magnesium, calcium and sodium for a set of 8 samples are given in Table V. These values represent the difference between their measured value in the ammonium acetate extract and the saturation extract. The values for the exchangeable sodium obtained by this procedure are considerably higher than that determined by replacing total sodium with 1N magnesium acetate at pH of 8.2.

For the purpose of comparison the cation exchange capacity determined by the standard ammonium acetate method are given in Table IV.

The exchangeable calcium ranges from about 11 to 40 me/100 gm and exchangeable magnesium between 13 and 38 me/100 gm of soil.

In general, the sum of the exchangeable cations far exceed the cation exchange capacity. The largest discrepancies are noted in field 242. It was this plot that had the highest salt content. The high value for exchangeable bases in excess of the cation exchange capacity may be interpreted as follows:

The soil might have salts which are considerably more soluble in 1N ammonium acetate pH of 7.0 than in water. Bower *et al* (1952) reported that the solubility of calcium carbonate is about 17 me/1, dolomite, 9.4 me/1 and magnesite, 1.44 me/1 in neutral ammonium acetate. Hence, the use of ammonium acetate gives erroneously higher concentration of these ions.

TABLE V. EXCHANGEABLE AND SOLUBLE CATION*S OF SOME SELECTED SOILS

Field No. and Depth	me/100 gm. CEC	Calcium me/100 gm. Total	Soluble	Exch.	Magnesium me/100 gm. Total	Soluble	Exch.	Sodium me/100 gm. Total	Soluble	Exch.
242										
0- 2"	33.35	37.52	0.25	37.27	25.00	0.54	24.46	2.29	0.05	2.24
10 - 22"	37.83	41.15	0.92	40.23	33.00	2.20	30.80	4.81	0.16	4.65
237										
0 - 6"	45.66	20.99	0.33	20.66	31.94	0.81	31.13	2.07	0.04	2.03
12 - 20"	46.92	11.32	0.35	10.97	40.34	1.52	38.82	7.17	0.21	6.96
11-5										
0 - 8"	35.80	28.33	0.19	28.14	19.12	0.20	18.92	0.27	0.01	0.26
A-1										
FR 0 - 8"	48.13	28.65	0.41	28.24	32.57	0.93	31.64	1.85	0.03	1.82
260										
0 - 12"	29.80	25.31	1.56	23.75	15.65	1.81	13.84	1.04	0.03	1.01

* The CEC and the total cationic amount was determined by Annie Chang.

CATION EXCHANGE CAPACITY

Cation exchange capacities of the soil samples were determined by using sodium as the exchange ion. Sodium in turn was measured with the sodium electrode and flame photometer.

Cation exchange capacity was also determined on 8 samples by the standard ammonium acetate method.

Table VI gives the cation exchange capacity of all 16 samples as determined by the electrode and flame photometer method. The difference in values of the two methods is not too large and is well within the errors encountered in CEC determination. It appears that the electrode method consistently gives lower values. However there exists a significant correlation between the two methods as shown in Figure 7.

This may be due to the interference of the magnesium ion in flame analysis, giving the sodium reading a higher value. The electrode, on the other hand, is quite insensitive to magnesium ions.

Table VIa gives data showing comparison of the cation exchange capacity values as measured by the electrode and standard ammonium acetate method. The average difference between methods is almost 7 me/100 gm and is too large to be neglected. The correlation is shown in Figure 8.

The most obvious explanation for these large discrepensies would seem to be the one attributable to incomplete washing of the sodium salt. Although a small reduction in cation exchange values was noted, the washing factor was

TABLE VI: COMPARISON OF CEC VALUES AS MEASURED BY THE ELECTRODE AND FLAME PHOTOMETER METHOD

Field		Cation Exchange Capacity		
No.	Depth	Flame Phot.	Na Electrode	Difference
242	0-2"	41.70	43.40	-1.7
	2-10"	42.20	41.00	1.2
	10-22"	45.20	43.80	1.4
	22-30"	36.50	36.80	-0.3
237	0-10" FR	55.30	53.10	2.1
	0-6"	52.20	50.20	2.0
	6-12"	51.60	49.70	1.9
	12-20"	53.80	52.70	1.1
11-5	0-10" FR	41.70	43.40	-1.7
	0-8"	42.10	39.90	2.2
	8-16"	41.00	42.70	-1.7
A-1	0-8" FR	63.30	61.00	2.3
	0-8"	57.30	55.80	1.5
	8-20"	56.40	56.40	0.0
260	0-10" FR	35.00	33.30	1.7
	0-12"	37.50	36.70	0.8

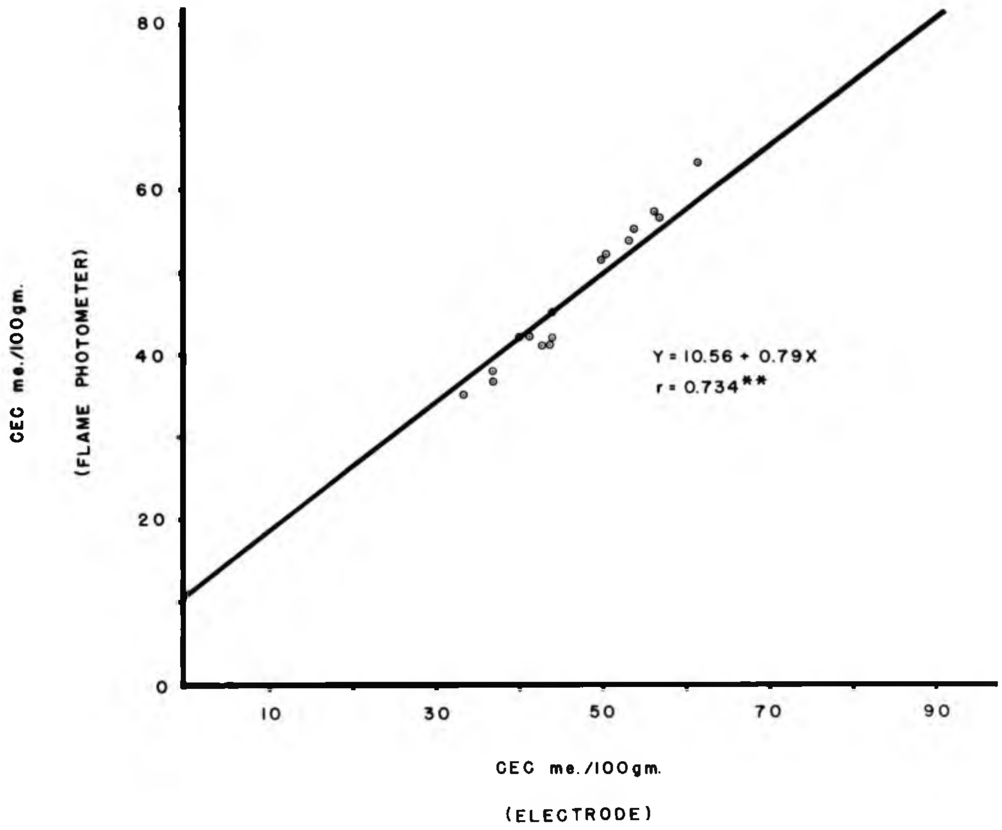

FIGURE 7. CORRELATION OF CATION EXCHANGE CAPACITIES DETERMINED BY MEASURING DISPLACED SODIUM BY A GLASS ELECTRODE AND FLAME PHOTOMETER.

TABLE VIa: COMPARISON OF CEC VALUES AS DETERMINED BY THE ELECTRODE AND STANDARD NH_4OA METHODS

Field No.	Depth	CEC/100 gm. Na Electrode	CEC/100 gm. NH_4OAc	Difference
242	0-2"	43.40	33.35	10.05
	10-22"	43.80	37.83	5.97
237	0-6"	50.20	45.66	4.54
	12-20"	52.70	46.92	5.78
11-5	0-8"	39.90	35.80	4.10
A-1	0-8" FR	61.00	48.13	12.87
260	0-12"	36.70	29.80	6.90

* Data analyzed by Annie Chang

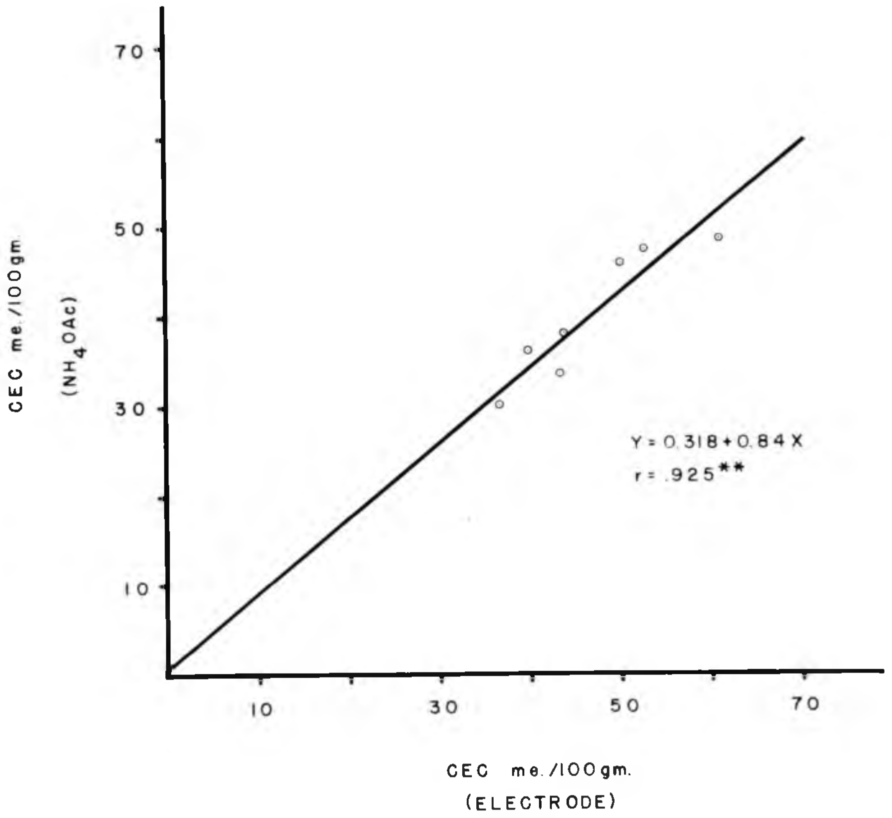

FIGURE 8. CORRELATION OF CATION EXCHANGE CAPACITIES DETERMINED BY A SODIUM GLASS ELECTRODE AND STANDARD NH_4OAc.

shown not to be the cause for the high values. Table VII gives CEC value after 7 alcohol washings for the electrode and flame method.

The higher CEC values in the sodium method can be predicted from the pH's of the saturating solution. The ammonium acetate method employs a pH of 7.0 whereas the sodium method uses a pH of 8.2. As would be expected, sodium saturation at pH 8.2 gave higher values. A pH of 8.2 was selected for two reasons. First, since the sodium electrode is sensitive to hydrogen ions below pH 7.0 a value greater than 7.0 was thought more reasonable; and second, since most saline and sodic soils tend to have pH's near 8.0, the higher value was considered more realistic than the commonly used 7.0.

The higher CEC values measured by the sodium method appear to be more reasonable for these soils and probably for most saline and sodic soils.

An additional advantage of the electrode method which merits consideration is its simplicity from an analytical and instrumental standpoint.

In view of this, the author utilized 1*N* sodium acetate solution buffered at pH 8.2. The process was closely studied during saturation with the sodium ion, and during successive removal of excess sodium by ethanol washings.

It was found that with the soils under study, at least 4 sodium acetate extractions are necessary for complete saturation of the exchange complex. The electrical conductivities of the filtrate were noted after each extraction. The results are shown in Table VIII. For all samples the electrical conductivity of the fourth extract was more or less the same, ranging between 18.6 to 19.4

TABLE VII: COMPARISON OF THE CEC VALUES OF THE SOILS WASHED SEVEN TIMES

Field No.	Depth	CEC me/100 gm. Flame	CEC me/100 gm. Electrode	Difference CEC
242	2-10"	39.90	40.00	-0.10
	10-22"	42.90	41.70	1.20
237	0-6"	47.70	47.20	0.50
	6-12"	49.20	48.70	0.50
11-5	0-8"	42.00	39.70	2.30
A-1	8-20"	53.60	56.00	2.40
260	0-10" FR	35.00	32.30	2.70
	0-12"	35.00	35.00	0.00

TABLE VIII: THE ELECTRICAL CONDUCTIVITIES OF THE SUCCESSIVE 1N NaOAc (pH 8.2) EXTRACTIONS

Field No.	Depth	Electrical Conducitivy mmhos/cm. 1st. Ext.	2nd. Ext.	3rd. Ext.	4th. Ext.
242	0-2"	36.02	30.20	20.50	19.40
	22-30"	37.36	31.52	24.60	19.03
237	0-10"FR	36.02	30.56	24.01	19.03
	12-20"	37.36	29.67	24.01	19.03
11-5	0-10"FR	34.78	26.54	20.17	19.03
	8-16"	34.08	31.52	24.01	19.03
A-1	0-8" FR	36.28	29.67	24.01	18.60
	0-8"	38.80	28.82	24.01	19.40

mmhos/cm. The average for the 8 samples was 19.06 mmhos/cm. This consistency shows that all soils have reached a certain degree of saturation. Bower et al (1952) also suggested 4 extractions.

An increase in pH was noted with each washing with sodium acetate (Table IX). Lowering of the hydrogen ion concentration shows the effectiveness of the saturating process. Since sodium has a weak replacing power and H^+ is strongly adsorbed, a study of the decrease in hydrogen ion concentration as a function of successive extraction with sodium acetate, provides a good measure of the effectiveness of the saturating solution. The hydrogen ion concentration ranged from 4.46×10^{-9} to 10×10^{-8} mols/l in the first extraction. However, in the fourth extraction the concentration was greatly reduced and ranged from 0.63×10^{-9} to 1.99×10^{-9} mols/l (Figure 9). The average for 8 samples was 1.66×10^{-9} mols/l. From this data it was concluded that 4 sodium acetate extractions provided satisfactory saturation. The relationship of H^+ to EC $\times 10^3$ is shown in Figure 10. Since hydrogen ions have high mobility, the specific electrical conductance is higher at low pH's.

To study the efficiency of washing, the sodium concentration in the extract, was measured after each washing. The results are shown in Table X. Washing was continued until the difference in sodium concentration was small. The result for 8 samples is shown in Table XI.

The sodium concentration in me/1 was plotted against the number of washings and it was seen that a maximum of 6 washings takes out almost 99.4

TABLE IX: THE pH VALUES OF THE SUCCESSIVE EXTRACTIONS OF THE SOIL WITH 1N NaOAc (pH 8.2)

		pH Values			
Field No.	Depth	1st. Ext.	2nd. Ext.	3rd. Ext.	4th. Ext.
242	0-2"	8.30	8.60	8.90	9.10
	22-30"	8.35	8.75	9.10	9.20
237	0-10" FR	8.10	8.35	8.55	8.70
	12-20"	8.20	8.40	8.60	8.70
11-5	0-10" FR	8.05	8.45	8.70	8.85
	8-16"	8.00	8.30	8.50	8.70
A-1	0-8" FR	8.00	8.35	8.55	8.70
	0-8"	8.05	8.35	8.55	8.70

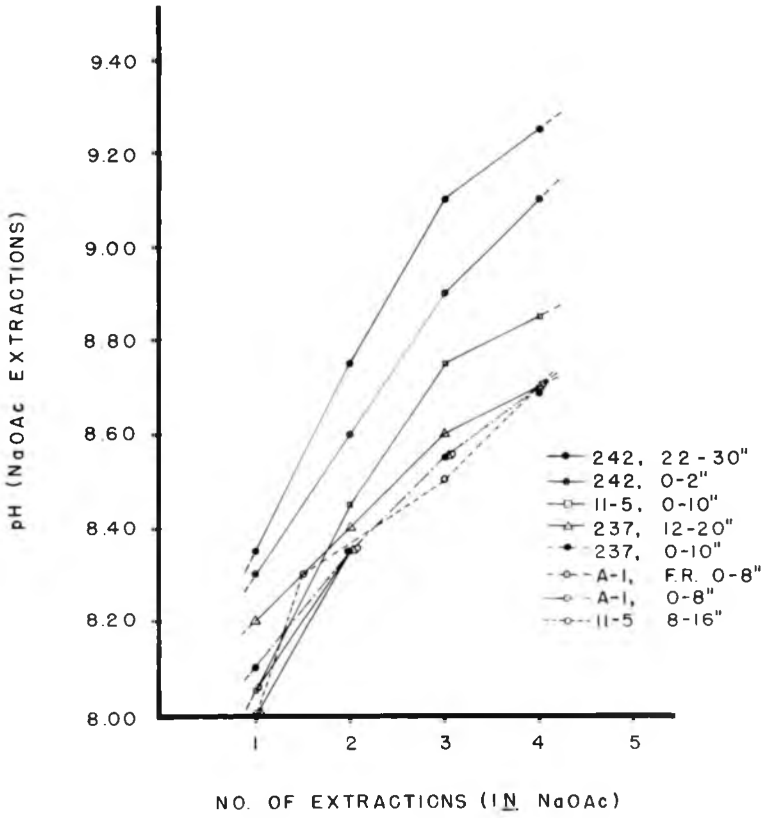

FIGURE 9. EQUILIBRIUM pH OF SOIL EXTRACT AFTER SUCCESSIVE EXTRACTION WITH 1N Na OAc SOLUTION.

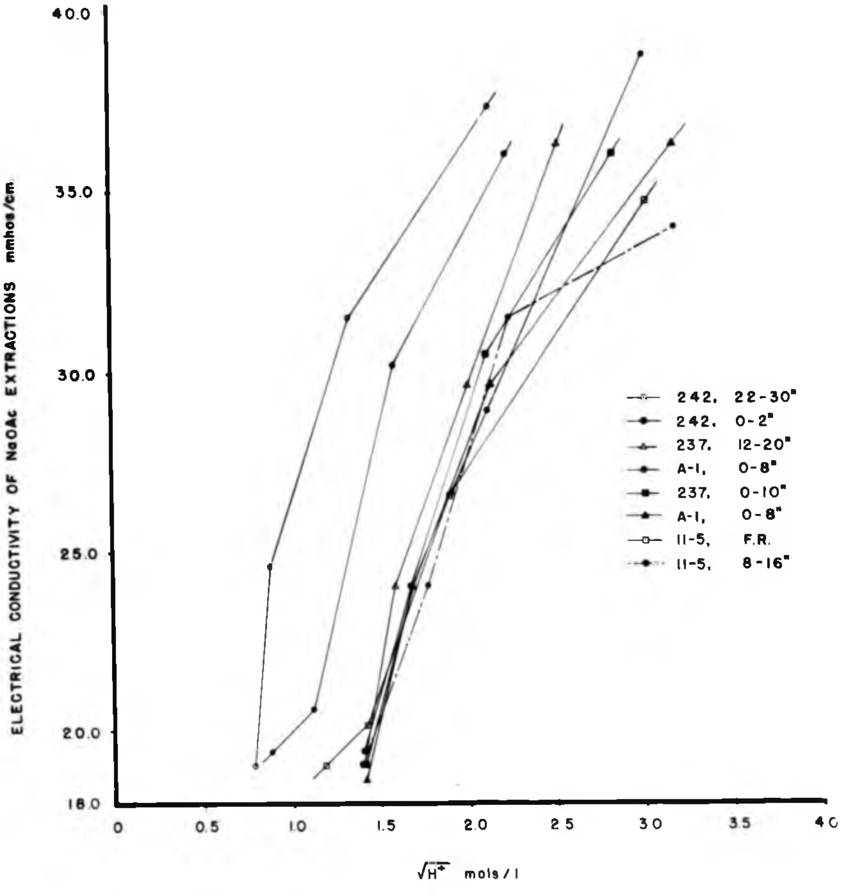

FIGURE 10. DEPENDENCE OF THE ELECTRICAL CONDUCTIVITY ON THE SQUARE ROOT OF THE HYDROGEN ION CONCENTRATION OF SUCCESSIVE NaOAc EXTRACTS.

TABLE X: THE CONCENTRATION OF THE Na+ IN THE SUCCESSIVE ETHANOL WASHINGS

Field No.	Depth	Na+ me/l 1st. Wash.	2nd. Wash.	3rd. Wash.	4th. Wash.	5th. Wash.
242	0-2"	100.00	15.00	7.50	2.95	1.10
	2-10"	85.00	16.10	7.90	3.00	1.70
	10-22"	84.50	16.10	8.00	3.15	2.30
	22-30"	67.00	15.00	7.50	2.85	1.20
237	0-10" FR	85.00	20.00	7.50	2.70	1.20
	0-6"	87.10	16.80	8.00	3.00	2.20
	6-12"	85.00	17.10	8.10	3.60	2.30
	12-20"	80.00	18.60	9.70	3.40	1.65
11-5	0-10" FR	85.00	14.60	7.10	2.40	1.00
	0-8"	88.10	16.00	8.20	2.70	1.50
	8-16"	60.00	15.00	9.00	2.70	1.40
A-1	0-8" FR	67.00	16.40	7.30	2.40	1.15
	0-8"	54.00	16.40	7.80	2.85	1.40
	8-20"	80.00	16.60	7.70	3.20	2.10
260	0-10" FR	89.50	17.20	8.10	3.60	2.10
	0-12"	86.90	17.50	8.20	3.00	1.90

percent of the excess salt. The seventh washing either removed the same amount of sodium or, in some cases, removed sodium slightly in excess of the sixth washing (Table XI).

When the sodium acetate treated soil was washed with successive portions of ethanol, the exchangeable sodium tends to hydrolyze and pass into solution. The pH value for the ethanol extractions are shown in Table Xa (Figure 11). Since incomplete removal of sodium acetate results in higher CEC values, whereas hydrolysis of exchangeable sodium lowers the CEC values, precision in CEC measurement depends upon the number of washings. It is seen that by the seventh washing the concentration of hydrogen and sodium is very low.

Some of the soils were slightly dispersed at the seventh washing, hence it is suggested that six washings are more reasonable for the balancing of errors caused by hydrolysis and the presence of excess salts.

The amount of sodium present in the first washing ranged from 80 to 89 me/1 (Table XI). The second washing shows a drop to about 17 me/1 and the sodium concentration is reduced to the range of 0.5 to 1.1 me/1 in the seventh wash. (Table XI) (Figure 12).

Previously it was thought that the absolute amount of sodium could not be measured in alcohol-water systems, but no significant difference was found in the trend of activity values in non-aqueous media and an expected difference of 55 millivolts was seen for each tenfold difference in concentration. Similar values were reported by Rechnitz and Zamochmick (1964) who concluded that the

TABLE Xa: THE pH VALUES OF THE SUCCESSIVE ETHANOL WASHINGS OF THE Na SATURATED CLAY

		pH Value				
Field No.	Depth	1st. Wash.	2nd. Wash.	3rd. Wash.	4th. Wash.	5th. Wash.
242	0-2"	9.20	9.25	9.35	9.35	9.40
	22-30"	9.20	9.40	9.40	9.30	9.30
237	0-10" FR	8.95	9.10	9.25	9.30	9.30
	12-20"	9.00	9.10	9.20	9.30	9.30
11-5	0-10" FR	9.00	9.10	9.20	9.20	9.20
	8-16"	8.90	9.00	9.20	9.20	9.20
A-1	0-8" FR	9.00	9.05	9.20	9.30	9.25
	0-8"	9.00	9.05	9.15	9.20	9.20

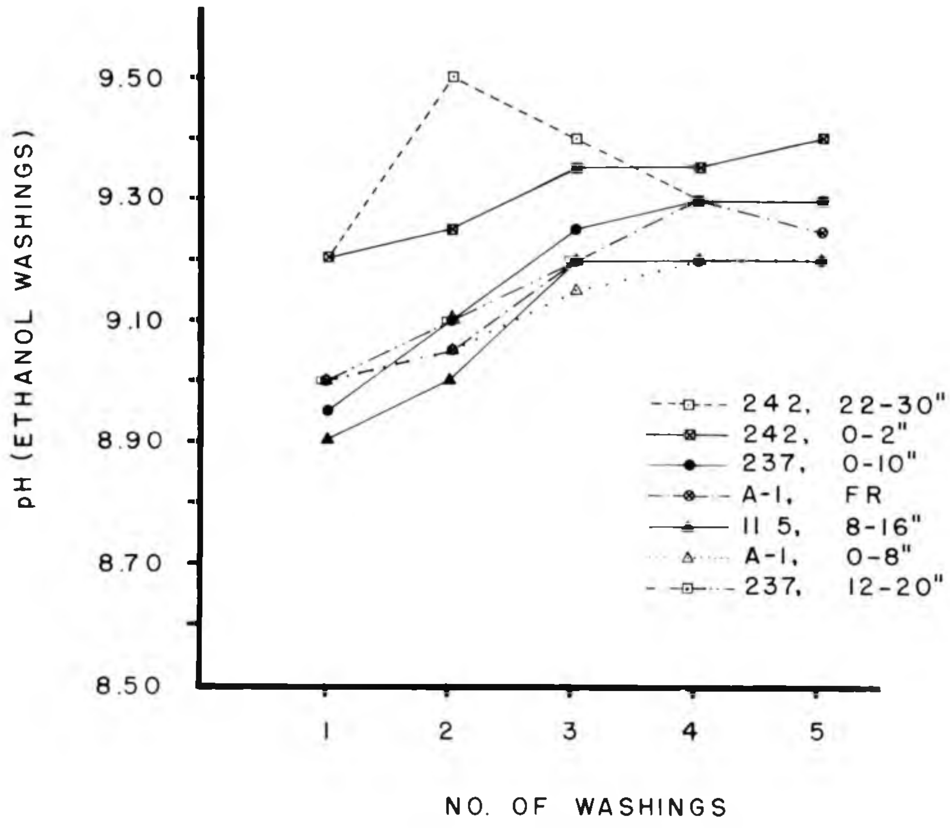

FIGURE 11. INCREASE IN THE pH OF THE SUCCESSIVE ALCOHOL WASHINGS.

TABLE XI: THE CONCENTRATION OF Na+ IN THE SUCCESSIVE ETHANOL WASHINGS

Field No.	Depth	Na+ Concentration me./1						
		1st. Wash.	2nd. Wash.	3rd. Wash.	4th. Wash.	5th. Wash.	6th. Wash.	7th. Wash.
242	2-10"	85.30	16.00	7.80	3.10	2.20	0.60	0.52
	10-22"	85.10	16.10	8.10	3.10	2.40	0.75	0.95
237	0-6"	87.90	16.90	8.10	3.00	2.30	0.75	0.80
	6-12"	89.10	17.20	8.10	3.45	2.40	0.85	0.80
11-5	0-8"	89.40	16.10	8.30	2.70	1.50	0.72	0.57
A-1	8-20"	80.50	16.70	7.90	3.30	2.20	0.62	0.65
260	FR0-10"	89.00	16.90	8.10	3.50	2.10	0.82	1.11
	0-12"	86.00	17.50	8.15	3.10	1.95	0.90	1.10

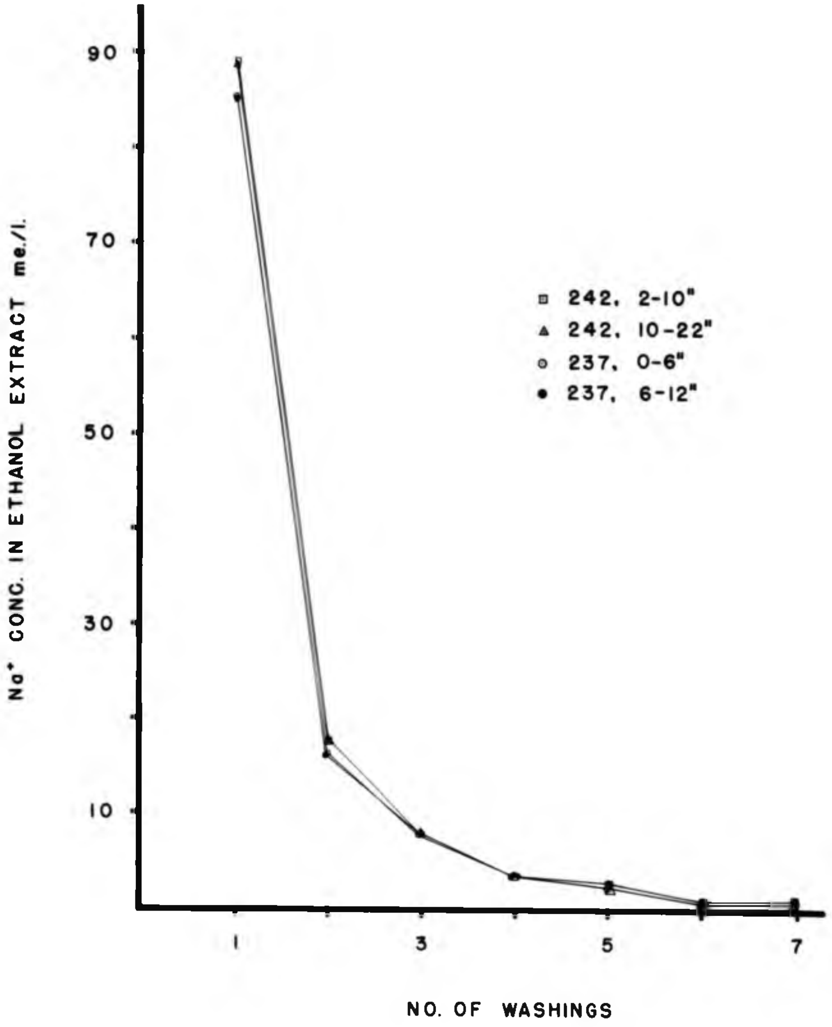

FIGURE 12. REDUCTION OF SODIUM ION CONCENTRATION IN THE SUCCESSIVE WASHINGS WITH ALCOHOL.

response of the cation sensitive glass electrode is essentially solvent independent, but depends only on the nature and concentration of the solute.

THE CHEMICAL COMPOSITION OF DRAINAGE WATERS

The irrigation water as recorded in office files and unpublished reports from American Factors, Limited contains high amounts of dissolved salt. Waters with electrical conductivity values as high as 14 and 18 millimhos/cm from Nohili Sump and Kawaiele pump respectively, are frequently used for both reclamation and irrigation. As a rule, water containing more than 1250 ppm of Cl is rejected. These waters should be classified as very saline since the EC x 10^3 exceeds the range of 2.25 to 5.0.

In terms of sodium hazard as measured by the sodium adsorption ratio (SAR), all the drainage waters studied were excellent. Since the residual sodium carbonate (RSC) was nil, there is no harm in using these waters. The proper use of these irrigation and drainage waters is of the utmost importance in soil reclamation.

These waters have been used for reclamation of the land with considerable success. The very fact that transmission rates of water through sodic soils depends markedly upon the electrolyte concentration of the water, the use of saline water for reclamation was suggested by (Fireman and Bodman 1940, Fireman, 1944, and Christiansen 1947.

The drainage waters studied were invariably used for reclamation purposes. The concentration of the soluble salts ranges between 50 to over

400 me/l (Table XII). Further, an examination of the chemical composition reveals that a large percentage of the electrolyte is chlorides and sulphates of calcium and magnesium. The effect of calcium and magnesium on the physical properties of the soil is generally considered to be beneficial (Brooks and Bower 1956). The beneficial effect of high electrolyte concentration for improving the permeability of the soil involves the "valency-dilution" principle of Gapon (1933). In the past, Eaton and Skoloff (1935), Matson and Wiklander (1940), Davis (1945) and Reitemeir (1946) have emphasized the importance of such phenomena in exchange reaction of saline soils. More recently, Krishamoorthy and Overstreat (1949), Erkison (1952), Bolt (1955) and Bower (1959) have suggested that Gapon-type equations are of practical importance when the system in question contained both monovalent and divalent cations.

The process of soil reclamation with high salt water, once started, accelerates as a function of time, so long as no appreciable changes in chemical composition of the soil water take place.

Although calcium and magnesium are essential nutrient elements, the relative abundance of each is of considerable importance when the efficiency of fertilizers used is considered. High amounts of magnesium disturb the nutritional level and mobility of some minor elements.

Mink (1962) reported values of 8.2 ppm of nitrate in waters from Ewa wells, but nitrates usually were not found in the saturation extract of the soil used in this study.

TABLE NO. XII: CHEMICAL COMPOSITION OF THE DRAINAGE WATERS

Field No.	OP Calc.	$EC \times 10^3$ *	% Salt Calc.	pH	Milliequivalent per liter						SAR++
					Ca	Mg	Na	CO_3+HCO_3	Cl	SO_4	
242	5.40	15.20	0.97	8.4	12.42	78.30	11.60	3.06	137.50	9.99	1.71
260	14.78	41.10	2.63	8.5	22.68	310.39	37.00	7.34	346.20	59.90	3.00
A-1	1.77	4.93	0.31	8.4	3.78	17.17	0.68	3.67	30.00	14.99	0.20
Main Canal	3.00	8.36	0.53	8.1	5.18	22.35	3.50	3.06	72.50	5.99	0.94

* Electrical conductivity of the water expressed as millimhos/centimeter at 25°C.

++ Sodium Adsorption Ratio

The use of saline water for irrigation leads to an increase in the total water potential of the soil solution. Osmotic pressures from 1.77 to 14.78 atmospheres were measured in the drainage waters. The carbonates and bicarbonates were low and a prolonged evapotranspiration would not be expected to cause appreciable precipitation of calcium and magnesium carbonates.

In field 260, the calculated osmotic pressure was about 2.3 atmospheres at field capacity. In field 242, salinity effects (leaf burn) were noticeable (Figure 13). It is interesting to note that at this high level of salinity cane variety H50-7209 is producing high yields (Ewart 1965, personal communication). Leverington (1960) using saline solutions of 0.5, 1.5, 2.5, 3.5 and 4.5 atmospheres of osmotic stress on the Pinder variety of sugarcane showed a continuous decline in stem elongation with an increase in stress. Robinson (1963) showed that the average rate of stalk elongation was reduced by 28 percent when soil moisture tension was increased from 0.6 bar to 4.0 bar. Further increase in tension reduced the average stalk elongation severely. In this experiment, the effect of salinity as a contributory factor in total moisture stress was not considered.

Recently, Bernstein et al (1964) studying the effect of salinity on the different varieties of sugarcane found similar results. He found that the Hawaiian variety H50-7209, which comprises 80 percent of the Kekaha production, was much more sensitive to salinity than the varieties NCo-293 and NC0-310. The effect of salinity was reflected in all the indices of growth. The reduction in the stalk number was about 36-38 percent of the control at moderate salinity levels.

FIGURE 13. VARIOUS DEGREES OF SALT-BURN; FROM LEFT TO RIGHT, LEAVES COLLECTED FROM FIELD 242, 237, A-1 AND A NORMAL FIELD.

The stalk weight was reduced by 40-58 percent. The adverse effect was more prominent in the length of the stalk than the diameter. At low salinity levels the yield reduction was about 14 percent of the control, and similar to the other varieties but at higher salinity levels the H50-7209 was affected more severely A 68 percent yield reduction was observed when waters of 7.5 mmhos/cm were used.

High salinity and high pH often result in micronutrient deficiency. Although the exact cause for the micronutrient imbalance, and the deficient element was not obvious, it appeared to be related to high pH and a resultant iron deficiency. Figure 14 shows an example of this problem.

From the present study it can be seen that the above mentioned levels of salinity are higher than those generally found in the Kekaha area. Robinson (1960) has shown that many varieties in Hawaii are tolerant to high soil moisture stress. An overall need for good drainage and good management is by far the most important consideration in the use of high salt water for irrigation.

IMPLICATIONS OF THE RESULTS

The results of this work in a sense merely confirm the high magnesium and low sodium content of Hawaiian saline soils reported by earlier investigators.

In the past, however, the relatively poor physical condition of high magnesium soils were attributed to this ion, but this belief should be reconsidered in the light of the known mechanical and mineralogical composition of these soils.

FIGURE 14. MICRO-ELEMENT DEFICIENCY NOTED IN SOME RECENTLY RECLAIMED LAND.

The high saturation percentages coincide not only with high clay content but also with the montmorillonitic minerology of these soils. On this basis alone these soils should be expected to be more difficult to till than the latosolic soils, and the physical behavior of these high magnesium soils can be explained purely on their high clay and montmorin contents. Under the circumstances, most students of soils should be impressed by the fact that these soils can be worked at all.

Two factors probably play important roles in the physics of these soils; first the relatively high free iron oxide content (approximately 5 percent of the plow layer)[5] and the presence of excess salts. Free salts prevent deflocculation of soil particles and free iron keeps the soil aggregated.

It would be interesting to see how these soils would behave under sodic conditions. Unfortunately for this study and fortunately for the plantation, sodic conditions were rare to non-existent in the area.

Secondly, the utilization of the saline drainage water now being discharged into the sea should be considered. Although economic factors do not permit its re-use at this time, this water may be a rich source of calcium and magnesium and probably silica and phosphorous as well. Because of its favorable composition, the water when applied to base deficient soils may have beneficial effects above and beyond the pure water requirement of plants.

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[5] Unpublished results of Mr. Roger Watanabe, Dept. of Agronomy and Soil Science, University of Hawaii.

Because of its high salt content, its limited supply and high cost of distribution, this water should be used sparingly. The validity of these claims, however, can be shown only by further experimentation. Finally, the usefulness of the sodium electrode for evaluating the quality of drainage and irrigation waters has been established. Normally, the quality of these waters is determined on the basis of (1) total soluble salt content as measured by electrical conductivity (2) sodium hazard (3) boron content, and (4) presence of carbonates and bicarbonates.

For Hawaiian soils where boron hazards normally are non-existent, the quality of drainage and irrigation waters can be evaluated by measuring conductivity, pH and sodium content.

The conductivity values immediately inform the investigator of the total soluble salt content, but tells nothing of its composition. Since the dominant cations are calcium, magnesium and sodium, a low value of sodium suggests a high calcium and magnesium ion concentration and a low pH. The low pH is related to low carbonate and bicarbonate ion concentration, for if the latter were present calcium and magnesium would necessarily precipate in the system.

The results of this thesis suggest that for Hawaiian soils and possibly for other areas as well, two simple measurements, electrical conductivity and sodium content, provide a rapid means for evaluating the quality of irrigation and drainage water.

SUMMARY

The objects of the present research were (1) to determine the salinity-status of some selected soils and drainage waters of Hawaii, and (2) to determine the applicability of the Na+ electrode for such investigations. The results obtained are summarized in the following:

Excessive accumulation of salts was found only in about 25% of the samples. In general, the area was free from salinity. Electrical conductivities of the saturation extracts of the soils was low. Exchangeable sodium percentage, sodium adsorption ratio were low and the residual sodium carbonate was nil.

The soils were generally high in cation exchange capacity and almost entirely base saturated. Magnesium was the dominant cation in both the soluble and exchangeable phases. The calcium concentration were lower than magnesium in the exchangeable and soluble phases, but the amount and concentration of both cations were considerably higher than sodium.

Among the anions, chloride concentration was highest. Low concentration of bicarbonates was measured in all fields. Carbonate ions were not present in any field. Similarly, sulphate was found in traces except in fields 242 and 260. In the latter field, it was the dominant anion.

The use of sodium electrode for the purpose of salinity investigation is found to be rapid and accurate in both aqueous and non-aqueous media.

The drainage waters were highly saline, but the sodium content was low. As a result, the sodium adsorption ratio and residual sodium carbonate was low. The drainage waters were high in calcium and magnesium.

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We certify that we have read this thesis and that in our opinion it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Soil Science.

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