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DEVELOPMENT AND COMPARISON OF SOME METHODS FOR LEACHING SALINE SOILS.

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DEVELOPMENT AND COMPARISON OF SOME METHODS FOR LEACHING SALINE SOILS

by

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TABLE OF CONTENTS

INTRODUCTION

General

The population of the world as a whole is increasing. The increase will be felt more and more with the advance in medical science and hygiene. No permanent solution for regulating the population in the world has been achieved.

One of the greatest tasks ahead of the future generation will, therefore, be to find food for the increasing population with the limited resources of land available. This will, therefore, necessitate amongst other things reclamation of agricultural land.

This is one side of the problem, the other side of it is water. Someone has said: "Whether man drinks it, bathes in it, removes his wastes by it, grows his food and fiber through it, meets his industrial needs with it -- regardless of how man uses water -- it is his most vital natural resource, a substance for which there is no substitute." The demand for water is steadily and sharply increasing, due not only to the rise in population but also to the increasing per capita consumption. From the dawn of recorded history of mankind, people have elected or have been compelled to move from places where water was deficient in amount, inferior in quality, or erratic in behavior. That is why in and around every river valley can always be traced the growth of a particular form or system of civilization.

In short, life as we know it on this planet cannot exist without water. A dependable source of water in a water-scarce region must be conserved, developed and effectively used without unnecessary waste. This naturally and perhaps inevitably, leads to organized, planned activity in all fields of endeavor, which is the basis of advanced civilization. The need to increase efficiency in use of water is clearly evident.

In Egypt, the River Nile is the chief source of water. The stringent natural limitations on the available land and water resources have made it imperative to rationalize their use with a view to having the optimum product with the least amount of water. On the whole, it is the amount of water available and not the lands with possible adaptation to agriculture that limits the extent of and scheme of development.

Adjustment

In many countries, such as India, Pakistan and Egypt, the system of irrigated agriculture has been known since ancient times. Ancient systems now still in operation were mostly built in flood plains and deltas of the lower parts of rivers. During several centuries of the operation of the ancient irrigation systems large salty zones with highly fertile soils have been formed along large and small irrigating canals. First noticeable signs of the formation of these zones along the irrigation canals are seen after the irrigation system has been operating 30-40 years. The belt of desalinized soils tends to spread in old irrigation systems, but rather slowly. The process of desalinization of the soils along the irrigation canals depends on the influence of the filtrating water and the local redistribution of salts. Soluble salts from soils, subsoils and ground waters are replaced by local flows and pushed aside to the lower lying areas, to the outer regions of irrigation systems and to further parts of irrigated areas. Stable and highly productive agriculture, with highly efficient use of the soil, is possible in areas with ancient irrigation systems without natural drainage, provided that they have a well-developed and well-operated network of drainage canals.

Excessive salinization tends to deplete the agricultural resources upon which the strength of any nation depends. That is why we need to prevent salinization and to reclaim salinized soils. The necessity for reclamation grows as the necessity grows to produce more food and raw materials on salinized areas, or on soils which are potentially subject to salinization.

Leaching

The process of leaching can be defined as the process of dissolving and removal of soluble salts by the movement of water through the soil in appropriate quantities and at appropriate times. Because salts move with water, salinity depends directly on water management, i.e., irrigation, leaching, and drainage. These three aspects of water management should be considered in any plan for an irrigated project if maximum efficiency is to be obtained. The process of leaching also depends on the influence of the filtering water and the local distribution of salts. Maximum water application efficiency requires good water control equipment, proper land preparation, correct canal system designs, and proper management of the system. This proper management requires increased understanding of the fundamental mechanics of water movement of soil leaching process, with which more accurate leaching -- prediction techniques and improved leaching -- control methods are anticipated.

At present, vigorous attempts are made to increase leaching efficiency, on the one side to avoid overleaching and the subsequent troubles as the subsequent rise of ground water table, and on the other side to extend the reclaimed areas and to transform in this way as much water into agricultural products and land reclamation as possible. To attain the best results it is necessary to depend heavily on the experimental study and on experience, and in the event that computed results are at variance with field experience, the equations should probably be considered less reliable than the field observations. A wise approach to the problem is to modify the analytical approach to make it agree with field experience.

Water and Salt Movement in Upper and Lower Egypt

Salinity problems in upper Egypt are different from those in lower Egypt. In upper Egypt the water table is deep, it contains some salts and is rising. In lower Egypt (below Cairo) the water table often reaches the surface and is often strongly saline. In both upper and lower Egypt a large part of the movement of salts is in connection with capillary action. Surface tension in water and adhesive forces in the walls of the capillary pores cause water to rise in soil pores. When the water table is at great depth, evaporation in the upward rising saline water occurs at great depth and the salt stays behind it at great depths. In places that are undisturbed by flooding, as in areas of upper Egypt, and where the water table is at considerable distance below the surface, soluble salts tend to accumulate due to irrigation, at some distance beneath, rather than at the surface of arid soils. In all of Egypt the rainfall is light, practically zero, and frequently so distributed that the moisture penetrates only a small distance in most soils. In upper Egypt much of the water that enters the soil is needed by the plants growing upon it and this water is extracted some distance below the surface.

The fact that the water table is now at relatively great depth (8 to 16 meters) in upper Egypt makes the salinity problem of lesser importance than in lower Egypt where the water table is often within a meter of the surface. In lower Egypt the soil water with its salts easily rises the short distance to the surface where evaporation causes the salts to remain behind. These salts must be leached out by excess irrigation water or crops cannot grow. In upper Egypt the salts rise by capillary action but very slowly. The salt effect will become serious in upper Egypt only if the water table continues to rise. In some places in upper Egypt the water table is rising rapidly. Thirty years ago the writer's father pumped water from a water table at 16 meters depth. The water table has now (1967) risen to 12 meters depth.

Amount of Water Used for Leaching

Due to limited rainfall and water supply in many countries including Egypt, the quantities of water used for leaching are of great importance. In Egypt the rainfall is significant only along the coastal region of the western desert where it amounts to about 15-20 cms. per year. The rainfall breaks off sharply to less than 2.5 cms. a few kilometers inland. The only other water supply is the Nile River besides the underground water. The quality of the Nile River water is excellent, low in salts (200 p.p.m. soluble solids).

The amounts of water used for leaching vary considerably from one locality to another. The differences in water use are not only related to the severity of the problem of salinization but also to the basic philosophy regarding the adequacy of leaching.

Leaching Methods

The methods used for leaching in most countries of the world are as follows:

1) Continuous ponding

2) Intermittent ponding

3) Ponding with a rice crop

4) Application of excess water during the irrigation of crops

Objectives of Research

The study reported in the following pages was conducted with the following objectives in mind:

1a. To see how salt diffuses from soil into surface water held at a steady depth. An objective here is to find out whether it is better to leave water standing for some period on saline soil while drains are "closed" than to have drains open from start when leaching. By "closed" is meant that the outlet ditches are not pumped out.

1b. To determine the effect of the time factor when non-salty water is kept on the surface of presalinized soil. How long should the water stand on the soil surface before subdrains or drainage ditches are allowed to empty?

2a. To investigate several other methods of leaching hoping to find out better processes of leaching than are now used.

2b. To improve the leaching efficiency for economical use of water. In other words to find out more intelligent application of the water to the land with the utilization of the combination of the water, soil and climate to the best advantage, that is to obtain the maximum returns from the amount of water available.

REVIEW OF LITERATURE

General

Reclamation and leaching were known and applied at the dawn of history. It will be seen later that leaching is a broad science drawing on many related fields as basic sciences for many of its data and much of its theory. Its study is not only a question of pure mathematics, but also of experimental science. In the past years many papers have been published dealing with the broad problem of leaching and the diffusion of salts. Because of the large number of publications and the shift in the approach utilized, the author has tried to keep this review limited to those publications that appeared to be the most pertinent and up to date.

Some Aspects on Diffusion and Leaching

Hissink (1907) carried out in his laboratory some leaching experiments with saline soils trying to prevent or to reduce the deterioration of the structure of soils. Before Hissink, Slichter (1904) attempted to follow groundwater movement through aquifers using salt as a tracer. He observed that a general dispersion or spreading of salt took place from the point of injection which he accounted for by flow velocity distribution in the pores.

Later, Sigmond (1924) described different methods of reclamation dividing them into four groups according to their main characteristics, namely:

1) Physical reclamation methods,

2) Methods of removing alkali,

3) Chemical methods of reclamation, and

4) Biological methods of reclamation.

In the report of the U.S. National Resources Committee, Scoffield and Hill (1938) proposed a formula for what was called "service equivalence", in which the concentration of the drainage water and the concentration of the irrigation water are taken into account. In addition to the salt removed through drainage, it is inherent with this formula that soluble salt is removed from the soil at a rate equal to the consumptive use of water times half the concentration of the irrigation water.

Carman (1948) indicated that the permeability of a medium to water or any other fluid under the action of a pressure difference may arise in various ways:

1) The fluid may dissolve and be transported by diffusion along a concentration gradient produced by the pressure difference.

2) In a porous medium the fluid may be absorbed at the internal walls of the capillary structure and be transported by diffusion along a concentration gradient.

3) The fluid may flow through capillaries of a porous medium at a rate limited merely by its viscosity.

Almost one year after Carman, Glueckauf (1949) developed his theory, assuming that at the boundary between leaching water and soil solution the two are in equilibrium, and that the diffuse boundary is caused by ionic or molecular diffusion. According to Glueckauf the disturbing factors operating in actual soil columns may be caused by the following factors: finite grain size, diffusion in the liquid between the grains, and nonequilibrium conditions.

A soil moisture law was proposed by Richards (1950) which he called the "outflow law". The law states that water will not flow out of the soil unless the soil water is at a pressure greater than atmospheric.

A further contribution to this subject, according to the U.S. Salinity Handbook (1954, p. 37), was made at the Irrigation Conference sponsored by the Texas Agricultural Experiment Station at Ysleta, Texas, in July, 1951. At this conference, F. M. Eaton proposed what he called a "drainage formula" for calculating the fraction of the irrigation water to be used for leaching. The U.S. Salinity Laboratory staff (1954) has a mimeographed paper entitled "Formulas for estimating drainage and gypsum requirements for irrigation waters" in which the base for the Ysleta formula are presented.

The mixing process of salts into soil water was studied by Danel (1953), who showed that as water flows between and around soil particles it mixes with the surrounding water and each small volume of water thus loses its identity.

It seemed apparent to Yuhara (1954), as he concluded that it was eddy diffusion rather than molecular diffusion that was the important factor in mixing.

Rifai, Kaufman, and Todd (1956) did an experiment involving fluid flow through sands under laboratory conditions. It seemed to them that dispersion could be caused completely by flow velocity distributions. Low (1955) developed an equation relating the hydraulic and osmotic pressure gradients to the rate of diffusion of water. His equation shows that the osmotic pressure acts as a negative hydraulic pressure in its influence on water diffusion. The equation was tested for clay suspensions and shown to be valid.

Richards, *et al.*, (1956) observed that the soil solution of an irrigated soil was less saline than the irrigation water with which it had been wetted. The salinity of this soil solution decreased greatly as the soil drained to lower moisture levels, except for the surface where some salts accumulated due to evaporation. They attributed this marked lowering of salt concentration in the soil solution to negative adsorption effects which became progressively more intense at lower moisture levels.

Day (1956) reported that the dispersion of salt may occur at a much greater rate than can be expected by ion diffusion. The effect has been attributed to a mechanism referred to as hydrodynamic dispersion, a general phenomenon arising from the fact that the velocity of the moving stream through saturated sand varies from point to point in the porous system. Then he concluded that diffusion must occur whenever a sharp concentration gradient occurs in the liquid phase. Although the hydrodynamic dispersion mechanism brings close together the "particles" of fluid originating in different parts of the flow system and intersperses them, it does not completely mix them because the streamlines never intersect. The final stage of mixing must depend upon ionic and molecular diffusion, which will become most effective when two streamlines carrying liquid of different chemical composition come close together.

Kaufman and Orlob (1956) indicated that the degree of front dispersion or dilution along the axis of flow may be considered as a function of several individual phenomena, as follows:

1) Gross or macroscopic variations in permeability may result in channeling of "fingering", causing very rapid travel of portions of the tracer front, while other portions of the front may actually be retarded. Such fingering may be either longitudinal or transverse to the major direction of flow.

2) Minute, or microscopic variations in permeability, resulting from the differing diameters of adjacent pores, will cause velocity differences from pore to pore and increase the length of the front.

3) Velocity distribution within a single capillary will cause further longitudinal dispersion with additional lengthening of the front.

4) Molecular diffusion in the direction of flow is probably of relatively small significance except in cases where the actual linear flow rate is extremely small. However, diffusion transverse to the direction of flow may be a significant factor

to determine the characteristics of the tracer front.

5) The presence of cavities connected to pores by small channels may help the interception and retention of some fluid causing diffusion.

About the same time, Van der Molen (1956) used Glueckauf's theory of chromatography to obtain theoretical curves which showed general agreement with data taken during the desalinization of Dutch soils subsequent to innundation by sea water.

Gardner and Brooks (1957) conducted experiments in the laboratory which indicated that at the flow rates which normally occur during the leaching of soils, the equilibrium condition is probably too slow to be of great significance. They reported that if a saline soil solution is displaced by fresh water, some of the saline water is bypassed and mixing occurs. As the flow continues, the mixing with the initially bypassed solution continues and leaching is accomplished. In other words, soil leaching processes are dominated by dispersion. They proposed equations in which it is assumed the flow process is responsible for the diffuse boundary between the soil solution and the leaching water and for the subsequent removal of the initially bypassed salt. They obtained satisfactory agreement between their theoretical equations and laboratory field data.

Gerald and Radhakrishne (1958) presented a paper on hydraulic characteristics of porous media. Their study indicated that a 10 percent accumulation of air in the voids of uniform materials may produce up to 15 percent reduction in effective porosity. In more heterogeneous natural media the isolation of pore volume by entrapped air would be even more pronounced. Variations in the time of flow or in the volume displacement may be partially accounted for by changes in the effective porosity because of air accumulation.

Working with larger flow velocities Handy (1959) concluded that ionic diffusion may be disregarded in its effect on tracer distributions within water saturated sands. In contrast to the above, Berg and Thomas (1959) measuring ion concentrations in column eluates consider diffusion to be the principal cause of dispersion, thereby entirely neglecting the effects of flow velocity distribution. Their results clearly indicate, however, that the amount of anion adsorption depends upon the chemical and mineralogical characteristics of the soil.

One year later Saffman (1959) published a theory of dispersion in a porous media. When a viscous fluid flows through the pores a material quantity carried by the fluid which is a substance in solution or heat is dispersed by: 1) molecular diffusion and 2) convective diffusion or mechanical diffusion. The latter effect arises from the irregular pattern of the streamlines through the voids, and the consequent tendency for fluid elements which are originally close together is to separate. This is actually similar to turbulent diffusion, the difference is the irregularity of the streamlines through the porous medium due to the complicated geometrical structure of it.

Jost (1960) found that diffusion coefficients depends upon concentration while Letey and Klute (1960) reported in the same year the importance of these coefficients when diffusion takes place in porous materials.

Another theory of dispersion in porous media is that of Scheidegger (1955, 1961). He agrees with Saffman that complexity of the pore system is the cause of individual fluid elements to be mixed with each other. This is the process of dispersion which is distinguished from diffusion which is caused by the intrinsic motion of the molecules. The dispersion or miscible displacement phenomenon depends upon the geometry of the pore-grain system of the porous medium.

Wilson, Luthin, and Biggar (1961) made studies that involved comparisons between: a) continuous ponding and intermittent ponding, b) continuous ponding and intermittent sprinkling and c) continuous ponding and intermittent rainfall. In each study the slow movement of water at the lower levels of saturation achieved by intermittent ponding, sprinkling, or rainfall resulted in significantly higher leaching efficiencies, i.e., removal of more salt per unit of applied water.

Dutt and Low (1962) found that the apparent diffusion coefficients for steady state diffusion of NaCl decreased with increasing salt concentration. They related the decrease to a salt-induced change in the fractions of cations and anions in the more-viscous adsorbed water.

In agreement with Scheidеger, Saddler, Taylor, Willardson, and J. Keller (1965) carried on a field experiment on leaching salt from soil. They reported that the individual elements of the moving liquid are continuously changing direction owing to collisions with the pore walls. This erratic flow causes individual fluid elements to be mixed with each other. The tortuosity of the channels in the porous media complicates severely the passage of the fluid through the media. They concluded that the hydrodynamic dispersion and the ionic diffusion both contributed salt to the effluent that was measured and analyzed during this field experiment on leaching of salt from soil. They also concluded that diffusion was of increasing importance with time and that it was also of increasing importance in removing salt from soil more distant from the drain. Israelsen and Hansen (1962) indicated that the amount of excess water that must pass through the root zone has been thought to be dependent only on the crop being grown and on the quality of the irrigation water.

Nielsen and Biggar (1961, 1962, 1963, 1964) worked extensively with miscible displacement in soils. Their studies indicate that miscible displacement results in a concentration distribution which depends upon microscopic flow velocities, diffusion rates, and other chemical processes. Owing to the magnitudes of convection, diffusion and the chemical processes which occur in different pore sequences, the paths of each fluid particle will be different. The existence of concentration or activity gradients of salts in aqueous solutions responsible for transfer by diffusion guarantees that the displacing and the displaced solutions do not generally have identical densities or viscosities. The differences in densities provide unbalanced forces and the differences in viscosities provide unequal drag forces. Furthermore, the presence of external force fields as a result of charges are recognized. These force fields responsible for absorption, adsorption, and exchange are also responsible for modifying both the density and the viscosity of the solutions. In brief Nielsen and Biggar showed that not only the flow velocity distribution but also diffusional effects, especially at small average flow velocities, are responsible for the mixing processes.

In another paper of Nielsen and Biggar they pointed out that the contribution of diffusion to the spreading of the moving front might be expected to increase as the velocity is decreased. Because the total number of contacts between aggregates decreases with increasing aggregate size, mixing becomes less complete and the effluent concentration is dominated by flow through the large pores. Nielsen and Biggar provided evidence that the degree of saturation and the rate of water movement affect the transport of salts through the soil. Their studies made on soil columns in the laboratory showed that small reductions in soil water content during leaching increased the efficiency of chloride removal from the soil.

Furthermore, displacement of the soil solutions was significantly different whenever the average flow velocity differed by several magnitudes.

Nielsen and Biggar (1962) tested the differential equation developed by Lapidus and Amundson (1952) which describes solute movement by molecular diffusion and velocity through porous material. They found general agreement between theoretical curves tabulated with this equation and actual displacement of Cl under different water contents and velocities.

A recent study by Carlson (1965) was made to determine the hydraulic action of tile drains in removing saline ground water. He constructed a model with a two foot depth of porous medium from the soil surface to a barrier. The two foot depth was to simulate an actual depth of 80 feet of porous medium in the field. Corresponding to field conditions the drains were at eight foot depths, 315, 630 and 1260 foot spacings. A one foot thick layer in the model of fine sand corresponded to 60 feet of fairly permeable surface soil in the field; and a one foot thick layer of course sand below the fine sand corresponded to material about 50 times (see page 17 and 19 of Carlson) more permeable than the upper material. Eight tests were made with different methods and rates of applying surface irrigation leaching water flowing into the upper aquifer and a continuous flow of drainage water from the drain(s). The lower aquifer (and in some tests the upper aquifer also) was charged with salt water. The results indicate that the tile drains in all cases discharged salt water with a maximum concentration that varied from about two-thirds to three-fourths of the salt concentration of the lower part of the aquifer. Carlson's results show that only after saline water is flushed from the aquifer to the extent that a stable interface is formed between the moving fresh water and the remaining stagnant salt water that fresh water will be discharged from the drains. He shows that a stable interface will always form eventually. The position of this stable interface will depend on the steady rate of surface leaching and the position of the drains. The position of the stable interface depends also on the difference in density of the leaching water and the saline groundwater.

GENERAL DESCRIPTION OF EXPERIMENTS

The goal is to determine the amount of water required to remove the most salt per unit of applied water. Several porous media were leached: Ida silt loam (loess), Clayton sand[1] and glass beads. In all cases the concentration of salt in the leaching water was determined by an electrical conductivity measurement with a solubridge (model RD-15).

Six methods of experiments for leaching were used. They may be described as follows:

Experiment I. Surface standing of water followed by gravity drainage (drains initially were kept closed). In this experiment salt mixing by diffusion was studied.

Experiment II. Surface leaching of different quantities of applied distilled surface water, keeping a head of 0-10 cm. during application, with amounts of leaching water as follows being applied:

a. 6000 cc. equivalent to 132.33 cm. height or more,

b. 4000 cc. equivalent to 88.22 cm. height,

c. 2000 cc. equivalent to 44.11 cm. height,

d. 1000 cc. equivalent to 22.05 cm. height,

e. 500 cc. equivalent to 11.028 cm. height,

f. 200 cc. equivalent to 4.41 cm. height and

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[1]Clayton sand is a product of the Clayton Silica Company, Cedar Rapids, Iowa. This sand approximates sands used in Egypt.

g. 50 cc. equivalent to 1.1 cm. height.

Experiment III. Leaching of water upward through the soil by subirrigation of distilled water applied under pressure, followed by surface drainage.

Experiment IV. Leaching of water upward through the soil by subirrigation of distilled water applied under pressure to create a ponded water condition followed by gravity drainage.

Experiment V. Leaching water was added by subirrigation to bring the water table up to a depth of 12.5 cm., for a soil column of 25 cm. length. The water was then permitted to stand until the capillary water rose to the soil surface followed then by gravity drainage.

Experiment VI. Same as V except that the water table was kept 2 cm. above the bottom of the column.

Materials and Preparation of Soil Samples

Soils for Experiment I are shown in Table 1. For the rest of the experiments only Clayton sand was used. This sand contains 22.4 percent sand and 0.60 percent clay and is similar to an irrigated sand in Egypt. Salts were sodium chloride, sodium bicharbonate and sodium sulfate. In all experiments these salts were mixed in the soil at a rate of 5 grams of salt per hundred grams of the sample soil. The reason for choosing this high percentage of salts is that some layers were found to contain nearly as much salt as in the 0-1.5 cm. depth layer of

Table 1. Soil samples and salts used in diffusion and leaching experiment

Salt	Soil	Soil column length cm.	No. of replicates
NaCl	Ida silt loam	25	4
$NaHCO_3$	Ida silt loam	25	4
Na_2SO_4	Ida silt loam	25	3
Na_2SO_4	Clayton sand	25	4
NaCl	Ida silt loam	50	1
$NaHCO_3$	Ida silt loam	50	1
Na_2SO_4	Ida silt loam	50	1
NaCl	Clayton sand	50	1
$NaHCO_3$	Clayton sand	50	1
$NaHCO_3$	Glass beads	50	1

profile 1 in the Sacramento Valley (see Janitzky and Whittig, 1964. p. 254). To get this 5 percent by weight concentration of salt in the soils a salt solution--enough to oversaturate the soil--was prepared and mixed into the samples to make a paste. This paste was then spread in 1 cm. layers and allowed to air-dry with stirring so that aggregates were formed and the salt would be uniformly mixed in the soil. This soil sample was taken, screened through a 2 mm. sieve, mixed well and packed into columns in either 25 centimeters length or 50 centimeters length. The dimensions of the cylinders are as follows:

For the 25 centimeters soil columns:

Internal diameter of cylinder = 7.6 cm.

External diameter of cylinder = 8.2 cm.

Length of cylinder = 38.0 cm.

Cross section = 45.3416 cm^2.

For the 50 centimeters soil columns:

Internal diameter of cylinder = 5.5" = 13.475 cm.

External diameter of cylinder = 6.0" = 15.24 cm.

Length of cylinder = 30.0" = 76.20 cm.

Packing of Soil Columns

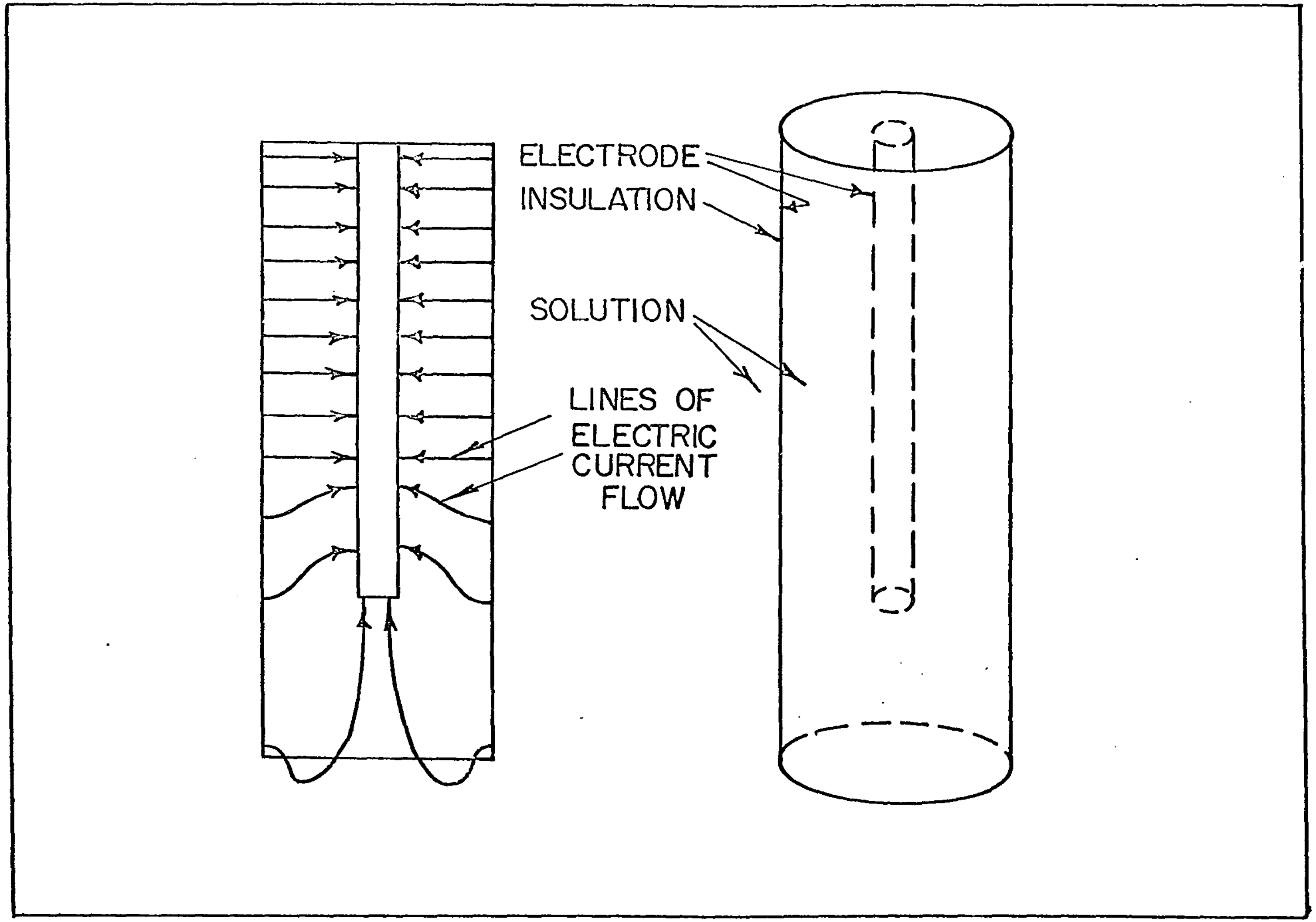
In packing the 25 centimeters columns, a cup full of soil was put in each cylinder and the cylinder given four taps on each of its four sides. Then another cup full was added to each cylinder, the soil was stirred with a long rod to mix with former soil, and the cylinder was given another four taps. This was continued until 25 centimeters of soil was in each column. By the manner of packing the cylinders, the soil which was originally put in received more taps than the soil which went in at the top. Therefore, the columns were somewhat more densily packed at the bottom than at the top, but all columns were the same.

In packing the 50 centimeter columns a 3 cm. diameter cylinder with a funnel is used. The soil was poured in the funnel until the thin 3 cm. cylinder was full. The 3 cm. diameter cylinder was then lifted and moved slowly in the big cylinder to form a thin layer of soil, then filled again with soil using the funnel and the process repeated until a 50 cm. soil length was obtained.

Measurement of Conductivity

The electrical conductivity of the soluble salts is determined by measuring the electrical resistance of solution. The electrical resistance measurements can be made quickly and accurately and has long been used for estimating soluble salt content of soil waters. However, electrical conductance, which is the reciprocal of resistance, is more suitable for salinity measurements because conductance increases with salt content. Figure 1 shows the type of conductivity bridge probe used in this study. The results obtained from the probe and bridge are expressed in terms of specific conductance (also called conductivity). The readings are (since the flow lines, Figure 1, are essentially all inside the probe) independent of the size and shape of the sample into which the probe is inserted. When the probe is immersed into the solution, the bridge scale reads directly from zero to 10.00 millimho $cm.^{-1}$. The bridge is operated by alternating current and makes use of a cathode ray tube null indicator. When the temperature of the solution is set on a temperature-compensating dial, the main dial, at balance, indicates the electrical conductivity at 25°C.

Figure 1. Schematic drawing of a conductivity bridge probe inserted in a conducting fluid, and lines of electric current flow


ELECTRODE
INSULATION
SOLUTION
LINES OF ELECTRIC CURRENT FLOW

The author chose the unit millimho cm.$^{-1}$ because it gives a more convenient location of the decimal point than the standard unit for conductivity, mho cm.$^{-1}$. The bridge was calibrated for each of the salts used (NaCl, $NaHCO_3$ and Na_2SO_4) to convert the measured conductivities to grams of salt per liter or to parts per million as shown later in Appendix B (Table 64 and Figure 60).

At the beginning of each series of measurements of the conductivity, a check measurement was made in a standard solution. (Potassium chloride solution, 0.01 N made by dissolving of 0.7456 gm. of dry potassium chloride in water to yield 1 liter of solution.) This standard reference solution has an electrical conductivity of 1.4118 millimhos cm.$^{-1}$ at 20°C. The probe was then rinsed in distilled water.

PROCEDURES, RESULTS AND DISCUSSIONS

In the interest of brevity the different procedures with results and a brief discussion will now be presented following the wisdom that one figure is worth ten thousand words. Later a general discussion will be presented when the results of the experiments will be compared.

PROCEDURE FOR EXPERIMENT I

Salt Mixing by Diffusion

In Experiment I where leaching water stands on the surface of soil with no drainage allowed before at least 120 days, the procedure differs for 25 cm. long and 50 cm. long soil columns. For 25 cm. long columns water was added to the surface of the soil rapidly to obtain a surface depth of water of 12.5 cm. and the water was then added in weekly increments as needed (7.5 cm. total in 70 days) to maintain this 12.5 cm. depth. Whereas for 50 cm. long column, a certain amount of water was applied to the surface and no more added. The field situation corresponding to these 25 cm. long and 50 cm. long columns is indicated in Figure 2 and the laboratory situation in Figure 3. For the 25 cm. long soil columns it was not necessary to add additional water after 70 days, as the soil (the drains were closed at the bottom) would take none.

In initially wetting the salinized air dry soil aggregates, the bottom of a tube coming out of the soil column as illustrated in the right side of Figure 3 was open so that a wetting front could go down the soil and let soil air go into the atmosphere. In the field case this will correspond to air going into field drains which will be open. After the water had reached the bottom of the column the opening there was clamped as shown on the right of Figure 3. The conductivity was measured at three positions in the surface water. Figure 3

Figure 2. Situation for leaching of salinized soil by means of drain tubes and a ditch which must be pumped out. The drain tubes in the salinized soil empty into the ditch when it is pumped out, just at the impervious layer

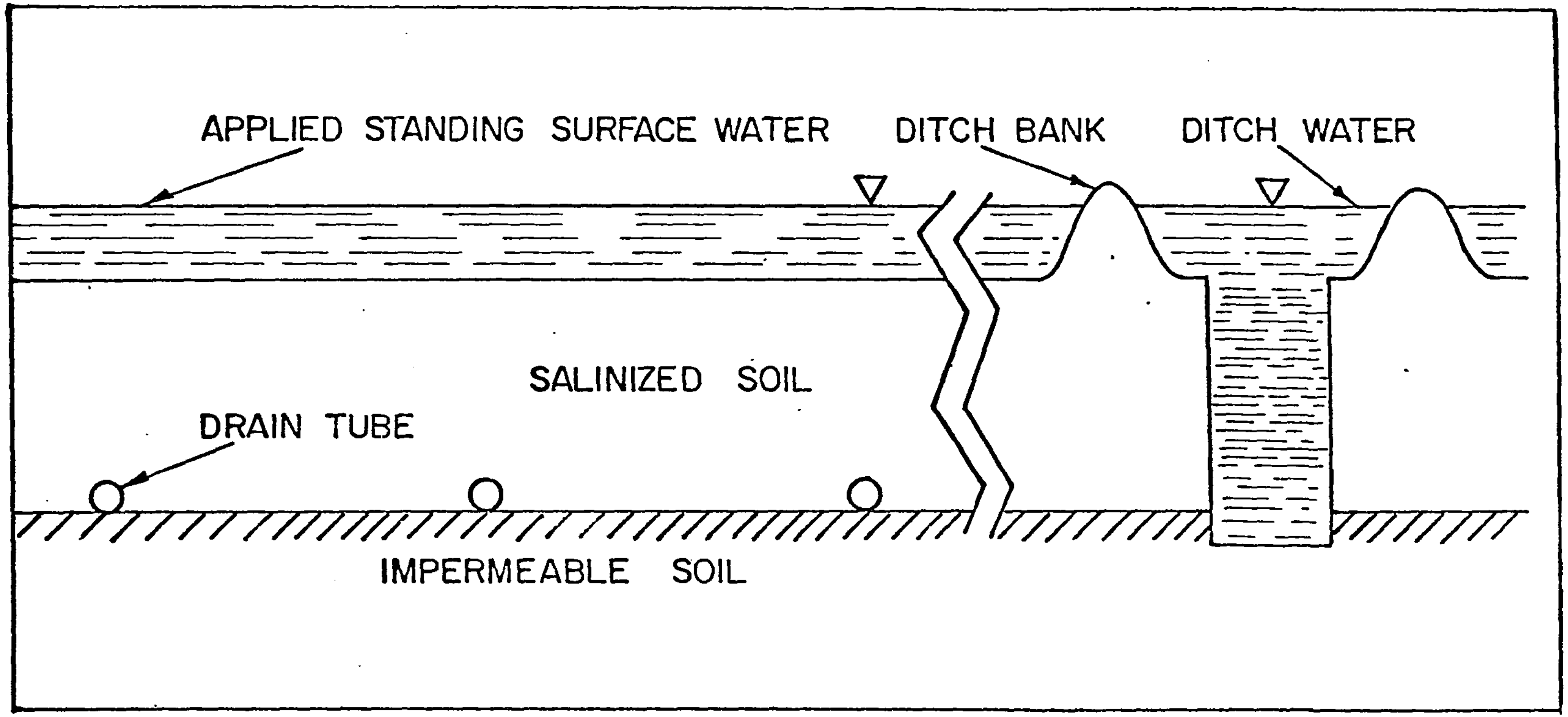
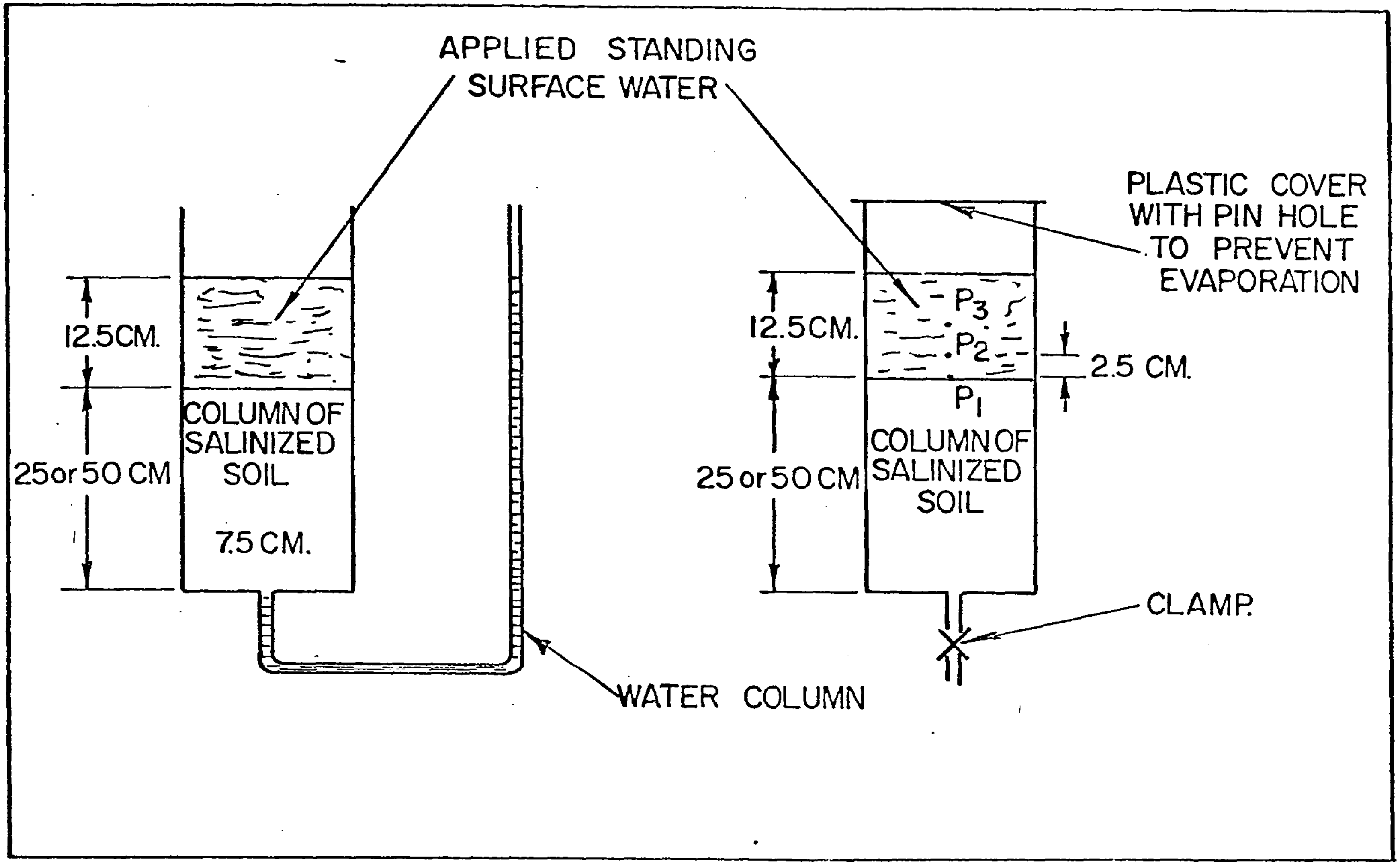

APPLIED STANDING SURFACE WATER
DITCH BANK
DITCH WATER
SALINIZED SOIL
DRAIN TUBE
IMPERMEABLE SOIL

Figure 3. (Left) Laboratory situation simulating the field condition of Figure 1 (width of soil columns not to scale)

(Right) Same as (left) except that a clamp rather than a water column prevents water flow from the column


APPLIED STANDING
SURFACE WATER
PLASTIC COVER
WITH PIN HOLE
TO PREVENT
EVAPORATION
12.5CM.
COLUMN OF
SALINIZED
SOIL
25 or 50 CM
7.5 CM.
12.5CM.
P3
P2
P1
2.5 CM.
COLUMN OF
SALINIZED
SOIL
25 or 50 CM
CLAMP.
WATER COLUMN

3 at the right shows three points at which the bottom edge of the probe was located while the readings of the solu-bridge were taken. One point (P_1) is just at the soil surface, another point (P_2) is 2.5 centimeters above the soil surface or as mentioned later, and the third (P_3) is at the middle of the surface water. The third reading was taken after the surface water had been stirred to make the salt concentration the same throughout.

RESULTS AND DISCUSSION OF EXPERIMENT I

Salt Mixing by Diffusion

In Experiment I the results, Figures 4-30, show that water standing on the surface of presalinized soil will pick up salt from the soil. This salted surface water will then carry down this salt solution plus additional salt picked up in the soil column as the surface water flows through the soil into a drainage outlet. But in Experiment I, the results showed practically no movement of leaching water through the soil profile. The sodium salts in the porous media had apparently reduced the hydraulic conductivity to essentially zero. Figure 4 shows a plot of conductivity of the surface water made at point P_1 in Figure 3 versus days of standing of the soil surface water. The soil is Ida silt loam (loess) treated with sodium chloride at the five percent level. The figure shows that the salt concentration builds up in the surface water, with the electrical conductivity rising from zero to 7.4 millimhos $cm.^{-1}$ in 124 days. Figures 5 and 6 are the same as Figure 4 except that the measurements of the conductivity are made 2.5 centimeters above the soil surface (point P_2, Figure 3) and at the middle of the surface water (point P_3) after the water had been stirred. The conductivity was always higher in the middle after stirring than that just above the soil surface (with no stirring), while the latter was always higher than that at 2.5 centimeters above the soil surface (no stirring) as

Figure 4. Conductivity versus time curve for 12.5 cm. of water standing on the surface of salinized soil when the conductivity measurement is made just above the surface of the soil (point P_1, Figure 3). From days 0 to 70 water was added in weekly increments (total 7.5 cm. in 70 days) to the soil as needed to maintain the 12.5 cm. level. After 70 days no more water was added as the level stayed constant. Data for the four replicates shown are in Tables 2-5

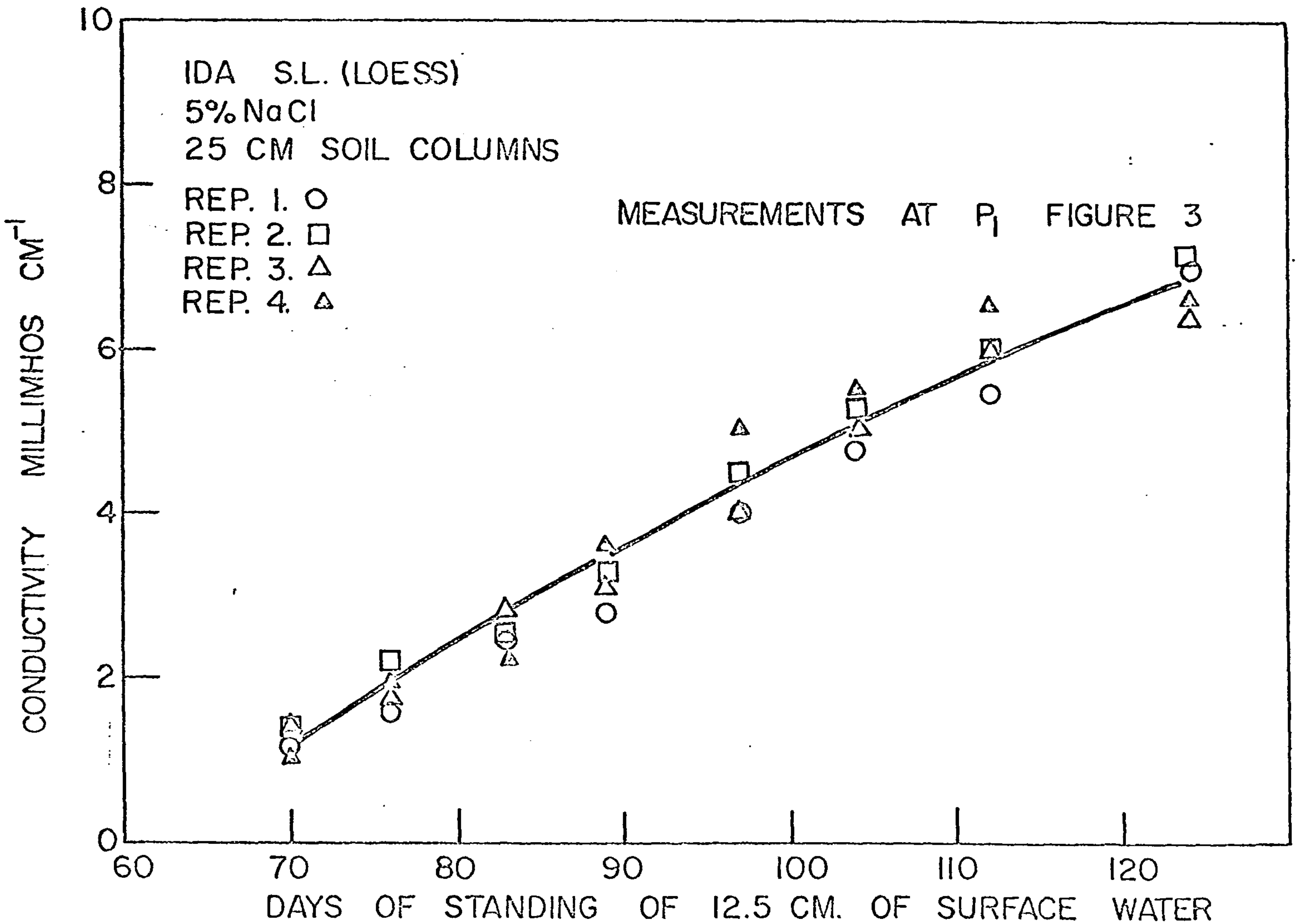

IDA S.L. (LOESS)
5% NaCl
25 CM SOIL COLUMNS
REP. 1. ○
REP. 2. □
REP. 3. △
REP. 4. △
MEASUREMENTS AT P1 FIGURE 3
CONDUCTIVITY MILLIMHOS CM-1
10
8
6
4
2
0
60
70
80
90
100
110
120
DAYS OF STANDING OF 12.5 CM. OF SURFACE WATER

Figure 5. Conductivity versus time curve for 12.5 cm. of water standing on the surface of salinized soil when the conductivity measurement is made 2.5 cm. above the surface of the soil (point P_2, Figure 3). From days 0 to 70 water was added in weekly increments (total 7.5 cm. in 70 days) to the soil as needed to maintain the 12.5 cm. level. After 70 days no more water was added as the level stayed constant. Data for the four replicates shown are in Tables 2-5

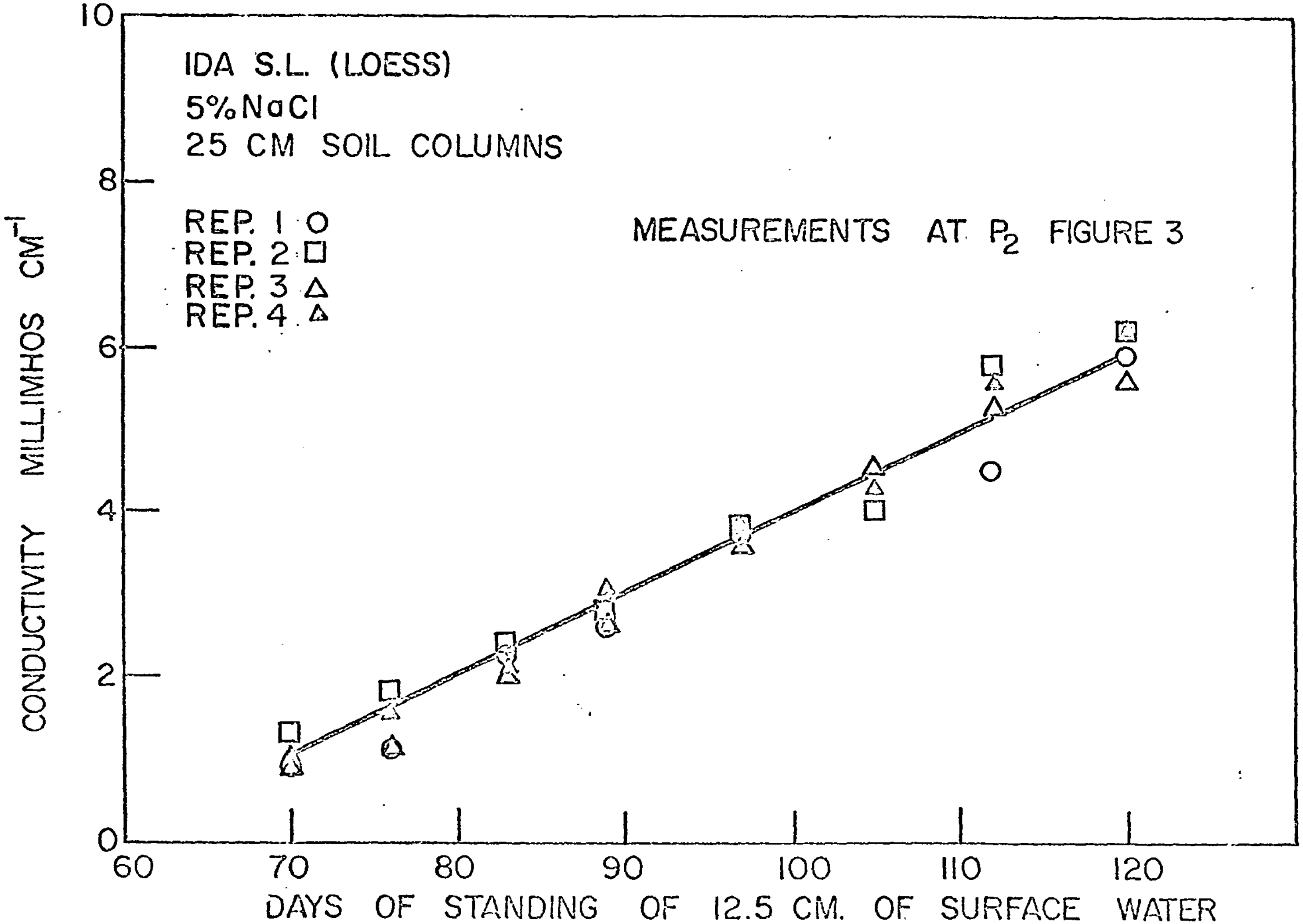

IDA S.L. (LOESS)
5% NaCl
25 CM SOIL COLUMNS
REP. 1 O
REP. 2 □
REP. 3 Δ
REP. 4 Δ
MEASUREMENTS AT P2 FIGURE 3
CONDUCTIVITY MILLIMHOS CM-1
0
2
4
6
8
10
60
70
80
90
100
110
120
DAYS OF STANDING OF 12.5 CM. OF SURFACE WATER

Figure 6. Conductivity versus time curve for 12.5 cm. of water standing on the surface of salinized soil when the conductivity measurement is made at the central depth of the surface water after it has been stirred (point P_3, Figure 3). From days 0 to 70 water was added in weekly increments (total 7.5 cm. in 70 days) to the soil as needed to maintain the 12.5 cm. level. After 70 days no more water was added as the level stayed constant. Data for the four replicates shown are in Tables 2-5

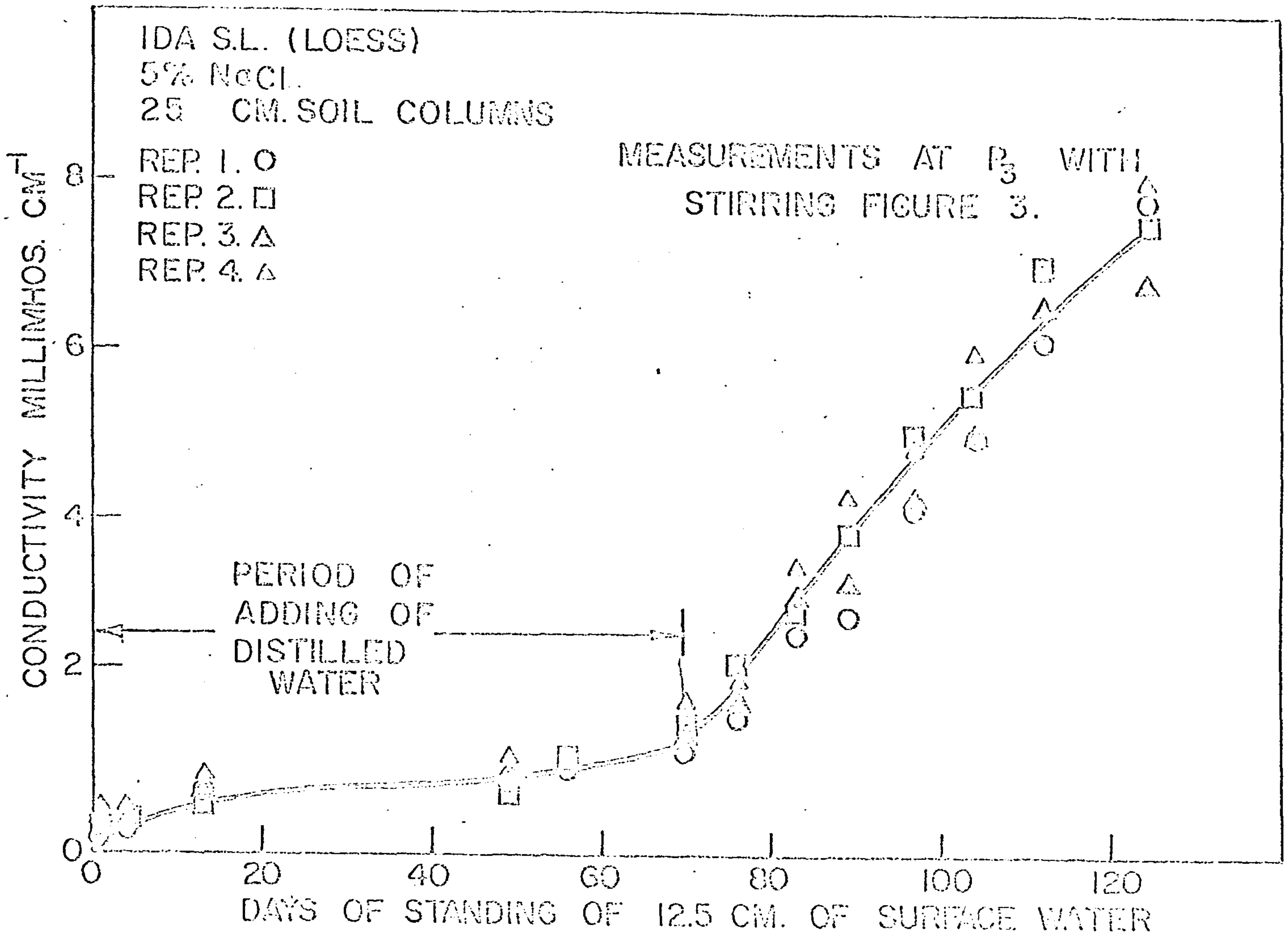

IDA S.L. (LOESS)
5% NaCl.
25 CM. SOIL COLUMNS
REP. 1. O
REP. 2. □
REP. 3. △
REP. 4. △
MEASUREMENTS AT P_3 WITH STIRRING FIGURE 3.
PERIOD OF ADDING OF DISTILLED WATER
CONDUCTIVITY MILLIMHOS. CM^{-1}
DAYS OF STANDING OF 12.5 CM. OF SURFACE WATER
0
2
4
6
8
0
20
40
60
80
100
120

Figure 7. Retraced curves (without data points) taken from Figures 4, 5 and 6 plotted on a single graph for comparison

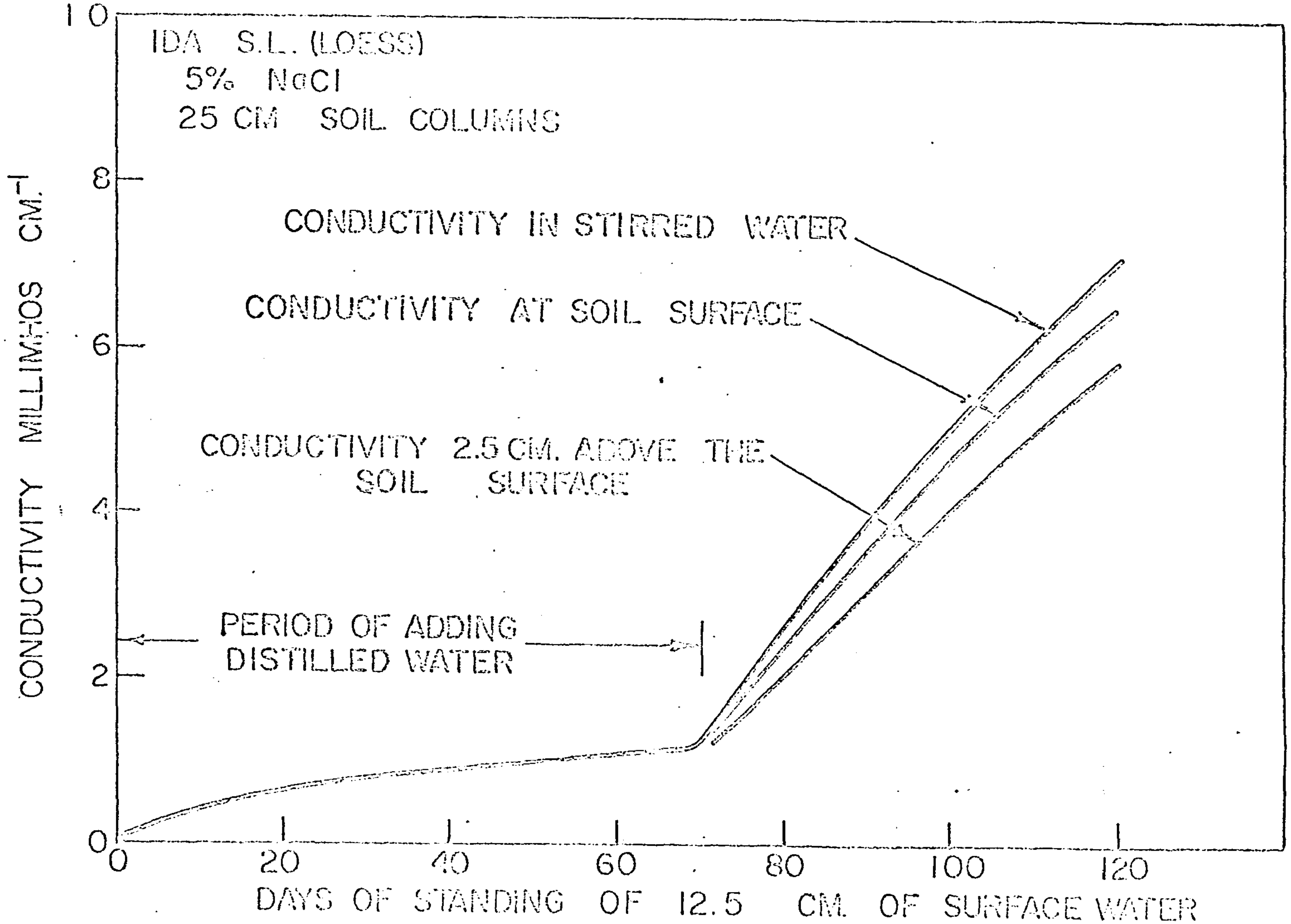

IDA S.L. (LOESS)
5% NaCl
25 CM SOIL COLUMNS
CONDUCTIVITY IN STIRRED WATER
CONDUCTIVITY AT SOIL SURFACE
CONDUCTIVITY 2.5 CM. ABOVE THE SOIL SURFACE
PERIOD OF ADDING DISTILLED WATER
CONDUCTIVITY MILLIMHOS CM.$^{-1}$
10
8
6
4
2
0
0
20
40
60
80
100
120
DAYS OF STANDING OF 12.5 CM. OF SURFACE WATER

Table 2. Conductivities of surface water standing on a 25 cm. long column of salinized (5 percent NaCl) Ida soil replicate 1

Elapsed time days	Conductivity in mmhos. cm^{-1}		
	At soil surface	2.5 cm. above soil surface	In stirred water
0			0
1			0.20
4			0.35
8			0.50
13			0.70
49			0.84
56			1.00
70	1.13	0.87	1.25
76	1.60	1.10	1.60
83	2.40	2.20	2.60
89	2.78	2.60	2.80
97	4.00	3.70	4.10
104	4.80	4.50	5.00
112	5.50	4.50	6.10
124	7.00	5.90	7.80

Table 3. Conductivities of surface water standing on a 25 cm. long column of salinized (5 percent NaCl) Ida soil replicate 2

Elapsed time	Conductivity in mmhos. cm^{-1}		
days	At soil surface	2.5 cm. above soil surface	In stirred water
0			0
1			0.23
4			0.38
8			0.49
13			0.57
49			0.80
56			1.04
70	1.40	1.35	1.50
76	2.20	1.85	2.25
83	2.45	2.40	2.85
89	3.30	2.80	3.80
97	4.50	3.80	5.00
104	5.30	4.00	5.50
112	6.00	5.80	7.00
124	7.20	6.20	7.50

Table 4. Conductivities of surface water standing on a 25 cm. long column of salinized (5 percent NaCl) Ida soil replicate 3

Elapsed time days	Conductivity in mmhos. cm^{-1}		
	At soil surface	2.5 cm. above soil surface	In stirred water
0			0
1			0.22
4			0.36
8			0.49
13			0.70
49			0.87
56			1.10
70	1.35	0.99	1.43
76	1.75	1.10	1.80
83	2.80	2.00	3.00
89	3.10	2.60	3.20
97	4.00	3.60	4.20
104	5.00	4.50	5.00
112	6.00	5.30	6.50
124	6.40	5.80	6.70

Table 5. Conductivities of surface water standing on a 25 cm. long column of salinized (5 percent NaCl) Ida soil replicate 4

Elapsed time days	Conductivity in mmhos. cm^{-1}		
	At soil surface	2.5 cm. above soil surface	In stirred water
0			0
1			0.30
4			0.44
8			0.59
13			0.75
49			0.88
56			1.20
70	1.00	0.20	1.80
76	1.90	1.50	2.07
83	2.20	2.00	3.40
89	3.80	3.00	4.20
97	5.00	4.80	4.85
104	5.50	5.30	6.00
112	6.50	5.80	7.00
124	6.60	6.20	8.00

shown in Figure 7.

In Figures 6 and 7 the curves are rather flat in the period of distilled water addition. The curves gradually go up for the rest of the elapsed time.

Tables 2-5 contain data plotted on Figures 6 and 7. For additional similar tables see Appendix A.

Figures 8-11 are the same as Figures 5-7 except that the soil is salinized with sodium bicarbonate instead of the sodium chloride.

Figures 12-15 are the same as Figures 8-11 except that the salt is sodium sulfate.

To compare the three different salts, namely, sodium chloride, sodium bicarbonate, and sodium sulfate, Figure 16 has been prepared by tracing curves from Figures 6, 10 and 14. Figure 16 shows that sodium chloride diffuses more than sodium bicarbonate, since the values of the conductivity varies from zero to higher than 7.0 while the conductivity for sodium bicarbonate varies only from zero to about 1.0. Also, the curve of the latter is always in between that of the sodium chloride and the sodium sulfate. Thus sodium sulfate diffuses much less than the sodium bicarbonate. The conductivity in the case of the sulfate only varies from zero to 0.7 in the 120 days elapsed time.

Figures 17-20 show the effect of soil types on diffusion behavior. To compare Clayton sand and Ida silt loam, Figure 21 was retraced from Figures 15 and 20. It can be observed that

Figure 8. Conductivity versus time curve for 12.5 cm. of water standing on the surface of soil salinized with $NaHCO_3$ when the conductivity measurements were made just above the surface of the soil (point P_1, Figure 3). From days 0 to 70 water was added in weekly increments (total 7.5 cm. in 70 days) to the soil as needed to maintain the 12.5 cm. level. After 70 days no more water was added as the level stayed constant. Data for the four replicates shown are in Tables 6-9

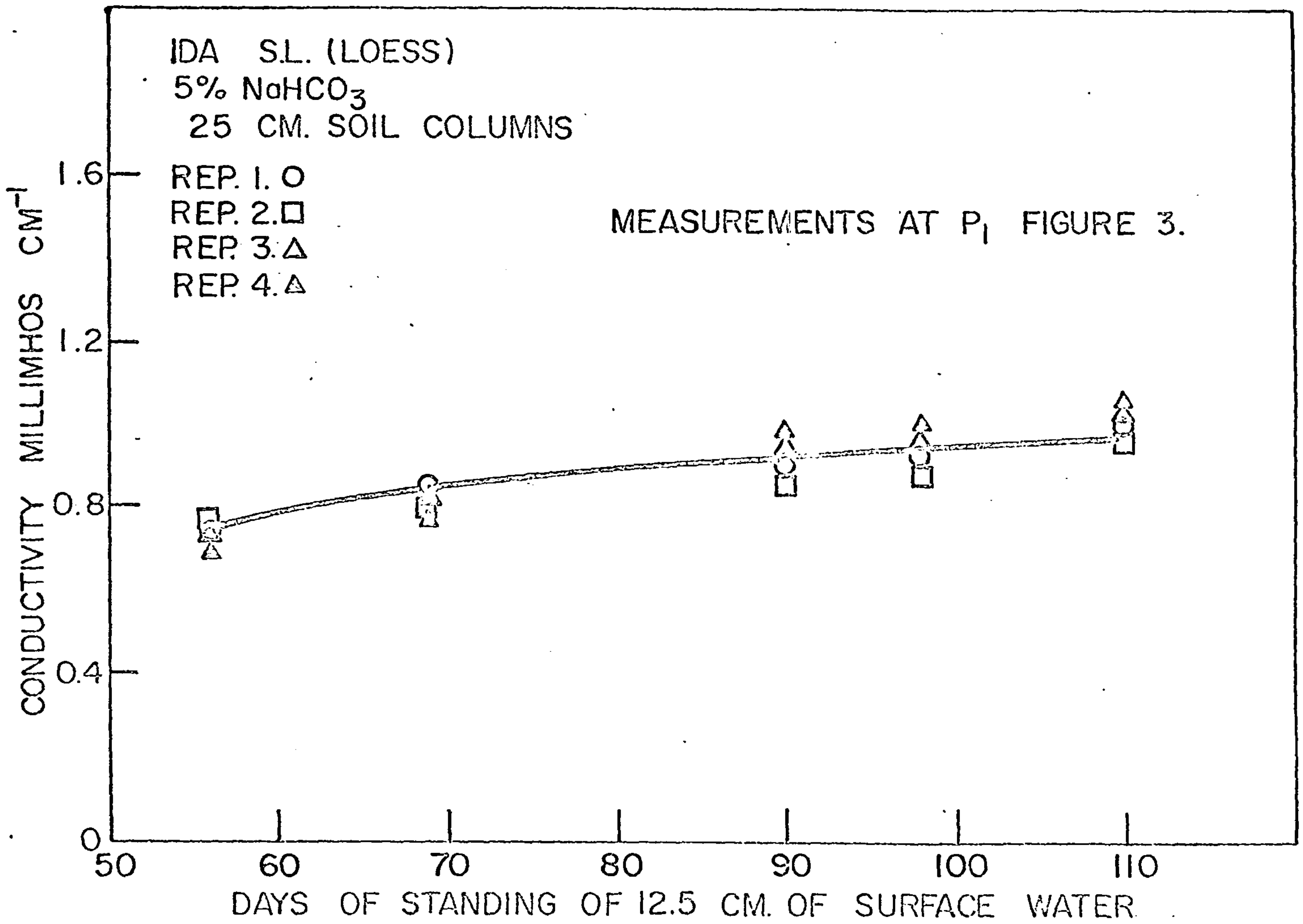

IDA S.L. (LOESS)
5% $NaHCO_3$
25 CM. SOIL COLUMNS
REP. 1. ○
REP. 2. □
REP. 3. △
REP. 4. △
MEASUREMENTS AT P_1 FIGURE 3.
CONDUCTIVITY MILLIMHOS CM^{-1}
1.6
1.2
0.8
0.4
0
50
60
70
80
90
100
110
DAYS OF STANDING OF 12.5 CM. OF SURFACE WATER

Figure 9. Conductivity versus time curve for 12.5 cm. of water standing on the surface of salinized soil with $NaHCO_3$ when the conductivity measurements were made 2.5 cm. (point P_2, Figure 3) above the soil surface. From days 0 to 70 water was added in weekly increments (total of 7.5 cm. in 70 days) to the soil as needed to maintain the 12.5 cm. level. After 70 days no more water was added as the level stayed constant. Data for the four replicates shown are in Tables 6-9

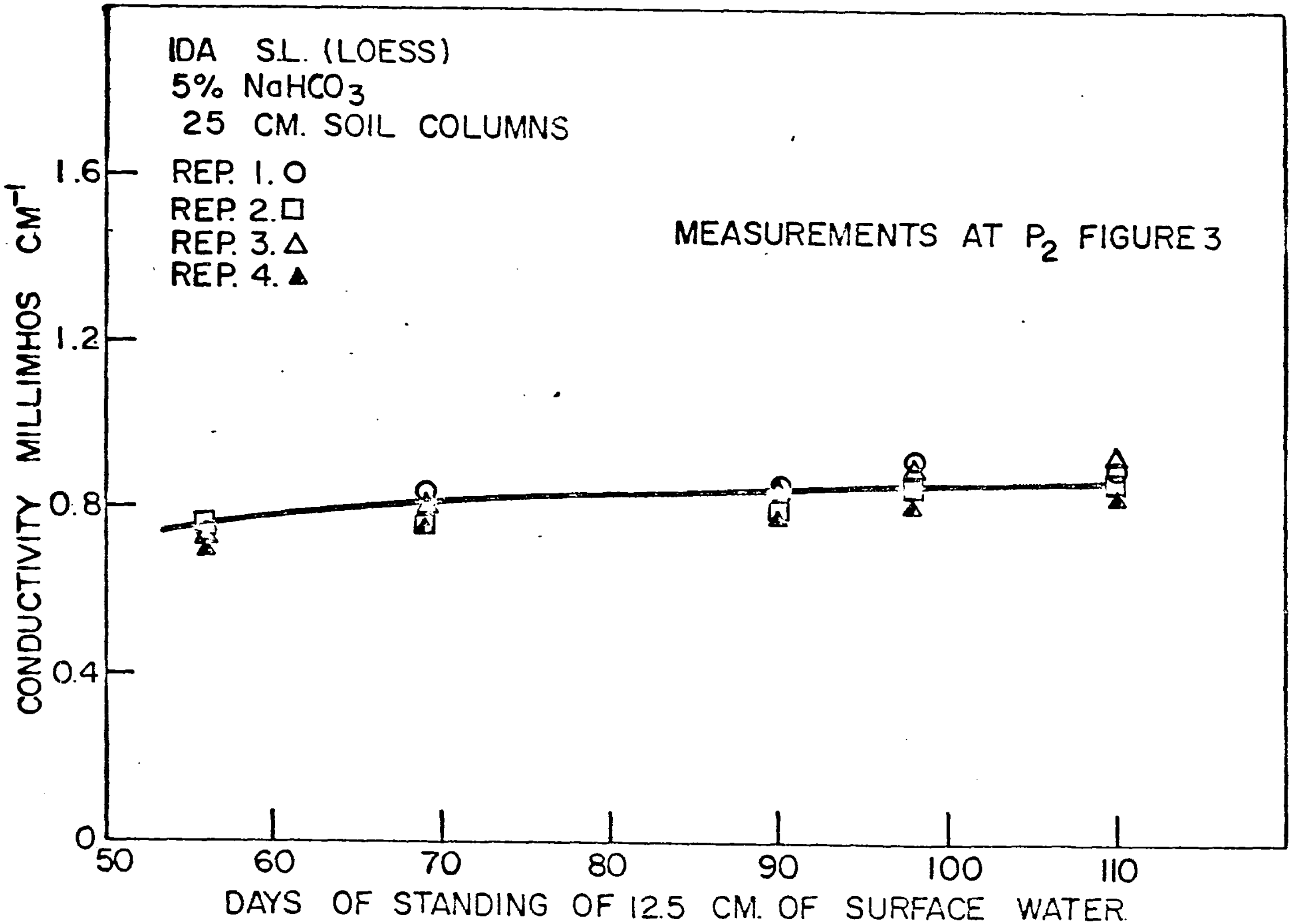

IDA S.L. (LOESS)
5% NaHCO3
25 CM. SOIL COLUMNS
REP. 1. ○
REP. 2. □
REP. 3. △
REP. 4. ▲
MEASUREMENTS AT P2 FIGURE 3
CONDUCTIVITY MILLIMHOS CM-1
1.6
1.2
0.8
0.4
0
50
60
70
80
90
100
110
DAYS OF STANDING OF 12.5 CM. OF SURFACE WATER

Figure 10. Conductivity versus time curve for 12.5 cm. of water standing on the surface of salinized soil with $NaHCO_3$ when the conductivity measurements were made at the central depth of the surface water after it had been stirred (point P_3, Figure 3). From days 0 to 70 water was added in weekly increments (total 7.5 cm. in 70 days) to the soil as needed to maintain the 12.5 cm. level. After 70 days no more water was added as the level stayed constant. Data for the four replicates shown are in Tables 6-9

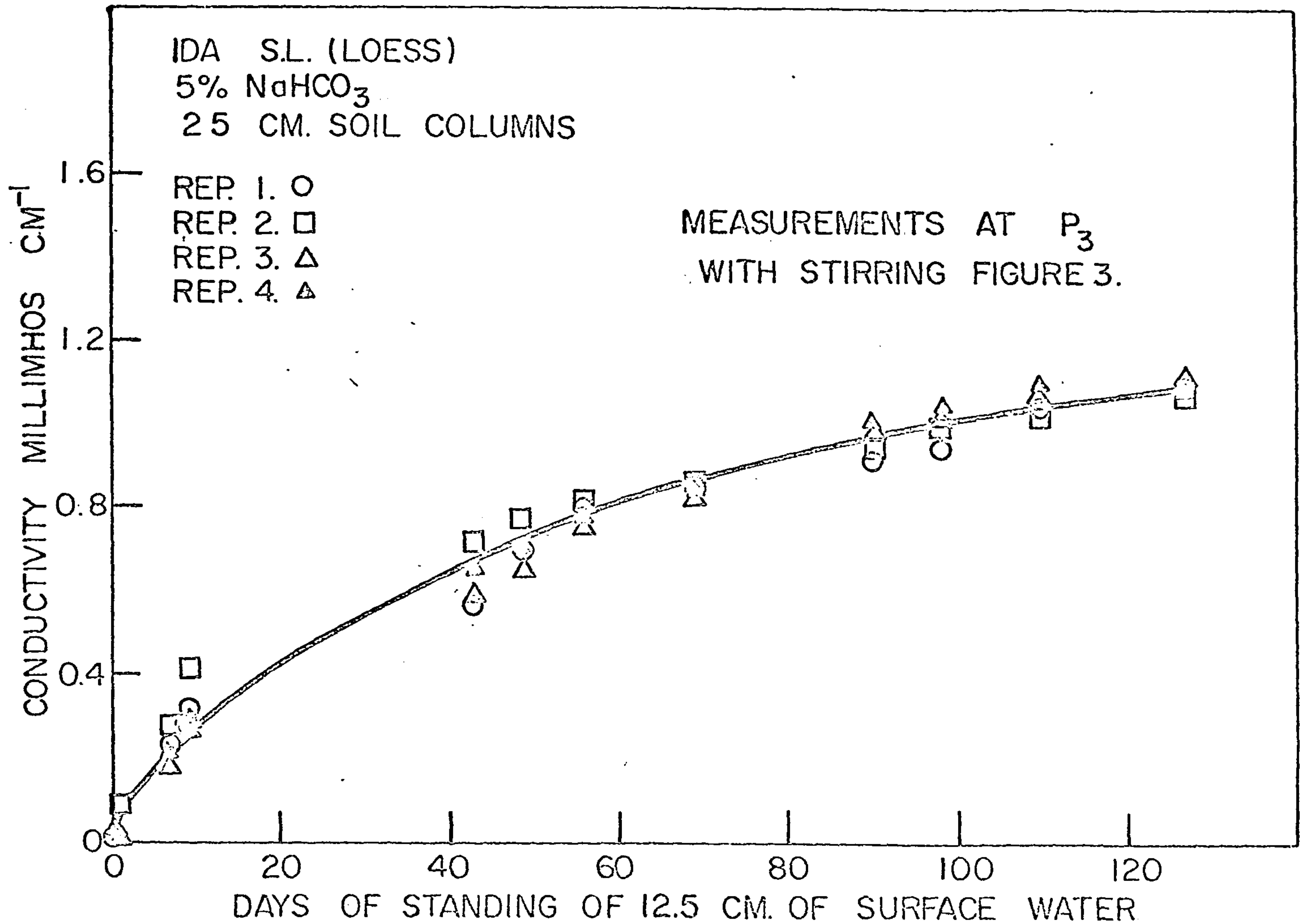

IDA S.L. (LOESS)
5% $NaHCO_3$
25 CM. SOIL COLUMNS
REP. 1. ○
REP. 2. □
REP. 3. △
REP. 4. ▲
MEASUREMENTS AT P_3
WITH STIRRING FIGURE 3.
CONDUCTIVITY MILLIMHOS CM^{-1}
1.6
1.2
0.8
0.4
0
0
20
40
60
80
100
120
DAYS OF STANDING OF 12.5 CM. OF SURFACE WATER

Figure 11. Retraced data curves (without data points) taken from Figures 8, 9 and 10 for $NaHCO_3$ silt, plotted on a single graph for comparison. Figure 11 may be compared with Figure 7 which is for NaCl

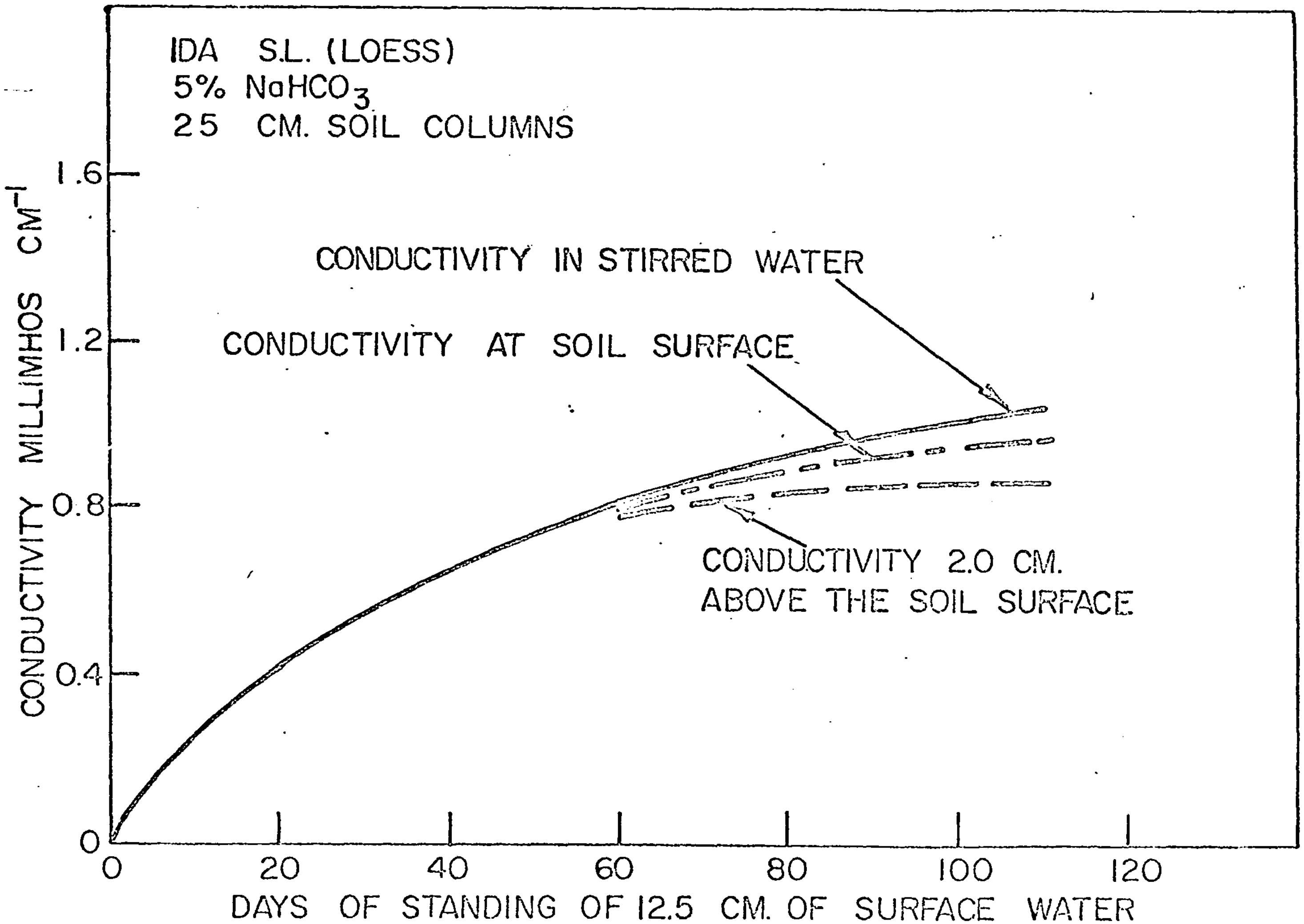

IDA S.L. (LOESS)
5% $NaHCO_3$
25 CM. SOIL COLUMNS
CONDUCTIVITY IN STIRRED WATER
CONDUCTIVITY AT SOIL SURFACE
CONDUCTIVITY 2.0 CM. ABOVE THE SOIL SURFACE
CONDUCTIVITY MILLIMHOS CM^{-1}
0
0.4
0.8
1.2
1.6
0
20
40
60
80
100
120
DAYS OF STANDING OF 12.5 CM. OF SURFACE WATER

Figure 12. Conductivity versus time curve for 12.5 cm. of water standing on the surface of salinized soil with Na_2SO_4 when the conductivity measurements were made just above the surface of the soil (point P_1, Figure 3). From days 0 to 70 water was added in weekly increments (total 7.5 cm. in 70 days) to the soil as needed to maintain the 12.5 cm. level. After 70 days no more water was added as the level stayed constant. Data for the three replicates shown are in Tables 10-12

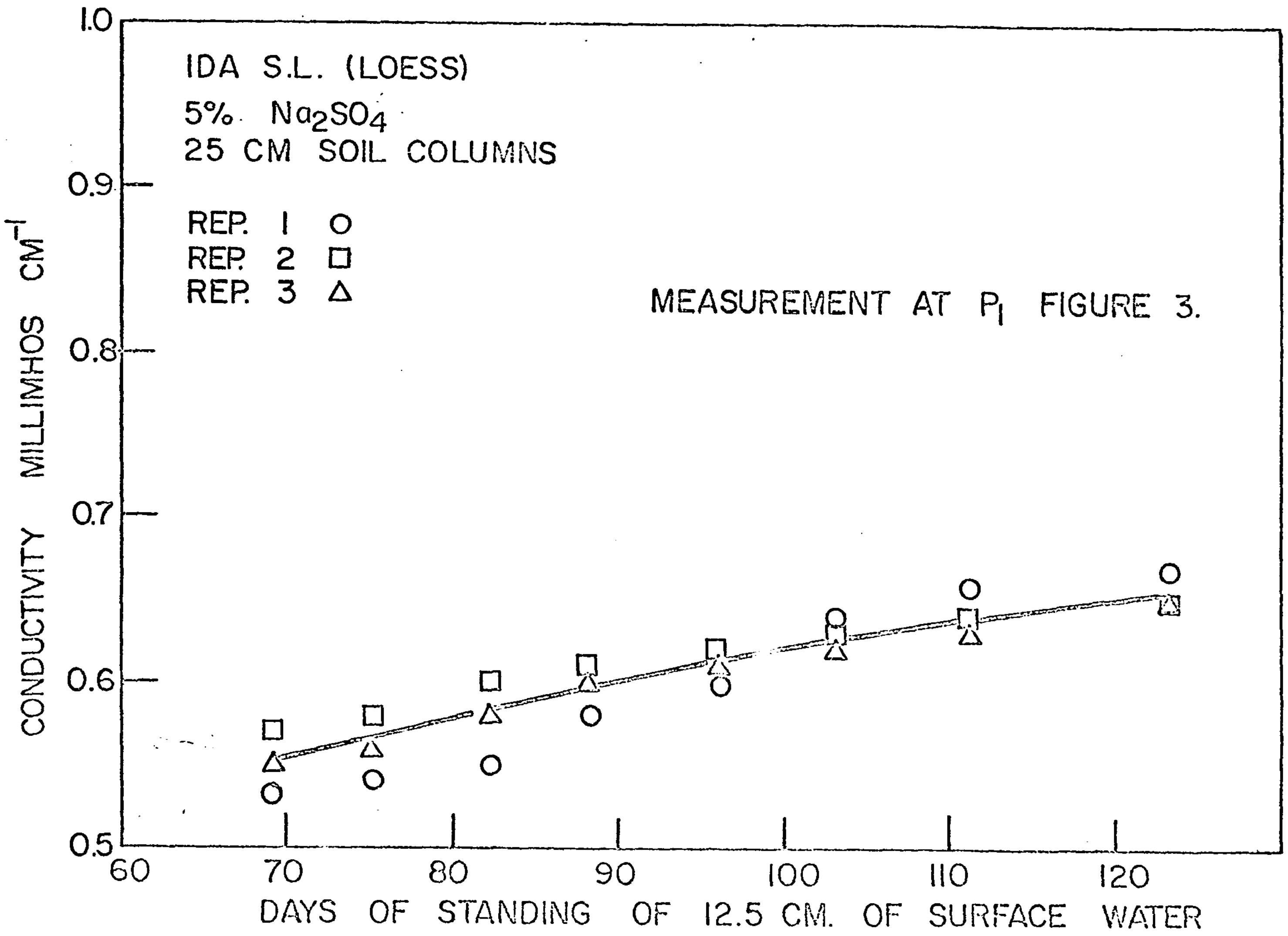

IDA S.L. (LOESS)
5% Na_2SO_4
25 CM SOIL COLUMNS
REP. 1 ○
REP. 2 □
REP. 3 △
MEASUREMENT AT P_1 FIGURE 3.
CONDUCTIVITY MILLIMHOS CM^{-1}
1.0
0.9
0.8
0.7
0.6
0.5
60
70
80
90
100
110
120
DAYS OF STANDING OF 12.5 CM. OF SURFACE WATER

Figure 13. Conductivity versus time curve for 12.5 cm. of water standing on the surface of salinized soil with Na_2SO_4 when the conductivity measurements were made 2.5 cm. above the surface of the soil (point P_2, Figure 3). From days 0 to 70 water was added in weekly increments (total 7.5 cm. in 70 days) to the soil as needed to maintain the 12.5 cm. level. After 70 days no more water was added as the level stayed constant. Data for the three replicates shown are in Tables 10-12

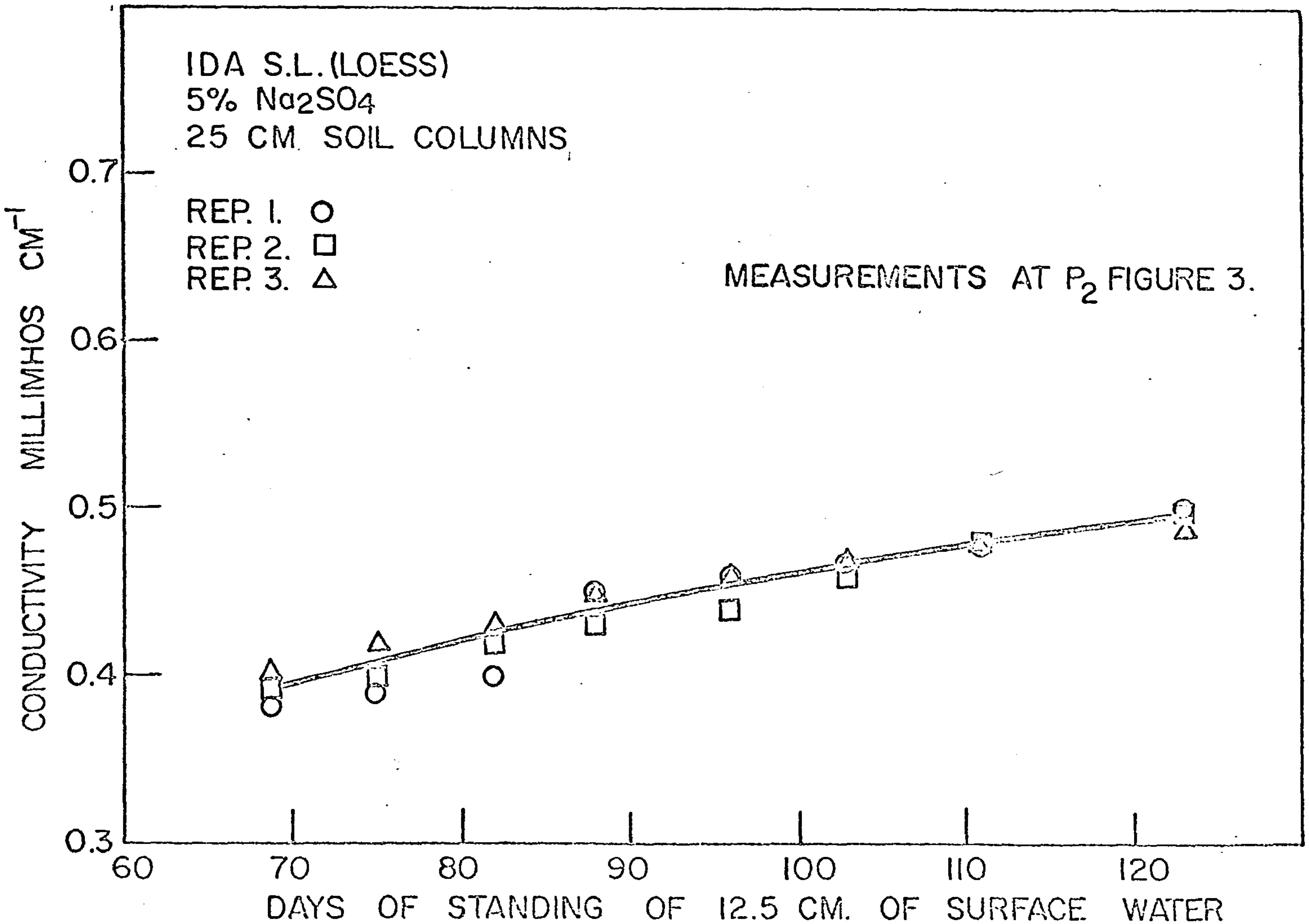
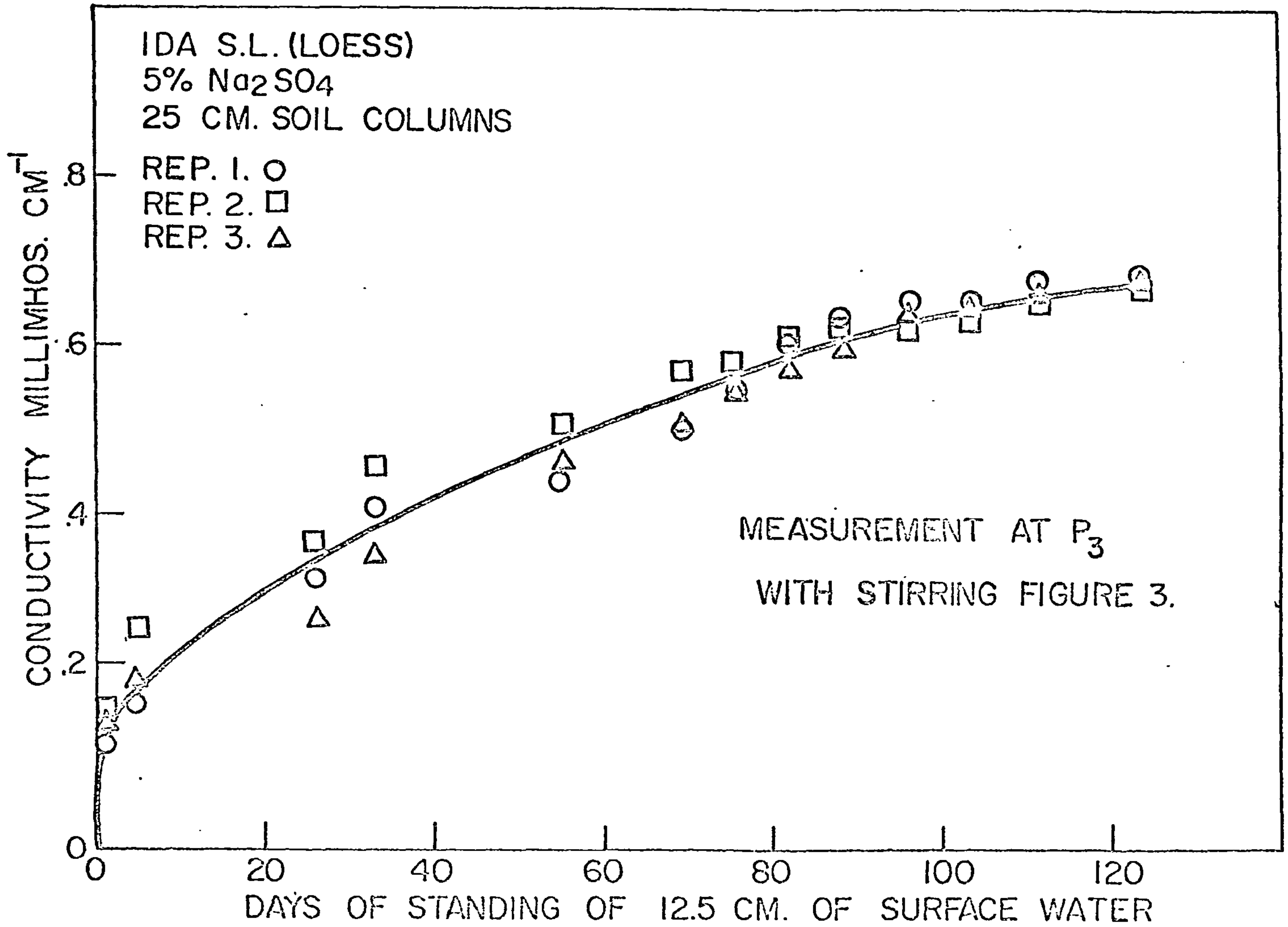

IDA S.L. (LOESS)
5% Na_2SO_4
25 CM. SOIL COLUMNS
REP. 1. ○
REP. 2. □
REP. 3. △
MEASUREMENTS AT P_2 FIGURE 3.
0.7
0.6
0.5
0.4
0.3
60
70
80
90
100
110
120
CONDUCTIVITY MILLIMHOS CM^{-1}
DAYS OF STANDING OF 12.5 CM. OF SURFACE WATER

Figure 14. Conductivity versus time curve for 12.5 cm. of water standing on the surface of salinized soil Na_2SO_4 when the conductivity measurements were made at the central depth of the surface water after it had been stirred (point P_3, Figure 3). From days 0 to 70 water was added in weekly increments (total 7.5 cm. in 70 days) to the soil as needed to maintain the 12.5 cm. level. After 70 days no more water was added as the level stayed constant. Data for the three replicates are in Tables 10-12



MEASUREMENT AT P_3 WITH STIRRING FIGURE 3.

Figure 15. Retraced data curves (without data points) taken from Figures 12, 13 and 14, for Na_2SO_4, plotted on a single graph for comparison, Figure 15 may be compared with Figures 7 and 11

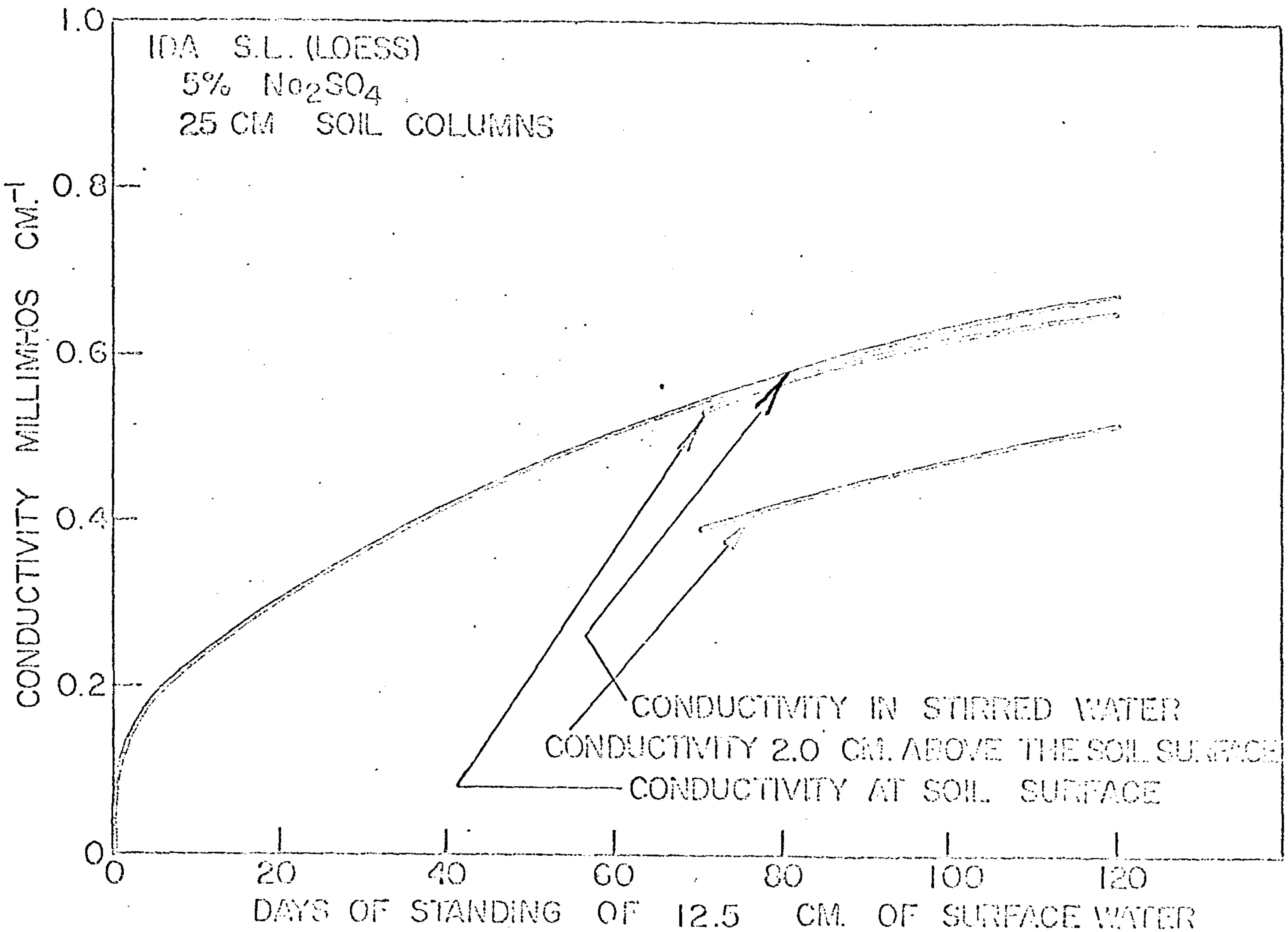

IDA S.L. (LOESS)
5% Na_2SO_4
25 CM SOIL COLUMNS
CONDUCTIVITY MILLIMHOS $CM.^{-1}$
1.0
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
120
DAYS OF STANDING OF 12.5 CM. OF SURFACE WATER
CONDUCTIVITY IN STIRRED WATER
CONDUCTIVITY 2.0 CM. ABOVE THE SOIL SURFACE
CONDUCTIVITY AT SOIL SURFACE

Figure 16. Retraced curves (without data points) for Figures 6, 10 and 14 to show influence of type of salt on the conductivity (salt concentration) observed in the standing surface water. NaCl diffused much more than the two other salts

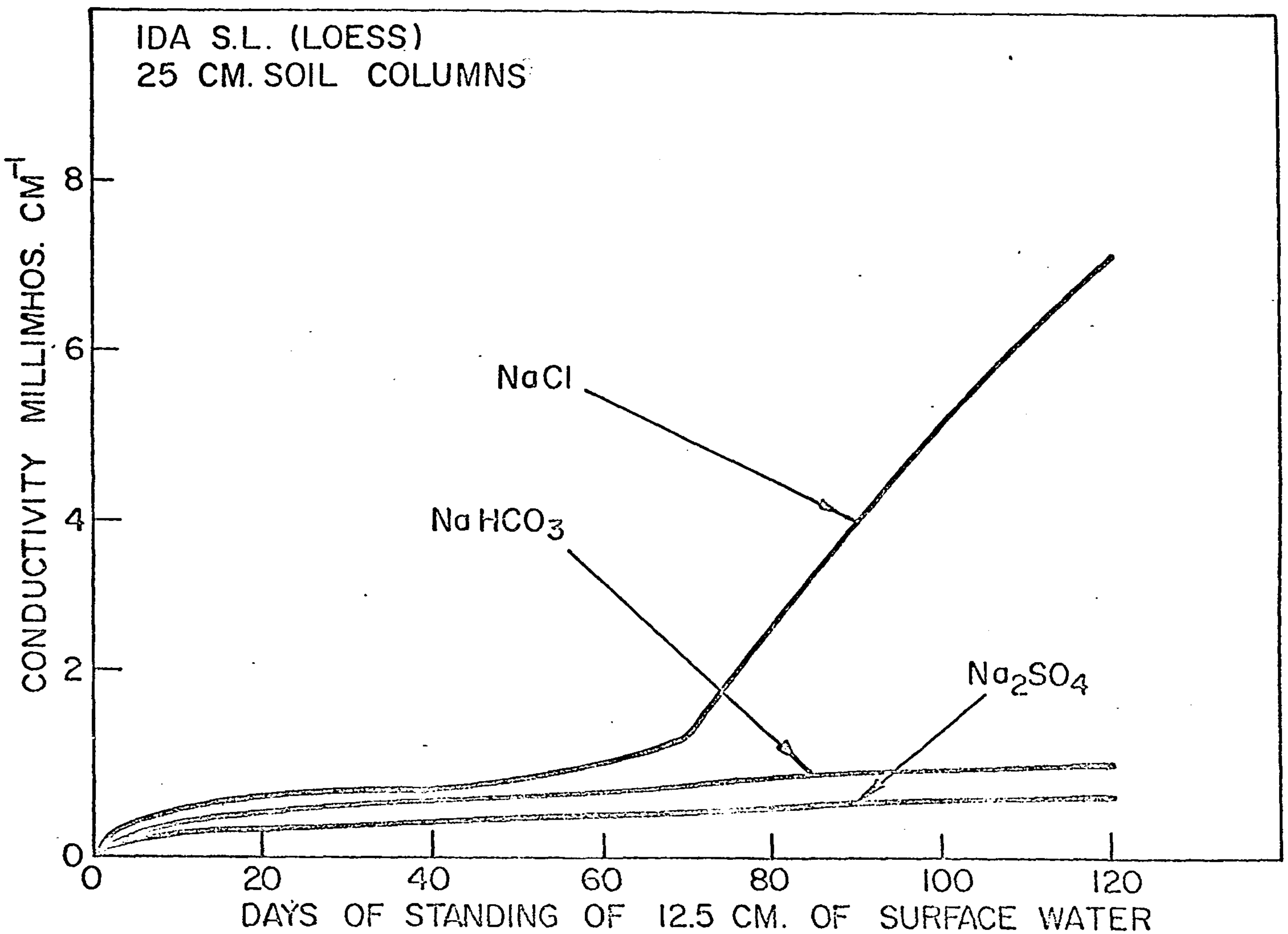
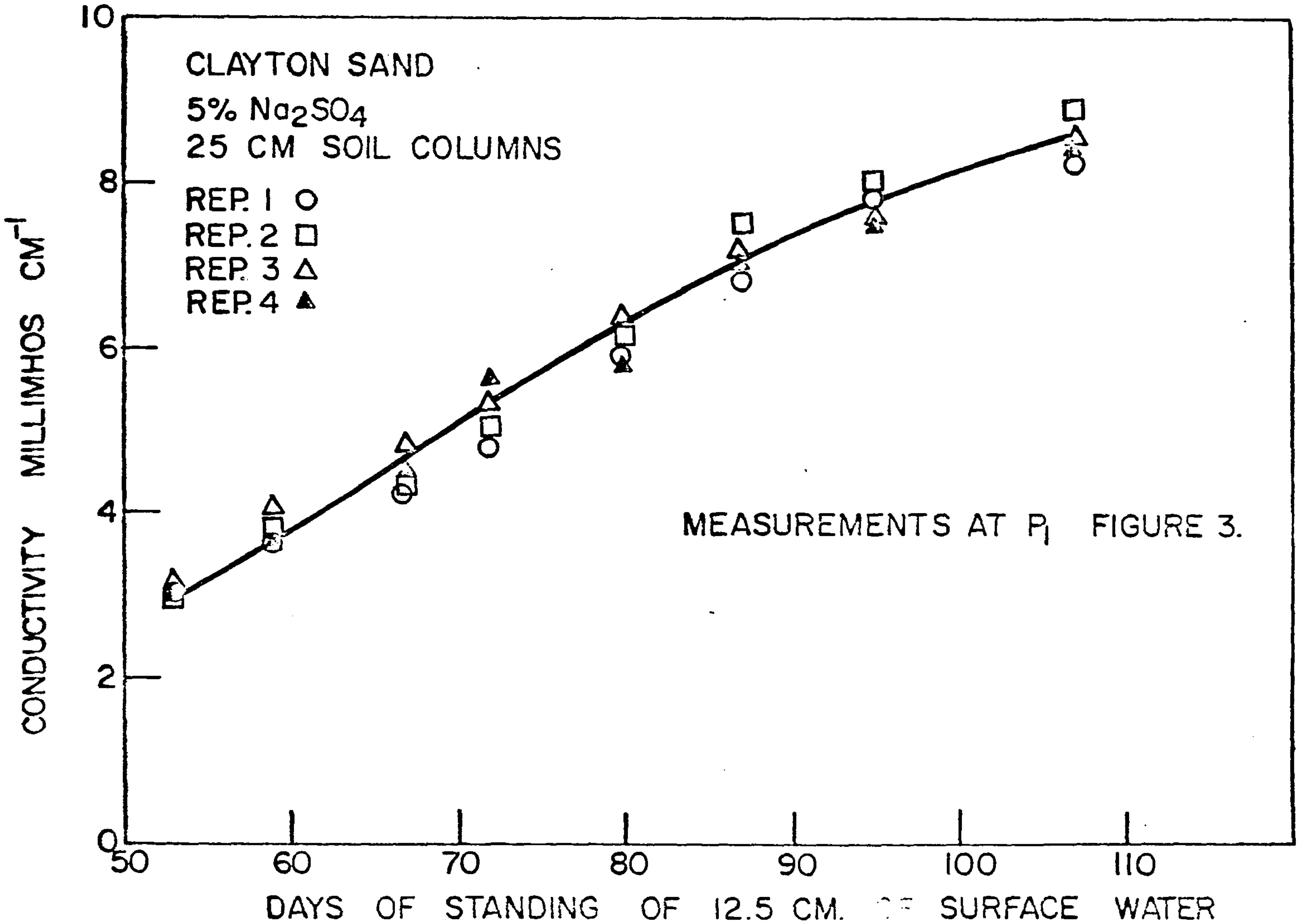

IDA S.L. (LOESS)
25 CM. SOIL COLUMNS
CONDUCTIVITY MILLIMHOS. CM^{-1}
NaCl
NaHCO$_3$
Na$_2$SO$_4$
0
2
4
6
8
20
40
60
80
100
120
DAYS OF STANDING OF 12.5 CM. OF SURFACE WATER

Figure 17. Conductivity versus time curve for 12.5 cm. of water standing on the surface of salinized Clayton sand with Na_2SO_4 when the conductivity measurements were made just above the surface of the sand (point P_1, Figure 3). Water was added at start of experiment (total 18.75 cm.). Data for the four replicates shown are in Tables 13-16



MEASUREMENTS AT P_1 FIGURE 3.

Figure 18. Conductivity versus time curve for 12.5 cm. of water standing on the surface of salinized Clayton sand with Na_2SO_4 when the conductivity measurements were made at 2.5 cm. (point P_2, Figure 3) above the sand surface. Water was added at start of experiment (total 18.75 cm.). Data for the four replicates shown are in Tables 13-16

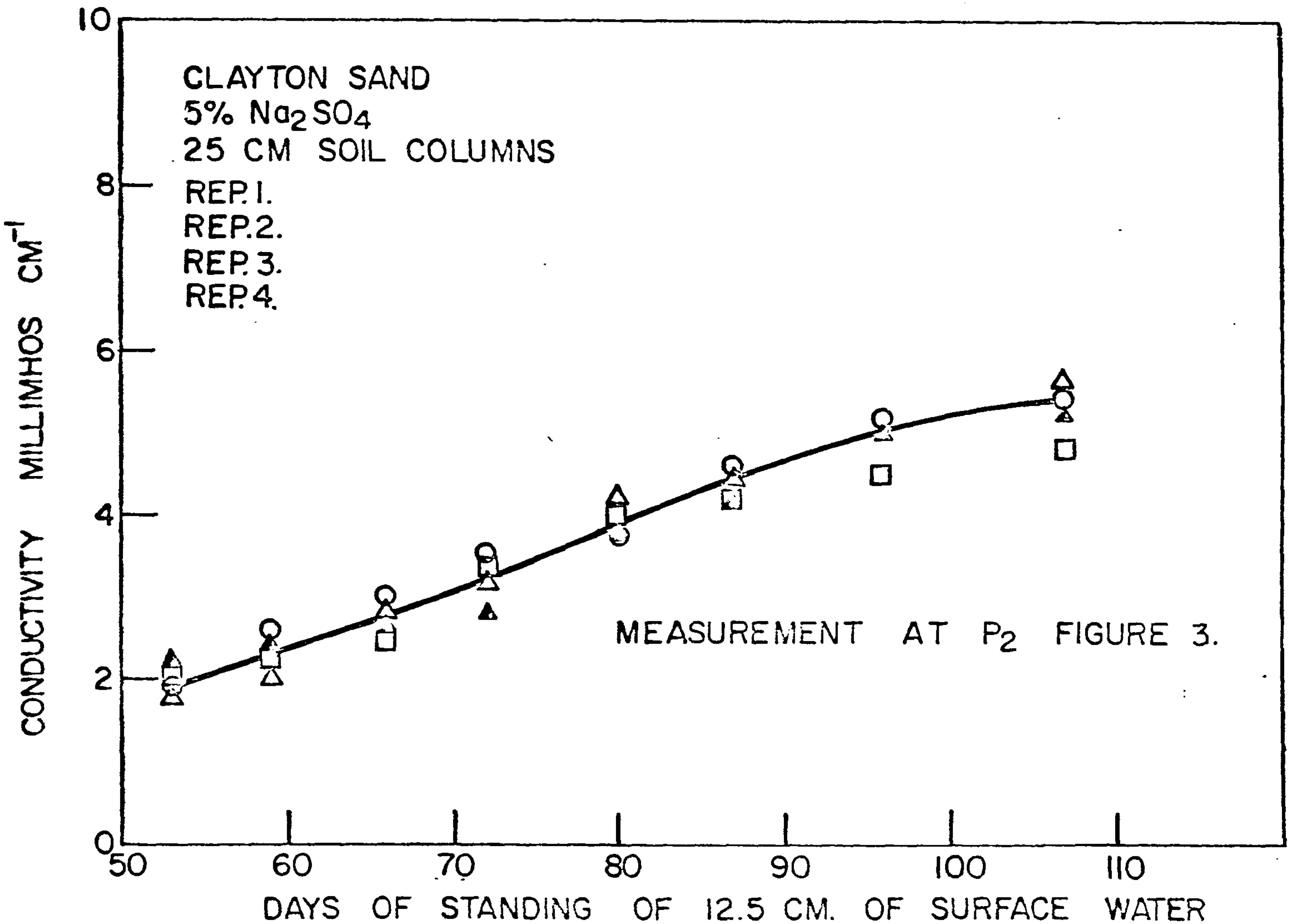

CLAYTON SAND
5% Na_2SO_4
25 CM SOIL COLUMNS
REP. 1.
REP. 2.
REP. 3.
REP. 4.
MEASUREMENT AT P_2 FIGURE 3.
CONDUCTIVITY MILLIMHOS CM^{-1}
DAYS OF STANDING OF 12.5 CM. OF SURFACE WATER
0
2
4
6
8
10
50
60
70
80
90
100
110

Figure 19. Conductivity versus time curve for 12.5 cm. of water standing on the surface of salinized Clayton sand with Na_2SO_4 when the conductivity measurements were made at the central depth of the surface water after it had been stirred (point P_3, Figure 3). Water was added at start of experiment (total 18.75 cm.). Data for the four replicates shown are in Tables 13-16

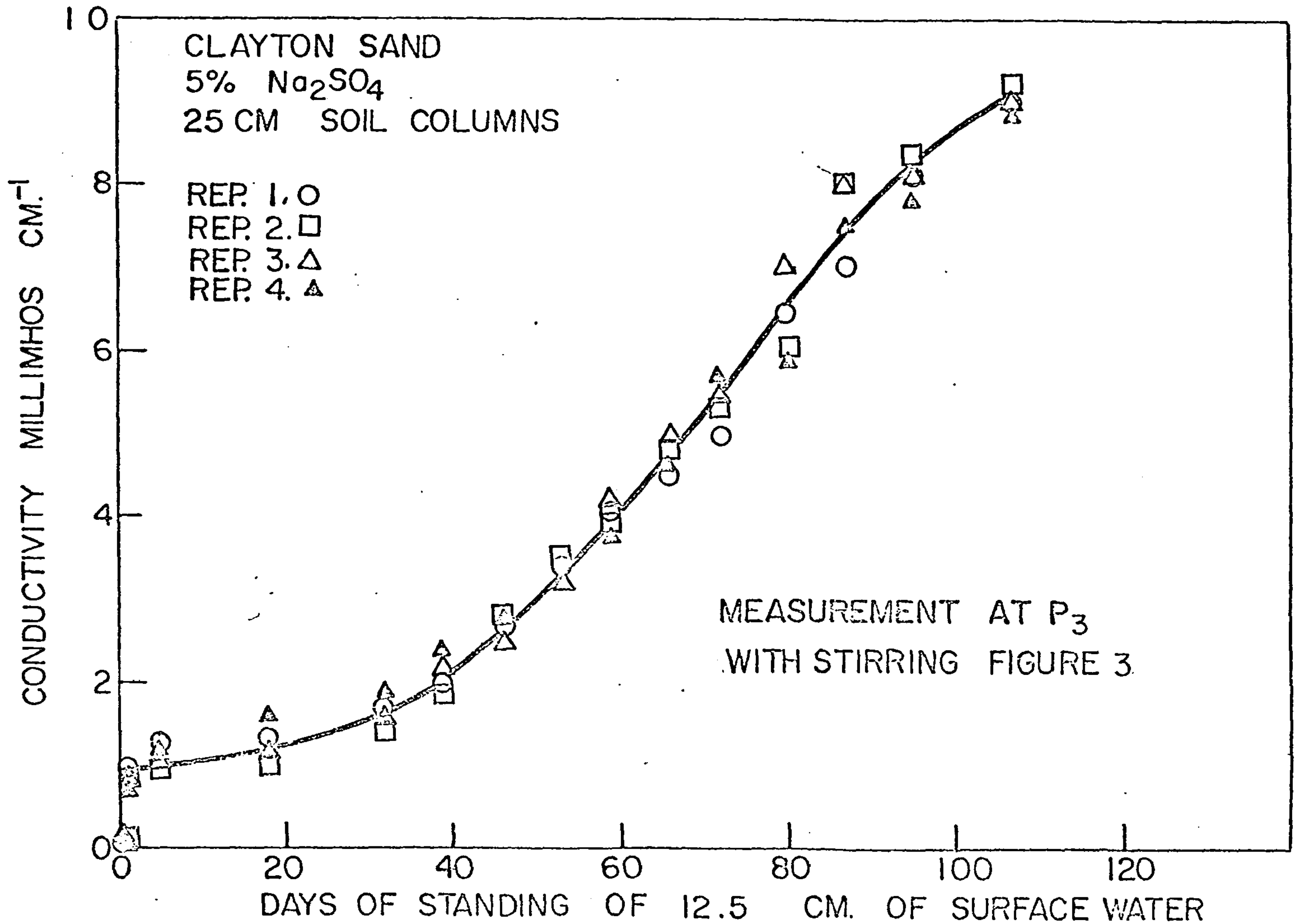

CLAYTON SAND
5% Na_2SO_4
25 CM SOIL COLUMNS
REP. 1. ○
REP. 2. □
REP. 3. △
REP. 4. ▲
MEASUREMENT AT P_3
WITH STIRRING FIGURE 3
CONDUCTIVITY MILLIMHOS CM^{-1}
DAYS OF STANDING OF 12.5 CM. OF SURFACE WATER
0
2
4
6
8
10
0
20
40
60
80
100
120

Figure 20. Retraced data curves (without data points) for the Clayton sand and the Na_2SO_4 of Figures 17, 18 and 19, to show how the conductivity varies with time for points P_1, P_2 and P_3 (with stirring) of Figure 3. Figure 20 may be compared with Figure 15 of the Ida silt loam salinized with Na_2SO_4

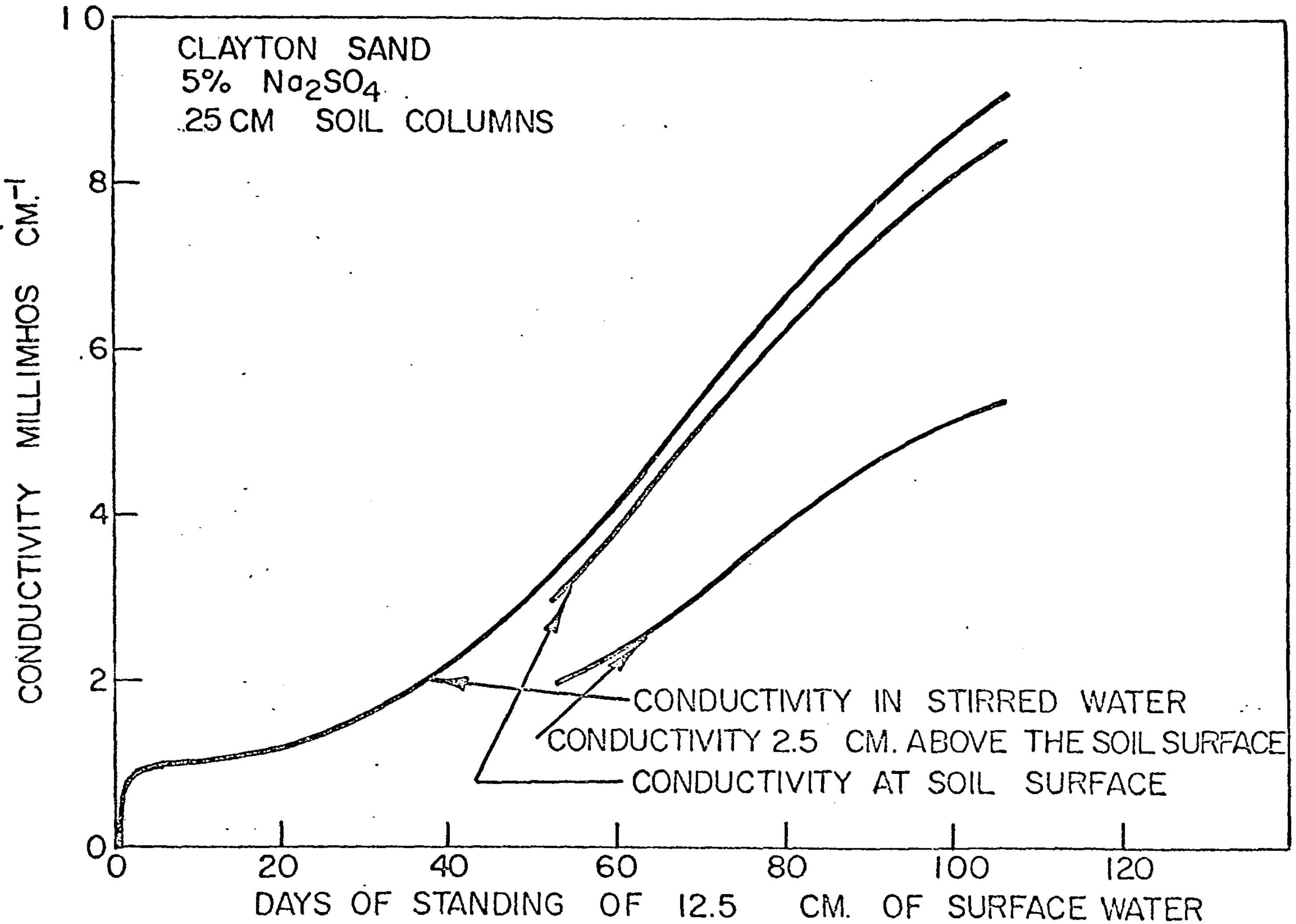
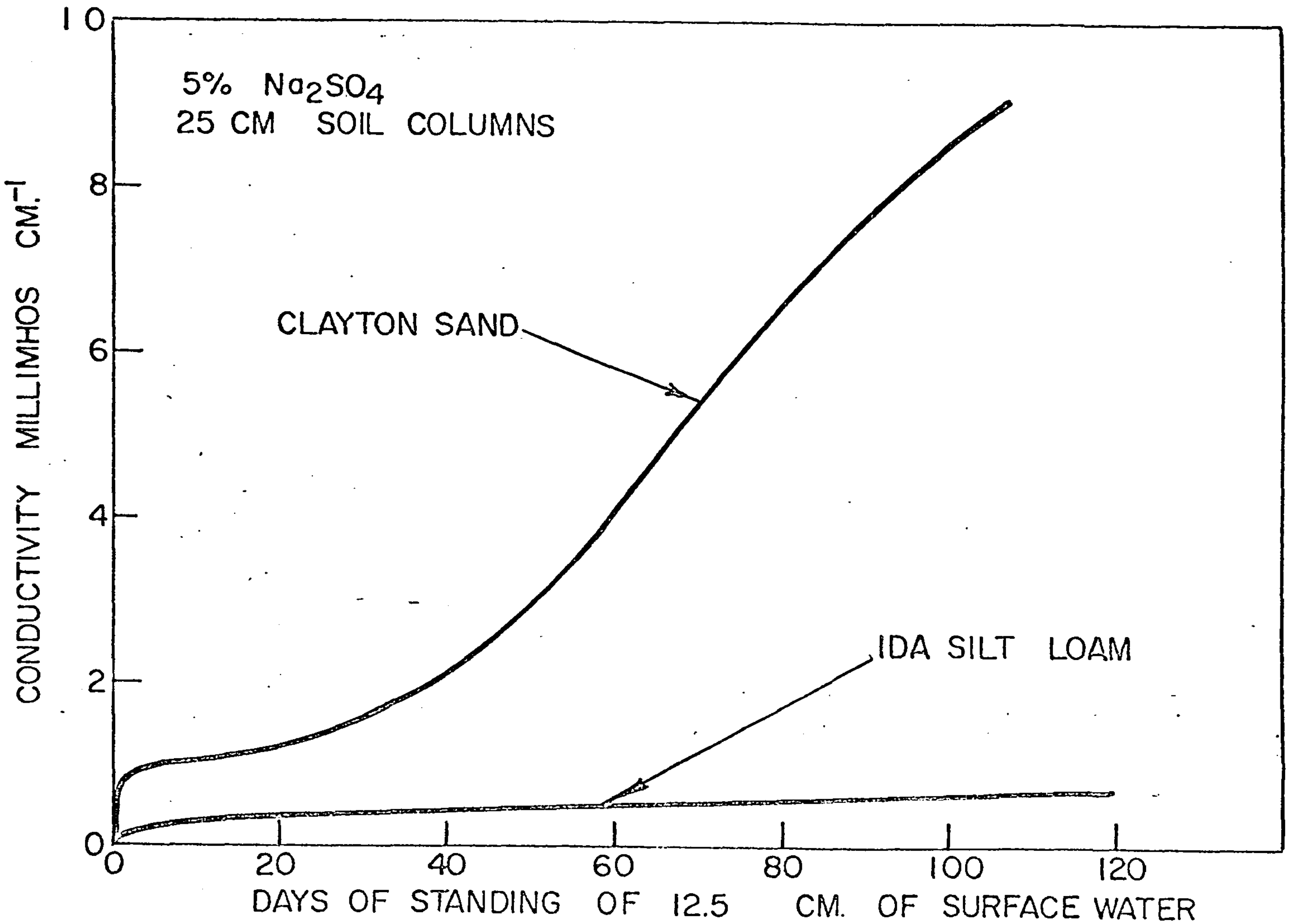

CLAYTON SAND
5% Na_2SO_4
25 CM SOIL COLUMNS
CONDUCTIVITY MILLIMHOS CM.$^{-1}$
CONDUCTIVITY IN STIRRED WATER
CONDUCTIVITY 2.5 CM. ABOVE THE SOIL SURFACE
CONDUCTIVITY AT SOIL SURFACE
DAYS OF STANDING OF 12.5 CM. OF SURFACE WATER
1.0
.8
.6
.4
.2
0
0
20
40
60
80
100
120

Figure 21. Retraced curves (without data points) taken from Figures 15 and 20 and plotted on the same graph for comparison


5% Na_2SO_4
25 CM SOIL COLUMNS
CLAYTON SAND
IDA SILT LOAM
CONDUCTIVITY MILLIMHOS CM.$^{-1}$
DAYS OF STANDING OF 12.5 CM. OF SURFACE WATER
0
2
4
6
8
10
0
20
40
60
80
100
120

the curves of Figure 21 differ markedly, suggesting a large difference between the Clayton sand and the Ida loess. It is apparent that for the Ida loess a large number of smaller pores act as static sinks to salt diffusion. That is, no salt diffuses from these small pores. The larger the pores contained in the porous media the greater is the diffusion influence -- at least for the same time lapse. Water from smaller pores interdiffuses into the big pores when drains are stopped. In Figure 21 the conductivity values for the Clayton sand were more than nine times those of the Ida soil after 60 days of standing of surface water.

A few other data for 6 columns of 50 centimeters length are shown in previously cited Table 1.

Figures 22-24, 26, 27 and 29, show that in all cases the conductivity is always higher in the stirred water (point P_3, Figure 3) than in the water at the soil surface (point P_1). Figures 25 and 28 confirm the result obtained before (Figure 16) indicating that diffusion is always greater for sodium chloride than for sodium bicarbonate or for sodium sulfate.

Figure 30 emphasizes that diffusion works more actively in the case of sand than in the glass beads or in the silt loam for the first 86 days of lapsed time. After this time the diffusion is greater in the glass beads indicating an important result, namely, the diffusion coefficient is not constant for all the time lapse. This diffusion coefficient may start with small values, getting larger and larger with time depending upon many factors among which are the type of salt, the size of pores contained in the porous medium, depth of soil and the time. It also can be concluded that the amounts of salt that will diffuse into the soil surface water even up to 130 days of leaching are small, and it is recommended that the soil be stirred in the upper few inches of depth by plowing as the Egyptian buffaloes do as they go over a flooded soil, if this method is used for leaching.

It is also recommended not to leave the water standing on the soil surface for a great length of time since the experiment results showed practically no movement of leaching water through the soil profile. The hydraulic conductivity was apparently reduced to essentially zero due to the effect of the sodium salts. Flooding with water for a great length of time may affect the structure of crystal lattices or may destroy the micro-crystals, even the diffusion action of sodium salts is increased by time duration.

Figure 22. Conductivity versus time of 29.37 cm. of water standing on the surface of a salinized column of 50 cm. length of Ida loess salinized with NaCl, when the conductivity measurements were made as indicated. Data shown are in Table 17

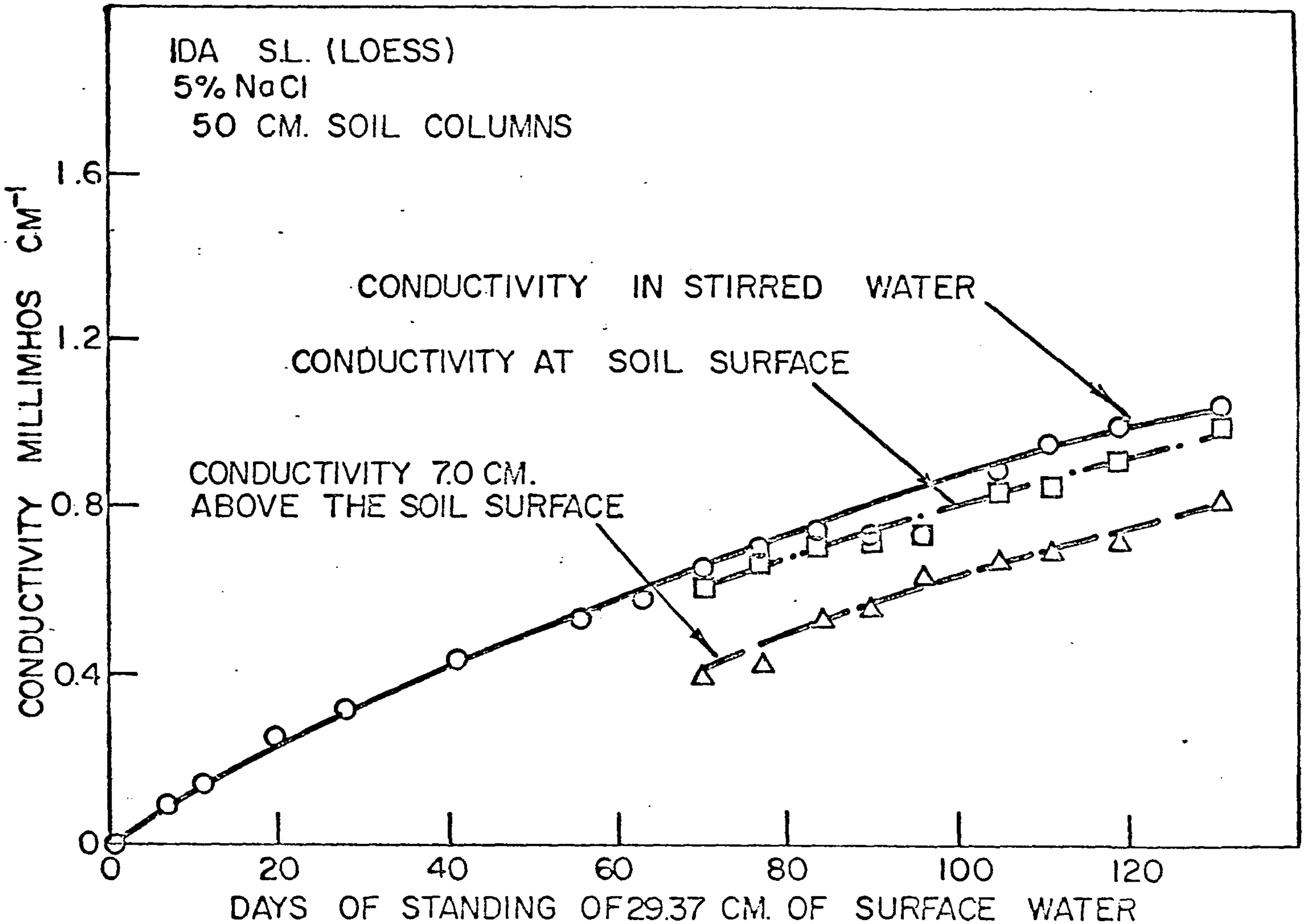

IDA S.L. (LOESS)
5% NaCl
50 CM. SOIL COLUMNS
CONDUCTIVITY IN STIRRED WATER
CONDUCTIVITY AT SOIL SURFACE
CONDUCTIVITY 7.0 CM.
ABOVE THE SOIL SURFACE
CONDUCTIVITY MILLIMHOS CM^{-1}
0
0.4
0.8
1.2
1.6
0
20
40
60
80
100
120
DAYS OF STANDING OF 29.37 CM. OF SURFACE WATER

Figure 23. Conductivity versus time of 29.37 cm. of water standing on the surface of a salinized column of 50 cm. length of Ida loess salinized with $NaHCO_3$, when the conductivity measurements were made as indicated. Data shown are in Table 18

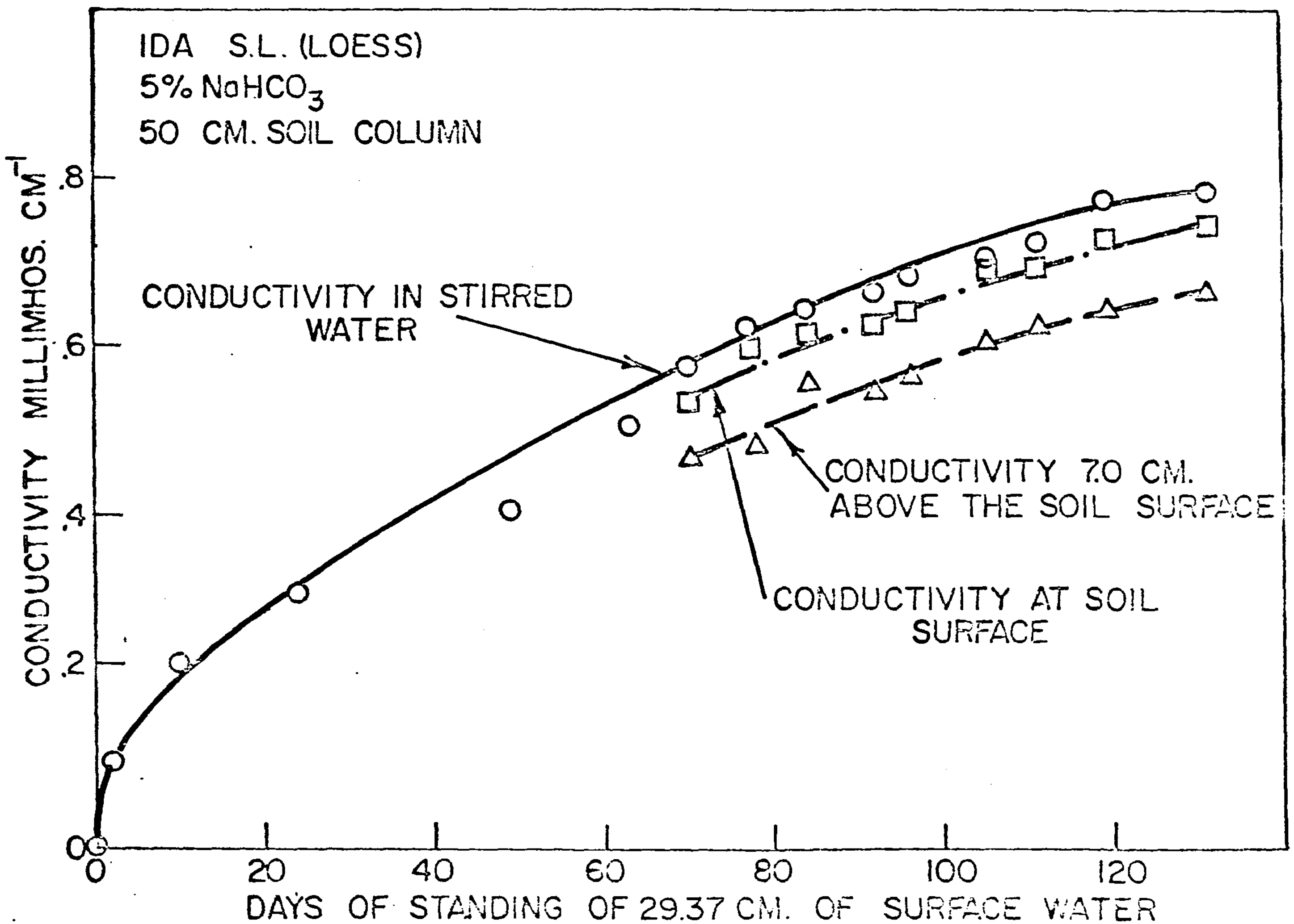
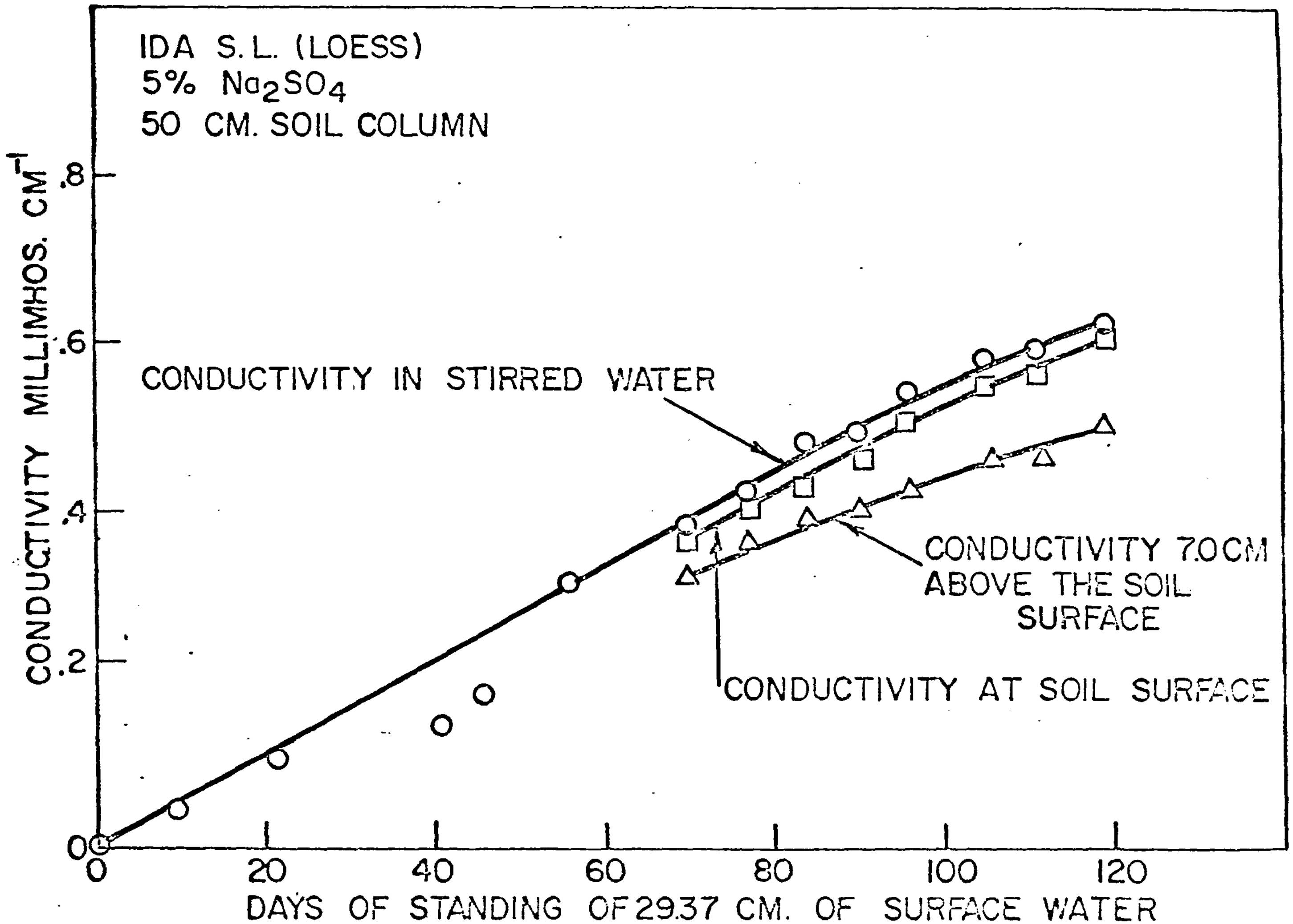

IDA S.L. (LOESS)
5% NaHCO3
50 CM. SOIL COLUMN
CONDUCTIVITY MILLIMHOS. CM-1
CONDUCTIVITY IN STIRRED WATER
CONDUCTIVITY 7.0 CM. ABOVE THE SOIL SURFACE
CONDUCTIVITY AT SOIL SURFACE
0
.2
.4
.6
.8
0
20
40
60
80
100
120
DAYS OF STANDING OF 29.37 CM. OF SURFACE WATER

Figure 24. Conductivity versus time of 29.37 cm. of water standing on the surface of a salinized column of 50 cm. length of the Ida loess salinized with Na_2SO_4, when the conductivity measurements were made as indicated. Data shown are in Table 19



IDA S.L. (LOESS)
5% Na_2SO_4
50 CM. SOIL COLUMN
CONDUCTIVITY MILLIMHOS. CM^{-1}
.8
.6
.4
.2
0
CONDUCTIVITY IN STIRRED WATER
CONDUCTIVITY 7.0 CM ABOVE THE SOIL SURFACE
CONDUCTIVITY AT SOIL SURFACE
0
20
40
60
80
100
120
DAYS OF STANDING OF 29.37 CM. OF SURFACE WATER

Figure 25. Retraced curves (without data points) for Figures 21, 22 and 23 to show influence of type of salt on the conductivity (salt concentration) observed in the standing surface water for 50 cm. columns of Ida loess

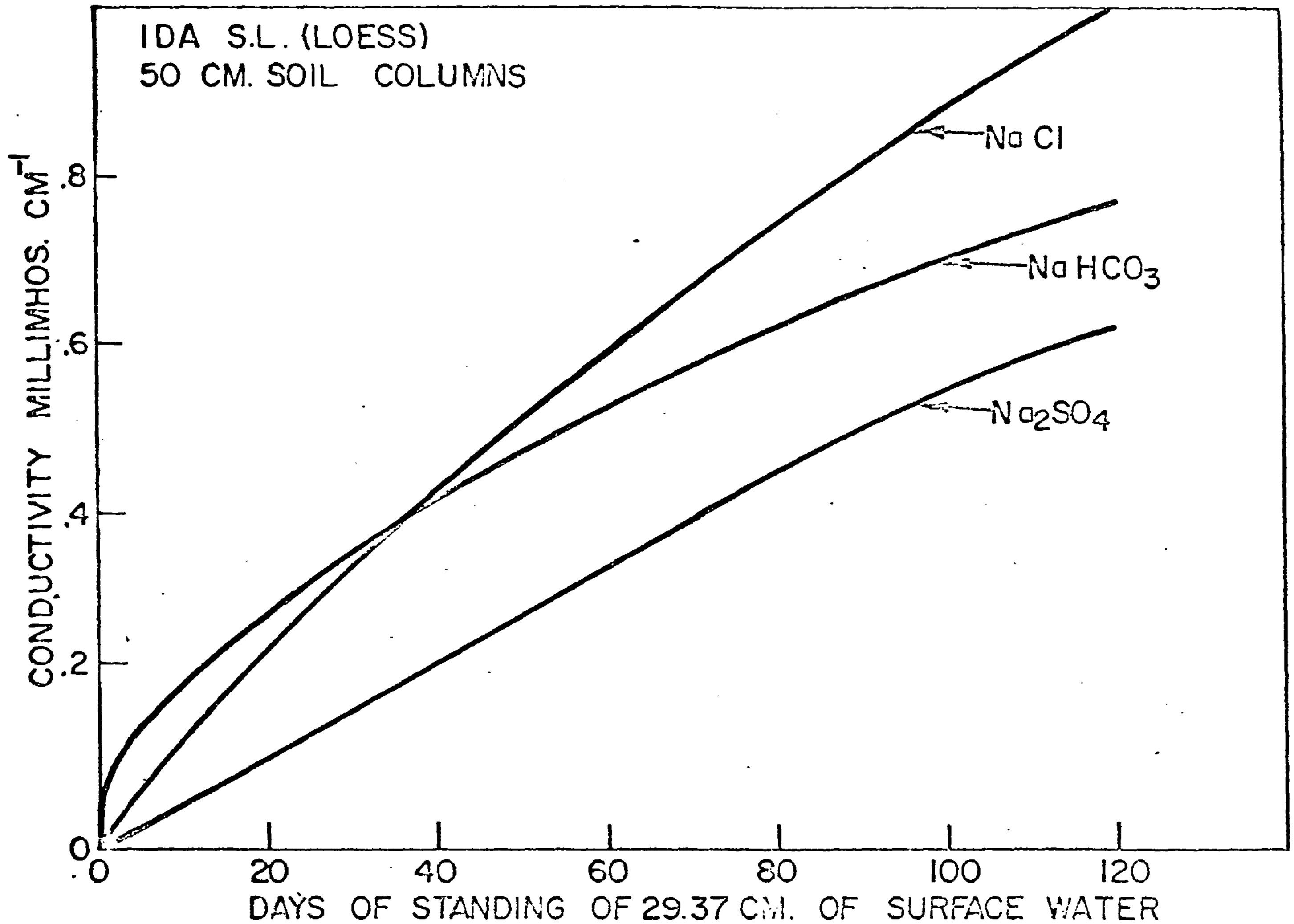

IDA S.L. (LOESS)
50 CM. SOIL COLUMNS
Na Cl
Na HCO3
Na2SO4
CONDUCTIVITY MILLIMHOS. CM-1
0
.2
.4
.6
.8
0
20
40
60
80
100
120
DAYS OF STANDING OF 29.37 CM. OF SURFACE WATER

Figure 26. Conductivity versus time of 37.0 cm. of water standing on the surface of salinized sand column of 50 cm. length, when the conductivity measurements are made as indicated. Data shown are in Table 20

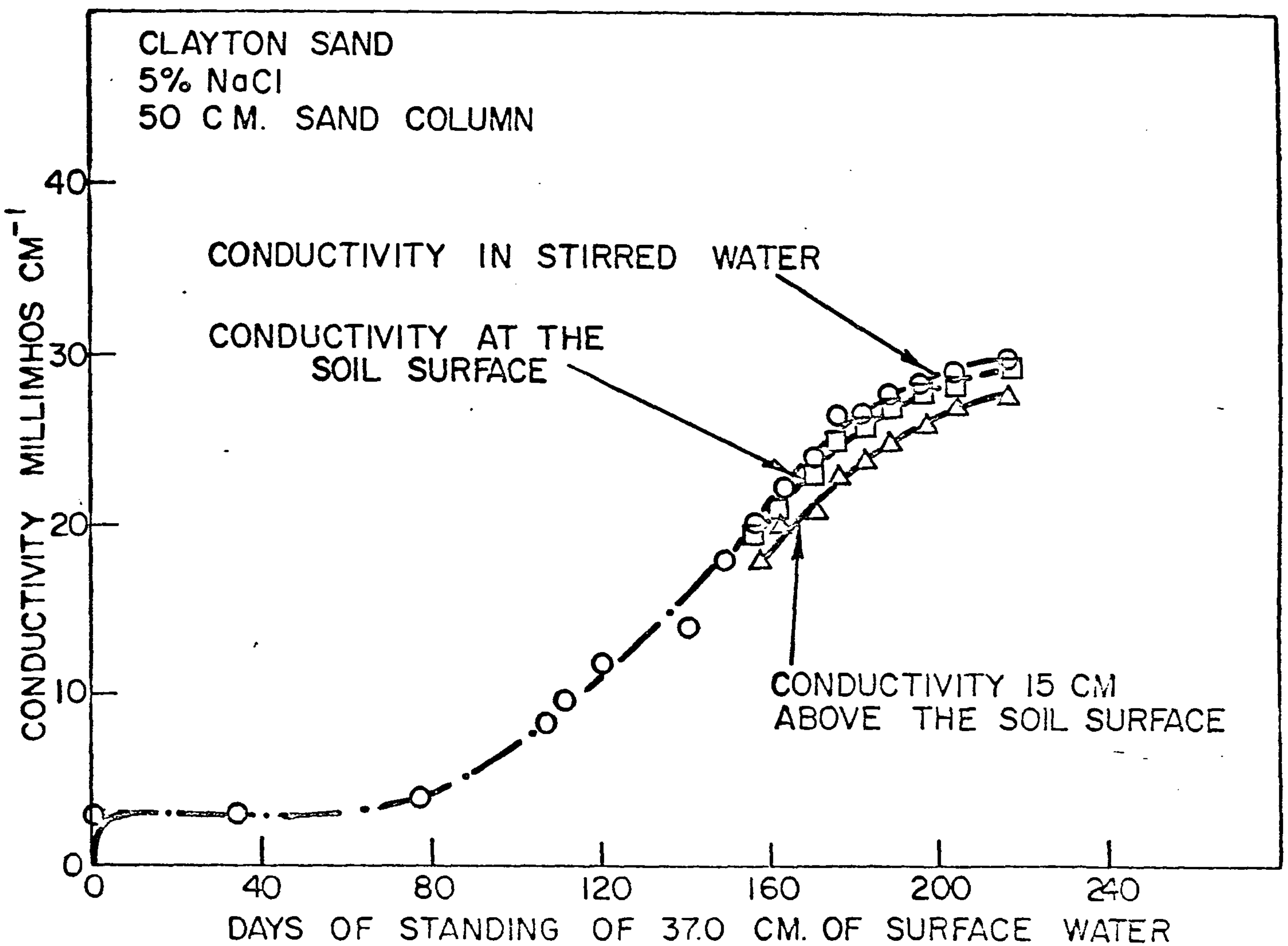

CLAYTON SAND
5% NaCl
50 C M. SAND COLUMN
CONDUCTIVITY IN STIRRED WATER
CONDUCTIVITY AT THE SOIL SURFACE
CONDUCTIVITY 15 CM ABOVE THE SOIL SURFACE
CONDUCTIVITY MILLIMHOS CM^{-1}
0
10
20
30
40
0
40
80
120
160
200
240
DAYS OF STANDING OF 37.0 CM. OF SURFACE WATER

Figure 27. Conductivity versus time of 37.0 cm. of water standing on the surface of salinized Clayton sand column salinized with $NaHCO_3$ of 50 cm. length, when the conductivity measurements were made as indicated. Data shown are in Table 21

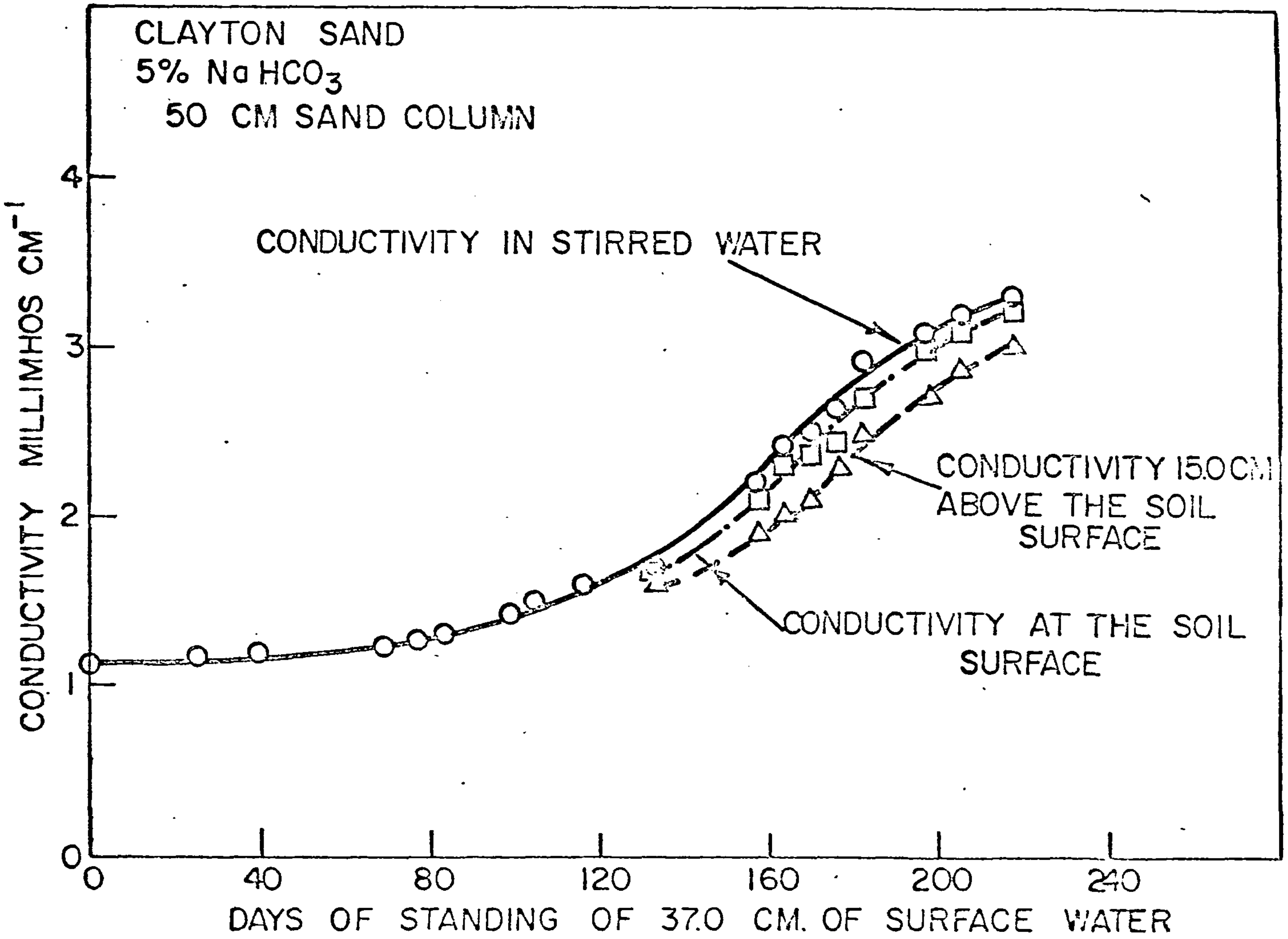
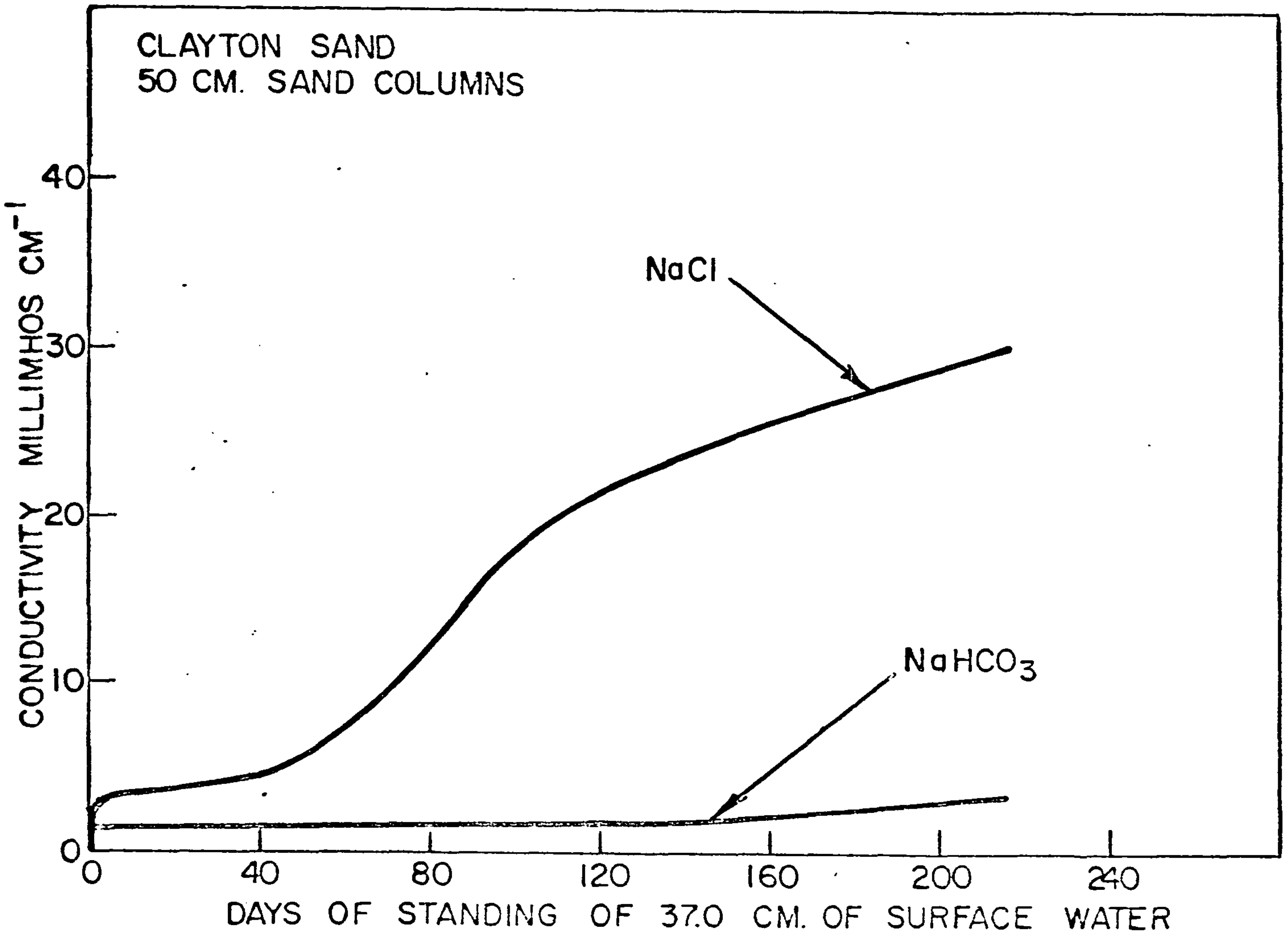

CLAYTON SAND
5% Na HCO3
50 CM SAND COLUMN
CONDUCTIVITY IN STIRRED WATER
CONDUCTIVITY 15.0 CM ABOVE THE SOIL SURFACE
CONDUCTIVITY AT THE SOIL SURFACE
CONDUCTIVITY MILLIMHOS CM^{-1}
0
1
2
3
4
0
40
80
120
160
200
240
DAYS OF STANDING OF 37.0 CM. OF SURFACE WATER

Figure 28. Retraced curves (without data points) for Figures 26 and 27 to show influence of type of salt on the conductivity (salt concentration) observed in the standing surface water for 50 cm. columns of Clayton sand



CLAYTON SAND
50 CM. SAND COLUMNS
NaCl
NaHCO3
CONDUCTIVITY MILLIMHOS CM-1
0
10
20
30
40
0
40
80
120
160
200
240
DAYS OF STANDING OF 37.0 CM. OF SURFACE WATER

Figure 29. Conductivity versus time of 37.0 cm. of water standing on the surface of salinized 28 micron glass beads column of 50 cm. length, when the conductivity measurements are made as indicated. Data show are in Table 22

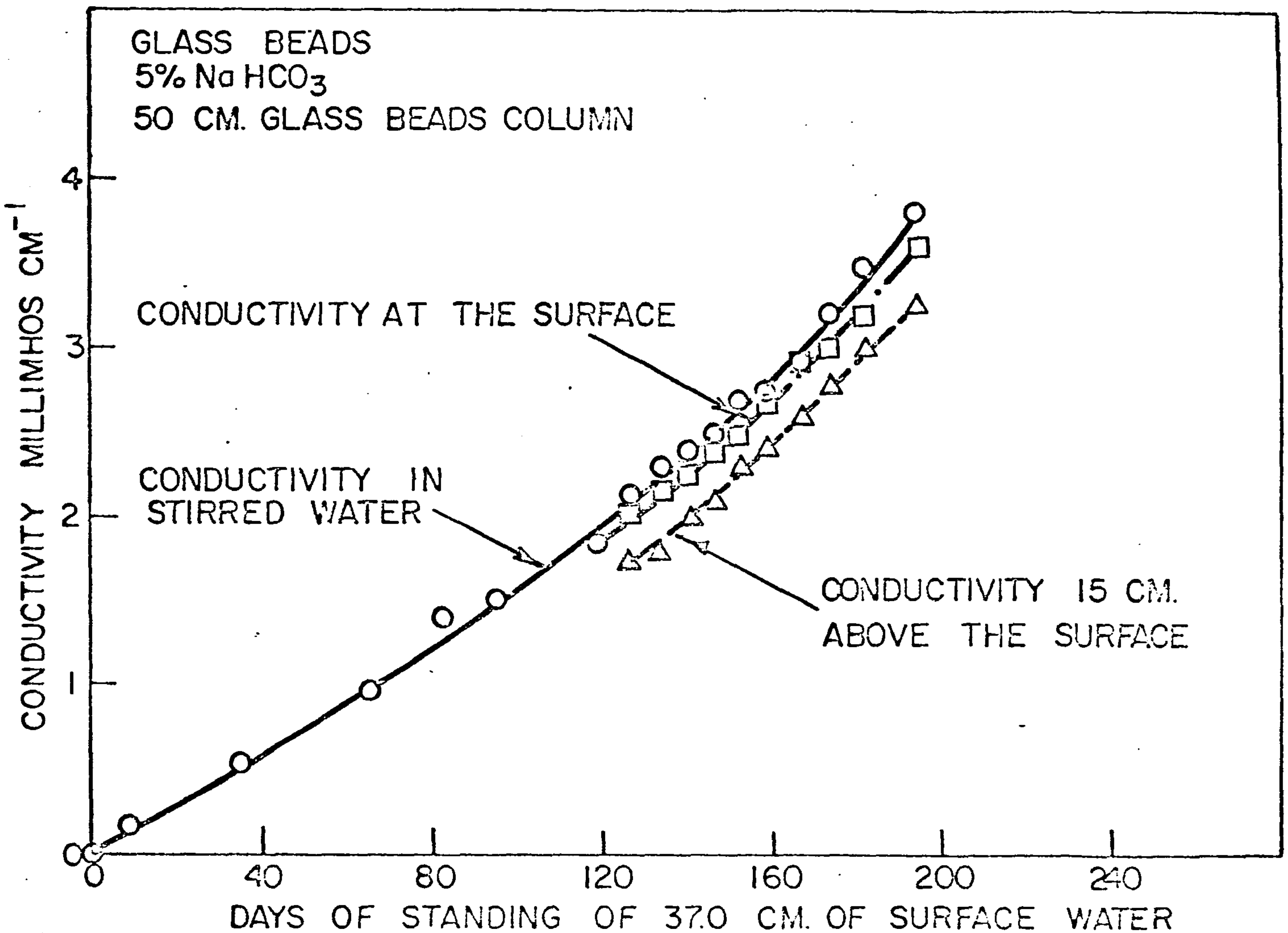
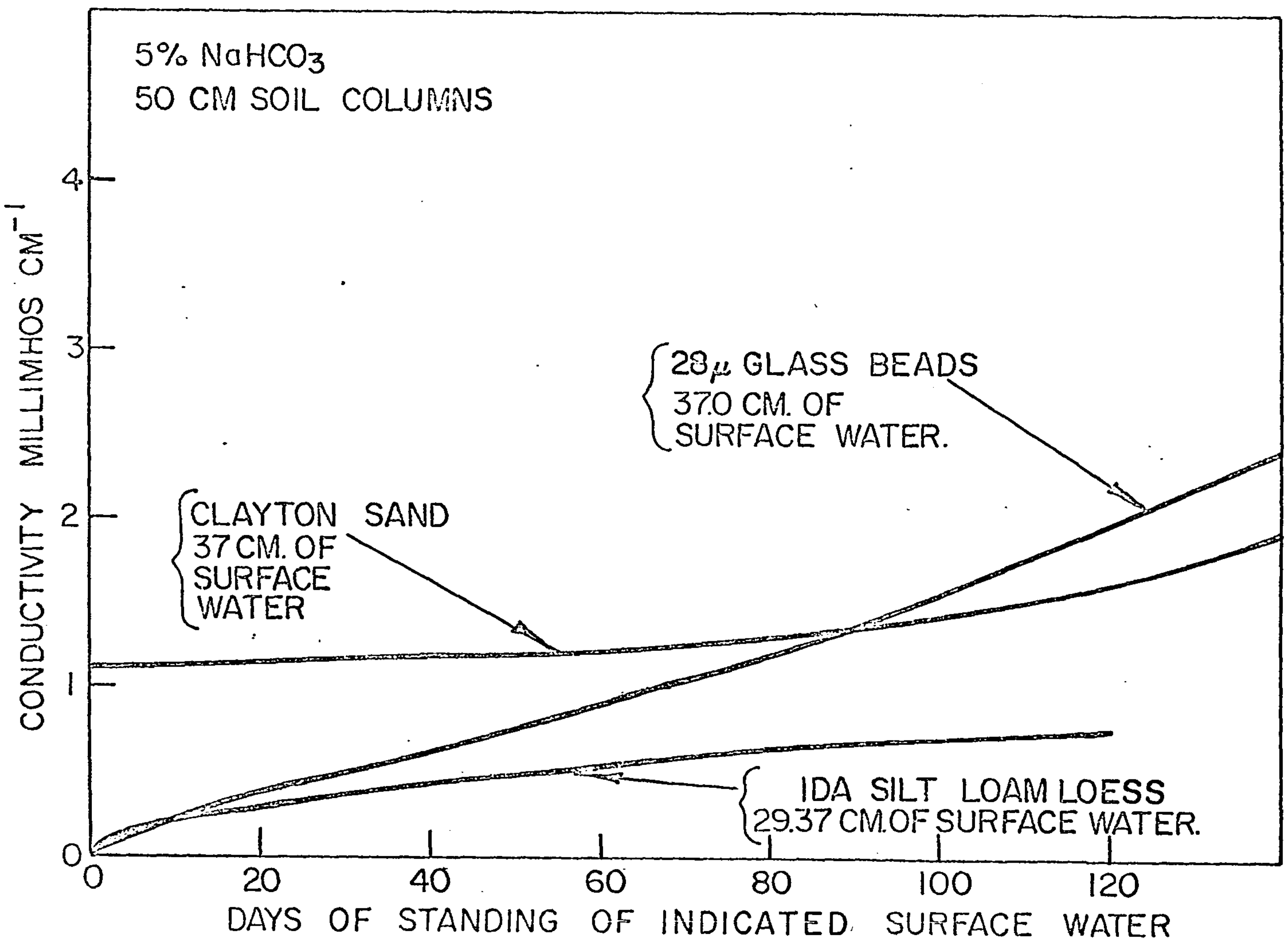

GLASS BEADS
5% Na HCO3
50 CM. GLASS BEADS COLUMN
CONDUCTIVITY AT THE SURFACE
CONDUCTIVITY IN STIRRED WATER
CONDUCTIVITY 15 CM. ABOVE THE SURFACE
CONDUCTIVITY MILLIMHOS CM-1
DAYS OF STANDING OF 37.0 CM. OF SURFACE WATER
0
40
80
120
160
200
240
1
2
3
4

Figure 30. Retraced curves (without data points) of Figures 23, 27 and 29 to show the influence of different porous media (a loess, sand and glass beads) on the conductivity of standing surface water when Na HCO_3 is the salt in the salinized porous media and when 29 cm. of surface water is added to the loess, and 37 cm. is added to the sand and the 28 micron glass beads


5% $NaHCO_3$
50 CM SOIL COLUMNS
CONDUCTIVITY MILLIMHOS CM^{-1}
0
1
2
3
4
0
20
40
60
80
100
120
DAYS OF STANDING OF INDICATED SURFACE WATER
28μ GLASS BEADS
37.0 CM. OF
SURFACE WATER.
CLAYTON SAND
37 CM. OF
SURFACE
WATER
IDA SILT LOAM LOESS
29.37 CM. OF SURFACE WATER.

PROCEDURES FOR EXPERIMENT II

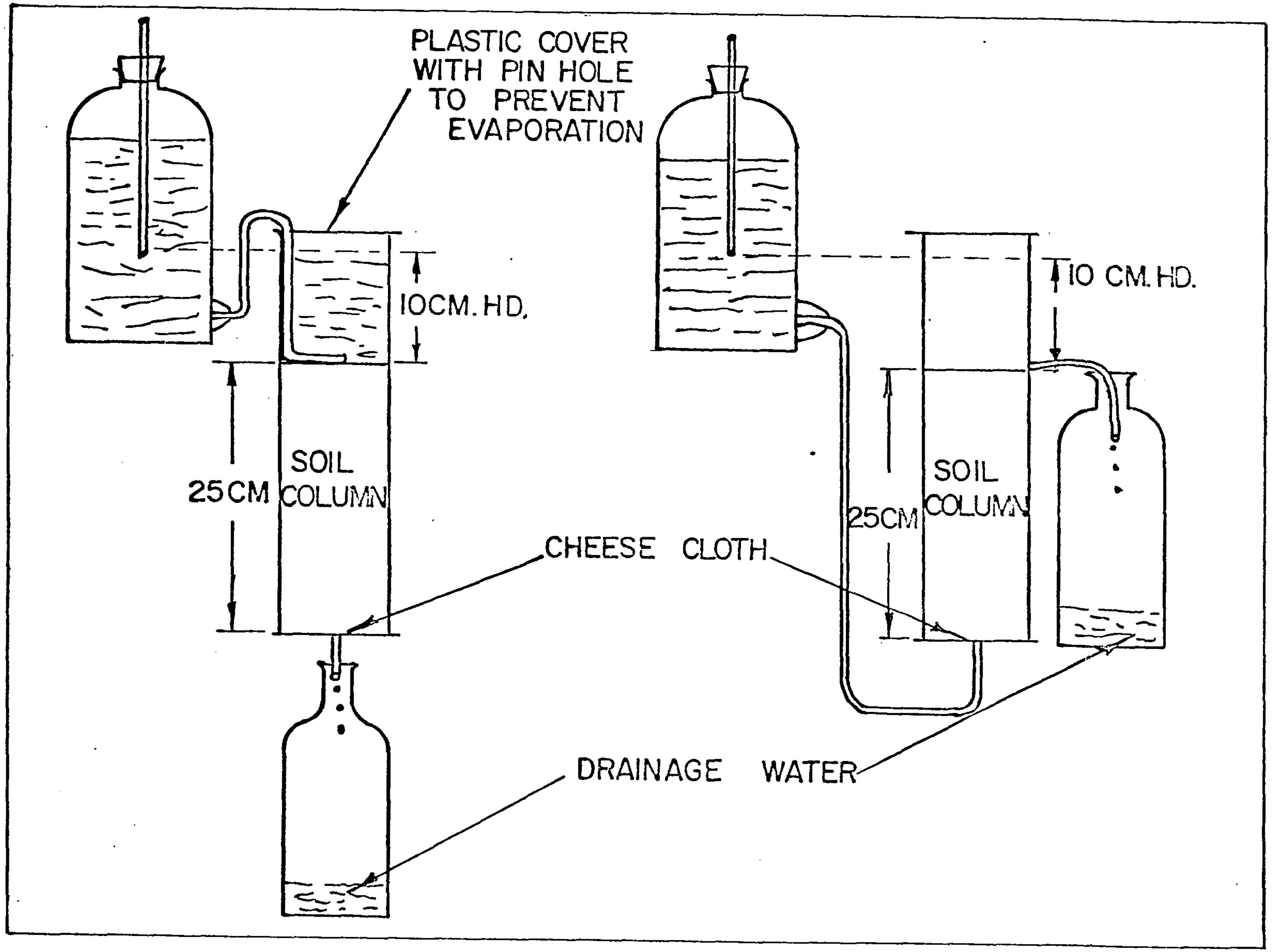
Leaching by Surface Water Application

Distilled water was applied to the surface of soil columns of 25.0 cm. length (Figure 31, left) which had been initially prepared as mentioned earlier. The soil was Clayton sand. The remaining figures of this thesis are for Clayton sand. Evaporation during the experiment was prevented by a plastic cover with a pin hole as shown in Figure 31. In all cases the sand columns were positioned vertically in a nearly constant temperature room where the temperature was 74°F plus or minus 2°F. The drainage water was collected after the time allowed for drainage as referred to in the third and fourth columns of Tables 23-52 and the electrical conductivity of these samples were measured. Also the cumulative amounts of drainage water and their electrical conductivity were determined as shown in the mentioned tables (see fifth and sixth columns of tables). The distilled water was applied as follows:

IIa) Continuous ponding with an initially constant head of 0-10 centimeters as shown in Figure 31 (left). The water was allowed to build up the 10 centimeters on the surface of the sand and then kept constant. After time of water application given in the second column of Tables 23-25, the water head was allowed to drop and penetrate through the sand surface. The amount of water used for leaching was as follows: 1) 6000 cc. (equivalent to 132.33 cm. height) in the case of salinized soil with sodium chloride. 2) 8000 cc. (equivalent to

Figure 31. (Left) Schematic drawing (not to scale) of a saline soil column with 10 cm. head of surface leaching water

(Right) Same as left except for subirrigation water application


PLASTIC COVER
WITH PIN HOLE
TO PREVENT
EVAPORATION
10CM. HD.
25CM
SOIL
COLUMN
CHEESE CLOTH
DRAINAGE WATER
10 CM. HD.
25CM
SOIL
COLUMN

176.44 cm. height) in the case of salinized soil with sodium bicarbonate. 3) 9000 cc. (equivalent to 198.50 cm. height) in the case of salinized soil with sodium sulfate.

These amounts were applied to allow for continuous ponding until all the salts were removed from the sand columns that had been salinized with either sodium chloride or sodium bicarbonate or sodium sulfate as shown earlier. The data are shown in Tables 23-30 given later in Appendix A.

IIb) Intermittent ponding of water increments of 4000 cc. (equivalent to 88.22 cm. height), or

IIc) Intermittent ponding of water increments of 2000 cc. (equivalent to 44.11 cm. height), or

IId) Intermittent ponding of water increments of 1000 cc. (equivalent to 22.05 cm. height), or

IIe) Intermittent ponding of water increments of 500 cc. (equivalent to 11.028 cm. height), or

IIf) Intermittent ponding of water increments of 200 cc. (equivalent to 4.41 cm. height), or

IIg) Intermittent ponding of water increments of 50 cc. (equivalent to 1.1 cm. height).

The water was kept from zero to 10 centimeter head and then allowed to drop after time indicated in the second column of Tables 31-52. The soil (Clayton sand) was presalinized with sodium bicarbonate at the 5.0 percent level.

RESULTS AND DISCUSSION OF EXPERIMENT IIa

Continuous Ponding

Figure 32 shows the electrical conductivity plotted versus the cc. drainage water collected after continuous surface application of distilled water of 6000 cc. kept initially at 10 cm. head to a 25 cm. long sand column of initially salinized (at the 5 percent level of sodium chloride). It can be seen that the average amount of water needed to get rid of all the salts in the sand column is 2060 cc. equivalent to 45.4 cm. height. In Figure 33 the percentage of salts removed from the column was plotted versus the drainage water collected. More than 90 percent of the salts were removed after collecting only 30 percent of the drainage water and the remaining salts took 70 percent of the total drainage water. Figure 34 and Figure 36 are the same as Figure 32 except that the salts are sodium bicarbonate and sodium sulfate respectively. The average amounts of collected drainage water needed to reduce the 5 percent level to zero of the sodium bicarbonate and sodium sulphate are 5409 cc. (119.3 cm. height), and 8169 cc. (180.2 cm. height) respectively. This indicates the important result that the amount of water required for leaching salts differs largely from one salt to another, since much less water is needed for leaching the sodium chloride than the sodium bicarbonate which in turn takes less than the sodium sulfate. Figures 35 and 37 are the same as Figure 33 except that the salts used are sodium bicarbonate and sodium sulfate respectively. Figures 33, 35 and 37 show that more than 90 percent of the salts are removed by collecting only 30 percent of the total drainage water.

To provide a favorable environment for plants, the electrical conductivity of the saturation extract of the soil must not exceed 4.0 millimhos $cm.^{-1}$ or 0.425 percent by weight for the sodium bicarbonate salts (see Figure 3, pp. 11 U.S. 60, United States Salinity Laboratory Staff, 1954). So the amount of salts that should be removed in our experiment is (5.00 - 0.425) = 4.575 percent or (4.575/5.00) = 91.5 percent of the salts. Figure 35 shows that for removing 91.5 percent of the sodium bicarbonate salts 25.0 percent of the collected drainage water was needed, i.e., 1352 cc. or 29.82 cm. height.

Figure 32. Conductivity versus cc. drainage water collected from 25 cm. long columns of Clayton sand initially at 5 percent NaCl concentration and after continuous applications of distilled water totaling 6000 cc. (132 cm. height) to each column; the applied leaching water was kept at 0-10 cm. head. Data for the three replicates shown are in Tables 23-25

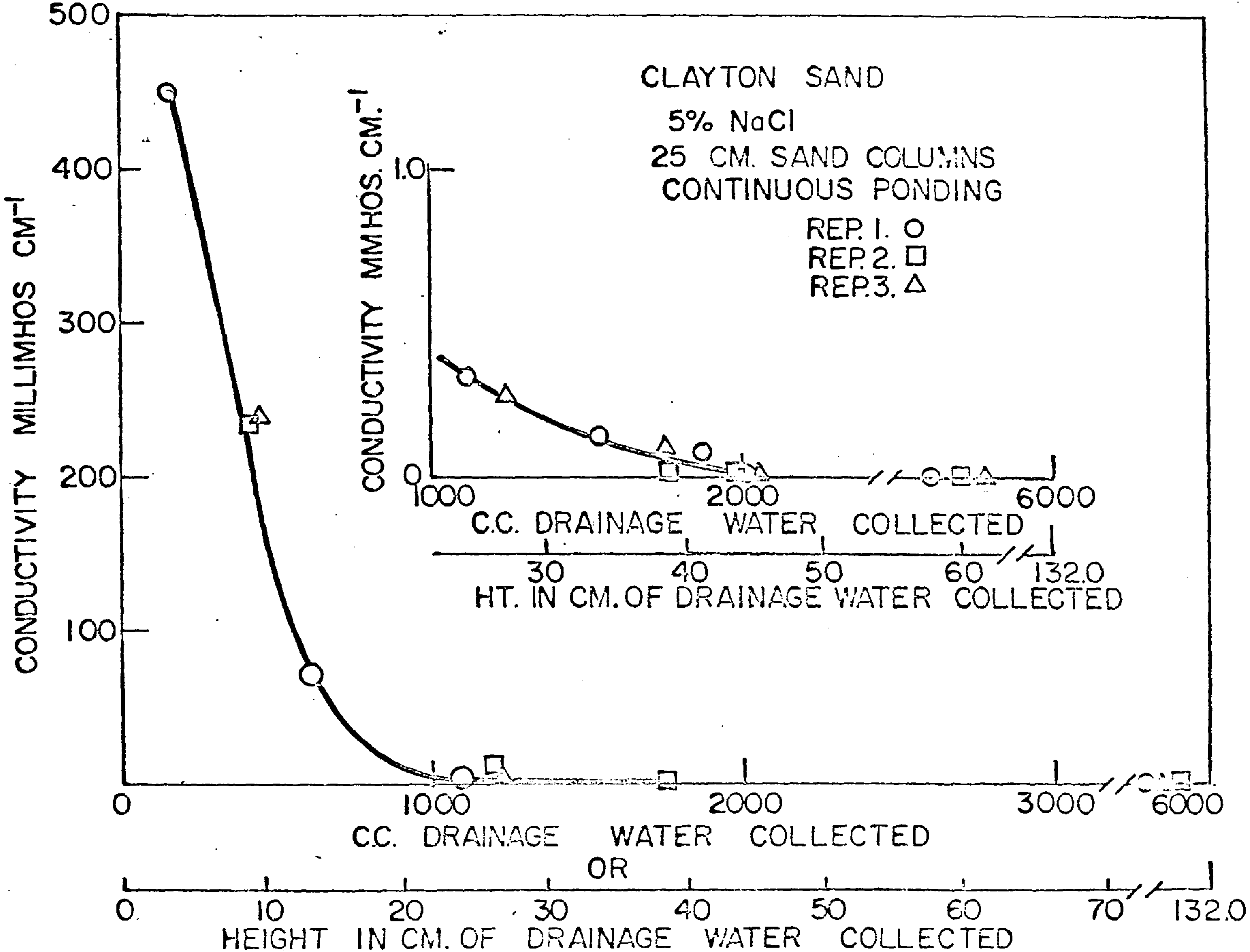

CLAYTON SAND
5% NaCl
25 CM. SAND COLUMNS
CONTINUOUS PONDING
REP. 1. ○
REP. 2. □
REP. 3. △
CONDUCTIVITY MILLIMHOS CM⁻¹
500
400
300
200
100
0
1000
2000
3000
6000
C.C. DRAINAGE WATER COLLECTED
OR
10
20
30
40
50
60
70
132.0
HEIGHT IN CM. OF DRAINAGE WATER COLLECTED
CONDUCTIVITY MMHOS. CM.⁻¹
1.0
0
1000
2000
6000
C.C. DRAINAGE WATER COLLECTED
30
40
50
60
132.0
HT. IN CM. OF DRAINAGE WATER COLLECTED

Figure 33. Percent of salts removed versus percent drainage water collected for a surface application of 6000 cc. of distilled water (132 cm. water height), kept at 0-10 cm. head, to presalinized 25 cm. long sand columns initially at a 5 percent level of NaCl. Data for the three replicates shown are in Tables 23-25. 97 percent of the salts were removed after collecting 30 percent of the drainage water

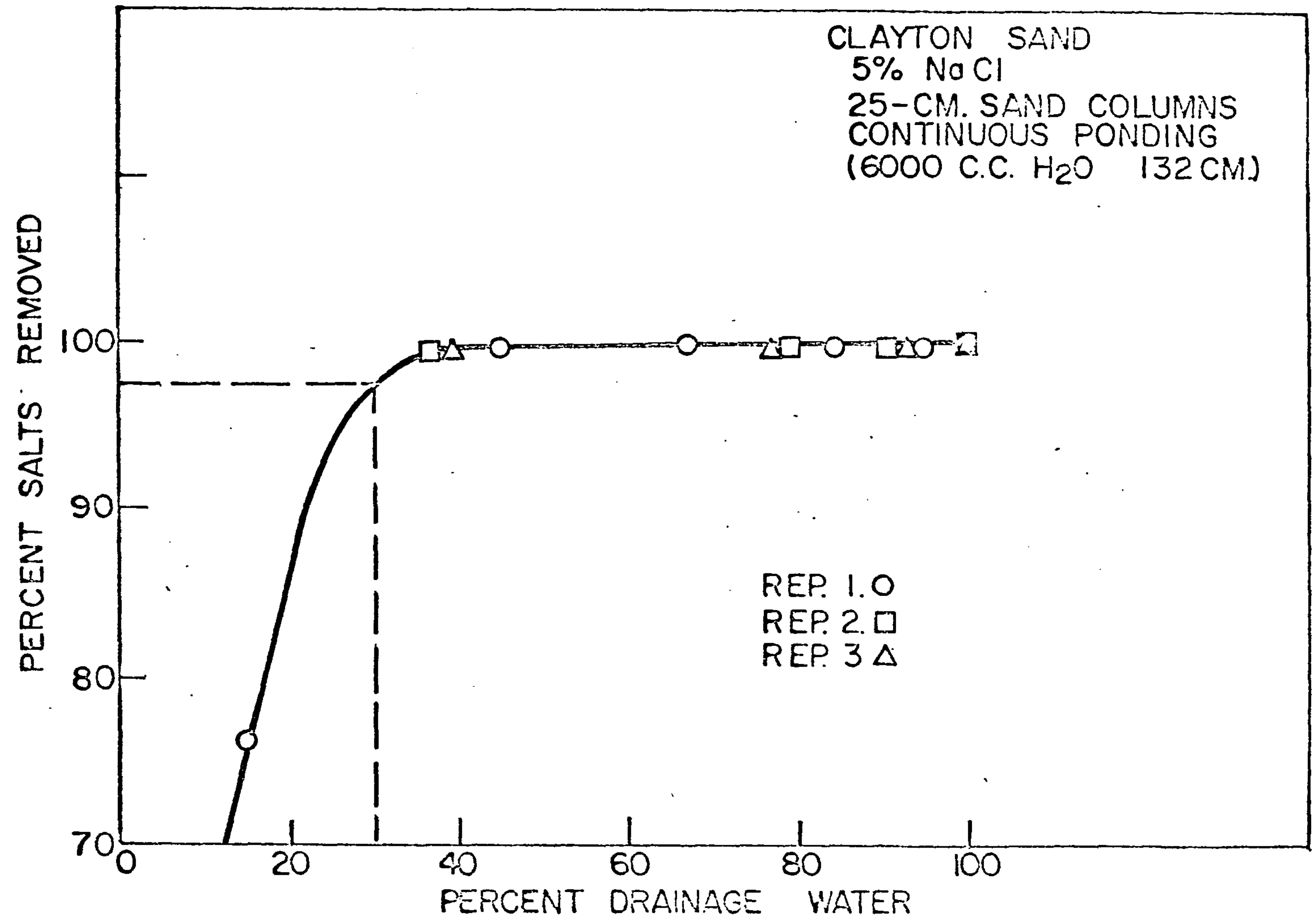

CLAYTON SAND
5% Na Cl
25-CM. SAND COLUMNS
CONTINUOUS PONDING
(6000 C.C. H2O 132 CM.)
REP. 1. O
REP. 2. □
REP. 3 △
PERCENT SALTS REMOVED
PERCENT DRAINAGE WATER
70
80
90
100
0
20
40
60
80
100

Figure 34. Electrical conductivity versus cc. drainage water collected from 25 cm. long column of Clayton sand initially at 5 percent $NaHCO_3$ concentration and after continuous applications of distilled water totaling 8000 cc. (176 cm. height) to each column; the applied leaching water was kept at 0-10 cm. head. Data for the three replicates shown are in Tables 26-28

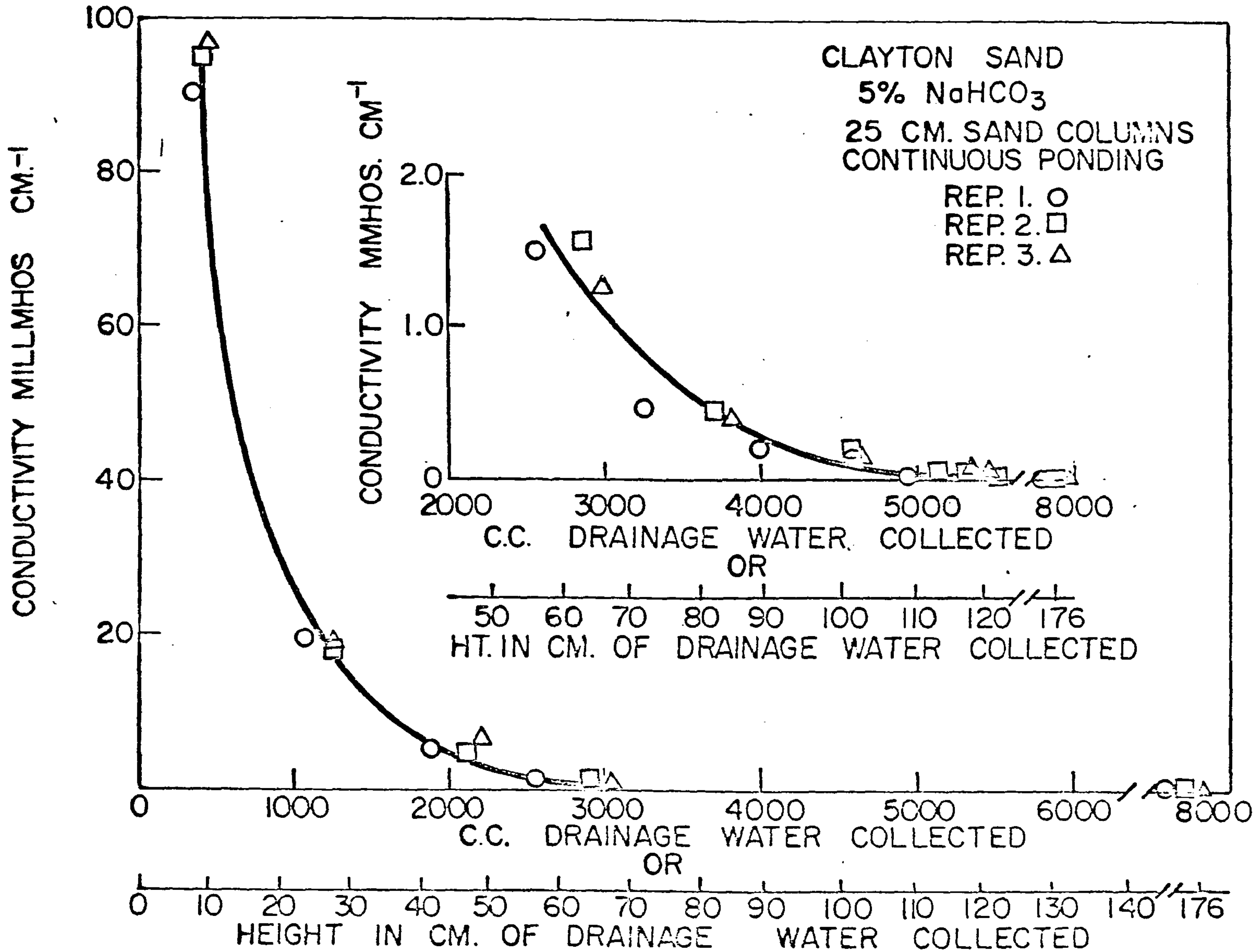

CLAYTON SAND
5% $NaHCO_3$
25 CM. SAND COLUMNS
CONTINUOUS PONDING
REP. 1. ○
REP. 2. □
REP. 3. △
CONDUCTIVITY MILLMHOS CM.$^{-1}$
100
80
60
40
20
0
0
1000
2000
3000
4000
5000
6000
8000
C.C. DRAINAGE WATER COLLECTED
OR
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
176
HEIGHT IN CM. OF DRAINAGE WATER COLLECTED
CONDUCTIVITY MMHOS. CM^{-1}
2.0
1.0
0
2000
3000
4000
5000
8000
C.C. DRAINAGE WATER COLLECTED
OR
50
60
70
80
90
100
110
120
176
HT. IN CM. OF DRAINAGE WATER COLLECTED

Figure 35. Percent of salts removed versus percent drainage water collected for a surface application of 8000 cc. of distilled water (176 cm. water height), kept at 0-10 cm. head, to presalinized 25 cm. long sand columns initially at a 5 percent level of $NaHCO_3$. Data for the three replicates shown are in Tables 26-28

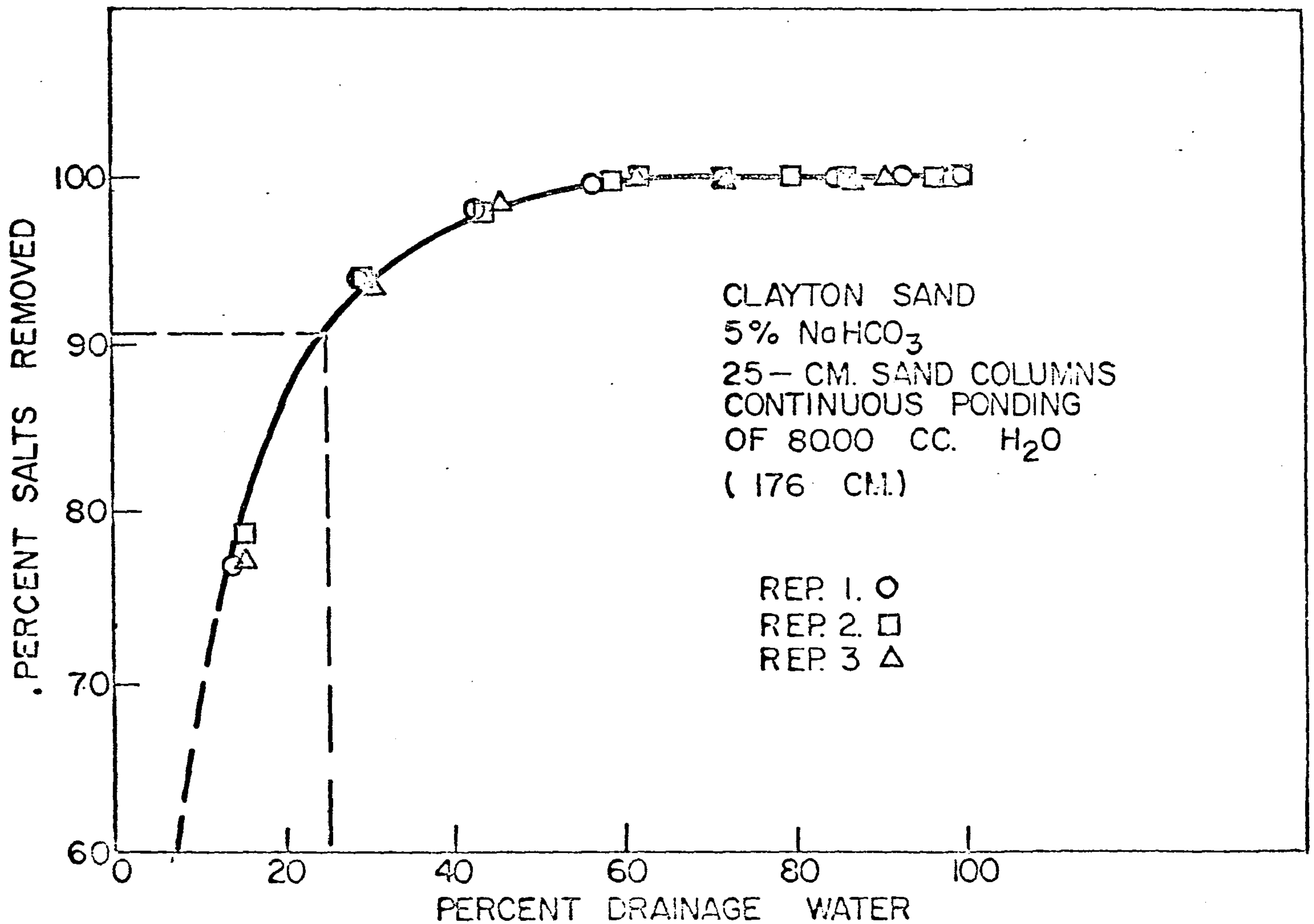

CLAYTON SAND
5% $NaHCO_3$
25 – CM. SAND COLUMNS
CONTINUOUS PONDING
OF 8000 CC. H_2O
(176 CM.)
REP. 1. ○
REP. 2. □
REP. 3 △
PERCENT SALTS REMOVED
PERCENT DRAINAGE WATER
100
90
80
70
60
0
20
40
60
80
100

Figure 36. Electrical conductivity versus cc. drainage water collected from 25 cm. column of Clayton sand initially at 5 percent Na_2SO_4 concentration and after continuous applications of distilled water totaling 9000 cc. (198.5 cm. height) to each column; the applied leaching water was kept at 0-10 cm. head; the figure shows conditions only up to about 8000 cc. of collected drainage water (176 cm. height). The data for the two replicates shown are in Tables 29 and 30

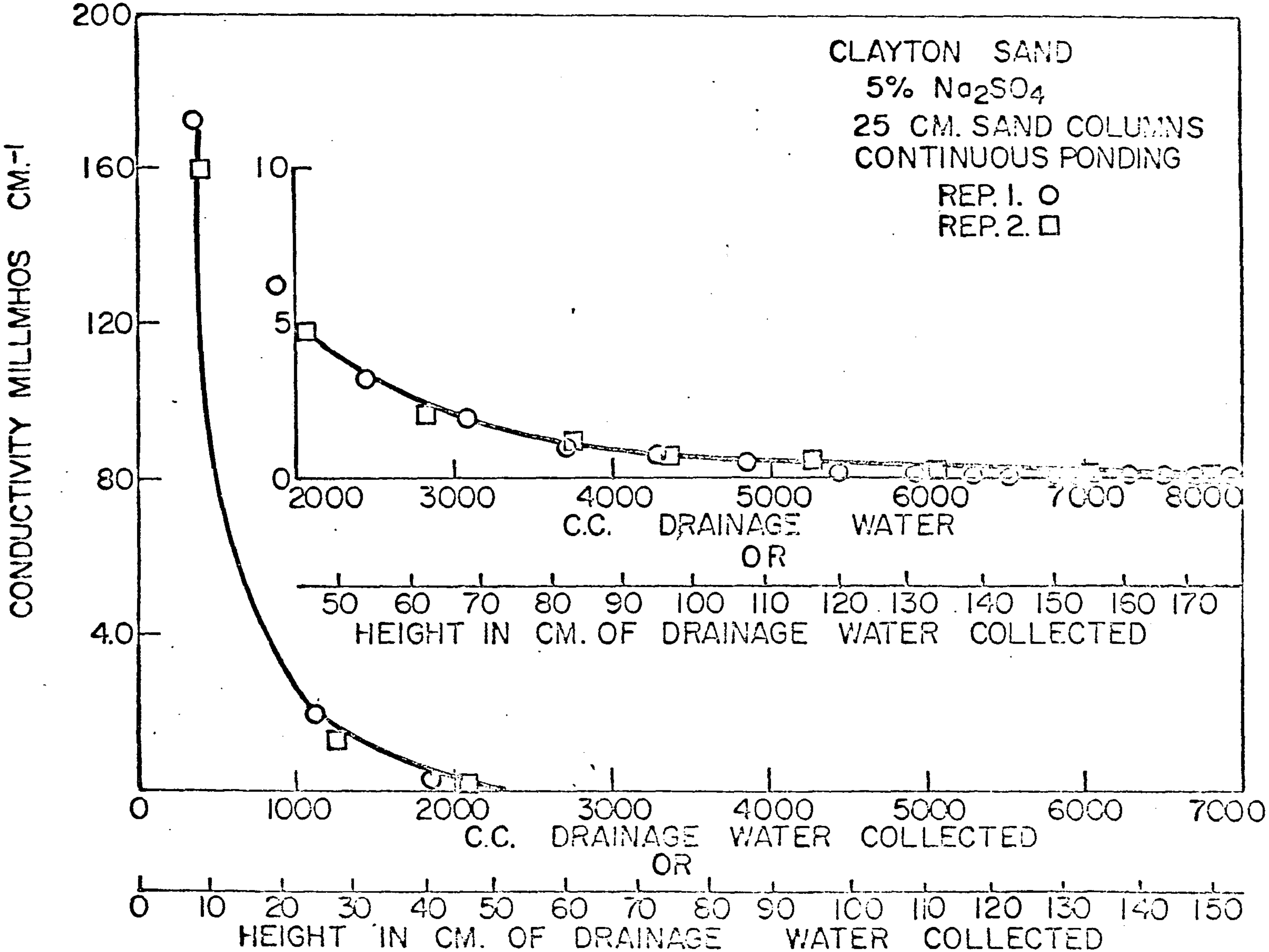
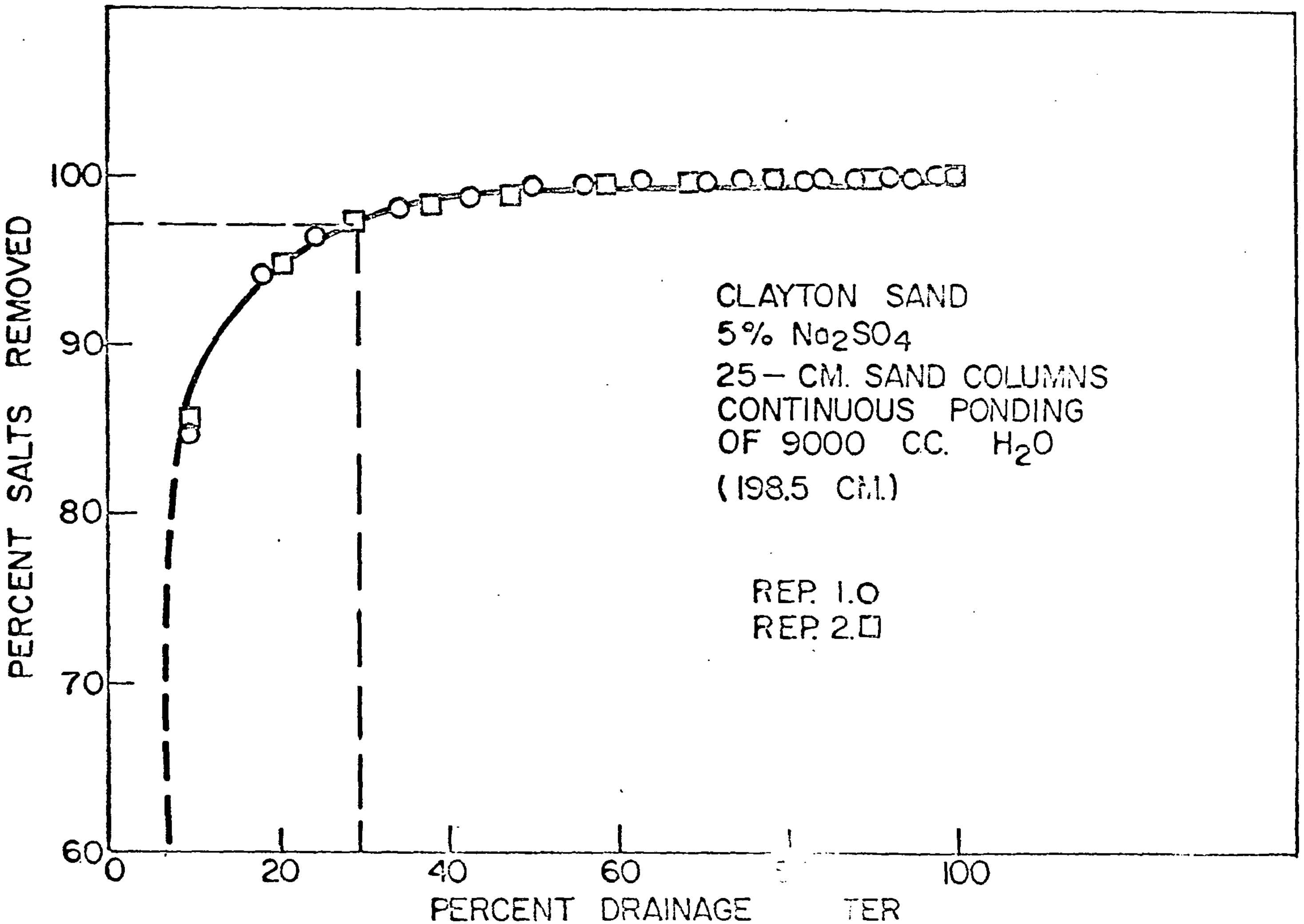

CLAYTON SAND
5% Na_2SO_4
25 CM. SAND COLUMNS
CONTINUOUS PONDING
REP. 1. O
REP. 2. □
CONDUCTIVITY MILLMHOS CM.-1
C.C. DRAINAGE WATER
OR
HEIGHT IN CM. OF DRAINAGE WATER COLLECTED
C.C. DRAINAGE WATER COLLECTED
OR
HEIGHT IN CM. OF DRAINAGE WATER COLLECTED

Figure 37. Percent of salts removed versus percent drainage water collected for a surface application of 9000 cc. of distilled water (198.5 cm. height), kept at 0-10 cm. head, to presalinized 25 cm. long columns initially at a 5 percent level of Na_2SO_4. The data for the two replicates shown are in Tables 29 and 30



PERCENT SALTS REMOVED
100
90
80
70
60
0
20
40
60
100
PERCENT DRAINAGE TER
CLAYTON SAND
5% Na2SO4
25 - CM. SAND COLUMNS
CONTINUOUS PONDING
OF 9000 CC. H2O
(198.5 CM.)
REP. 1. O
REP. 2. □

RESULTS AND DISCUSSION OF EXPERIMENT IIb

Intermittent Ponding of 4000 cc. (88 cm. Height)

In Figure 38 the electrical conductivity was plotted versus the cc. drainage water collected after surface application of distilled water of 4000 cc. increments (equivalent to 88.22 cm. height) kept initially at 10 cm. head to 25 cm. long columns of initially salinized Clayton sand at the 5 percent level of sodium bicarbonate. The amount of collected drainage water averaged 4461 cc. (equivalent to 98.4 cm. height) to remove all the salts from the soil. This amount was approximately 0.82 the amount needed where continuous ponding was applied to the soil surface which means that applying two increments of irrigation water instead of one is going to save approximately 18 percent of water compared to continuous ponding. Figure 39 shows a plotting of the percent of salt removed versus percent of drainage water collected. It can also be easily noticed that 91.5 percent of salts were removed by using only 28.5 percent of the total drainage water collected. This amount is 1271 cc. (equivalent to 28.04 cm. height). For Figures 38 and 39 one may find data in Tables 31-33 in Appendix A.

Figure 38. Electrical conductivity versus cc. drainage water collected after surface application of distilled water of two 4000 cc. increments (88 cm. height per increment), kept at 0-10 cm. head, to 25 cm. long columns of initially salinized (5 percent $NaHCO_3$) Clayton sand. Data for the three replicates shown are in Tables 31-33

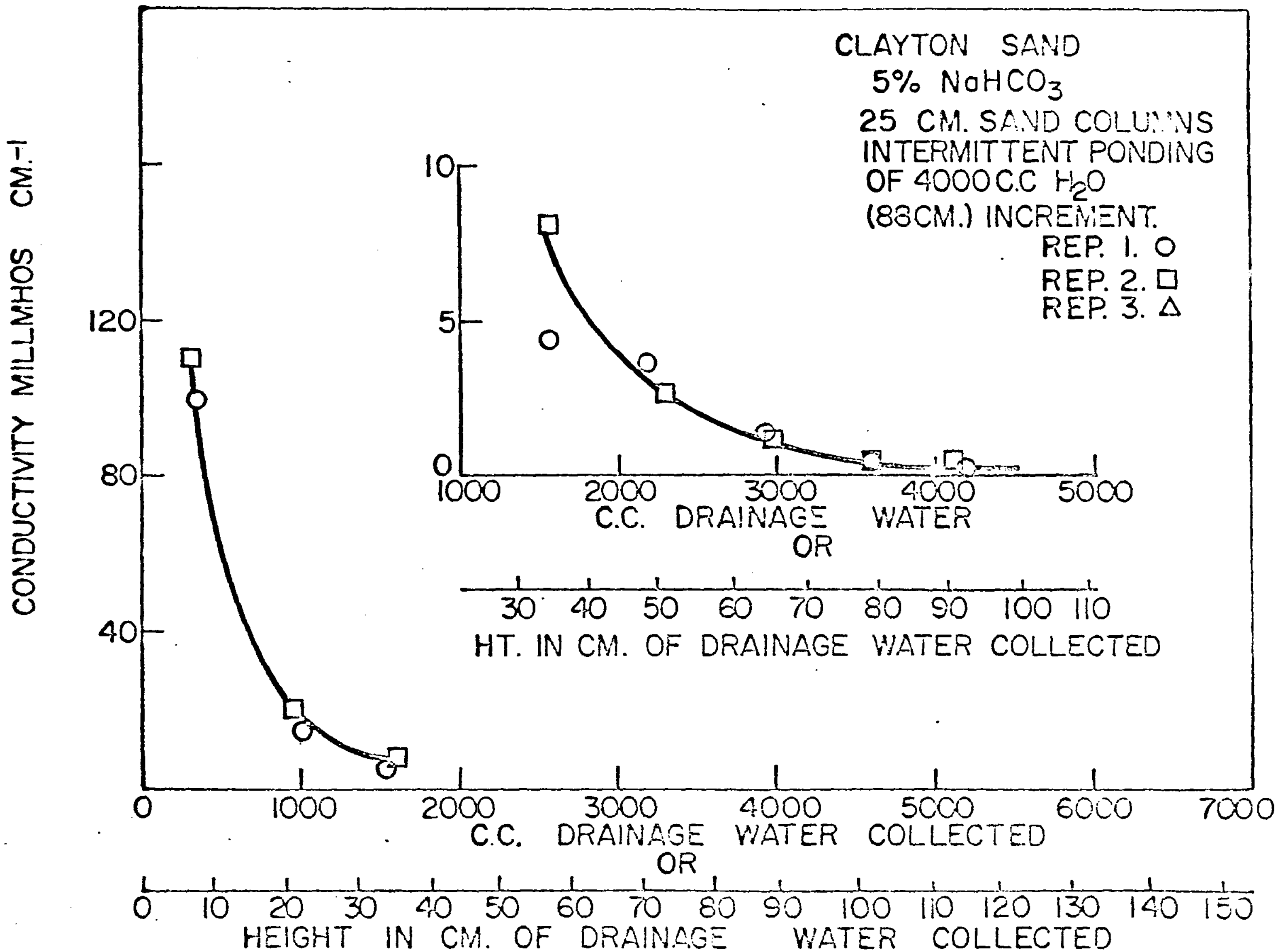
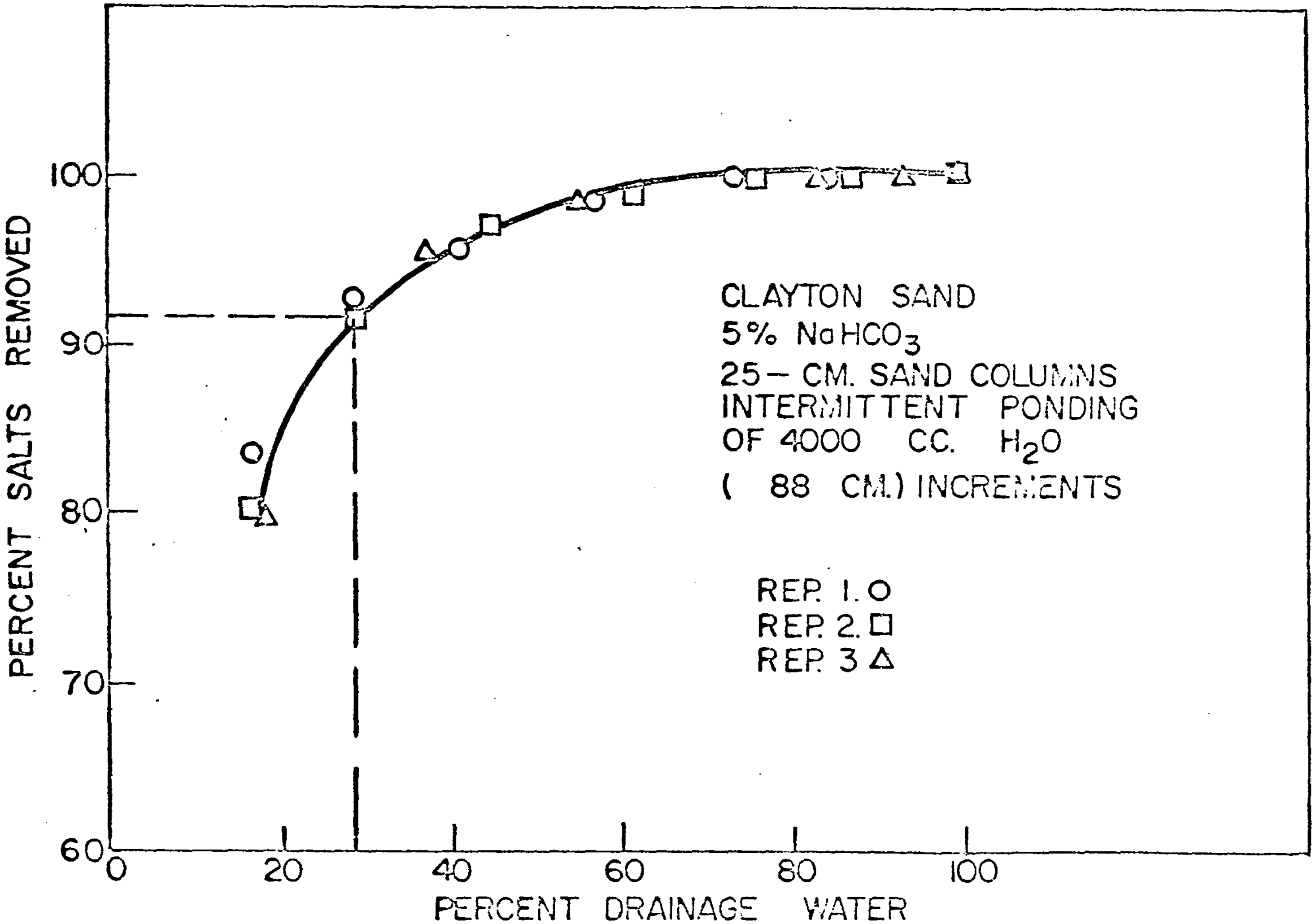

CLAYTON SAND
5% $NaHCO_3$
25 CM. SAND COLUMNS
INTERMITTENT PONDING
OF 4000 C.C H_2O
(88CM.) INCREMENT.
REP. 1. ○
REP. 2. □
REP. 3. △
CONDUCTIVITY MILLMHOS CM.$^{-1}$
C.C. DRAINAGE WATER COLLECTED
OR
HEIGHT IN CM. OF DRAINAGE WATER COLLECTED
C.C. DRAINAGE WATER
OR
HT. IN CM. OF DRAINAGE WATER COLLECTED

Figure 39. Percent of salts removed versus percent drainage water collected for surface application of two 4000 cc. increments of distilled water (88 cm. height per increment), kept at 0-10 cm. head, to 25 cm. long columns of initially salinized (5 percent $NaHCO_3$) Clayton sand. Data for the three replicates shown are in Tables 31-33


CLAYTON SAND
5% NaHCO3
25 – CM. SAND COLUMNS
INTERMITTENT PONDING
OF 4000 CC. H2O
(88 CM.) INCREMENTS
REP. 1. O
REP. 2. □
REP. 3 △
PERCENT SALTS REMOVED
PERCENT DRAINAGE WATER
100
90
80
70
60
0
20
40
60
80
100

RESULTS AND DISCUSSION OF EXPERIMENT IIc

Intermittent Ponding of 2000 cc. (44 cm. Height)

Figures 40 and 41 (and Appendix A Tables 34-36) show results for the 2000 cc. increments. The average total drainage water required for leaching the initially salinized sand columns at the 5 percent sodium bicarbonate to the extent of no salts was 3214 cc., i.e., 70.9 cm. height. This amount is 72.0 percent the amount used earlier (4000 cc. increments) in Experiment IIb and 59.4 percent the amount used in the case of continuous ponding (Experiment IIa). Thus decreasing each increment amount to 2000 cc. (44 cm. height), i.e., half that used in Experiment IIb, saved 28.0 percent of the total drainage water, which is much recommended in the field application of irrigation water. It also saved 40.6 percent the amount used in Experiment IIa which is continuous ponding. Figure 41 shows that the first 32.2 percent of the drainage water collected was able to take out 91.5 percent of the salts in the sand columns, while the remaining salts required 67.8 percent of the total drainage water collected. The amount of drainage water containing the 91.5 percent salts is 1035 cc., i.e., 22.82 cm. height.

Figure 40. Electrical conductivity versus cc. drainage water collected after surface application of distilled water of two or three 2000 cc. increments (44 cm. height per increment), kept at 0-10 cm. head, to 25 cm. long columns of initially salinized (5 percent $NaHCO_3$) Clayton sand. Data for the three replicates shown are in Tables 34-36

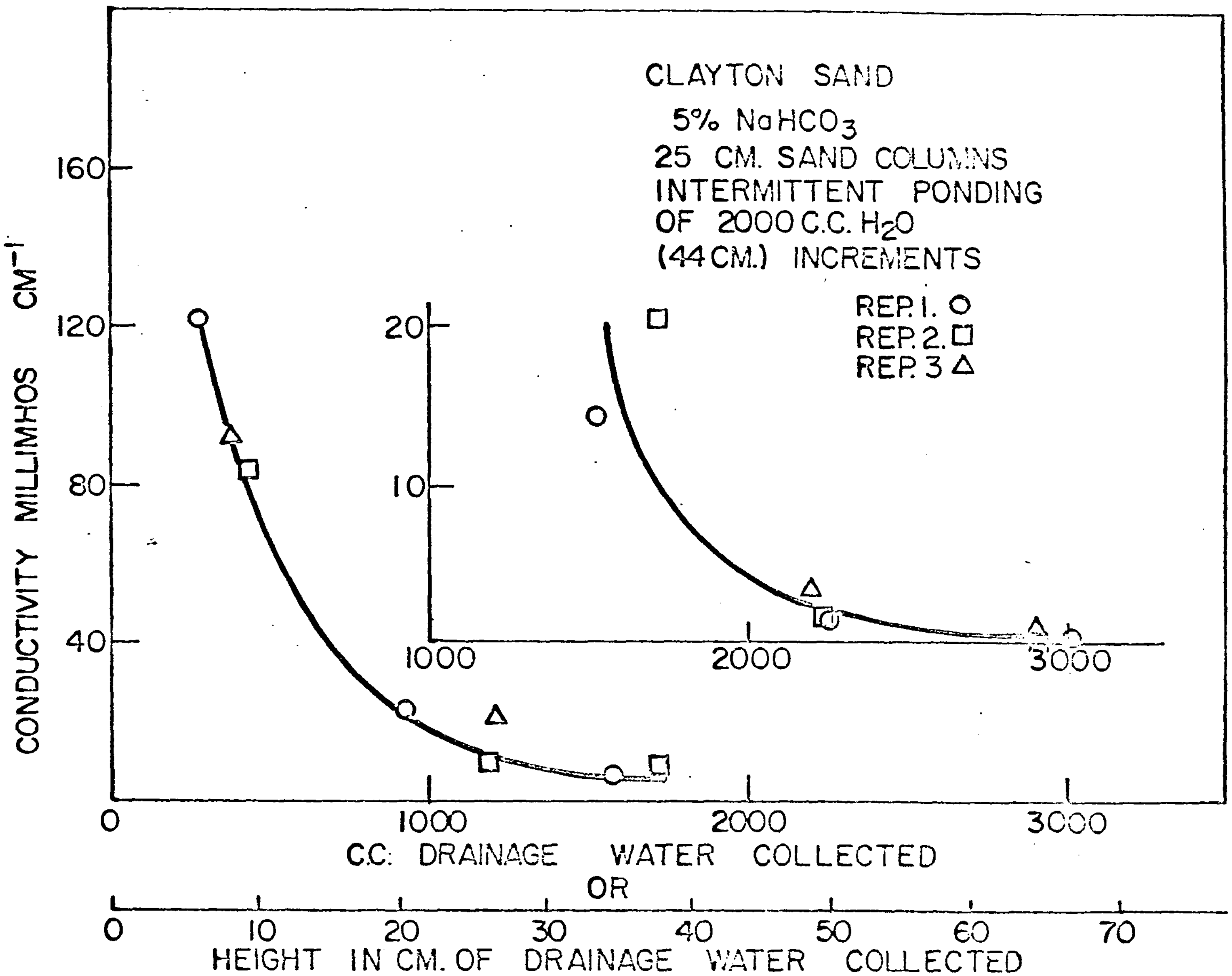
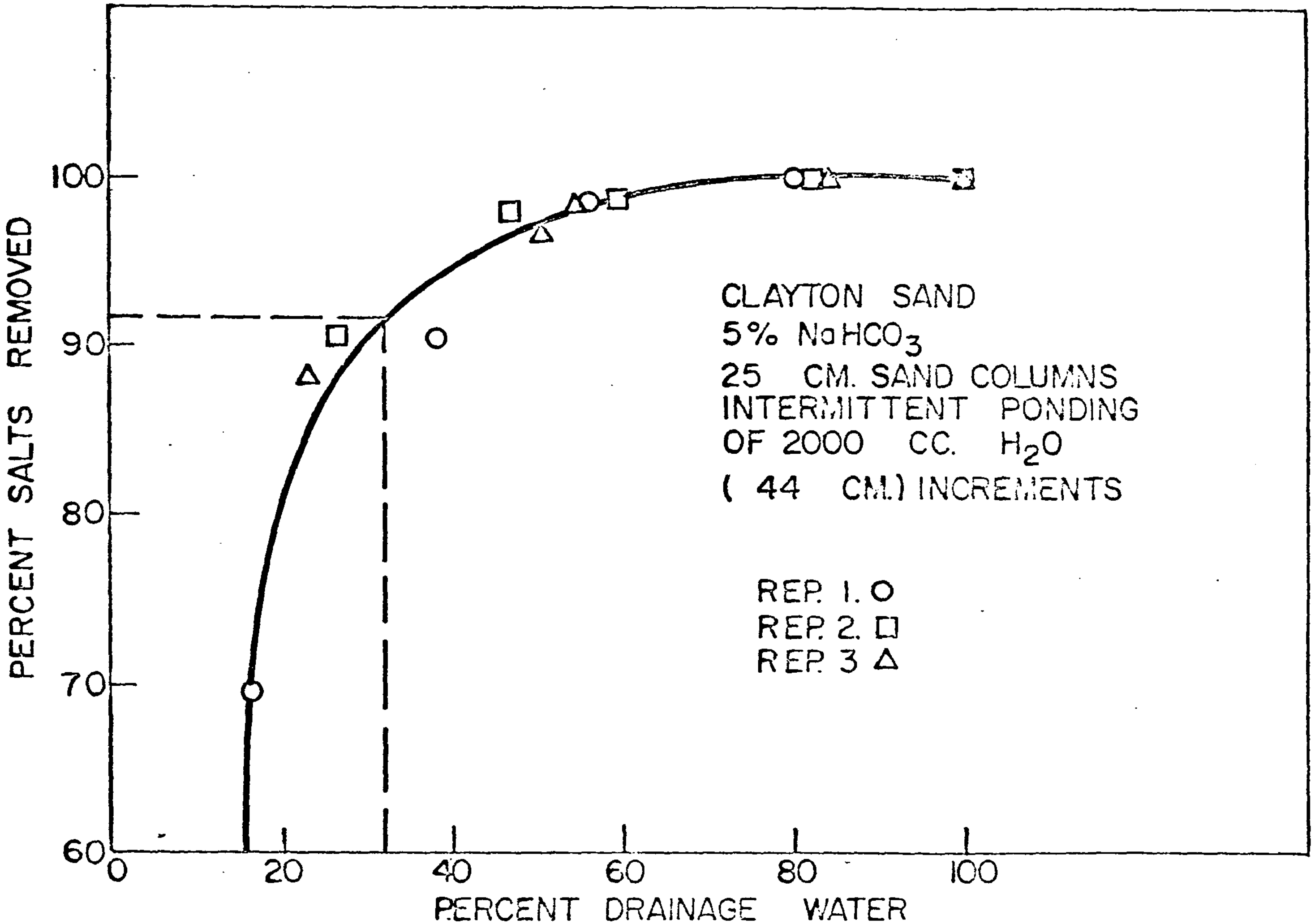

CLAYTON SAND
5% NaHCO3
25 CM. SAND COLUMNS
INTERMITTENT PONDING
OF 2000 C.C. H2O
(44 CM.) INCREMENTS
REP. 1. ○
REP. 2. □
REP. 3 △
CONDUCTIVITY MILLIMHOS CM⁻¹
160
120
80
40
20
10
1000
2000
3000
0
C.C. DRAINAGE WATER COLLECTED
OR
10
20
30
40
50
60
70
HEIGHT IN CM. OF DRAINAGE WATER COLLECTED

Figure 41. Percent of salts removed versus percent drainage water collected for surface application of two or three 2000 cc. increments of distilled water (44 cm. height per increment), kept at 0-10 cm. head, to 25 cm. long columns of initially salinized (5 percent $NaHCO_3$) Clayton sand. Data for the three replicates shown are in Tables 34-36


PERCENT SALTS REMOVED
100
90
80
70
60
0
20
40
60
80
100
PERCENT DRAINAGE WATER
CLAYTON SAND
5% $NaHCO_3$
25 CM. SAND COLUMNS
INTERMITTENT PONDING
OF 2000 CC. H_2O
(44 CM.) INCREMENTS
REP. 1. O
REP. 2. □
REP. 3 △

RESULTS AND DISCUSSION OF EXPERIMENT IId

Intermittent Ponding of 1000 cc. (22 cm. Height)

Figure 42 is the same as Figure 40 except that the applied water increments were 1000 cc. (22 cm. height). Notice that the total amount of drainage water required for removing all salts from the sand columns dropped to 2037 cc. (46.8 cm. height) which means that as long as we are decreasing the amount of each leaching water increment we are saving water. Instead of using 119.3 cm. height for leaching all the salts in the case of continuous ponding only, 46.8 cm. height was used, i.e., 39.2 percent, saving 60.8 percent which is a tremendous saving, relatively. The data contained in Figure 42 and (in the next figure) are shown in Tables 37-39 (Appendix A).

Figure 43 shows that for leaching 91.5 percent of the salts, only 33 percent of the total drainage water collected was needed. The 4000 cc. increments of Figure 39 when compared with the 1000 cc. increments of Figure 43 show that 28.5 percent of the total drainage water collected was needed to remove 91.5 percent of the salts for the 4000 cc. increments while the same percent of salts required 33 percent water (672 cc. or 14.83 cm. height) from Figure 43 for the 1000 cc. increments. Thus the amount of water required for leaching salts depends upon the lowered salt concentration required. Also to get rid of a certain percentage of salts from a soil column the amount of water required for leaching differs according to the method of application of the irrigation water.

Figure 42. Electrical conductivity versus cc. drainage water collected after surface application of distilled water of three 1000 cc. increments (22 cm. height per increment), kept at 0-10 cm. head, to 25 cm. long columns of initially salinized (5 percent $NaHCO_3$) Clayton sand. Data for the three replicates shown are in Tables 37-39

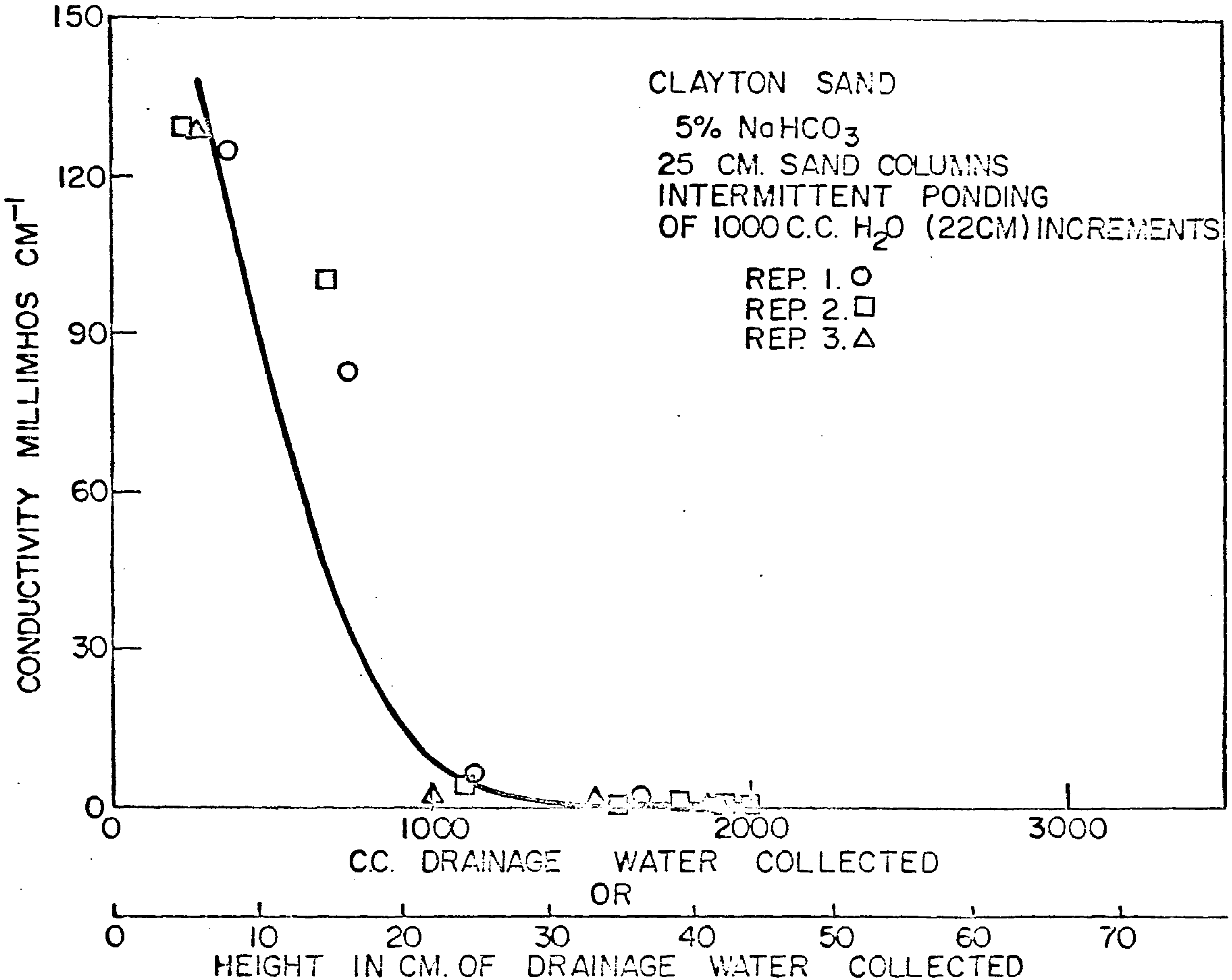
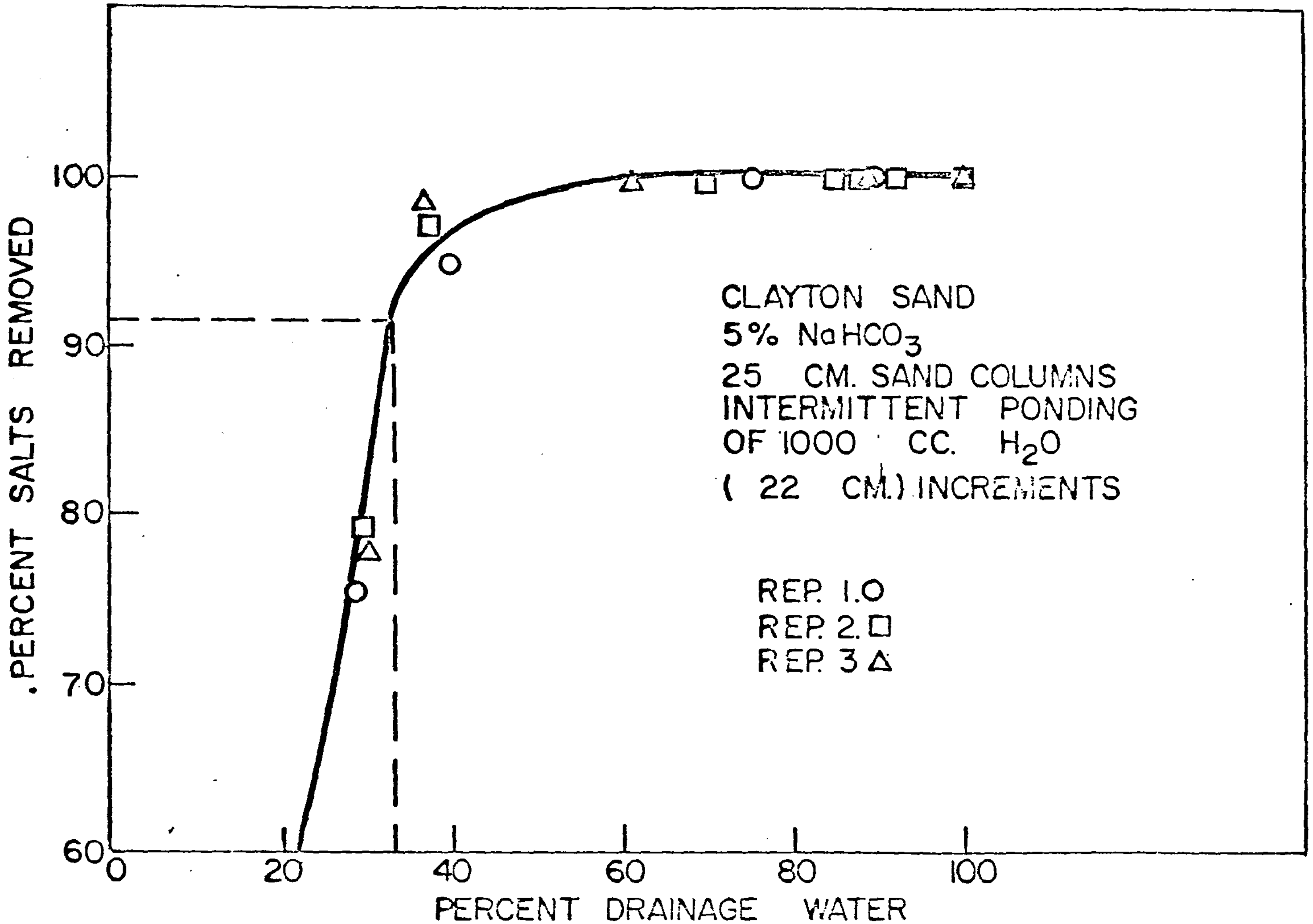

CLAYTON SAND
5% $NaHCO_3$
25 CM. SAND COLUMNS
INTERMITTENT PONDING
OF 1000 C.C. H_2O (22CM) INCREMENTS
REP. 1. ○
REP. 2. □
REP. 3. △
CONDUCTIVITY MILLIMHOS CM^{-1}
150
120
90
60
30
0
0
1000
2000
3000
C.C. DRAINAGE WATER COLLECTED
OR
0
10
20
30
40
50
60
70
HEIGHT IN CM. OF DRAINAGE WATER COLLECTED

Figure 43. Percent of salts removed versus percent drainage water collected for surface application of three 1000 cc. increments (22 cm. height per increment), kept at 0-10 cm. head, to 25 cm. long columns of initially salinized (5 percent $NaHCO_3$) Clayton sand. Data for the three replicates shown are in Tables 37-39



CLAYTON SAND
5% $NaHCO_3$
25 CM. SAND COLUMNS
INTERMITTENT PONDING
OF 1000 CC. H_2O
(22 CM.) INCREMENTS
REP. 1. O
REP. 2. □
REP. 3 △
PERCENT SALTS REMOVED
PERCENT DRAINAGE WATER
60
70
80
90
100
0
20
40
60
80
100

RESULTS AND DISCUSSION OF EXPERIMENT IIe

Intermittent Ponding of 500 cc. (11 cm. Height)

Figures 44 and 45 are the same as Figures 42 and 43 respectively, except that water was applied at 500 cc. (11 cm. height) increments. By applying water in the 11 cm. height increments of Figures 44 and 45, the amount used for leaching the salts in the sand columns from the 5 percent levels, down to zero levels, was reduced from 5409 cc. (119 cm. height) for continuous ponding to 1821 cc. (40 cm. height). The percent drainage water collected was 33.7 that of continuous ponding case (Experiment IIa), i.e., saving 66.3 percent, and also 86 percent less than that used in the 1000 cc. increments case of Experiment IId. The data plotted on the Figures 44 and 45 are contained in Tables 40-43 of Appendix A. Figure 45 shows that 26.5 percent of the collected drainage or 484.4 cc. (10.68 cm. height) water contained approximately 91.5 percent of the salts initially contained in the sand column, and only 8.5 percent (i.e., remaining salts) were washed out by 73.5 percent of the total amount of drainage water.

Figure 44. Electrical conductivity versus cc. drainage water collected after surface application of distilled water of five or six 500 cc. increments (11 cm. height per increment), kept at 0-10 cm. head, to 25 cm. long columns of initially salinized (5 percent $NaHCO_3$) Clayton sand. Data for the four replicates shown are in Tables 40-43

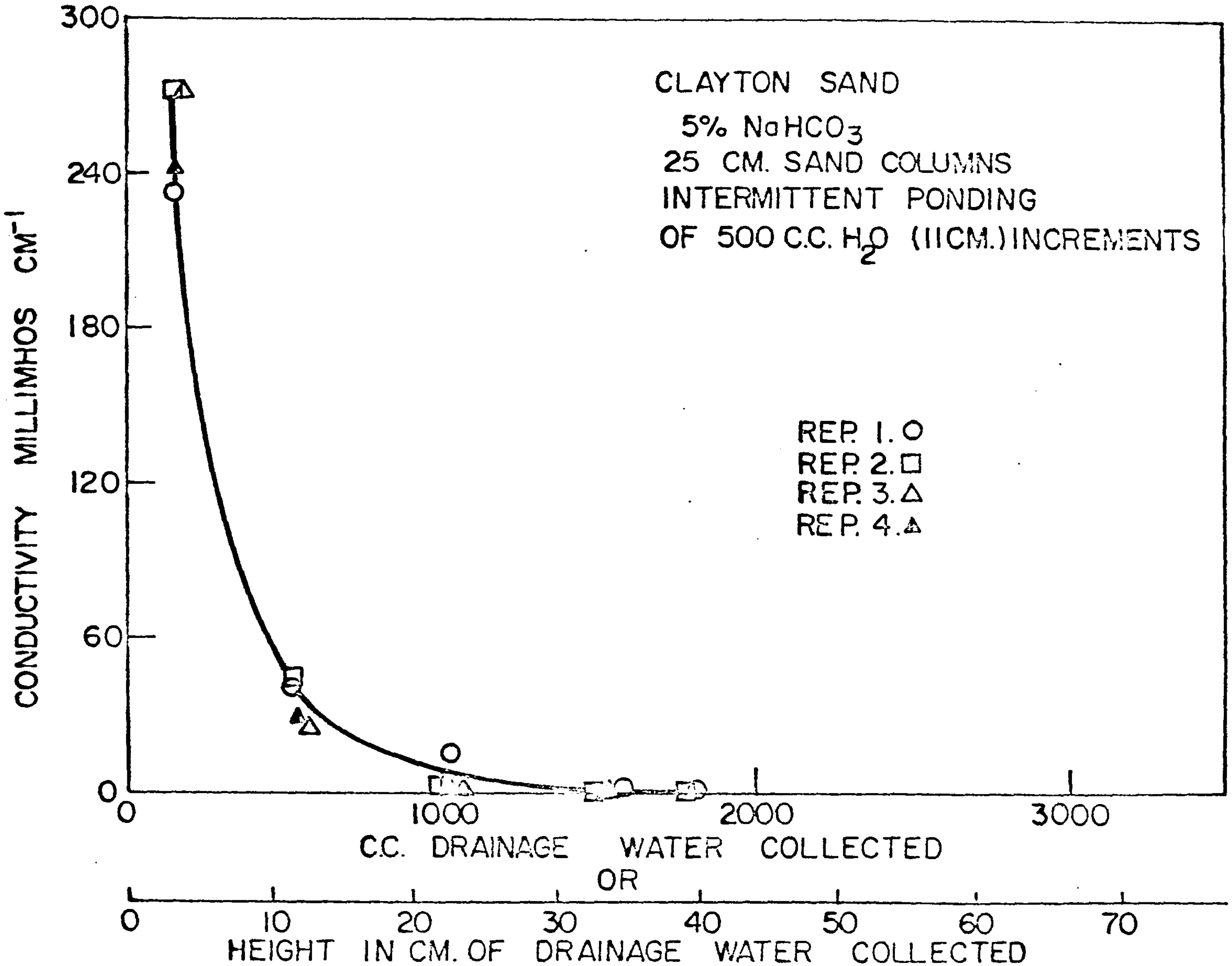
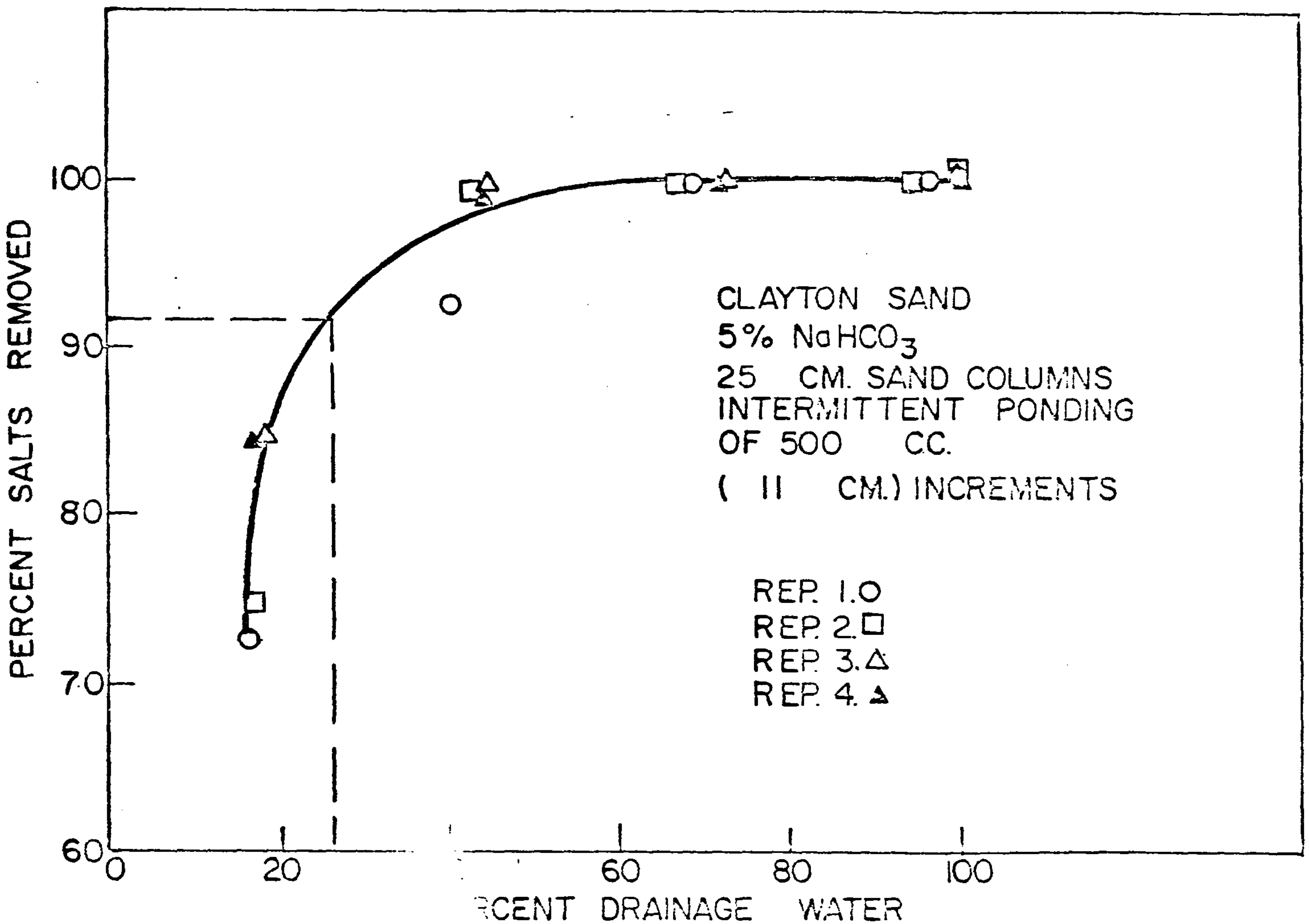

CLAYTON SAND
5% $NaHCO_3$
25 CM. SAND COLUMNS
INTERMITTENT PONDING
OF 500 C.C. H_2O (11CM.) INCREMENTS
REP. 1. ○
REP. 2. □
REP. 3. △
REP. 4. ▲
CONDUCTIVITY MILLIMHOS CM^{-1}
300
240
180
120
60
0
0
1000
2000
3000
C.C. DRAINAGE WATER COLLECTED
OR
0
10
20
30
40
50
60
70
HEIGHT IN CM. OF DRAINAGE WATER COLLECTED

Figure 45. Percent of salts removed versus percent drainage water collected for surface application of five or six 500 cc. increments (11 cm. height per increment), kept at 0-10 cm. head, to 25 cm. long columns of initially salinized (5 percent $NaHCO_3$) Clayton sand. Data for the four replicates shown are in Tables 40-43


CLAYTON SAND
5% $NaHCO_3$
25 CM. SAND COLUMNS
INTERMITTENT PONDING
OF 500 CC.
(11 CM.) INCREMENTS
REP. 1. O
REP. 2. □
REP. 3. △
REP. 4. ▲
PERCENT SALTS REMOVED
100
90
80
70
60
0
20
60
80
100
RCENT DRAINAGE WATER

RESULTS AND DISCUSSION OF EXPERIMENT IIf

Intermittent Ponding of 200 cc. (4.4 cm. Height)

Figures 46 and 47 give the results. They are the same as Figures 38 and 39, respectively, except that each increment of water used for leaching the sodium bicarbonate salts in the sand columns were 200 cc. (4.4 cm. height). The data plotted on Figures 46 and 47 are given in Tables 44-46 (see Appendix A). The total drainage water that carried out all the salt content of the sand column averaged 1607 cc. (35.4 cm. height) which is less than that in Experiment IIe. This amount is 29.7 percent the amount used in the case of continuous ponding (Experiment IIa). So, 70.3 percent of the collected water was saved by applying intermittent ponding of 200 cc. (4.0 cm. height). So, evidence continues to accumulate that indicates that decreasing the amount of each water increment used for leaching is more efficient for leaching salts.

Figure 47 shows the percent of salts removed corresponding to percent of drainage water collected. For 25 percent of the drainage water collected (equivalent to 402 cc. or 8.87 cm. height) 91.5 percent of the salts in the columns were removed.

Figure 46. Electrical conductivity versus cc. drainage water collected after surface application of distilled water of eleven or twelve 200 cc. increments (4.4 cm. height per increment), kept at 0-10 cm. head, to 25 cm. long columns of initially salinized (5 percent $NaHCO_3$) Clayton sand. Data for the three replicates shown are in Tables 44-46

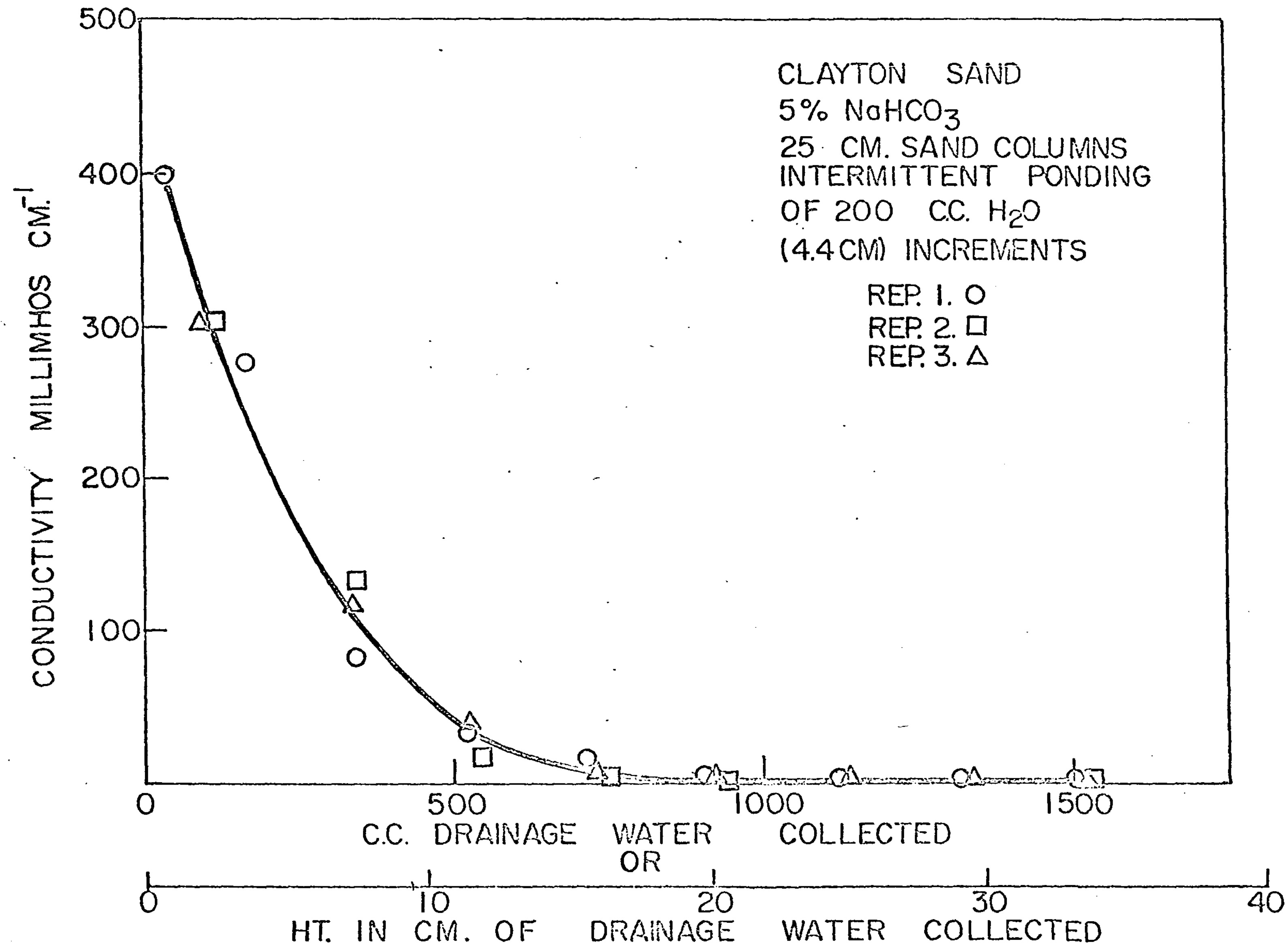
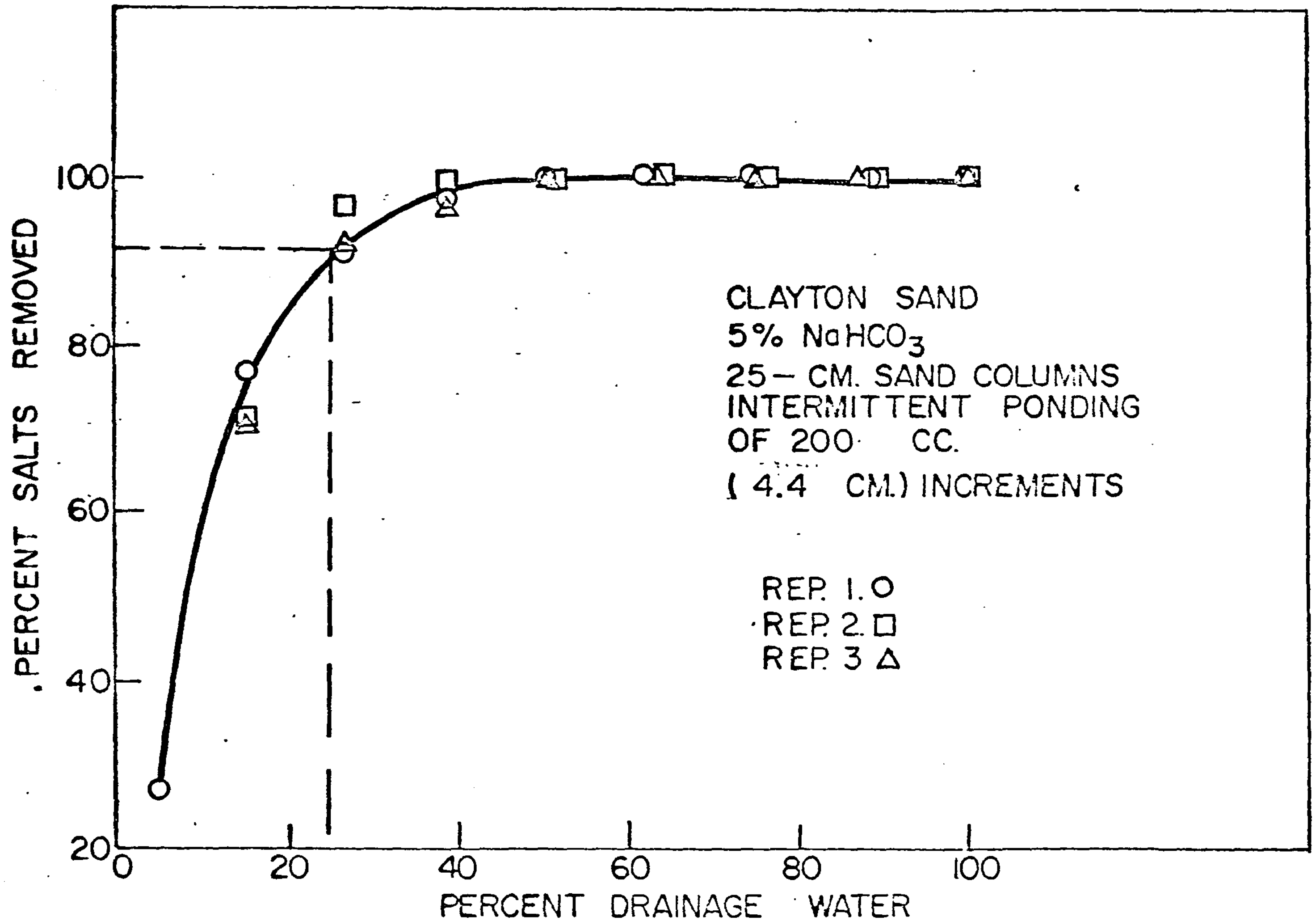

CLAYTON SAND
5% $NaHCO_3$
25 CM. SAND COLUMNS
INTERMITTENT PONDING
OF 200 C.C. H_2O
(4.4 CM) INCREMENTS
REP. 1. ○
REP. 2. □
REP. 3. △
CONDUCTIVITY MILLIMHOS $CM.^{-1}$
500
400
300
200
100
0
500
1000
1500
C.C. DRAINAGE WATER COLLECTED
OR
0
10
20
30
40
HT. IN CM. OF DRAINAGE WATER COLLECTED

Figure 47. Percent of salts removed versus percent drainage water collected for surface application of eleven or twelve 200 cc. increments (4.4 cm. height per increment), kept at 0-10 cm. head, to 25 cm. long columns of initially salinized (5 percent $NaHCO_3$) Clayton sand. Data for the three replicates shown are in Tables 44-46



PERCENT SALTS REMOVED
100
80
60
40
20
0
20
40
60
80
100
PERCENT DRAINAGE WATER
CLAYTON SAND
5% $NaHCO_3$
25 – CM. SAND COLUMNS
INTERMITTENT PONDING
OF 200 CC.
(4.4 CM.) INCREMENTS
REP. 1. ○
REP. 2. □
REP. 3 △

RESULTS AND DISCUSSION OF EXPERIMENT IIg

Intermittent ponding of 50 cc. (1.1 cm. Height)

Figures 48 and 49 are for the surface intermittent leaching of 50 cc. (1.1 cm. height) increments of distilled water. The amount of collected drainage water after removing all the sodium bicarbonate salts in the Clayton sand columns averaged 1192 cc. (26.29 cm. height). This amount is 22.04 percent of the amount drained in the case of continuous ponding (Experiment IIa) i.e., 77.96 percent was saved by the application of intermittent ponding of 50 cc. rather than continuous application. One must realize that in the field evaporation of the water will occur during leaching. The amount of evaporation will depend on how long the water is exposed to evaporating energy (the sun). With intermittent applications longer exposure to evaporation may occur than for a single ponding application. Thus the 77.96 percent of water saved by intermittent application of water in the laboratory, where evaporation can occur only through the pinhole of Figure 31, may be reduced by an amount which will depend on the evaporation potential of the area where the leaching is occurring. In upper Egypt the evaporation potential may be as equal as 10 mm. per day while near Alexandria the average for 14 years (1954-1962) is 3.4 mm. per day in December and 7.4 cm. per day in May (see El-attar and Bakr, 1963). An unfortunate situation here is that leaching water is mostly available in July, August and September during the Nile flood.

Figure 49 is the same as Figure 39 except for 50 cc. intermittent water applications. To remove 91.5 percent of the total salts, 23.5 percent of the drainage water was needed which was 280 cc. or 6.18 cm. height.

Figure 48. Electrical conductivity versus cc. drainage water collected after surface application of distilled water of thirty one or thirty three 50 cc. increments (1.1 cm. height per increment), kept at 0-10 cm. head, to 25 cm. long columns of initially salinized (5 percent $NaHCO_3$) Clayton sand. Data for the four replicates shown are in Tables 47-50

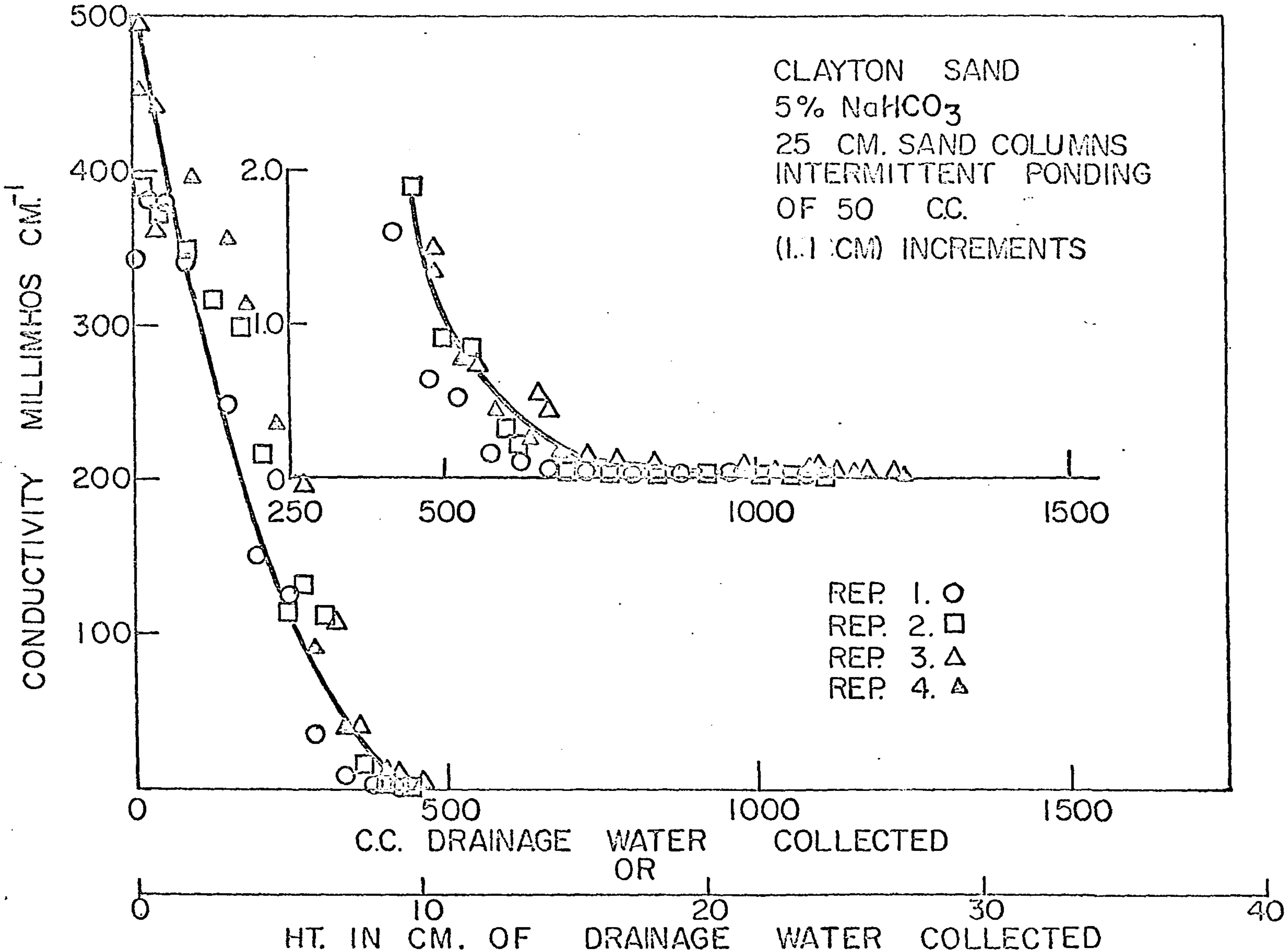
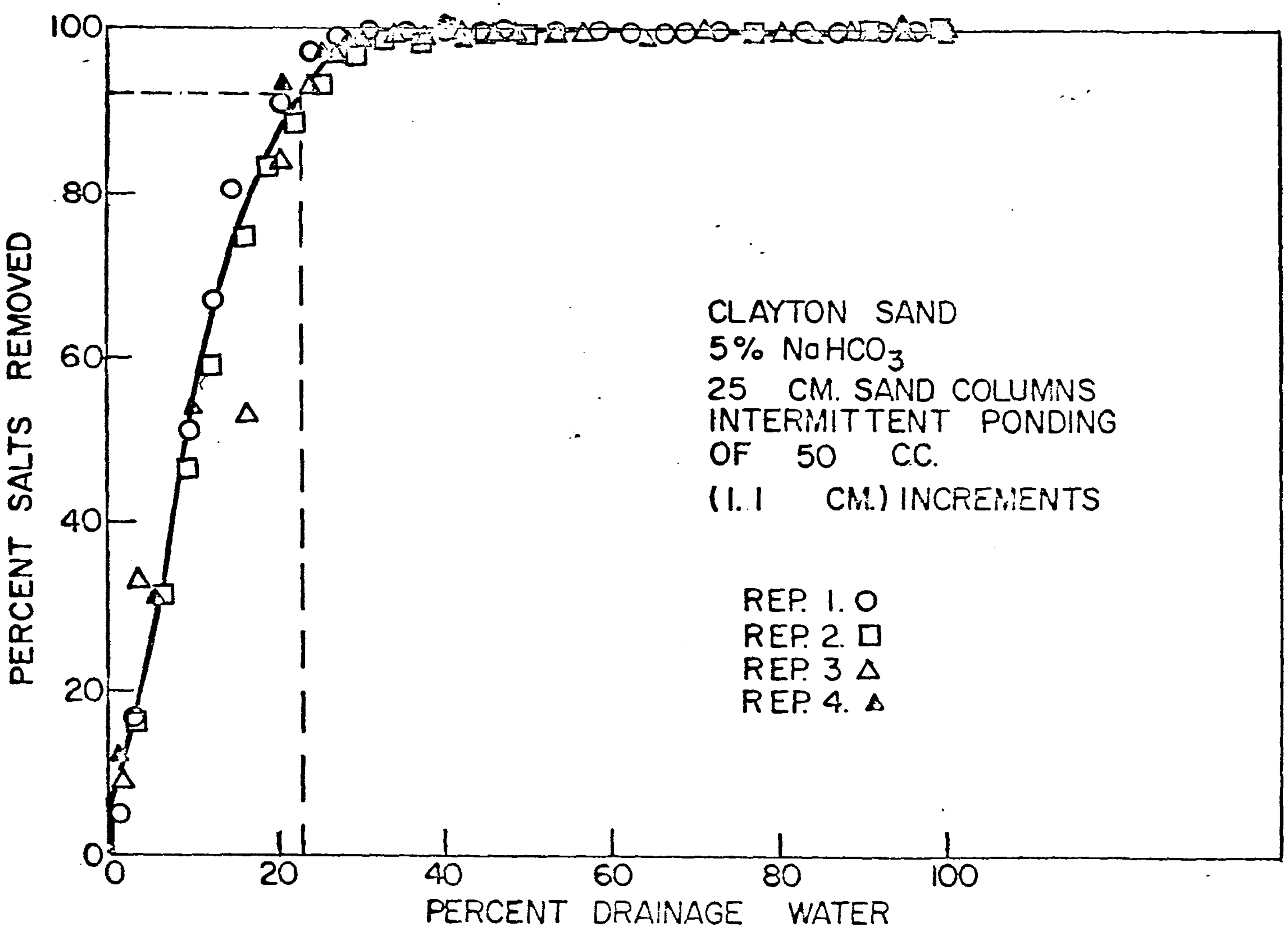

CLAYTON SAND
5% NaHCO3
25 CM. SAND COLUMNS
INTERMITTENT PONDING
OF 50 CC.
(1.1 CM) INCREMENTS
CONDUCTIVITY MILLIMHOS CM.-1
500
400
300
200
100
2.0
1.0
0
250
500
1000
1500
REP. 1. ○
REP. 2. □
REP. 3. △
REP. 4. △
0
500
1000
1500
C.C. DRAINAGE WATER COLLECTED
OR
0
10
20
30
40
HT. IN CM. OF DRAINAGE WATER COLLECTED

Figure 49. Percent of salts removed versus percent drainage water collected for surface application of thirty one or thirty three 50 cc. increments (1.1 cm. height per increment), kept at 0-10 cm. head, to 25 cm. long columns of initially salinized (5 percent Na HCO_3) Clayton sand. Data for the four replicates shown are in Tables 47-50



CLAYTON SAND
5% $NaHCO_3$
25 CM. SAND COLUMNS
INTERMITTENT PONDING
OF 50 CC.
(1.1 CM.) INCREMENTS
REP. 1. O
REP. 2. □
REP. 3 Δ
REP. 4. ▲
PERCENT SALTS REMOVED
PERCENT DRAINAGE WATER
0
20
40
60
80
100

COMPARISON OF RESULTS PROCEDURES a THROUGH g, OF METHOD II

In Method II, procedures a through g surface water was supplied continuously and intermittently, using different increments of water. Procedures a and g are compared in Figure 50. In Figure 50 continuous ponding, procedure a, one sees that 5409 cc. (119.3 cm. height), removed the quantity of salts represented by the area under the curve with vertical hatching. Intermittent ponding, procedure g, represented by the area under the curve with horizontal hatching, removed about the same quantity of salts, as the areas under the two curves are about equal.

Figure 51 gives the different amounts of drainage water collected for removing all salts in the sand columns represented by the vertical solid columns and the water amounts containing 91.5 percent of the salts represented by the horizontally hatched columns. Table 51 (in Appendix A) contains data for the different procedures of Method II. One sees in Table 51 that the rate of water application increased as the amount of a water increment decreased. This was due to the decrease of moisture content of the sand columns during the time allowed for drainage.

In noticing this result it should be remembered that drainage occurred both during and after application of water and that there was a period when the surface of the soil had no ponding water.

Figure 50. Curves, showing by the areas beneath them that the same amount of salts was removed by the two treatments indicated; the curves are traced for Figures 34 and ~~50~~ 49.

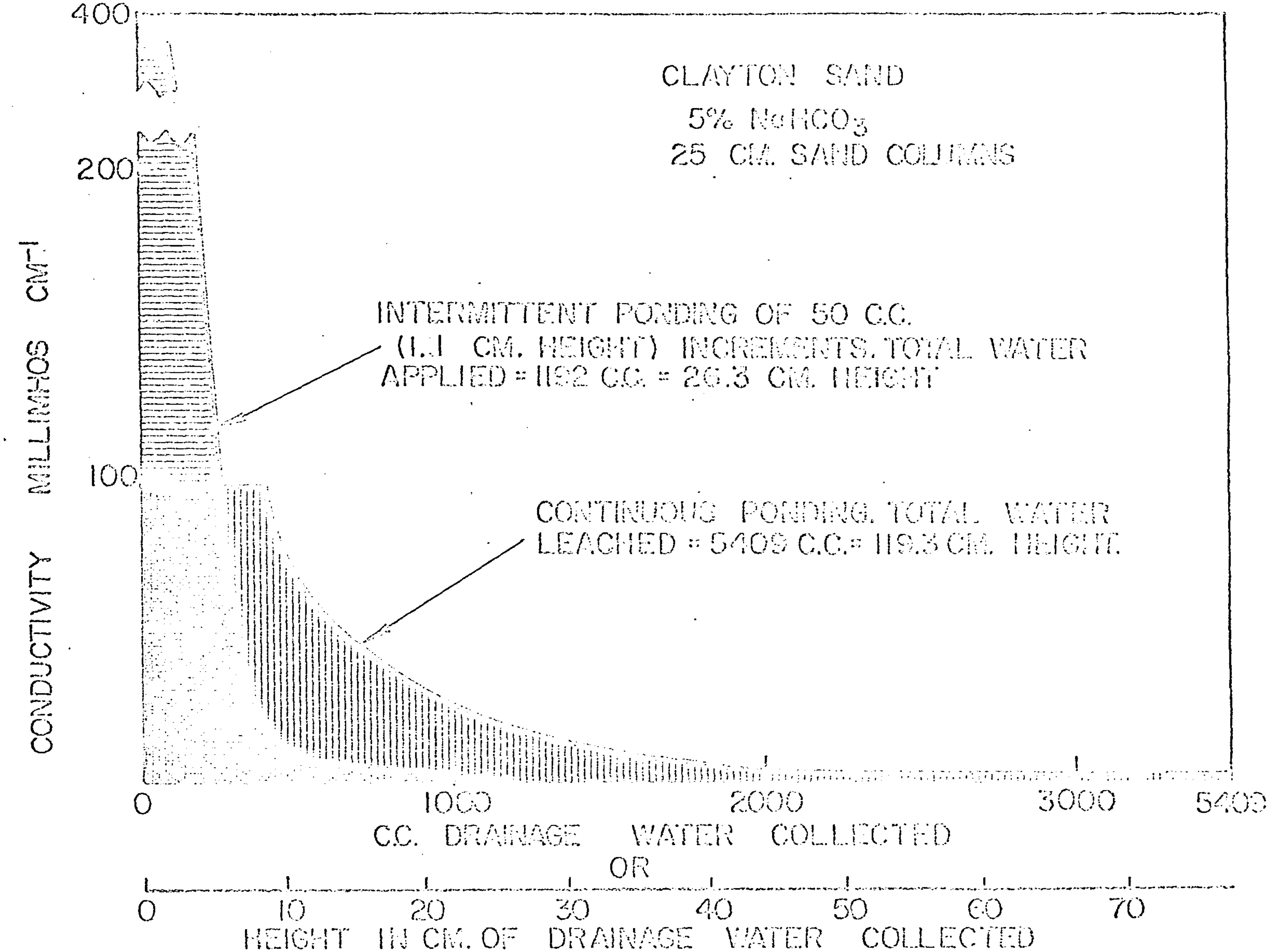
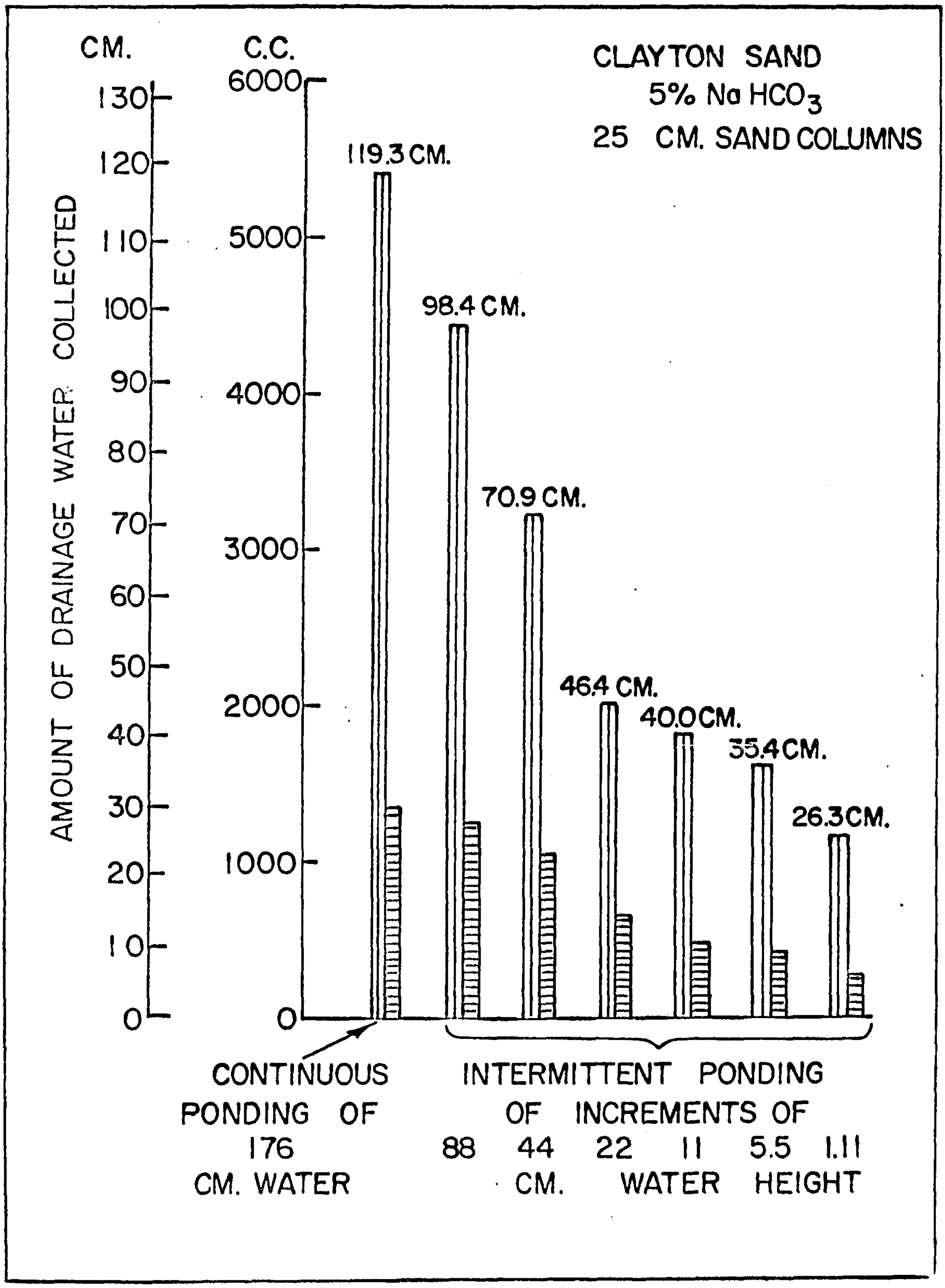

CLAYTON SAND
5% $NaHCO_3$
25 CM. SAND COLUMNS
INTERMITTENT PONDING OF 50 C.C.
(1.1 CM. HEIGHT) INCREMENTS. TOTAL WATER
APPLIED = 1192 C.C. = 26.3 CM. HEIGHT
CONTINUOUS PONDING. TOTAL WATER
LEACHED = 5409 C.C. = 119.3 CM. HEIGHT
CONDUCTIVITY MILLIMHOS CM^{-1}
400
200
100
0
1000
2000
3000
5400
C.C. DRAINAGE WATER COLLECTED
OR
0
10
20
30
40
50
60
70
HEIGHT IN CM. OF DRAINAGE WATER COLLECTED

Figure 51. Histogram showing amount of drainage water collected for continuously and intermittently applied surface water. The tall bars show the amount of water used to remove 100 percent of the salts; the shorts, 91.5 percent


CLAYTON SAND
5% Na HCO3
25 CM. SAND COLUMNS
CM.
C.C.
AMOUNT OF DRAINAGE WATER COLLECTED
119.3 CM.
98.4 CM.
70.9 CM.
46.4 CM.
40.0 CM.
35.4 CM.
26.3 CM.
CONTINUOUS PONDING OF 176 CM. WATER
INTERMITTENT PONDING OF INCREMENTS OF
88 44 22 11 5.5 1.11
CM. WATER HEIGHT

PROCEDURE FOR EXPERIMENT III

Upward Leaching With Surface Drainage Runoff

In this procedure subirrigation of distilled water was applied under a pressure of 10 cm. In other words the water head was maintained at 10 cm. above the soil surface as illustrated in Figure 31. Columns were prepared as mentioned earlier. The soil was Clayton sand presalinized with sodium bicarbonate at the 5 percent level. Only one increment size was used. Each increment of distilled water applied was 500 cc. (equivalent to 11 centimeter height). The time needed for the application of each increment was recorded in Tables 52-54 of Appendix A. Drainage was allowed from the surface as shown in Figure 31, at the right. Enough time for drainage was allowed, so that all upward supplied water that was not absorbed by the soil was collected. The electrical conductivity of increments of the surface runoff (drained) water was then measured by the solu-bridge and tabulated. Also the electrical conductivity of the total drainage water was measured as given in column 8 of the Tables 52-54 of Appendix A. The percentage of each amount of drainage water collected to the total amount of drainage water was calculated. Also the percentage of removed salts to the total salts removed was calculated as in the last column of the Tables 52-54 in the Appendix.

RESULTS AND DISCUSSION OF EXPERIMENT III

Upward Leaching With Surface Drainage Runoff

This experiment can be applied in nature by feeding the field tiles (in Egypt each is usually called "zarook" or fourth degree drain) with irrigation water under pressure or hydraulic head. This head can be created by applying fresh water to the drains at 10 or more cm. higher than the soil surface at the drain inlets (or outlets). Later, the water after passing through the soil will flow on the soil surface and then can be collected by open collector drains (each, named "sanawy" or third degree drain).

As illustrated in Figure 52, to get rid of all salts in the sand columns, 4264 cc. equivalent to 94 centimeters height was needed. This amount was less than that used for continuous surface ponding (Experiment IIa), but it is more than twice that collected when surface intermittent ponding of 500 cc. (Experiment IIe) was applied. Thus 500 cc. increments of surface water application is better than 500 cc. increments of subirrigation application, since ponded evaporation losses accompanying surface application are not too large. Subirrigation is normally considered as a saver of waste against evaporation losses. This is true if the subirrigation water level stays considerably below the soil surface. In the leaching method mentioned here the subirrigation water penetrates and stands on the surface so there may be heavy evaporation losses.

Figure 53 gives the percentages of salts removed corresponding to the percentages of drainage water collected. It can be seen that 41 percent of the drainage water collected was needed to get rid of 91.5 percent of the salts removed. This amount (41 percent = 1748 cc. = 38.6 cm. height) is relatively greater than that used in Experiment IIe (500 cc. = 11.0 cm. increments). So the leaching by the procedure of Experiment III is not recommended since no water will be saved by using it.

Figure 52. Electrical conductivity versus cc. drainage water collected after application of distilled water of 500 cc. (11 cm. height) maintained at 10 cm. head, upward through 25 cm. long columns of initially salinized (5 percent $NaHCO_3$) Clayton sand and allowing drainage from soil surface as runoff

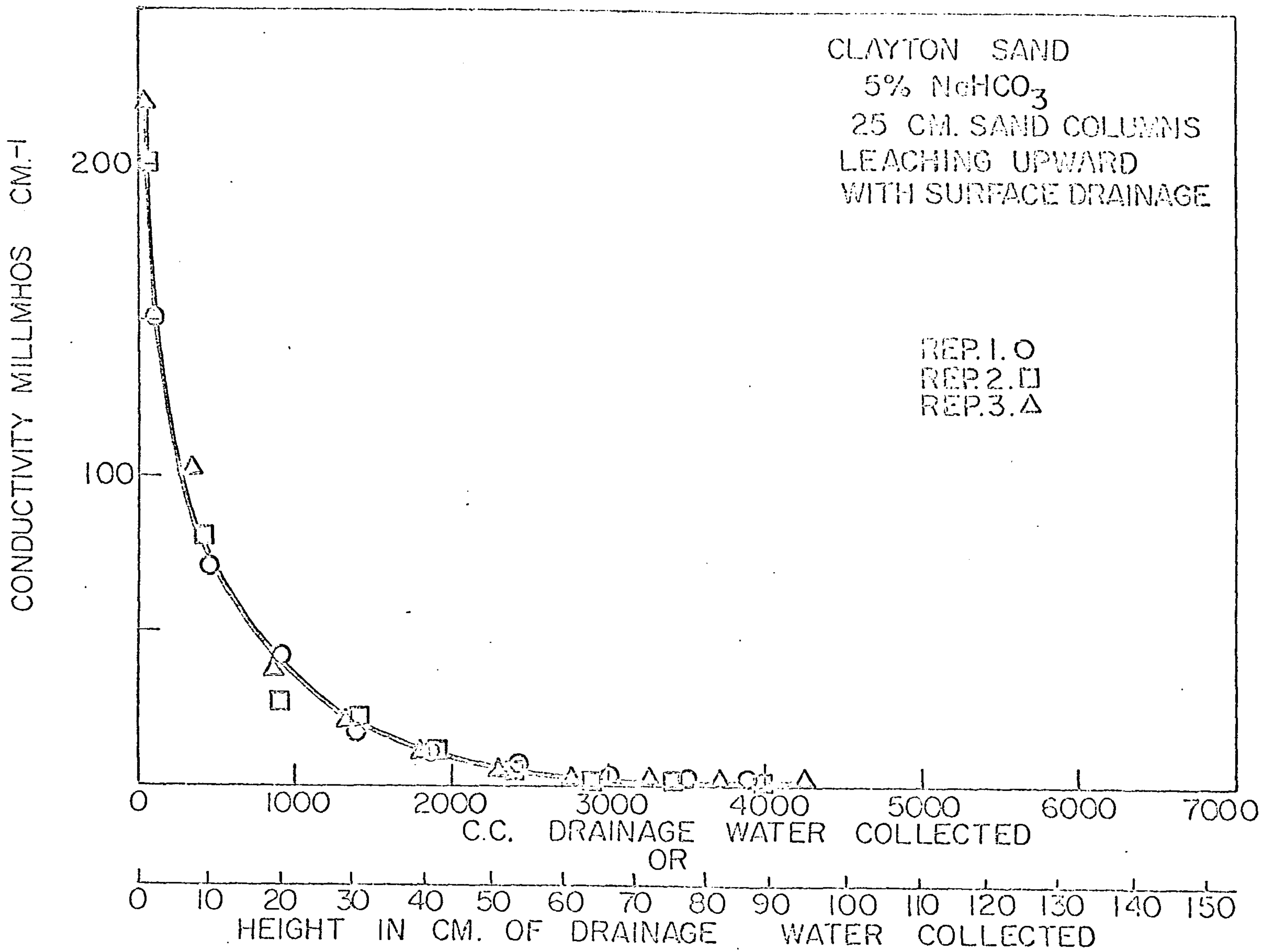
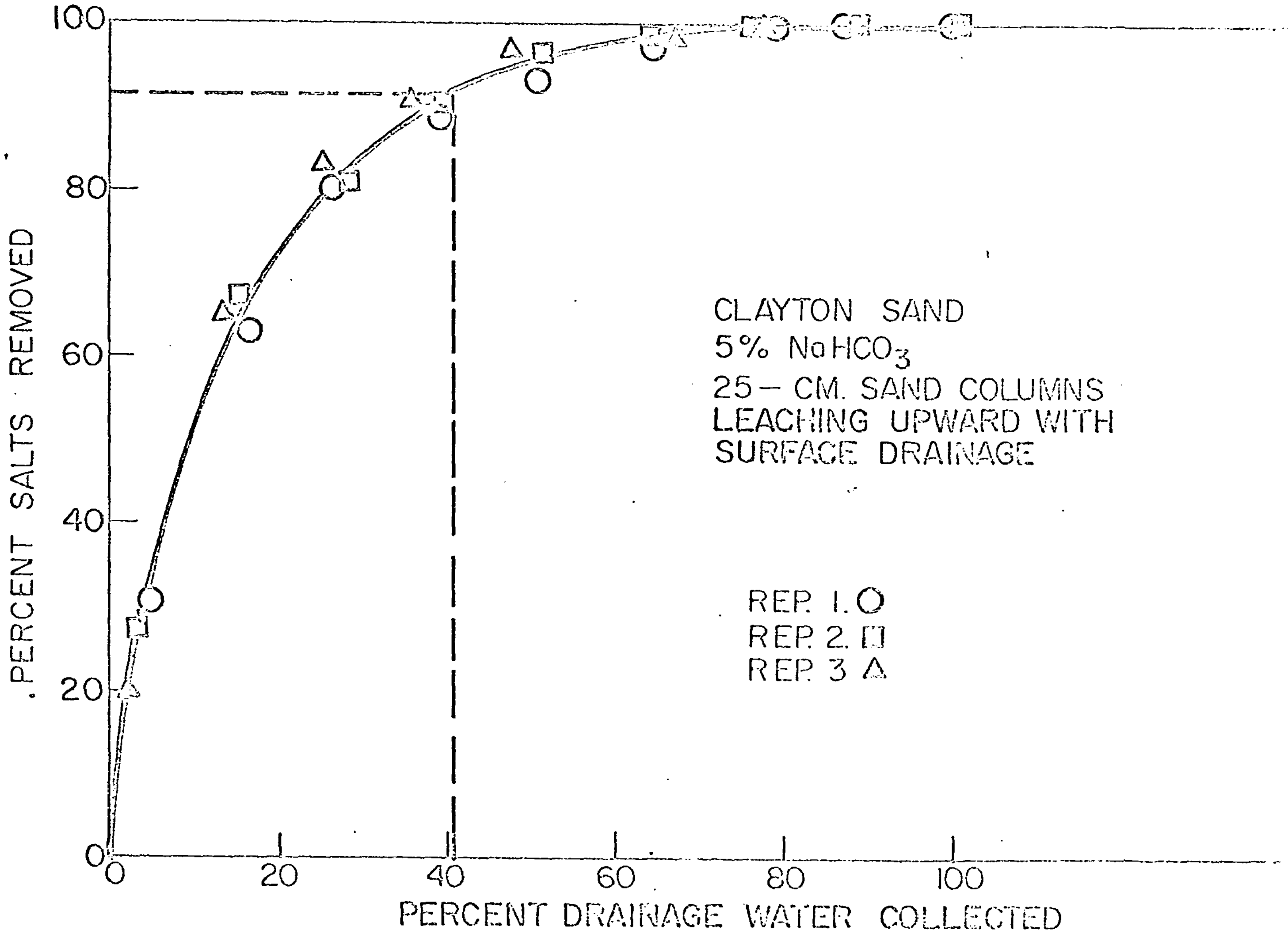

CLAYTON SAND
5% NaHCO3
25 CM. SAND COLUMNS
LEACHING UPWARD
WITH SURFACE DRAINAGE
REP. 1. O
REP. 2. □
REP. 3. Δ
CONDUCTIVITY MILLMHOS CM.-1
200
100
0
1000
2000
3000
4000
5000
6000
7000
C.C. DRAINAGE WATER COLLECTED
OR
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
HEIGHT IN CM. OF DRAINAGE WATER COLLECTED

Figure 53. Percent of salts removed versus percent drainage water collected for an application of 500 cc. (11 cm. height) maintained at 10 cm. head applied upward through 25 cm. long columns of initially salinized (5 percent $NaHCO_3$) Clayton sand and allowing drainage from soil surface as runoff


CLAYTON SAND
5% $NaHCO_3$
25 – CM. SAND COLUMNS
LEACHING UPWARD WITH
SURFACE DRAINAGE
REP. 1. O
REP. 2. □
REP. 3 △
PERCENT SALTS REMOVED
PERCENT DRAINAGE WATER COLLECTED
0
20
40
60
80
100

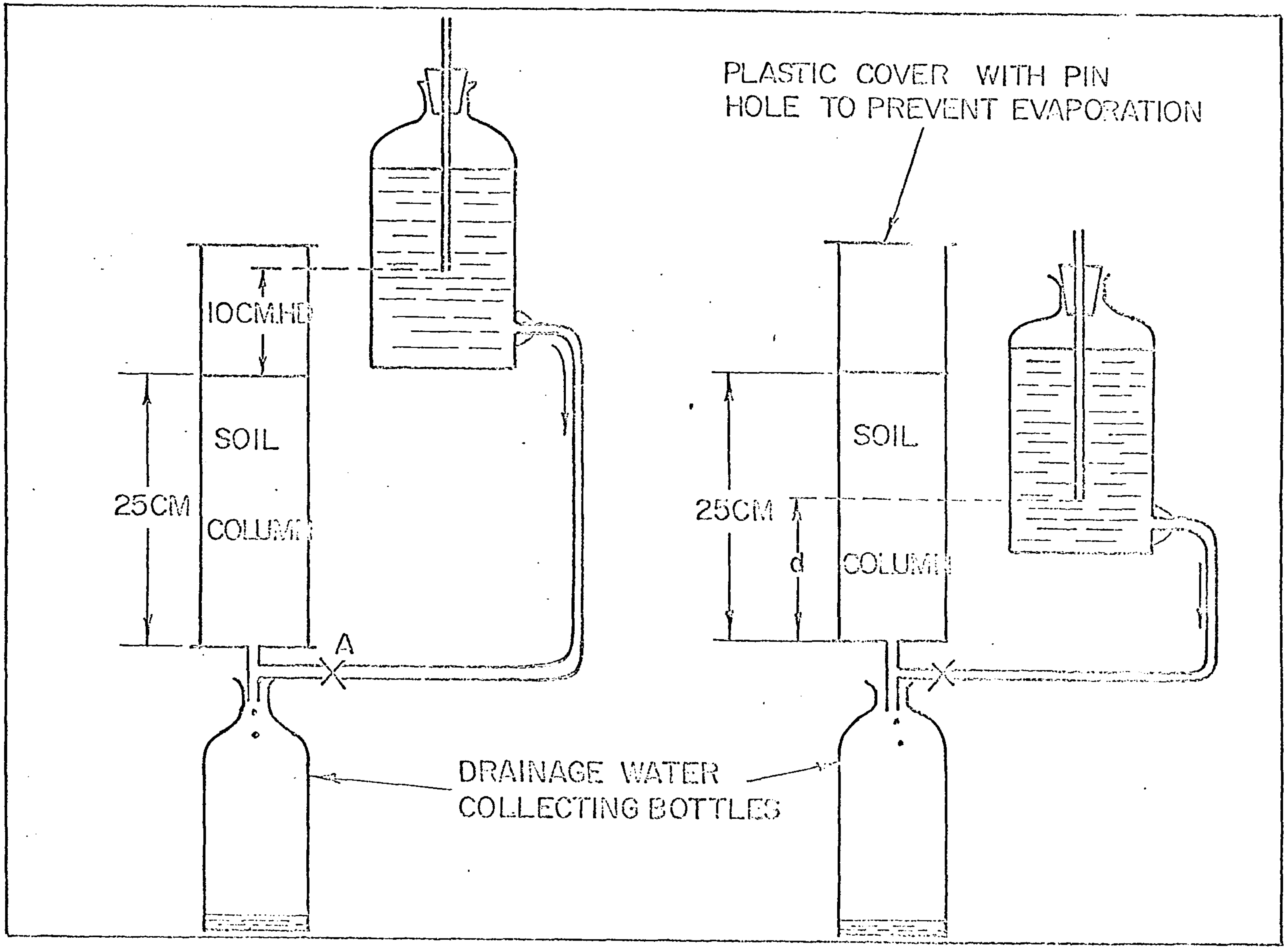
PROCEDURE FOR EXPERIMENT IV

Upward Leaching With Gravity Drainage

A cross-sectional sketch of the appartus is given in Figure 54 left. The x's in the figure are necessary "on-off" clamps. In the experiment the water is pushed upward into the soil column (see Figure 54, left) under a head difference of 10 cms. between the water and the soil surface. After 500 cc. increments were allowed to pass through the soil column, the feeding tube was clamped (as illustrated by clamp A in Figure 54, left), and the drainage was allowed to proceed by opening the drainage tube to the drainage water collecting bottle. After an elapse of enough time to allow for drainage the above procedure was repeated until the electrical conductivity of the collected drainage samples was practically zero. The soil used for this experiment was Clayton sand which was initially salinized with sodium bicarbonate at the 5 percent level, prepared as given earlier.

Figure 54. (Left) Schematic drawing (not to scale) of a saline soil column with leaching water applied upward through the soil followed by gravity drainage

(Right) Same as left except the water table is maintained at a distance d from the bottom of the soil column


PLASTIC COVER WITH PIN
HOLE TO PREVENT EVAPORATION
10CM.HD
SOIL
25CM
COLUMN
A
SOIL
25CM
d
COLUMN
DRAINAGE WATER
COLLECTING BOTTLES

RESULTS AND DISCUSSION OF EXPERIMENT IV

Upward Leaching With Gravity Drainage

The above experiment can be simulated in the field by feeding field tiles with fresh irrigation water under a hydraulic head of 10 centimeters (or more as required). The water will pass through the soil and pick up some of the salts. After time needed to pass the required quantity of water, the irrigation water may be stopped and gravity drainage can be started. The drainage water will pass through the tiles to larger drains where it can be pumped out.

By this method it was found that the total amount of drainage water collected containing the whole amount of salts was smaller than that used for continuous surface leaching, but greater than that used in the former experiment (III) and also much greater than that used for intermittent ponding of 500 cc. increments. Therefore, the method of Experiment IV is not recommended for the complete leaching of salts.

Figure 56 gives the percent of salts removed that corresponds to the percent drainage water collected. The first 21 percent of the drainage water collected was needed to get rid of 91.5 percent of the removed salts. This amount is 1158 cc. (25.5 cm. height) and indicates a higher efficiency than Experiment III, provided we are concerned only with 91.5 percent salt removal.

In the field for Experiment IV to be successful certain conditions must exist as follows:

1. The site conditions must permit maintaining a desirable height of water table without excessive water requirements. That is, an impermeable layer must exist at a reasonable depth.

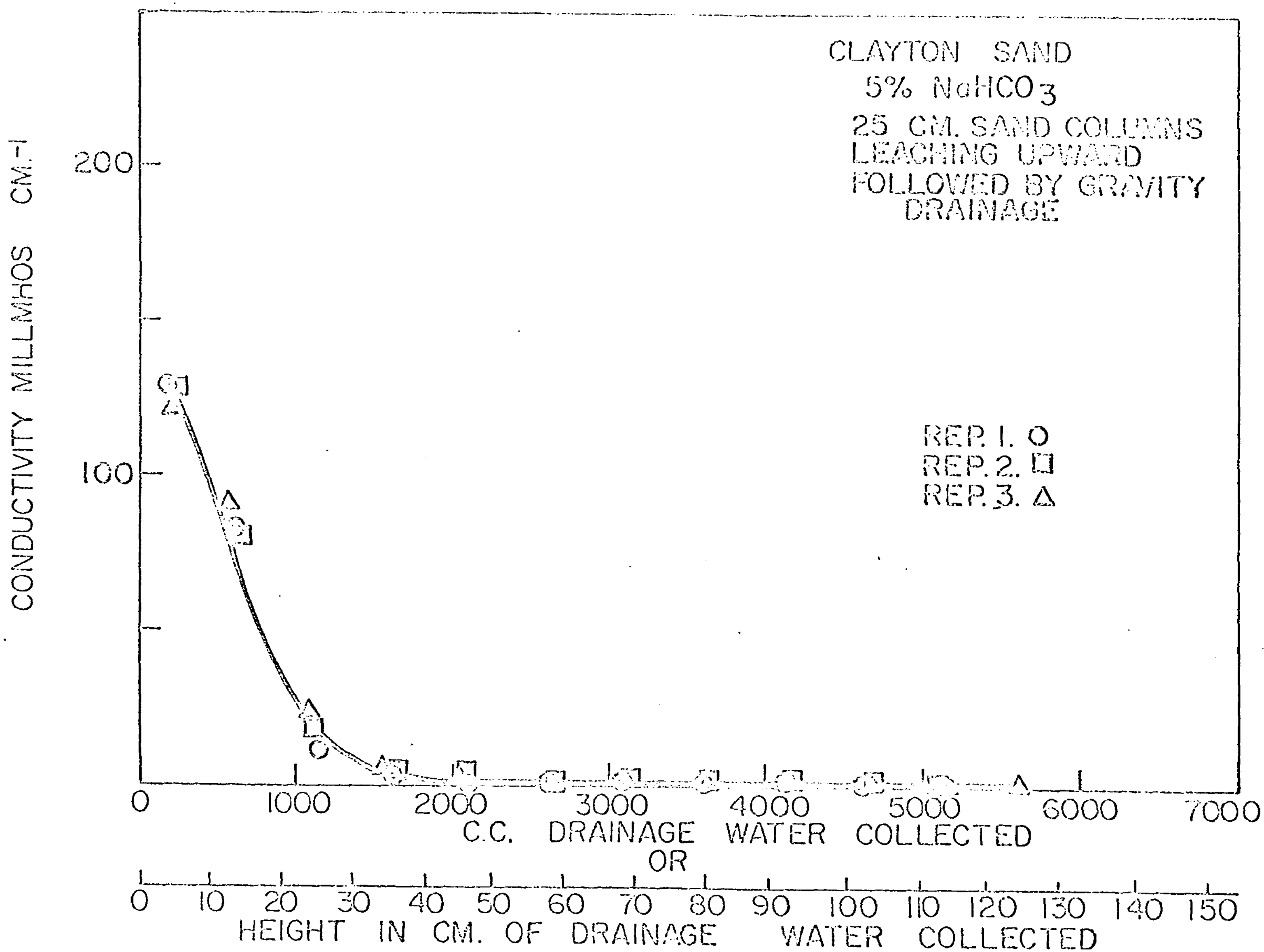
2. The land surface must be level or smooth with only a gentle slope.

3. For proper control of water in the drainage system, checks and dams are needed.

4. Leaching from below should be more effective where tiles can be placed in layers of shells or gravel or sand strata.

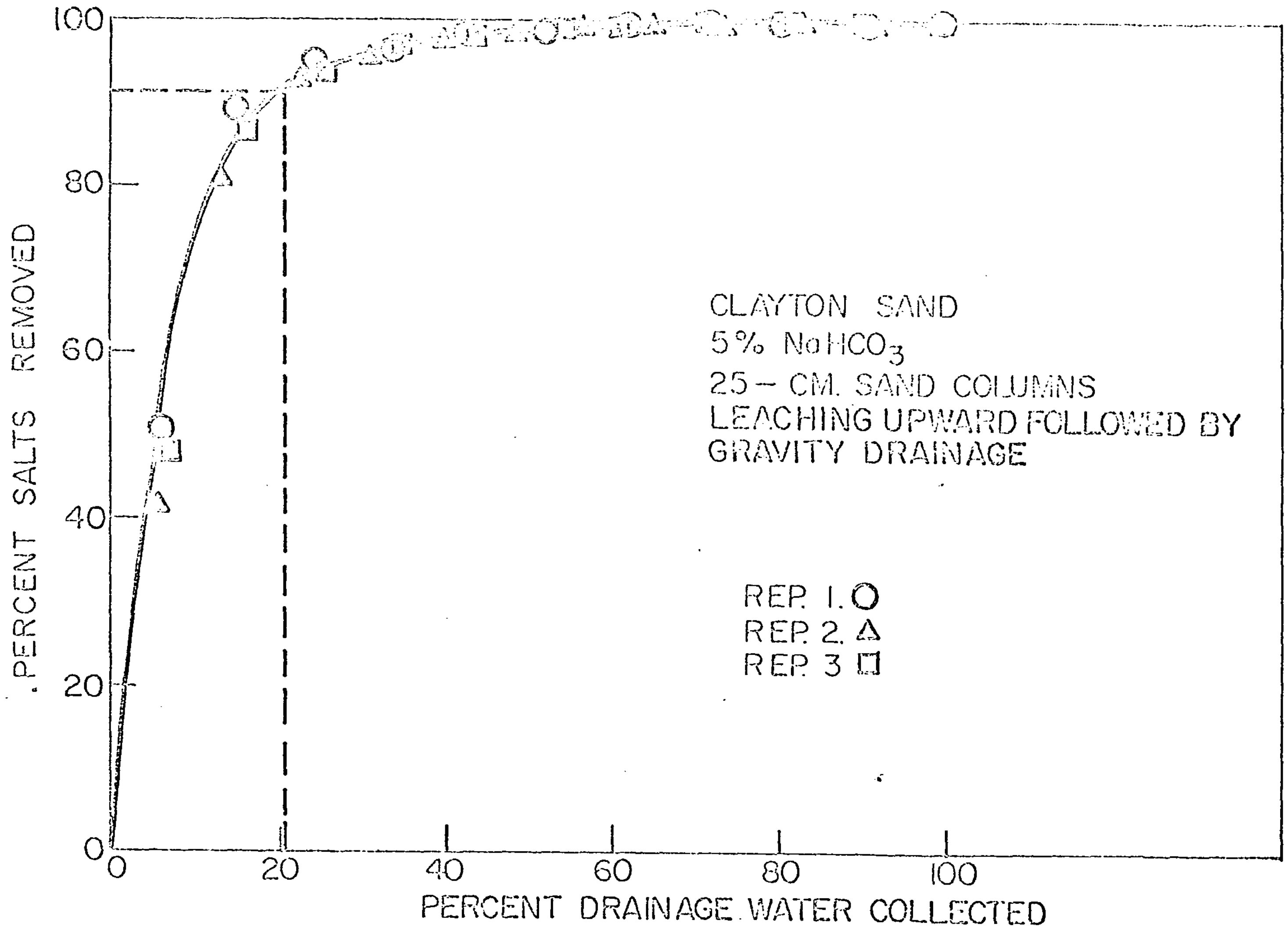
In general, it may be said that the results of Experiments I, II, III and IV considering the effectiveness of leaching or reclamation is judged by the depth of water passing through the soil and the method of application of this water depth.

Figure 55. Electrical conductivity versus cc. drainage water collected after application of 500 cc. (11 cm. height) maintained at 10 cm. head, upward through 25 cm. long columns of initially salinized (5 percent $NaHCO_3$) Clayton sand followed by gravity drainage



CLAYTON SAND
5% NaHCO3
25 CM. SAND COLUMNS
LEACHING UPWARD
FOLLOWED BY GRAVITY
DRAINAGE
REP. 1. O
REP. 2. □
REP. 3. Δ
CONDUCTIVITY MILLMHOS CM.-1
200
100
0
1000
2000
3000
4000
5000
6000
7000
C.C. DRAINAGE WATER COLLECTED
OR
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
HEIGHT IN CM. OF DRAINAGE WATER COLLECTED

Figure 56. Percent of salts removed versus percent drainage water collected for an application of 500 cc. (11 cm. height) maintained at 10 cm. head, applied upward through 25 cm. long columns of initially salinized (5 percent $NaHCO_3$) Clayton sand followed by gravity drainage

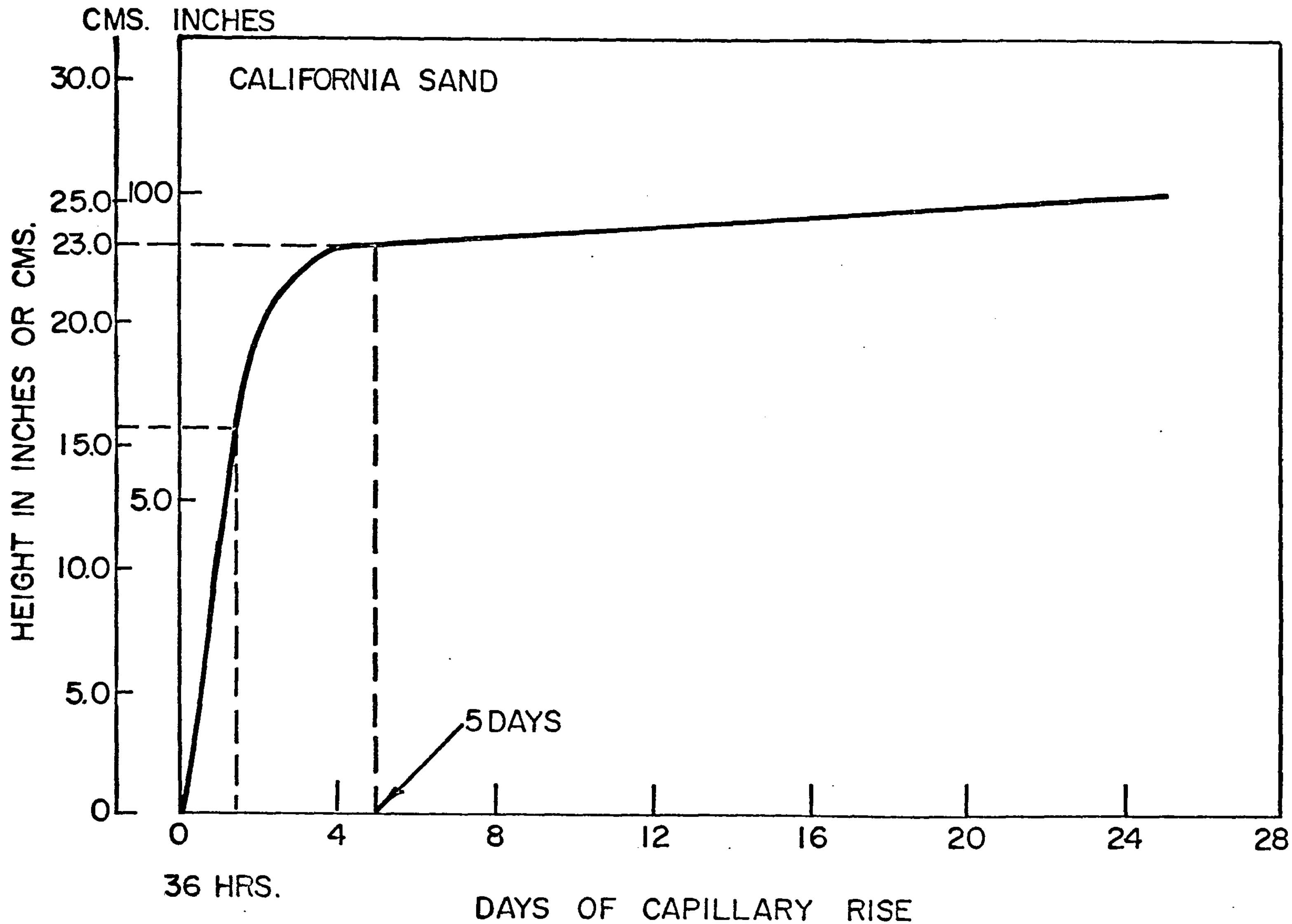

CLAYTON SAND
5% NaHCO3
25 – CM. SAND COLUMNS
LEACHING UPWARD FOLLOWED BY
GRAVITY DRAINAGE
REP. 1.
REP. 2.
REP. 3
PERCENT SALTS REMOVED
PERCENT DRAINAGE WATER COLLECTED
0
20
40
60
80
100

PROCEDURE FOR EXPERIMENT V

Leaching by Subirrigation to Bring Water Table Up to a Depth of 12.5 cm. From the Surface of 25 cm. Long Columns

In this experiment leaching water was added by subirrigation to bring the water table up to a distance of 12.5 centimeters (referred to as d in Figure 54 right) from the surface of the 25 cm. sand columns. The soil was Clayton sand and the salt used was sodium bicarbonate. The columns were of the same 25 centimeters length and were prepared as mentioned before. Starting the experiment, the feeding tube clamp as shown in Figure 54 (right) was opened and water was allowed to rise in the column. An elapse time of not less than 36 hours was allowed to be sure that the capillary rise would cause essentially all capillary water to reach the soil surface. This 36 hours was determined from Tolman (1937) as shown in Figure 57. After the elapse time allowed for the capillary rise, the feeding tube was clamped and drainage was allowed for sufficient time as tabulated in Tables 58-60 given in Appendix A. The process of capillary rise followed by drainage was then repeated until the electrical conductivity reached less than 4 millimhos $cm.^{-1}$. For each drainage time the volume of the collected water was determined, electrical conductivity of drainage water and the electrical conductivity of the cumulative amount of drainage water was then measured.

Figure 57. Rate and extent of capillary rise as reported by Tolman (Figure 66, page 157 in California sand)


CMS.
INCHES
CALIFORNIA SAND
30.0
25.0
100
23.0
20.0
15.0
5.0
10.0
5.0
0
HEIGHT IN INCHES OR CMS.
5 DAYS
0
4
8
12
16
20
24
28
36 HRS.
DAYS OF CAPILLARY RISE

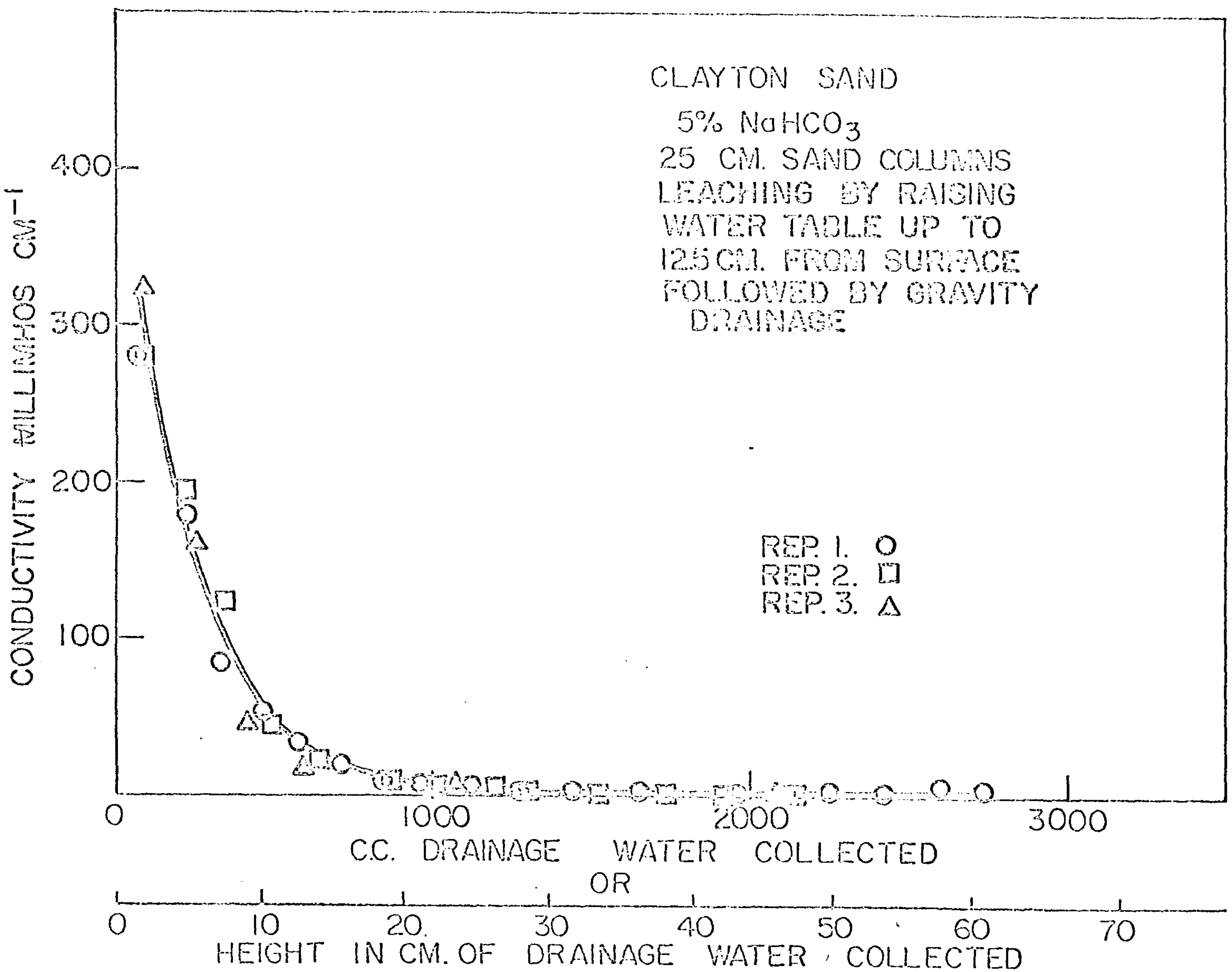
RESULTS AND DISCUSSION OF EXPERIMENT V

Leaching by Subirrigation to Bring Water Table Up to a Depth of 12.5 cm. From the Surface of 25 cm. Long Columns

Figure 58 shows the curve obtained by plotting the electrical conductivity versus the cubic centimeters of collected drainage water. The curve has the same general shape as the curves of Figures 32, 34, 36, 38, 40, 42, 44, 46, 48, 52 and 55 except that in Figure 58 the curve starts at a different value of electrical conductivity, but still the electrical conductivity decreases with the collected drainage water.

The average amount per replicate of drainage water collected to reach a lower value of 4.00 millimhos $cm.^{-1}$ for the electrical conductivity was 1158 cc. equivalent to 25.5 cm. height. This is the same amount as for Experiment IV (leaching upward with gravity drainage). The congruent nature of the experimental data for the three replicates indicates good precision of the measurement. The average amount of distilled water used per replicate was 1287 cc. equivalent to 28.6 cm. height. (The water retained by the initially air dry soil was 1287 - 1158 = 129 cc. for the 25 cm. long by 15.34 $cm.^2$ (= 1133.5 $cm.^3$) column, or (129/1133.5) x 100 = 11.4 percent, for the average drainage tension of 25/2 = 12.5 cm.)

Figure 58. Electrical conductivity versus cc. drainage water collected after sub-irrigation of distilled water maintained at 10 cm. head as shown in Figure 31, left, to bring the water table up to a depth of 12.5 cm. in 25 cm. long columns of initially salinized (5 percent $NaHCO_3$) Clayton sand. The water table was held at the 12.5 cm. depth for not less than 36 hours before gravity drainage water was allowed and the drainage water collected


CLAYTON SAND
5% NaHCO3
25 CM. SAND COLUMNS
LEACHING BY RAISING
WATER TABLE UP TO
12.5 CM. FROM SURFACE
FOLLOWED BY GRAVITY
DRAINAGE
REP. 1. O
REP. 2. □
REP. 3. △
CONDUCTIVITY MILLIMHOS CM-1
400
300
200
100
0
1000
2000
3000
C.C. DRAINAGE WATER COLLECTED
OR
0
10
20.
30
40
50
60
70
HEIGHT IN CM. OF DRAINAGE WATER COLLECTED

PROCEDURE FOR EXPERIMENT VI

Leaching by Subirrigation to Bring the Water Table Up to a Depth of 23 cm. in 25 cm. Long Columns

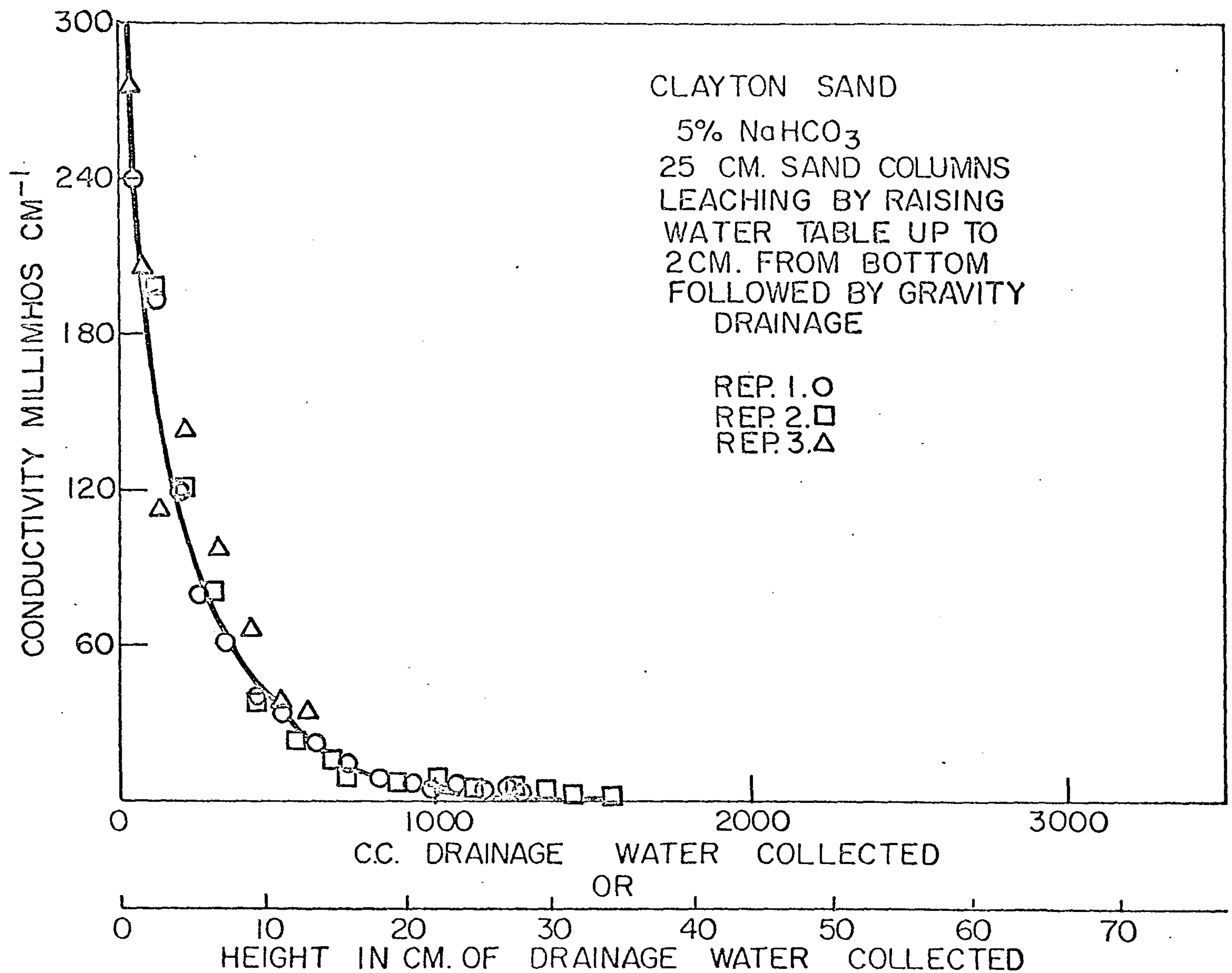
The procedure for this method was the same as that for Experiment V except that the applied water was supplied to maintain the water table at a distance of 2 cm. (see distance d in Figure 54, right) from the bottom of the 25 cm. long columns, i.e., at a depth of 23 cm. from the soil surface. An elapsed time of not less than five days was allowed for the capillary rise to be complete, a time shown in Figure 57.

RESULTS AND DISCUSSION OF EXPERIMENT VI

Leaching by Subirrigation to Bring the Water Table Up to a Depth of 23 cm. in 25 cm. Long Columns

Results for Experiment VI are given in Figure 59 and Tables 61-63 of Appendix A. Figure 59 shows a curve plotted from the data contained in Tables 61-63. The electrical conductivity decreases as more drainage water is collected. In this method, more drainage water was collected than in Experiments IV and V, to reach a salinity level of less than 4.0 millimhos $cm.^{-1}$. The collected water averaged 1267 cc. (27.9 cm. height) while the distilled water used was 1603 cc. (30.9 cm. height).

Figure 59. Electrical conductivity versus cc. drainage water collected after subirrigation of distilled water maintained at 10 cm. head as shown in Figure 31, right, to bring the water table up to a depth of 23 cm. in 25 cm. columns of initially salinized (5 percent $NaHCO_3$) Clayton sand. The water table was held at the 23 cm. depth for not less than 5 days before gravity drainage was allowed and the drainage water collected


CLAYTON SAND
5% $NaHCO_3$
25 CM. SAND COLUMNS
LEACHING BY RAISING
WATER TABLE UP TO
2 CM. FROM BOTTOM
FOLLOWED BY GRAVITY
DRAINAGE
REP. 1. ○
REP. 2. □
REP. 3. △
CONDUCTIVITY MILLIMHOS CM^{-1}
300
240
180
120
60
0
1000
2000
3000
C.C. DRAINAGE WATER COLLECTED
OR
0
10
20
30
40
50
60
70
HEIGHT IN CM. OF DRAINAGE WATER COLLECTED

GENERAL DISCUSSION

Movement of Water in Soils

The resultant force acting on a volume element of water may be regarded as made up to five components or forces (see Kirkham's notes of Alexandria, p. 35, 1963). Each component or force makes a greater or lesser contribution according to the nature of the solid surface, the moisture content, the content of soluble salts, and the location of the element considered. These five forces that move water in soils are:

1. electrical forces,
2. chemical forces,
3. gravity forces,
4. pressure forces, and
5. capillary forces.

The electrical forces in some cases are those referred to as disjoining pressures because they then tend to disjoin, that is, pull (force) the water particles apart.

The chemical forces or salt forces (which in a sense are also electrical) are known as the osmotic pressure or suction due to differences of content of soluble salts. Anions and cations in double-layers associated with the solid surfaces seem to cause osmotic pressures according to Childs and George (1948) and Low (1955).

Kemper (1960) showed the effect of the electrical and chemical forces on the movement of water solution through films of thickness encountered at moisture contents less than field capacity, i.e., water at about one-third atmospheric pressure. The electrostatic charge and diffuse layer associated with clay mineral surfaces can extend more than 100 angstroms into the soil solution. Since the ions in the solution are charged and the passing water is not, a partial separation of the solute and solvent "salt sieving" might be expected as the solution passes through the thin films between and on particles. The gravitational forces are always acting vertically downwards and can be computed as a product of three factors ρgh, where ρ is the density of water, g the gravity acceleration, and h is the height above a reference plane in the soil. The gravitational forces are most important in saturated soils.

The pressure forces are most important in unsaturated soils and the pressure forces are then negative and may be due to other forces than in the list of five given. Pressure forces may overcome viscous drag forces, a type of force not listed as such on Kirkham's list. Low (1959) has discussed these forces for clay water systems.

Cohesion forces cause water molecules to hang together, and together with adhesion forces are responsible for water rise in capillary tubes. In unsaturated flow the pressure is generally negative and is commonly called the capillary potential. The moisture in this case will move from point to point if the total potential is greater regardless of the dryness of each point. (See Kirkham and Power's notes of Advanced Soil Physics Notes, 1965.) The capillary forces or matric suction (Richards and Ogata, 1960) are considered physical in nature, not chemical or electrical. Willard Gardner (1939) has described the many types of electrical and non-electrical forces operating in soil. The term matric suction was not invented when he spoke.

It simplifies matters if we speak in terms of the scalar potential rather than the vector forces. The total scalar potential ϕ is defined as (Childs and George, 1948):

$$\phi = \rho gh + (P - p - \pi)$$

where:

ϕ = total potential

ρgh = gravity potential

P = hydrostatic potential

p = osmotic pressure potential

π = capillary potential

$$\pi = \sigma\left(\frac{1}{r_1} \pm \frac{1}{r_2}\right)$$

where σ denotes surface tension and r_1 and r_2 are regarded as the radii of curvature of curves made by intersections of two perpendicular planes with the surface at the point in question. In using the scalar potentials consistent units must be used. In the above list ρgh implies ergs as units whereas the capillary potential formula implies pressure units dynes/cm^2. Ordinarily scalar potential terms are expressed as cm. of water column.

Spreading of Salts in Soil-Water System

Salts spreading is due to the following processes:

1. adsorption process,
2. exchange process,
3. ionic or molecular diffusion process, and
4. hydrodynamic dispersion process.

The adsorption and exchange processes are chemical phenomena.

The ionic diffusion or molecular diffusion process results from the motion of individual ions or molecules that make up the solution. This process becomes important at low velocities and in unsaturated conditions. Diffusive flow takes place in response to the gradient of the molar free energy of the water. Changes in molar free energy of the water cause pressure. Molar free energy pressure changes occur whenever the activity of any particular molecular or ionic species is not the same throughout the solution. Ions then move from the region of higher concentration near the particles surfaces to regions of lower concentration out in solution. Water is transferred as a result of a net diffusion of water molecules within the solution. This transfer of the molecules is in respect to the solution (see Corey and Kemper, 1961).

Salt mixing may occur as a result of the drag forces caused by differences in viscosities. Mixing also occurs as a result of weight forces caused by differences in densities.

The hydrodynamic dispersion is the spreading of a solute as the carrier fluid moves through the porous medium due to the complexities of the pore system. It is attributed to micro flow velocity distribution alone and depends on the length of travel of the water front and on the soil material.

What Happens to a Highly Permeable Soil Profile After and During Water Application?

Case of continuous ponding followed by gravity drainage

When fresh water drops are first applied to an air dry soil they form a microfilm around the particles. This microfilm of water increases in thickness with the addition of further drops of water and local wetting of the soil occurs. After a certain thickness is reached and the particles become locally saturated, water tends to drain until the next drops of water are incident on the soil surface. Further, drops of water incident on the surface will be carried into the interstices of the medium by the surrounding solution, and the particles will soon be interspersed with particles from other drops of water. A clear distinction will be drawn here between the actual streamlines and the conventional streamlines commonly used to describe the flow in porous media. The conventional streamlines can be described as lines drawn everywhere tangent to the average velocity vector. They are vertical in the present case. The actual streamlines are obviously different from the conventional streamlines, and are more complicated geometrically. Another feature of the flow which should be noted is the variation of velocity along the streamlines. A particle may be delayed or accelerated at various points along its path. The particle's average velocity over the entire length of path may differ greatly from the average velocity of the whole fluid (see Scheidegger, 1961).

During water application there are three basic zones, transmission zone, wetting zone, and wetting front. The transmission zone is characterized by an essentially constant hydraulic conductivity and approximately 80 percent saturation (see Hansen, 1955).

The wetting zone extends from the transmission zone to the wetting front where the hydraulic conductivity and degree of saturation both are reduced as the wetting front is approached.

The wetting front is the farthest point of advance of moving water which becomes more difficult to define as the initial moisture content of the soil increases.

The rate of advance of the liquid front in porous media is limited partly by the viscosity of thin films of water at the leading edges of menisci and partly by the rate of extension of the air-water interface (see Anderson, Sposito, and Linville, 1963).

When the depth of wetting becomes sufficiently great, the potential distribution down the profile is such as to permit the drainage of water from the saturated materials near the surface. At this stage the material near the surface is draining while that near the moisture front is wetting.

Finally, when water application is stopped and drainage commences out of the soil the ponded water disappears from the soil surface, and the initial zone of high moisture content near the surface gradually disappears to form an unsaturated zone above the moisture front. The hydraulic head drops rapidly and negative pressures exist throughout the profile with the exception of the lowest layers where the pressure is slightly above atmospheric (see Luthin and Miller, 1953).

As drainage proceeds, the tension increases throughout the soil profile and the discharge rate decreases. The water continues to drain out until the capillary forces resisting the downward movement of water are sufficient to neutralize the downward forces. At this time, the upper part of the soil profile is unsaturated.

The presence of soluble salts in the soil-water system changes the physical properties of a soil-water depending on the surface tension system and density of the soil solution or hydration and flocculation of the soil colloid (see Richards and Weaver, 1944).

Case of intermittent ponding followed by gravity drainage

In intermittent ponding all that occurs in continuous ponding is repeated after each water increment application. Two more processes also occur. First, air is allowed to enter and pass through the soil after each increment of water. Second, the process of drying out the soil is repeatedly done.

After the application of each water increment, the gravity forces tend to pull down the water in the soil and capillary forces are exceeded, causing the water to descend in the capillaries and air to enter the soil. The descent of water in the soil pores is not instantaneous, but require some time. Entry of air into the soil proceeds with the same irregular, discontinuous motion called "stalking motion" in engineering literature (see Luthin and Miller, 1953).

There appear to be three main distributions of air in a partially saturated soil:

1. confined air,
2. entrapped air, and
3. dissolved air.

A large volume of air confined between bulk liquid volumes, or between a bulk liquid volume and an impermeable layer, is defined as confined air. The confined air can be moved in soils when bulk fluid is moved.

Entrapped air is that air distributed in the form of small bubbles, within a bulk volume of water.

Air in solution, that is dissolved air, moves along with water in which it is dissolved. If released from solution by a change of pressure, it becomes entrapped air.

A part of the confined air may be displaced and moved by water behind a wetting front in the form of bubbles, that is entrapped air; some may go in solution if the changes of pressure are sufficient, the rest may remain stationary or displaced ahead of the wetting front, designated as piston flow.

Entrapped air may be carried along with water or move upward, depending on the existing forces, depending on the heads, capillary, viscous, and bouyancy forces (see Smith, Olsen, Bognold and Rice, 1966).

The process of drying is highly important for the improvement of permeability, since it causes the formation of cracks which will increase both the permeability and water-storing capacity (see Zuur, 1952). Drying out the soil between leaching periods aids aggregation and this in turn improves the physical condition of the soil (see Magistad and Christiansen, 1966). The drying process also helps the salt to get out on the surface of the soil particles, and so, mixing of these salts with leaching water will be much easier.

This explains why less water for leaching is used, as the number of water application increments are increased, which means the reduction of the amount of the increments.

This agrees with the conclusions of Kirkham (1949) and Luthin (1957). They independently worked out the theory for movement of ponded water into drain tubes when there was an impervious layer below the drain tubes. The drainage rate is extensively small compared with that over the drain tiles. Thus, there will be a high leaching of salt over the tiles and practically none midway between the tiles. To remedy this situation, they recommended not to maintain ponded water on the surface, but to apply successive rinsings. Kirkham concluded that an even better way is to apply water at the midway position between the drains. Also the author's work agrees with the field experiments done recently by Robinson and Luthin (February 1967). They reported that more salt was removed per unit of time by constant flooding than with intermitting flooding but that intermittent irrigation removed more salt per unit of water applied -- indicating that where water is expensive or land values low, the intermittent irrigation treatment would be the better treatment than the constant flooding treatment. This work also agrees with an experiment done in the field for continuous and intermittent ponding by the author (see El-attar and Bakr, 1963). It was reported that intermittent ponding is more efficient than continuous ponding for salt removal starting with a certain level down to a lower level of salinity.

Case of leaching upward with surface drainage

In leaching upward with surface drainage all the soil pores, which amounts to 50 percent by volume of the soil, are going to be filled completely with leaching water and, consequently, no air will be captured in the soil especially when the rising of water is very slow. The electrostatic forces of attraction tends to concentrate the salts in the vicinity of the soil particles or in other words tends to make layers coating the surfaces of the soil particles. Only the water close to the particles surfaces will contact the salts and mix. Only a very small percentage will mix with the water far from the particles surfaces. With respect to salt leaching, the efficiency of water will be different resulting from its distance from the soil particles surfaces. The part of water which is far from the particles surfaces will have very low efficiency, while its efficiency gets higher and higher when the water approaches the particles surfaces. This interpretation can be the only meaning of why leaching upward with surface drainage consumes more water than intermittent surface leaching followed by gravity drainage.

An explanation of why continuous surface leaching requires more leaching water than upward leaching may be the relatively higher rate of flow through the soil which gives lesser chance for salt mixing with the passing water than that for upward leaching.

Case of leaching upward followed by gravity drainage

In the author's opinion and based on his experimental work, this method will consume more leaching water than the case just considered due to:

1. The waste of water that fills all the big and small pores and that amounts to 50 percent of the soil bulk volume.

2. The upward flow of water through the soil that will remove most if not all the soil air out of the capillaries and replace that air by water especially when the rate of flow is very slow.

3. The fact that when drainage starts the fluid in the

the soil will be driven out by that in the upper layers without the fluid in the lower layers having the chance to pass through the whole length of soil column or profile so mixing of salts will be less than, for example, the case of upward leaching with surface drainage.

These three items and perhaps others explain why more water is needed for upward leaching with gravity drainage than when there is upward leaching with surface drainage.

Case of leaching by raising the water table up to half the depth of sand columns

In this case only the lower half of the sand column is completely saturated. The upper half will be influenced by capillary rise. The height of rise inside the capillaries may be approximated by the capillary rise formula, $h = \frac{2\sigma \cos\theta}{r \rho g}$, where h is the capillary rise, σ is the surface tension, θ is the contact or wetting angle with the pore wall, r is the radius of the pore, ρ is the density of fluid and g is the gravity acceleration. From the capillary rise formula the height is inversely proportional to the pore radius. Thus, the height in the upper half of the sand columns will be greater where the pore radius is small and lesser where the pore radius is relatively big. Hence, in these big pores there will be no salt mixing. Moreover, in the small pores which will be completely full of water the part of water close to the pore walls will have greater leaching efficiency than that far from the walls. As a conclusion, if the salinized soil contains large pores, leaching by raising the fresh water table up to half the depth will leave numerous regions where the big pores are located without salt mixing. These regions will need later to be leached in one way or the other.

Case of leaching by raising water table up to 2 cm. from the bottom of the sand column

The leaching process works exactly the same as in the latter case except that many large pores will not receive water due to the increase of depth of the water table. This may be the reason why it requires more leaching water to get rid of the (bicarbonate) salts.

Conclusions Regarding the Different Methods

As a final decision, the intermittent surface water application with the increments of fresh water, as small as practical, (Experiment IIg) will be the most economic and efficient method for leaching all the salts. But to get rid of the most salts until the stage that plants can grow without any harm, the method of raising water table up to a certain depth of the profile may be taken into consideration followed by gravity leaching (Experiments V and VI). According to field conditions with regard to evaporation and the many other circumstances encountered in the field it may save water and hence may be recommended.

Merits of Proposed Methods

There are several major merits that can be stated for the method of intermittent surface leaching and also several major merits for the method of raising the water table to a certain depth. They are as follows:

1) Both methods can easily be applied in the field without asking for any more required instrumentation or unusual work that practicing engineers can use with great ease.

2) The surface of application of small increments of fresh leaching water is highly recommended due to the lack of water especially at the leaching seasons where many areas have relatively less irrigation water that can be used for leaching.

3) Although the results obtained by the methods may still require some field experiments for final adoption, the methods should provide unique solutions and should produce close answers even if the methods are applied by different individuals.

4) The methods can be readily improved by further application in the laboratory and the field. The improvements will not change the basic scheme. Like most methods in scientific and engineering work, the proposed methods have disadvantages as well as advantages. The major disadvantage is the fact that both methods need highly permeable soils. The permeability is one of the major problems that should be improved as necessary. Another major disadvantage for leaching by raising the water table is that an impermeable layer must exist at a shallow depth. Compiled field data should show which one of the two methods might best be used.

SUMMARY AND CONCLUSIONS

Six different methods of water application were used for leaching sodium salts from porous media. The sodium salts were sodium chloride, sodium bicarbonate and sodium sulfate. The porous media were Ida loess, 28 microns glass beads and Clayton sand and were presalinized with salt at five percent level. Not all salts and all porous media were used in each of the six methods. The presalinized porous media were packed in columns with 25 and 50 cm. depths and 7.6 and 13.5 cms. internal diameters, respectively. Measurement of electrical conductivity of the water were used as a measure of the leaching effectiveness.

The Six Methods of Leaching

I. All salts, all porous media and both 25 cm. and 50 cm. length columns were used. There was surface standing of water of 12.5 cm. depth kept constant by adding water in the first 70 days for the 25 cm. long columns only. Here the electrical conductivity was measured just above the soil surface, and either 2.0 or 2.5 cm. above the soil surface for the 25 cm. long columns. For the 50 cm. long columns the surface standing water was initially 29 or 37 cms. depth and the electrical conductivity was measured at the soil surface and at either 7 or 15 cm. above the soil surface. These measurements were made without stirring the standing surface leaching water. In addition to these measurements where there was no water stirring, measurements of the electrical conductivity were made of the stirred surface water for all the columns. This stirring was done after the earlier noted measurements were taken.

II. Clayton sand, 25 cm. long columns and different increments of leaching water were used. There was surface leaching with different amounts of distilled surface water. A head of 0-10 cm. of surface water was maintained during application. The increments of leaching water were 6000 cc. (132 cm. height) or more depending on the salt when a single increment was used, 4000 cc. (88 cm. height), 2000 cc. (44 cm. height), 1000 cc. (22 cm. height), 500 cc. (11 cm. height), 200 cc. (44 cm. height) and 50 cc. (1.1 cm. height). The soil was salinized with sodium bicarbonate when more than single water increment was applied. During and following the application of each increment gravity drainage was allowed and the drainage water was collected in sample increments and the electrical conductivity of the samples of drainage water and combined or total drainage water was measured. Two graphs for each case were plotted; the electrical conductivity in mmho $cm.^{-1}$ versus cc. drainage water and the percent salts removed versus percent drainage water.

III. Sodium bicarbonate, Clayton sand, 25 cm. long columns and increments of 500 cc. (11 cm. height) were used. There was leaching of water upward through the soil columns by subirrigation of distilled water applied under a pressure equal to the height of a column of water standing from the bottom of the sample to 10 cm. height above the soil surface. In other words, the water pressure applied at the base of the columns was equal to the length of the columns plus 10 cm. additional head. Drainage was allowed only from the soil surface as runoff and collection and electrical conductivity measurements of drainage water samples were taken as in Method II.

IV. Same as III except that gravity drainage was allowed after each application of 500 cc. (11 cm. height) increment by reducing the pressure to atmospheric.

V. Sodium bicarbonate, Clayton sand and 25 cm. long columns were used. There was leaching of water upward through the soil columns by subirrigation of distilled water applied to bring the water table up from the bottom of the soil columns to a height of 12.5 cm. The water pressure applied at the base of the columns was equal to 12.5 cm. The water was then allowed to stand for at least 36 hours so that by capillary rise the water could reach the soil surface. After this time lapse gravity drainage was then permitted and drainage water samples were collected and electrical conductivity measurements were made. Also the amounts of applied distilled water increments were determined and recorded.

VI. Same as V except that the water table was kept at 2 cm. above the bottom of the columns for at least five days to allow capillary rise.

Conclusions of the Respective Six Methods of Leaching

Conclusions of Method I

1. The salts, NaCl, $NaHCO_3$ and Na_2SO_4 as determined by electrical conductivity versus time curves, mixed with initially distilled water at different diffusion rates depending on: the type of the porous medium, the type of salt, location of measurements and the lengths of soil columns (see Figures 4-30).

2. For the Ida loess and 25 cm. long columns the sodium chloride always mixed with the standing surface water at a higher diffusion rate than did the sodium bicarbonate, which in turn mixed at a higher diffusion rate than did the sodium sulfate (see Figure 16).

3. For the Ida loess and 50 cm. long columns, the sodium chloride mixed initially with the standing surface water at a lower diffusion rate than did the sodium bicarbonate that mixed always at a higher diffusion rate than did the sodium sulfate, but after about 40 days of surface water standing sodium chloride diffused at a higher rate than did the sodium bicarbonate. This statement was true for the electrical conductivity measurements as determined in the stirred surface water (see Figure 25). For the unstirred surface water initial diffusion rates were not taken, but after about 70 days the diffusion rates were: $NaCl > NaHCO_3 > Na_2SO_4$ (see Figures 22, 23 and 24).

4. For the Clayton sand and where only sodium sulfate and 25 cm. long columns were used the electrical conductivity readings were higher than those for the Ida loess. In other words the diffusion rate of sodium sulfate has a higher rate in the Clayton sand than in the Ida loess (see Figure 21).

5. For the Ida loess and where only sodium bicarbonate and 50 cm. long columns were used the electrical conductivity readings were lower than those for the Clayton sand and for the glass beads. This means that the diffusion of sodium bicarbonate has a lower rate in the Ida loess than either in the Clayton sand or the glass beads (see Figure 30).

6. Electrical conductivities in the stirred water for the 25 and 50 cm. long columns, for all the sodium salts used (NaCl, $NaHCO_3$ and Na_2SO_4), and for all porous media used, were always higher than electrical conductivities at the soil surface. Also, electrical conductivities at the soil surface were always higher than electrical conductivities at some distance above the soil surface (see Figures 7, 11, 15, 20, 22, 23, 24, 26, 27 and 29).

7. The mixing rates, in general, were very slow and this method can not be recommended for leaching, since evaporation losses will be too high and drainage may not occur due to clogging of the soil pores

Conclusions of Method II

1. Continuous ponding (use of one large increment) required the largest amount of water for leaching (see Figures 32, 34, 36, 50 and 51).

2. Different salts needed different amounts of surface water to be leached out of the soil. The amounts were in order: $NaCl < NaHCO_3 < Na_2SO_4$. When the amount of each increment was decreased and the number of surface water applications were increased, more water was saved in leaching the sodium bicarbonate (see Figures 34, 38, 40, 42, 44, 46, 48, 50 and 51).

3. With the 50 cc. (1.1 cm. height) increments of water we got better efficiency of water application than with larger increments. Compared with continuous water application, 78 percent of the water was saved for 100 percent salt removed and 79 percent of the water was saved for 91.5 percent salt removed. This may be due to several reasons as follows:

a. The passage of air before and after the application of each increment which took some volume of the pores of the porous media resulting bulk or/and entrapped or/and dissolved air movement.

b. The drying of soil that occurred after gravity drainage following each applied increment which helped the sodium bicarbonate to surround the soil particles and to form thin films around the soil particles, facilitating the mixing process and consequently the leaching procedure.

Conclusions of Methods III and IV

For the methods of leaching upward through the soil with either surface drainage or gravity drainage it can be concluded that:

1. With surface drainage less water was required than that when gravity drainage was allowed due to the longer way fluid took, having more chance to mix with the sodium bicarbonate. In the case of gravity drainage the leaching water in the lower layers didn't have the chance to pass through the upper layers and it just drained out after gravity drainage was allowed.

2. Method IV is better than Method III when 91.5 percent of the sodium bicarbonate was removed since less water was needed, which is practically desired in the field. Leaching upward through the soil with gravity drainage may be recommended under certain circumstances to get rid of part of the salts since, in this case, it required less amount of water than the method of surface drainage.

Conclusions of Methods V and VI

For the last two methods (V and VI), it may be concluded that even they required more water for leaching the sodium bicarbonate than the method of intermittent surface water application of 50 cc. (1.1 cm. height), but each may be recommended in certain cases especially in the existence of high rates of evaporation. Further experiments should be carried on with different depths of water table and/or with more time elapse for capillary rise and/or with more time allowed for gravity drainage.

Final Word

In general, leaching processes are controlled by the joint action of many factors. Factors that are critical in one soil may have no significant effect in another because of differences between the porous media concerned. Thus, both the magnitude of the effect and the importance of each factor may vary from one case to another. The method of leaching application depends on the type of soil, the nature and level of salinity, the nature of ground water, its depth, depth of soil required to be leached, etc.

It is hoped that the work reported will be basic material for further studies in the laboratory and in the field. For instance, a study in the laboratory and the field should be carried on to know the effect of evaporation on leaching requirements. In the laboratory it may be done with vertical columns or/and with models to see the differences between the two cases. Another experiment that may come with more efficient leaching requirements or amounts is the continuation of leaching by raising the water table to different depths. This can be carried out either with or without taking into consideration the evaporation effect. In such experiments, the author suggests that the periods of gravity drainage will be longer than those allowed in this study. Also varying the compaction of soils under study should be studied to know exactly its influence on the leaching methods.

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APPENDIX A

Table 6. Electrical conductivities of surface water standing on a 25 cm. long column of salinized (5 percent $NaHCO_3$) Ida soil. Replicate 1

Elapsed time days	Electrical conductivity in mmhos. $cm.^{-1}$		
	At soil surface	2.0 cm. above soil surface	In stirred water
0			0
1			0.02
7			0.23
9			0.32
43			0.58
49			0.70
56	0.75	0.74	0.80
69	0.85	0.83	0.86
90	0.90	0.85	0.92
98	0.93	0.88	0.95
110	1.00	0.90	1.06
127			1.10

Table 7. Electrical conductivities of surface water standing on a 25 cm. long column of salinized (5 percent $NaHCO_3$) Ida soil. Replicate 2

Elapsed time days	Electrical conductivity in mmhos. $cm.^{-1}$		
	At soil surface	2.0 cm. above soil surface	In stirred water
0			0
1			0.10
7			0.26
9			0.41
43			0.72
49			0.78
56	0.78	0.76	0.81
69	0.80	0.77	0.86
90	0.85	0.80	0.95
98	0.87	0.85	1.00
110	0.88	0.86	1.02
127			1.08

Table 8. Electrical conductivities of surface water standing on a 25 cm. long column of salinized (5 percent $NaHCO_3$) Ida soil. Replicate 3

Elapsed time days	Electrical conductivity in mmhos. cm.$^{-1}$		
	At soil surface	2.0 cm. above soil surface	In stirred water
0			0
1			0.02
7			0.18
9			0.28
43			0.60
49			0.65
56	0.75	0.74	0.75
69	0.81	0.80	0.83
90	0.95	0.85	0.99
98	0.96	0.90	1.01
110	1.04	0.92	1.08
127			1.12

Table 9. Electrical conductivities of surface water standing on a 25 cm. long column of salinized (5 percent $NaHCO_3$) Ida soil. Replicate 4

Elapsed time days	Electrical conductivity in mmhos. cm.$^{-1}$		
	At soil surface	2.0 cm. above soil surface	In stirred water
0			0
1			0.01
7			0.20
9			0.26
43			0.66
49			0.70
56	0.70	0.69	0.75
69	0.78	0.76	0.83
90	0.90	0.77	1.00
98	1.00	0.80	1.04
110	1.04	0.83	1.08
127			1.10

Table 10. Electrical conductivities of surface water standing on a 25 cm. long column of salinized (5 percent Na_2SO_4) Ida soil. Replicate 1

Elapsed time days	Electrical conductivity in mmhos. cm.$^{-1}$		
	At soil surface	2.0 cm. above soil surface	In stirred water
0			0
1			0.12
5			0.17
26			0.32
33			0.40
55			0.44
69	0.53	0.38	0.50
75	0.55	0.39	0.55
82	0.58	0.40	0.60
88	0.60	0.45	0.63
96	0.62	0.46	0.64
103	0.64	0.47	0.65
111	0.66	0.48	0.67
123	0.67	0.50	0.68

Table 11. Electrical conductivities of surface water standing on a 25 cm. long column of salinized (5 percent Na_2SO_4) Ida soil. Replicate 2

Elapsed time days	Electrical conductivity in mmhos. cm.$^{-1}$		
	At soil surface	2.0 cm. above soil surface	In stirred water
0			0
1			0.16
5			0.26
26			0.36
33			0.45
55			0.50
69	0.57	0.39	0.57
75	0.58	0.40	0.58
82	0.60	0.42	0.60
88	0.61	0.43	0.61
96	0.62	0.44	0.62
103	0.63	0.46	0.63
111	0.64	0.48	0.65
123	0.65	0.50	0.67

Table 12. Electrical conductivities of surface water standing on a 25 cm. long column of salinized (5 percent Na_2SO_4) Ida soil. Replicate 3

Elapsed time days	Electrical conductivities in mmhos. cm.$^{-1}$		
	At soil surface	2.0 cm. above soil surface	In stirred water
0			0
1			0.15
5			0.20
26			0.27
33			0.34
55			0.46
69	0.55	0.40	0.50
75	0.56	0.42	0.55
82	0.58	0.43	0.58
88	0.60	0.45	0.60
98	0.61	0.46	0.63
103	0.62	0.47	0.65
111	0.63	0.48	0.66
123	0.65	0.49	0.68

Table 13. Electrical conductivities of surface water standing on a 25 cm. long column of salinized (5 percent Na_2SO_4) Clayton sand. Replicate 1

Elapsed time days	Electrical conductivity in mmhos. $cm.^{-1}$		
	At soil surface	2.5 cm. above soil surface	In stirred water
0			0
1			0.94
5			1.25
18			1.30
32			1.70
39			2.00
46			2.70
53	3.00	1.90	3.40
59	3.60	2.60	4.00
66	4.20	3.00	4.50
72	4.80	3.50	5.00
80	5.90	3.80	6.50
87	6.80	4.60	7.00
95	7.80	5.20	8.10
107	8.20	5.40	9.00

Table 14. Electrical conductivities of surface water standing on a 25 cm. long column of salinized (5 percent Na_2SO_4) Clayton sand. Replicate 2

Elapsed time days	Electrical conductivity in mmhos. cm.$^{-1}$		
	At soil surface	2.5 cm. above soil surface	In stirred water
0			0
1			0.83
5			0.87
18			0.99
32			1.43
39			1.90
46			2.75
53	3.00	2.00	3.50
59	3.80	2.25	4.00
66	4.30	2.55	4.80
72	5.00	3.35	5.30
80	6.10	4.00	6.10
87	7.50	4.20	8.00
95	8.00	4.50	8.40
107	8.90	4.80	9.20

Table 15. Electrical conductivities of surface water standing on a 25 cm. long column of salinized (5 percent Na_2SO_4) Clayton sand. Replicate 3

Elapsed time	Electrical conductivity in mmhos. cm.$^{-1}$		
days	At soil surface	2.5 cm. above soil surface	In stirred water
0			0
1			0.80
5			1.00
18			1.20
32			1.60
39			2.20
46			2.50
53	3.10	1.80	3.20
59	4.00	2.00	4.20
66	4.80	2.80	5.00
72	5.30	3.20	5.50
80	6.40	4.20	7.00
87	7.20	4.40	8.00
95	7.60	4.90	8.10
107	8.60	5.60	9.00

Table 16. Electrical conductivities of surface water standing on a 25 cm. long column of salinized (5 percent Na_2SO_4) Clayton sand. Replicate 4

Elapsed time days	Electrical conductivity in mmhos. cm.$^{-1}$		
	At soil surface	2.5 cm. above soil surface	In stirred water
0			0
1			0.70
5			1.20
18			1.60
32			1.90
39			2.60
46			2.80
53	3.00	2.20	3.60
59	3.60	2.40	3.80
66	4.50	2.60	4.60
72	5.60	2.80	5.70
80	5.80	3.80	5.90
87	7.00	4.20	7.50
95	7.50	5.00	7.80
107	8.40	5.20	8.90

Table 17. Electrical conductivities of surface water standing on a 50 cm. long column of salinized (5 percent NaCl) Ida soil

Elapsed time days	Electrical conductivity in mmhos. $cm.^{-1}$		
	At soil surface	7.0 cm. above soil surface	In stirred water
0			0
7			0.10
11			0.15
20			0.26
28			0.33
41			0.45
56			0.54
63			0.59
70	0.63	0.40	0.66
77	0.68	0.43	0.70
84	0.70	0.53	0.75
90	0.72	0.55	0.75
96	0.75	0.64	0.75
105	0.80	0.67	0.85
111	0.85	0.70	0.86
119	0.92	0.72	0.90
131	1.00	0.82	1.05

Table 18. Electrical conductivities of surface water standing on a 50 cm. long column of salinized (5 percent $NaHCO_3$) Ida soil

Elapsed time days	Concentration in mmhos. cm.$^{-1}$		
	At soil surface	7.0 cm. above soil surface	In stirred water
0			0
2			0.10
10			0.22
24			0.30
49			0.40
63			0.50
70	0.55	0.46	0.57
77	0.60	0.48	0.62
84	0.61	0.55	0.64
90	0.62	0.54	0.66
96	0.64	0.56	0.68
105	0.70	0.60	0.70
111	0.71	0.62	0.72
119	0.72	0.64	0.77
131	0.74	0.66	0.78

Table 19. Electrical conductivities of surface water standing on a 50 cm. long column of salinized (5 percent Na_2SO_4) Ida soil

Elapsed time days	Concentration in mmhos. cm.$^{-1}$		
	At soil surface	7.0 cm. above soil surface	In stirred water
0			0
10			0.04
22			0.10
41			0.14
46			0.18
56			0.31
70	0.38	0.32	0.38
77	0.40	0.38	0.42
84	0.46	0.39	0.48
90	0.46	0.40	0.49
96	0.50	0.42	0.54
105	0.55	0.46	0.58
111	0.56	0.46	0.59
119	0.60	0.50	0.62

Table 20. Electrical conductivities of surface water standing on a 50 cm. long column of salinized (5 percent NaCl) Clayton sand

Elapsed time days	Electrical conductivity in mmhos. cm.$^{-1}$		
	At soil surface	15 cm. above soil surface	In stirred water
0			3.00
35			3.00
77			4.00
107			8.50
112			9.80
120			12.00
141			14.00
149			18.00
156	19.80	18.00	20.20
163	21.00	20.00	22.40
170	23.00	21.00	24.00
176	25.00	23.00	26.60
182	26.00	24.00	26.80
188	27.00	25.00	28.00
197	28.00	26.00	28.50
203	28.50	27.00	29.00
211	29.20	27.60	30.00

Table 21. Electrical conductivities of surface water standing on a 50 cm. long column of salinized (5 percent $NaHCO_3$) Clayton sand

Elapsed time days	Electrical conductivity in mmhos. cm.$^{-1}$		
	At soil surface	15 cm. above soil surface	In stirred water
0			1.10
26			1.15
40			1.18
70			1.22
78			1.25
84			1.30
100			1.40
105			1.50
117			1.60
134	1.65	1.60	1.70
157	2.10	1.90	2.20
164	2.30	2.00	2.42
171	2.38	2.10	2.50
177	2.65	2.30	2.62
183	2.70	2.50	2.90
198	3.00	2.70	3.10
206	3.10	2.85	3.20
218	3.20	3.00	3.30

Table 22. Conductivities of surface water standing on a 50 cm. long column of salinized (5 percent $NaHCO_3$) glass beads

Elapsed time days	Electrical concentration in mmhos. cm.$^{-1}$		
	At soil surface	15 cm. above soil surface	In stirred water
0			0
5			0.18
35			0.56
66			0.98
83			1.40
96			1.50
120			1.85
127	2.00	1.75	2.10
134	2.15	1.80	2.30
141	2.30	2.00	2.40
147	2.40	2.10	2.50
153	2.50	2.30	2.70
159	2.70	2.40	2.75
168	2.90	2.60	2.90
174	3.00	2.80	3.20
182	3.20	3.00	3.48
194	3.60	3.25	3.80

Table 23. Electrical conductivities of drainage water collected after continuous ponding of 6000 cc. (equivalent to 132 cm. height) of applied distilled water kept initially from zero to 10 cm. head on a 25 cm. long sand column, 45.34 $cms.^2$ cross section initially salinized (5 percent NaCl) Clayton sand. Replicate 1

Amount of applied water	Time of application of increment water*	Time between collection of samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of drainage water	Conductivity of total drainage water	Percent salt removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos $cm.^{-1}$	mmhos $cm.^{-1}$	percent
6000	258.7	-	10.2	310	310	15.09	450.00	450.00	76.470
		-	25.7	610	920	44.77	70.00	198.00	99.880
		-	14.4	475	1395	67.88	0.33	130.70	99.960
		-	8.5	333	1728	84.09	0.14	105.60	99.989
		-	5.9	220	1948	94.79	0.08	93.60	99.999
		-	2.7	107	2055	100.00	0.01	88.77	100.000
		-	3.1	119			0		
		-	1.5	55			0		
		-	24.5	865			0		
		-	30.9	1100			0		
		-	23.7	822			0		
		23	14.6	690			0		

*Head of water on soil never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 310/2055 = 15.09 percent.

Table 24. Electrical conductivities of drainage water collected after continuous ponding of 6000 cc. (equivalent to 132 cm. height) of applied distilled water kept initially from zero to 10 cm. head on a 25 cm. long sand column, 45.34 $cms.^2$ cross section initially salinized (5 percent NaCl) Clayton sand. Replicate 2

Amount of applied water	Time of application of incre- ment water*	Time between collection of samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of drainage water	Conductivity of total drainage water	Percent salt removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm^{-1}	mmhos $cm.^{-1}$	percent
6000	96.2	-	17.0	790	790	38.63	232.00	232.00	97.770
		-	15.7	835	1625	79.46	5.00	115.40	99.996
		-	2.7	220	1845	90.22	0.02	101.60	99.998
		-	2.6	200	2045	100.00	0.01	91.70	100.000
		-	6.0	320			0		
		-	15.2	865			0		
		-	14.5	878			0		
		10	42.0	1602			0		

*Head of water on soil never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example 790/2045 = 38.63 percent.

Table 25. Electrical conductivities of drainage water collected after continuous ponding of 6000 cc. (equivalent to 132 cm. height) of applied distilled water kept initially from zero to 10 cm. head on a 25 cm. long sand column, 45.34 $cms.^2$ cross section initially salinized (5 percent NaCl) Clayton sand. Replicate 3

Amount of applied water	Time of application of water*	Time between collection of samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of drainage water	Conductivity of total drainage water	Percent salt removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos $cm.^{-1}$	mmhos $cm.^{-1}$	percent
6000	134.7	-	26.1	812	812	39.02	236.00	236.00	99.740
		-	21.2	792	1604	77.13	0.62	120.00	99.996
		-	7.9	330	1934	92.98	0.02	99.30	99.999
		-	3.5	146	2080	100.00	0.01	92.3	100.000
		-	6.9	270			0		
		-	20.4	825			0		
		-	20.4	898			0		
		-	19.0	850			0		
		-	15.3	680			0		
		3	41.0	99			0		

Average total drainage water = 1/3(2055 - 2045 + 2080) = $\frac{6180}{3}$ = 2060 cc. = 45.4 cm. height.

*Head of water on soil never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 812/2080 = 39.02 percent.

Table 26. Electrical conductivities of drainage water collected after continuous ponding of 8000 cc. of applied distilled water kept initially at zero to 10 cm. head on a 25 cm. long column, 45.34 $cm.^2$ cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 1

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos $cm.^{-1}$	mmhos $cm.^{-1}$	percent
8000	164.2	-	11.5	720	720	14.14	95.00	95.00	77.45
		-	10.3	750	1470	28.86	19.40	56.40	93.93
		-	10.6	740	2210	43.93	5.10	39.20	98.20
		-	10.1	688	2898	56.90	1.49	30.28	99.36
		-	10.6	745	3643	71.53	0.47	24.27	99.76
		-	10.0	685	4328	84.98	0.20	20.40	99.91
		-	5.4	405	4733	92.93	0.13	18.65	99.97
		-	4.8	360	5093	100.00	0.02	17.34	100.00
		-	2.6	194			0		
		-	10.4	777			0		
		-	10.0	740			0		
		-	10.1	745			0		
		20	3.0	202			0		

Average rate of water application $= \frac{8000}{164.2 \times 60} = 0.812$ cc./sec. $= \frac{0.812}{45.34} = 0.018$ cm./sec.

*Head of water on soil never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 720/5093 = 14.14 percent.

Table 27. Electrical conductivities of drainage water collected after continuous ponding of 8000 cc. of applied distilled water kept initially at zero to 10 cm. head on a 25 cm. long column, 45.34 $cm.^2$ cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 2

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos $cm.^{-1}$	mmhos $cm.^{-1}$	percent
8000	152.0	-	11.7	822	822	14.69	94.80	94.80	78.890
		-	11.5	832	1654	29.55	18.00	56.20	94.040
		-	12.9	857	2511	44.86	4.80	38.60	98.210
		-	12.4	790	3301	58.98	1.55	29.80	99.450
		-	13.0	860	4161	74.34	0.45	23.70	99.840
		-	14.4	885	5046	90.16	0.14	19.60	99.970
		-	5.0	250	5296	94.62	0.05	18.70	99.990
		-	1.0	52	5348	95.55	0.04	18.46	99.995
		-	1.5	72	5420	96.83	0.03	18.22	99.997
		-	1.3	67	5487	98.03	0.02	18.00	99.998
		-	2.1	110	5597	100.00	0.01	17.65	100.000
		-	1.3	77			0		
		-	17.7	880			0		
		-	20.5	910			0		
		23	17.7	280			0		

Average rate of water application = $\frac{8000}{152 \times 60}$ = 0.877 cc./sec. = $\frac{0.877}{45.34}$ = 0.019 cm./sec.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 822/5597 = 14.69 percent.

Table 28. Electrical conductivities of drainage water collected after continuous ponding of 8000 cc. of applied distilled water kept initially at zero to 10 cm. head on a 25 cm. long column, 45.34 cm.^{2} cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 3

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
8000	157.9	-	14.8	840	840	15.27	96.00	96.00	77.37
		-	14.6	890	1730	31.36	18.80	56.30	93.42
		-	13.7	830	2560	46.40	6.40	40.10	98.52
		-	14.4	860	3420	61.99	1.25	30.30	99.55
		-	14.3	830	4250	77.03	0.40	24.50	99.87
		-	13.9	807	5057	91.66	0.15	20.60	99.98
		-	6.4	360	5418	98.20	0.03	19.24	99.99
		-	1.9	100	5517	100.00	0.01	18.89	100.00
		-	1.1	66					
		-	15.1	834					
		-	17.7	910					
		20	33.8	424					

Average rate of application $= \frac{8000}{157.9 \times 60} = 0.866$ cc./sec. $= \frac{0.844}{45.34} = 0.019$ cm./sec.

Average rate of application for the three replicates = (0.018 + 0.019 + 0.019)/3 = 0.0187 cm./sec.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 840/5517 = 15.27 percent.

Average total drainage water = 1/3(5093 + 5597 + 5517) = 5409 cc. = 119.3 cm. height.

Table 29. Electrical conductivities of drainage water collected after continuous ponding of 9000 cc. of applied distilled water kept initially at zero to 110 cm. head on a 25 cm. long sand column, 45.34 cms.^{2} cross section of initially salinized (5 percent Na_2SO_4) Clayton sand. Replicate 1

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
9000	106.8	-	33.4	770	770	9.50	172.00	172.00	84.89
		-	21.0	725	1495	18.51	19.60	98.00	94.00
		-	22.4	693	2188	27.09	6.20	67.00	96.76
		-	19.0	590	2778	34.40	3.10	55.00	97.93
		-	18.7	680	3458	42.82	1.95	44.56	98.78
		-	14.9	590	4048	50.13	1.11	38.40	99.70
		-	11.1	480	4528	56.07	0.78	34.26	99.44
		-	11.7	631	5159	63.89	0.54	30.14	99.66
		-	10.7	588	5747	71.17	0.36	27.08	99.79
		-	6.4	363	6110	75.67	0.26	25.50	99.85
		-	4.9	275	6385	79.07	0.21	24.40	99.89
		-	4.9	288	6673	82.64	0.17	23.36	99.92
		-	4.4	251	6924	85.75	0.14	22.52	99.94

Average rate of water application = $\frac{9000}{106.8 \times 60}$ = 1.40 cc./sec. = $\frac{1.40}{45.34}$ = 0.031 cm./sec.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 770/8075 = 9.5 percent.

Table 29. (Continued)

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	$mmhos\ cm.^{-1}$	$mmhos\ cm.^{-1}$	percent
		-	4.0	229	7153	88.36	0.13	21.80	99.96
		-	5.6	322	7475	92.57	0.10	20.87	99.98
		-	4.2	249	7724	95.65	0.07	20.20	99.99
		-	3.4	200	7924	98.13	0.03	19.69	99.99
		-	2.6	151	8075	100.00	0.01	19.32	100.00
		-	3.2	180					
		20	8.0	440					

Table 30. Electrical conductivities of drainage water collected after continuous ponding of 10000 cc. of applied distilled water kept at zero to 10 cm. head on a 25 cm. long sand column, 45.34 cms.[2] cross section of initially salinized (5 percent Na_2SO_4) Clayton sand. Replicate 2

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos $cm.^{-1}$	mmhos $cm.^{-1}$	percent
10000	120.2	-	20.1	811	811	9.85	160.00	160.00	85.60
		-	18.4	845	1656	20.11	16.40	86.70	94.75
		-	19.4	790	2446	29.70	4.40	60.13	97.04
		-	17.7	750	3196	38.81	2.15	46.50	98.10
		-	14.6	835	4031	48.94	1.30	37.10	98.82
		-	12.4	870	4901	59.51	.86	30.70	99.31
		-	11.7	839	5740	69.69	.63	26.30	99.66
		-	11.3	832	6572	79.80	.40	23.04	99.88
		-	11.9	861	7433	90.25	.20	20.39	99.99
		-	11.8	830	8263	100.00	.01	18.40	100.00
		-	4.6	377			0		
		23	6.7	1185			0		

Rate of water application = $\frac{10,000}{120.2 \times 60} = 1.39\ cm.^3/sec. = \frac{1.39}{45.34} = 0.031$ cm./sec.

Average total drainage water = $\frac{1}{2}(8075 + 8263) = \frac{16338}{2} = 8169$ cc. = 180.2 cm. height.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for eaxmple, 811/8263 = 9.85 percent.

Table 31. Electrical conductivity of drainage water collected after intermittent ponding of 4000 cc. increments of applied distilled water kept at zero to 10.00 cm. head to a 25 cm. long sand column, 45.34 cm.^{2} cross section initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 1

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
1) 4000	59.9	-	13.0	730	730	16.21	100.00	100.00	83.21
		-	10.6	550	1280	28.42	15.00	63.50	92.61
		-	9.3	595	1875	41.64	4.40	44.70	95.60
		-	11.3	680	2555	56.74	3.60	33.80	98.39
		-	13.5	760	3315	73.61	1.30	26.40	99.51
		11	2.6	498	3813	84.68	0.44	23.00	99.76
2) 4000	92.0	-	14.9	690	4503	100.00	0.30	19.50	100.00
8000	151.9								
		-	12.5	608			0		
		-	13.8	720			0		
		-	15.6	765			0		
		-	15.7	775			0		
		9	43.6	462			0		

Average rate of application = $\frac{8000}{151.9 \times 60}$ = 0.88 cc./sec. = $\frac{0.88}{45.34}$ = 0.019 cm./sec.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 730/4503 = 16.21 percent.

Table 32. Electrical conductivity of drainage water collected after intermittent ponding of 4000 cc. increments of applied distilled water kept at zero to 10.00 cm. head to a 25 cm. long sand column, 45.34 cm.^{2} cross section initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 2

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
1) 4000	60.3	-	13.7	710	710	16.43	110.00	110.00	80.20
		-	10.5	545	1255	29.03	20.00	71.00	91.39
		-	10.6	673	1928	44.61	8.00	49.00	96.92
		-	12.2	735	2663	61.61	2.70	36.20	98.96
		-	11.2	615	3278	75.84	0.95	29.60	99.56
		6	56.4	447	3725	86.19	0.48	26.10	99.78
2) 4000 / 8000	98.0 / 158.3	-	19.9	597	4322	100.00	0.36	22.53	100.00
		-	25.6	825			0		
		-	22.0	762			0		
		-	23.2	795			0		
		-	23.2	755			0		
		11	53.2	240			0		

Average rate of water application = $\frac{8000}{158.3 \times 60}$ = 0.84 cc./sec. = $\frac{0.84}{45.34}$ = 0.019 cm./sec.

*Haed of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 710/4322 = 16.43 percent.

Table 33. Electrical conductivity of drainage water collected after intermittent ponding of 4000 cc. increments of applied distilled water kept at zero to 10.00 cm. head to a 25 cm. long sand column, 45.34 cm.^{2} cross section initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 3

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
1) 4000	69.1	-	15.6	835	835	18.32	100.00	100.00	79.71
		-	14.8	875	1710	37.51	18.80	58.40	95.58
		-	14.3	842	2552	55.98	3.90	60.45	98.55
		-	14.4	848	3400	74.58	1.18	30.66	99.50
		1	14.2	379	3779	82.89	0.55	27.66	99.70
2) 4000	80.0	-	6.6	490	4269	93.64	0.54	24.55	99.95
8000	149.1	-	3.8	290	4559	100.00	0.17	23.00	100.00
		-	2.3	189			0		
		-	10.8	800			0		
		-	12.0	873			0		
		-	13.0	898			0		
		21	8.9	465			0		

Average rate of water application = $\frac{8000}{149.1 \times 60}$ = 0.89 cc./sec. = 0.02 cm./sec.

Average rate of water application for the three replicates = (0.019 + 0.019 + 0.02)/3 = 0.0193 cm./sec.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example 835/4559 = 18.32 percent.

Average collected drainage water = 1/3(4503 + 6322 + 4559) = 4461 cc. = 98.4 cm. height.

Table 34. Electrical conductivity of drainage water collected after intermittent ponding of 2000 cc. increments of applied distilled water kept at zero to 10 cm. head to a 25 cm. long sand column, 45.34 cm.^{2} cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 1

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
1) 2000	26.4	-	14.3	550	550	16.64	122.0	122.0	69.71
		-	11.8	730	1285	38.88	27.0	68.8	90.18
		12	23.2	575	1860	56.27	14.2	51.4	98.66
2) 2000	27.2	-	16.3	825	2685	81.24	1.5	36.1	99.95
		-	10.2	620	3305	100.00	0.08	29.3	100.00
		1	48.2	558			0		
3) 2000	29.3	-	18.7	890			0		
6000	82.9	-	16.5	870			0		
		3	44.1	240			0		

$$\text{Average rate of water application} = \frac{6000}{82.9 \times 60} = 1.21 \text{ cc./sec.} = 0.027 \text{ cm./sec.}$$

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 550/3305 = 16.64 percent.

Table 35. Electrical conductivity of drainage water collected after intermittent ponding of 2000 cc. increments of applied distilled water kept at zero to 10 cm. head to a 25 cm. long sand column, 45.34 $cm.^2$ cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 2

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos $cm.^{-1}$	mmhos $cm.^{-1}$	percent
1) 2000	26.8	-	16.5	850	850	26.79	105.00	105.00	90.64
		-	11.4	650	1500	47.29	11.00	64.27	97.90
		19	31.5	390	1890	59.57	2.08	51.43	98.72
2) 2000	29.3	-	14.1	713	2603	82.04	1.75	37.80	99.99
4000	56.1	-	9.9	570	3173	100.00	.01	31.03	100.00
		-	1.3	64			0		
		1	55.5	642			0		

$$\text{Average rate of water application} = \frac{4000}{56.1 \times 60} = 1.18 \text{ cc./sec.} = 0.026 \text{ cm./sec.}$$

*Head of water never exceeded 10 cm. above the soil surface

**Percent of drainage water with respect to the total collected; for example, 850/3173 = 26.79 percent.

Table 36. Electrical conductivity of drainage water collected after intermittent ponding of 2000 cc. increments of applied distilled water kept at zero to 10 cm. head to a 25 cm. long sand column, 45.34 cm.^{2} cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 3

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
1) 2000	24.0	-	12	745	745	23.54	120.00	120.00	88.12
		-	12.5	848	1593	50.33	10.40	61.66	96.81
		18	37.7	154	1747	55.13	4.80	57.22	98.52
2) 2000	24.7	-	14.7	928	2675	84.52	1.60	37.92	99.98
4000	48.7	-	6.7	490	3165	100.00	0.03	32.05	100.00
		-	0.9	66			0		
		-	2.3	167			0		
		5	17.7	331			0		

Average rate of water application = $\frac{4000}{48.7 \times 60}$ = 1.37 cc./sec. = $\frac{1.37}{45.34}$ = 0.03 cm./sec.

Average rate of water application for the three replicates = (0.027 + 0.026 + 0.03)/3 = 0.0277 cm./sec.

Average collected drainage water = 1/3(3305 + 3173 + 3165) = $\frac{9643}{3}$ = 3214 cc. = 70.9 cm. height.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 745/3165 = 23.54 percent.

Table 37. Electrical conductivity of drainage water collected after intermittent ponding of 1000 cc. increments of applied distilled water kept at zero to 10 cm. head to a 25 cm. long sand column, 45.34 cm.^{2} cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 1

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
1) 1000	2.8	-	14.2	572	572	28.56	124.00	124.00	75.19
		2	40.3	215	787	39.29	86.00	113.60	94.79
2) 1000	12.0	-	16.0	730	1517	75.74	6.00	61.83	99.44
		23	24.0	252	1769	88.32	2.00	53.30	99.97
3) 1000	20.7	-	4.1	234	2003	100.00	0.12	47.09	100.00
3000	42.5								
		-	5.1	300			0		
		27	43.2	447			0		

Average rate of water application = $\frac{3000}{42.5 \times 60}$ = 1.17 cc./sec. = $\frac{1.17}{45.34}$ = 0.026 cm./sec.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 572/2003 = 28.56 percent.

Table 38. Electrical conductivity of drainage water collected after intermittent ponding of 1000 cc. increments of applied distilled water kept at zero to 10 cm. head to a 25 cm. long sand column, 45.34 cm.^{2} cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 2

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
1) 1000	9.2	-	13.5	598	598	28.86	128.00	128.00	78.590
		26	1.5	175	773	37.31	104.00	122.57	97.280
2) 1000	12.9	-	6.7	658	1431	69.06	4.00	68.05	99.986
		18	49.3	320	1751	84.51	0.01	55.61	99.989
3) 1000	11.8	-	1.7	75	1826	88.13	0.07	53.33	99.994
3000	33.8	-	2.7	98	1924	92.86	0.02	50.62	99.996
		-	2.2	148	2072	100.00	0.02	47.00	100.00
		-	2.1	131			0		
		20	3.0	600			0		

$$\text{Average rate of application} = \frac{3000}{33.8 \times 60} = 1.48 \text{ cc./sec.} = \frac{1.48}{45.34} = 0.033 \text{ cm./sec.}$$

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 598/2072 = 28.86 percent.

Table 39. Electrical conductivity of drainage water collected after intermittent ponding of 1000 cc. increments of applied distilled water kept at zero to 10 cm. head to a 25 cm. long sand column, 45.34 cm.^{2} cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 3

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
1000	10.8	-	21.7	610	610	30.12	128.00	128.00	77.86
		21	32.2	126	736	36.35	164.00	134.16	98.47
1000	16.7	-	15.2	490	1226	60.54	3.00	81.74	99.93
		24	3.8	510	1736	85.73	0.08	57.75	99.97
1000	14.8	-	8.4	289	2025	100.00	0.09	49.52	100.00
3000	32.3								
		-	5.0	170			0		
		23	25.3	535			0		

Average rate of application = $\frac{3000}{32.3 \times 60}$ = 1.54 cc./sec. = $\frac{1.54}{45.34}$ = 0.034 cm./sec.

Average rate of application for the three replicates = (0.026 + 0.033 + 0.034)/3 = 0.031 cm./sec.

Average collected drainage water = 1/3(2003 + 2072 + 2025) = 6110/3 = 2037 cc. = 44.9 cm. height.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 610/2025 = 30.12 percent.

Table 40. Electrical conductivity of drainage water collected after intermittent ponding of 500 cc. increments of applied distilled water kept at zero to 10 cm. head to a 25 cm. long sand column, 45.34 cm.^{2} cross section initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 1

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
1) 500	4.1	23	12.1	300	300	16.18	232.00	232.00	72.280
2) 500	4.6	24	10.1	480	780	42.07	40.00	113.85	92.230
3) 500	5.0	27	20.0	498	1278	68.93	15.00	75.33	99.980
4) 500	5.0	24	45.3	507	1785	96.28	0.03	53.94	99.999
5) 500	5.0	16	41.6	69	1854	100.00	0.01	51.93	100.000
2500	23.7								
		-	1.7	80			0		
		20	17.0	413			0		

Average rate of application = $\frac{2500}{23.7 \times 60}$ = 1.76 cc./sec. = $\frac{1.76}{45.34}$ = 0.039 cm./sec.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 300/1856 = 16.18 percent.

Table 41. Electrical conductivity of drainage water collected after intermittent ponding of 500 cc. increments of applied distilled water kept at zero to 10 cm. head to a 25 cm. long sand column, 45.34 $cm.^2$ cross section initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 2

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water **	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos $cm.^{-1}$	mmhos $cm.^{-1}$	percent
1) 500	4.5	26	22.5	300	300	16.24	272.00	272.00	79.530
2) 500	5.2	25	20.5	480	780	42.23	42.00	130.46	99.170
3) 500	5.1	19	50.8	457	1237	66.97	1.80	82.93	99.970
4) 500	5.2	13	20.7	512	1749	94.69	0.05	58.67	99.999
5) 500	5.2	-	2.3	98	1847	100.00	0.01	55.55	100.000
2500	25.2								
		-	3.7	168			0		
		10	52.4	234			0		

Average rate of water application = $\frac{2500}{25.2 \times 60}$ = 1.65 cc./sec. = $\frac{1.65}{45.34}$ = 0.036 cm./sec.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 300/1867 = 16.26 percent.

Table 42. Electrical conductivity of drainage water collected after intermittent ponding of 500 cc. increments of applied distilled water kept at zero to 10 cm. head to a 25 cm. long sand column, 45.34 cm.^{2} cross section initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 3

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
1) 500	5.1	26	17.5	337	337	18.50	272.00	272.00	88.650
2) 500	5.6	25	32.9	480	817	44.84	24.00	126.29	99.790
3) 500	5.7	19	50.4	507	1324	72.67	0.40	78.09	99.999
4) 500	5.8	13	33.4	498	1822	100.00	0.02	56.75	100.000
5) 500	5.5	-	1.6	53			0		
2500	27.7								
		10	38.9	432			0		

Average rate of application = $\frac{2500}{27.7 \times 60}$ = 1.50 cc./sec. = $\frac{1.50}{45.34}$ = 0.033 cm./sec.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 337/1822 = 18.50 percent.

Table 43. Electrical conductivity of drainage water collected after intermittent ponding of 500 cc. increments of applied distilled water kept at zero to 10 cm. head to a 25 cm. long sand column, 45.34 $cm.^2$ cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 4

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos $cm.^{-1}$	mmhos $cm.^{-1}$	percent
1) 500	4.3	21	6.5	310	310	17.61	240.00	240.00	84.480
2) 500	4.4	34	44.7	470	780	44.31	26.80	111.53	98.790
3) 500	4.7	45	58.6	490	1270	72.16	2.00	69.27	99.899
4) 500	4.6	11	27.4	490	1760	100.00	0.18	50.04	100.000
5) 500	5.0	15	51.8	508			0		
6) 500	4.7	22	8.7	480			0		
3000	27.7								

Average rate of water application = $\frac{3000}{27.7 \times 60}$ = 1.81 cc./sec. = $\frac{1.81}{45.34}$ = 0.039 cm/sec.

Average rate of water application for the four replicates = (0.039 + 0.036 + 0.033 + 0.039)/3 = 0.036 cm./sec.

Average collected drainage water = ¼(1854 + 1847 + 1822 + 1760) = 7283/4 = 1820.75 cc. = 40.16 cm. height.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 310/1760 = 1761 percent.

Table 44. Electrical conductivity of drainage water collected after intermittent ponding of 200 cc. increments of applied distilled water kept at zero to 10 cm. head to a 25 cm. long sand column, 45.34 $cm.^2$ cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 1

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos $cm.^{-1}$	mmhos $cm.^{-1}$	percent
1) 200	1.7	19	36.8	68	68	4.25	400.00	400.00	27.15
2) 200	1.6	14	4.4	180	248	15.49	276.00	310.00	76.74
3) 200	1.5	10	17.3	177	425	26.55	80.00	214.00	90.88
4) 200	1.6	12	31.3	196	621	38.79	32.00	156.00	97.14
5) 200	1.5	6	18.3	184	805	50.28	14.00	124.10	99.71
6) 200	1.5	12	4.3	205	1010	63.08	1.17	99.00	99.95
7) 200	1.5	14	22.7	206	1216	75.95	0.15	82.40	99.98
8) 200	1.5	12	34.2	197	1413	88.26	0.08	70.90	99.99
9) 200	1.4	8	30.9	188	1601	100.00	0.02	62.60	100.00
10) 200	1.5	11	31.8	192			0		
11) 200	1.6	12	31.5	206			0		
12) 200	1.5	27	37.6	193			0		
2400	19.2								

$$\text{Average rate of water application} = \frac{2400}{19.2 \times 60} = 2.08 \text{ cc./sec.} = \frac{2.08}{45.34} = 0.046 \text{ cm./sec.}$$

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 68/1601 = 4.25 percent.

Table 45. Electrical conductivity of drainage water collected after intermittent ponding of 200 cc. increments of applied distilled water kept at zero to 10 cm. head to a 25 cm. long sand column, 45.34 cm.^{2} cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 2

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
1) 200	1.8								
2) 200	1.9	12	27.5	240	240	14.91	304.00	304.00	71.040
3) 200	2.0	12	15.2	197	437	27.14	132.00	226.00	96.360
4) 200	1.8	12	3.6	193	630	39.13	16.80	162.00	99.510
5) 200	1.8	14	22.4	200	830	51.56	1.80	123.60	99.860
6) 200	1.9	12	33.7	200	1030	63.97	0.55	100.00	99.970
7) 200	1.9	8	30.5	195	1225	76.09	0.12	83.80	99.994
8) 200	1.9	11	31.6	193	1618	88.07	0.02	72.40	99.998
9) 200	1.8	10	50.7	192	1610	100.00	0.01	63.80	100.000
10) 200	1.9	27	15.4	205			0		
11) 200	1.9	11	48.8	138			0		
2200	20.6								

$$\text{Average rate of water application} = \frac{2200}{20.6 \times 60} = 1.78 \text{ cc./sec.} = 0.04 \text{ cm./sec.}$$

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 240/1610 = 14.91 percent.

Table 46. Electrical conductivity of drainage water collected after intermittent ponding of 200 cc. increments of applied distilled water kept at zero to 10 cm. head to a 25 cm. long sand column, 45.34 cm.^{2} cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 3

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
1) 200	1.9								
2) 200	1.8	12	30.3	243	243	15.09	305.00	305.00	71.190
3) 200	1.9	12	13.3	182	425	26.40	116.00	224.00	91.470
4) 200	1.9	12	13.9	195	620	38.51	37.20	165.00	98.440
5) 200	1.9	14	12.7	202	822	51.06	6.90	126.00	99.780
6) 200	1.9	12	34.0	200	1022	63.48	0.98	101.80	99.970
7) 200	1.9	8	30.8	197	1219	75.71	0.15	85.40	99.990
8) 200	1.8	11	31.9	193	1412	87.70	0.02	73.70	99.998
9) 200	1.9	6	51.1	198	1610	100.00	0.01	64.70	100.000
10) 200	1.9	27	15.8	208			0		
11) 200	1.9	11	48.3	194			0		
2200	20.7								

Average rate of water application = $\frac{2200}{20.7 \times 60}$ = 1.77 cc./sec. = 0.04 cm./sec.

Average rate of water application for the three replicates = (0.046 + 0.04 + 0.04)/3 = 0.042 cm./sec.

Average collected water application = 1/3(1601 + 1610 + 1610) = 4821/3 = 1607 cc. = 35.4 cm. height.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 243/1610 = 15.09 percent.

Table 47. Electrical conductivity of drainage water collected after intermittent ponding of 50 cc. increments of applied distilled water kept at zero to 10 cm. head to a 25 cm. long sand column, 45.34 cm.^{2} cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 1

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
1) 50	0.30	22	39.8						
2) 50	0.28	22	45.0						
3) 50	0.28	18	15.8						
4) 50	0.27	46	-						
5) 50	0.30	28	19.9	13	13	1.17	340.00	340.00	5.910
6) 50	0.27	13	41.5	22	35	3.14	380.00	365.00	17.090
7) 50	0.27	22	41.0	68	103	9.24	380.00	375.00	51.640
8) 50	0.24	23	5.5	35	138	12.39	340.00	366.00	67.560
9) 50	0.25	19	19.8	39	177	15.89	248.00	340.00	80.490
10) 50	0.23	23	36.0	52	229	20.56	150.00	297.00	90.920
11) 50	0.25	21	6.5	39	268	24.06	124.00	271.70	97.390
12) 50	0.30	20	48.0	40	308	27.64	34.00	240.90	99.210
13) 50	0.25	46	-	48	356	31.96	6.50	209.30	99.620
14) 50	0.27	14	42.8	41	397	35.64	3.10	188.00	99.790
15) 50	0.30	13	54.2	50	447	40.13	1.48	167.10	99.890
16) 50	0.26	20	3.5	52	499	44.79	0.65	149.77	99.930
17) 50	0.26	11	51.7	49	548	49.19	0.42	136.42	99.960
18) 50	0.29	12	59.5	49	597	53.59	0.15	125.23	99.970
19) 50	0.30	19	6.9	53	650	58.35	0.10	115.03	99.980
950	5.17								

Average rate of water application = $\frac{1550}{8.49 \times 60}$ = 3.04 cc. = 0.067 cm./sec.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 13/1114 = 1.17 percent.

Table 47. (Continued)

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos $cm.^{-1}$	mmhos $cm.^{-1}$	percent
950	5.17								
20) 50	0.30	14	29.9	44	694	62.30	0.08	107.74	99.987
21) 50	0.28	12	7.4	44	738	66.25	0.04	101.32	99.989
22) 50	0.26	19	41.3	41	779	69.93	0.02	96.00	99.990
23) 50	0.26	11	24.1	41	820	73.61	0.02	91.19	99.991
24) 50	0.30	13	9.9	48	868	77.92	0.02	86.15	99.993
25) 50	0.30	25	30.0	58	926	83.12	0.02	80.75	99.994
26) 50	0.28	12	19.3	47	973	87.34	0.01	76.85	99.995
27) 50	0.30	23	41.1	54	1027	92.19	0.04	72.81	99.998
28) 50	0.24	21	50.0	47	1074	96.41	0.02	69.63	99.999
29) 50	0.24	18	50.2	40	1114	100.00	0.01	67.13	100.000
30) 50	0.26	23	57.6	41			0		
31) 50	0.30	23	39.0	65			0		
1550	8.49								

Table 48. Electrical conductivity of drainage water collected after intermittent ponding of 50 cc. increments of applied distilled water kept at zero to 10 cm. head to a 25 cm. long sand column, 45.34 $cm.^2$ cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 2

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos $cm.^{-1}$	mmhos $cm.^{-1}$	percent
1) 50	0.30	22	41.0						
2) 50	0.30	22	45.0						
3) 50	0.30	18	14.8						
4) 50	0.30	45	59.0	36	36	3.19	388.00	388.00	16.320
5) 50	0.28	28	3.1	37	73	6.47	356.00	371.00	31.710
6) 50	0.27	13	46.8	37	110	9.75	348.00	364.00	46.750
7) 50	0.24	22	49.6	35	145	12.85	316.00	352.00	59.670
8) 50	0.30	23	6.7	41	186	16.49	300.00	341.00	74.090
9) 50	0.25	19	16.8	38	224	19.86	216.00	320.00	83.630
10) 50	0.25	23	36.1	41	265	23.49	112.00	287.50	89.000
11) 50	0.27	21	5.7	29	294	26.06	132.00	272.00	93.470
12) 50	0.30	20	50.0	41	335	29.70	110.00	252.30	98.740
13) 50	0.30	46	1.0	45	380	33.69	14.40	224.10	99.490
14) 50	0.27	21	23.0	44	424	37.59	4.10	201.30	99.700
15) 50	0.28	13	51.0	49	473	41.93	1.90	180.62	99.810
16) 50	0.22	20	4.0	52	525	45.43	0.92	162.83	99.870
17) 50	0.25	12	3.3	47	572	50.71	0.89	149.52	99.92-
18) 50	0.24	12	59.3	55	627	55.59	0.33	136.43	99.940
19) 50	0.21	19	7.4	27	654	57.98	0.23	130.81	99.950
950	5.13								

Average rate of water application = $\frac{1550}{8.18 \times 60}$ = 3.18 cc. = 0.069 cm./sec.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 36/1128 = 3.19 percent.

Table 48. (Continued)

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos $cm.^{-1}$	mmhos $cm.^{-1}$	percent
950	5.13								
20) 50	0.24	14	30.9	36	690	61.17	0.35	124.00	99.960
21) 50	0.28	18	48.0	54	744	65.96	0.20	115.00	99.963
22) 50	0.26	13	0.4	44	788	69.86	0.19	108.59	99.970
23) 50	0.20	14	44.2	36	824	73.05	0.11	103.85	99.978
24) 50	0.24	13	11.3	65	869	77.04	0.14	98.48	99.985
25) 50	0.30	25	27.2	60	929	82.36	0.08	92.13	99.991
26) 50	0.30	18	59.2	60	989	87.68	0.05	86.54	99.994
27) 50	0.24	23	41.9	56	1045	92.64	0.04	81.91	99.997
28) 50	0.24	21	50.0	46	1089	96.54	0.03	78.60	99.998
29) 50	0.26	18	49.7	39	1128	100.00	0.02	75.88	100.000
30) 50	0.25	24	3.4	36			0		
31) 50	0.24	23	34.1	60			0		
1550	8.18								

Table 49. Electrical conductivity of drainage water collected after intermittent ponding of 50 cc. increments of applied distilled water kept at zero to 10 cm. head to a 25 cm. long sand column, 45.34 cm.^{2} cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 3

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
1) 50	0.30								
2) 50	0.30								
3) 50	0.28								
4) 50	0.27	20	5.4	19	19	1.52	495.00	495.00	9.110
5) 50	0.25	13	55.0						
6) 50	0.22	19	58.3	68	87	6.97	360.00	390.00	32.820
7) 50	0.25	16	30.0						
8) 50	0.25	12	37.3						
9) 50	0.26	12	8.9	122	209	16.73	340.00	360.60	73.010
10) 50	0.27	12	5.6	45	254	20.34	260.00	342.80	84.340
11) 50	0.28	14	42.0	48	302	24.18	192.00	318.80	93.270
12) 50	0.27	12	16.6	45	347	27.78	104.80	291.00	97.800
13) 50	0.26	18	30.9	38	385	30.82	40.80	266.30	99.300
14) 50	0.24	11	29.6	51	436	34.91	8.00	236.00	99.670
15) 50	0.25	10	59.0	40	476	38.11	2.80	216.50	99.810
16) 50	0.24	15	9.1	50	526	42.11	1.50	196.00	99.880
17) 50	0.24	22	35.1	46	572	46.12	0.73	180.30	99.910
18) 50	0.25	11	34.7	48	620	49.64	0.55	166.40	99.940
19) 50	0.24	10	17.0	51	671	53.72	0.40	153.80	99.960
950	4.92								

Average rate of water application = $\frac{1650}{8.41 \times 60}$ = 3.27 cc./sec. = 0.072 cm./sec.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 19/1249 = 1.52 percent.

Table 49. (Continued)

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos $cm.^{-1}$	mmhos $cm.^{-1}$	percent
950	4.92								
20) 50	0.25	15	58.0	51	722	57.81	0.20	142.90	99.970
21) 50	0.24	17	37.0	50	772	61.81	0.12	133.70	99.970
22) 50	0.23	14	33.0	42	814	65.17	0.11	126.80	99.983
23) 50	0.24	18	0	47	861	68.94	0.09	119.90	99.983
24) 50	0.25	11	31.0	46	907	72.62	0.08	113.80	99.986
25) 50	0.26	12	8.5	52	959	76.78	0.07	107.60	99.990
26) 50	0.25	13	49.8	46	1005	80.46	0.06	102.70	99.992
27) 50	0.24	19	57.5	52	1057	84.63	0.05	97.70	99.995
28) 50	0.25	11	23.9	45	1102	88.23	0.04	93.67	99.997
29) 50	0.26	16	26.6	48	1150	92.07	0.03	89.76	99.998
30) 50	0.25	17	16.1	50	1200	96.08	0.02	86.00	99.999
31) 50	0.24	19	49.4	43	1249	100.00	0.01	82.65	100.000
32) 50	0.26	17	50.0	45			0		
33) 50	0.27	18	38.0	50			0		
1550	8.41								

Table 50. Electrical conductivity of drainage water collected after intermittent ponding of 50 cc. increments of applied distilled water kept at zero to 10 cm. head to a 25 cm. long sand column, 45.34 cm.^{2} cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand. Replicate 4

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
1) 50	0.30								
2) 50	0.24								
3) 50	0.25								
4) 50	0.25	19	20.0	22	22	1.72	450.00	450.00	9.610
5) 50	0.30	13	55.6	49	71	5.56	440.00	443.00	30.570
6) 50	0.30	10	6.9	59	130	10.19	396.00	422.00	53.280
7) 50	0.28	14	6.2	43	173	13.56	356.00	405.00	68.160
8) 50	0.28	17	14.8	45	218	17.08	312.00	386.00	81.800
9) 50	0.27	12	14.6	54	272	21.32	232.00	356.00	93.980
10) 50	0.30	12	4.8	41	313	24.53	90.00	321.00	97.560
11) 50	0.29	14	42.8	46	359	28.13	38.80	284.60	99.300
12) 50	0.28	12	19.7	47	406	31.82	8.80	252.70	99.700
600	3.34								

Average rate of water application = $\frac{1600}{8.65 \times 60}$ = 3.08 cc./sec. = $\frac{3.08}{45.34}$ = 0.07 cm./sec.

Average rate of water application for the four replicates = (0.067 + 0.069 + 0.072 + 0.07)/4 = 0.0745 cm./sec.

Average water collected = ¼(1114 + 1128 + 1249 + 1276) = 4767/4 = 1192 cc. = 26.29 cm. height.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 22/1276 = 1.72 percent.

Table 50. (Continued)

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
600	3.34								
13) 50	0.28	18	24.5	48	454	35.58	2.80	226.30	99.830
14) 50	0.27	11	32.8	48	502	39.34	1.35	204.80	99.890
15) 50	0.26	15	58.8	47	549	43.03	0.78	187.30	99.930
16) 50	0.25	15	8.7	43	602	47.18	0.41	170.80	99.950
17) 50	0.26	22	36.6	46	648	50.78	0.22	158.70	99.960
18) 50	0.27	11	34.6	48	696	54.55	0.17	147.80	99.970
19) 50	0.26	10	16.3	45	741	58.07	0.13	138.80	99.973
20) 50	0.26	15	58.2	48	789	61.83	0.12	130.40	99.980
21) 50	0.27	17	37.0	47	836	65.52	0.10	123.10	99.983
22) 50	0.27	14	32.0	56	892	69.91	0.09	115.34	99.988
23) 50	0.26	18	0.6	46	938	73.51	0.08	109.70	99.991
24) 50	0.27	11	31.2	47	985	77.19	0.05	104.45	99.993
25) 50	0.25	12	17.8	49	1034	81.03	0.04	99.51	99.995
26) 50	0.26	13	50.5	44	1078	84.48	0.03	95.45	99.997
27) 50	0.27	19	57.3	43	1121	87.85	0.02	91.79	99.997
28) 50	0.26	11	23.3	52	1173	91.93	0.02	87.72	99.998
29) 50	0.27	16	26.6	49	1222	95.77	0.01	84.20	99.999
30) 50	0.28	17	16.1	54	1276	100.00	0.01	80.64	100.000
31) 50	0.27	19	49.4	44			0		
32) 50	0.27	18	30.0	46			0		
1600	8.65								

Table 51. Water application rates, average amount of total drainage water collected, amount of drainage water collected containing 91.5 percent of removed salts ($NaHCO_3$)

Method of water application	Average rate of water application of an increment*	Average amount of water used for leaching all $NaHCO_3$		Amount of drainage water collected containing 91.5 percent of removed salts	
	cm./sec.	cc.	cm.	cc.	cm.
II-a Continuous ponding of 8000 cc. (176 cm. height)	0.0187	5409	119.3	1352	29.82
II-b Intermittent ponding of 4000 cc. (88 cm. height)	0.0193	4461	98.4	1271	28.04
II-c Intermittent ponding of 2000 cc. (44 cm. height)	0.0277	3214	70.9	1035	22.82
II-d Intermittent ponding of 1000 cc. (22 cm. height)	0.031	2037	44.9	672	14.83
II-e Intermittent ponding of 500 cc. (11 cm. height)	0.036	1821	40.2	484	10.68
II-f Intermittent ponding of 200 cc. (5.5 cm. height)	0.042	1607	35.4	402	8.87
II-g Intermittent ponding of 50 cc. (1.38 cm. height)	0.075	1192	26.3	280	6.18

*For time lapsed between application of an increment see Tables 23-50, where the times are to be read under "Time between collection of drainage samples," since the period between sampling collection was equal to the period between addition of two consecutive increments.

Table 52. Electrical conductivity of drainage water collected after subirrigation of distilled water of 500 cc. (11 cm. height) increments maintained at 10 cm. head above soil surface to a 25 cm. long sand column, 45.34 $cm.^2$ cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand with drainage allowed from soil surface. Replicate 1

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos $cm.^{-1}$	mmhos $cm.^{-1}$	percent
1) 500	37.6	21	33	220	220	5.27	150.00	150.00	30.64
2) 500	42.4	17	30	460	680	16.29	75.00	99.26	62.68
3) 500	45.5	17	22	460	1140	27.32	40.80	70.91	80.10
4) 500	41.3	17	57	525	1665	39.89	17.00	53.90	88.39
5) 500	40.9	23	43	490	2155	51.64	11.20	44.20	93.48
6) 500	41.3	28	61	543	2698	64.65	8.30	36.97	97.67
7) 500	42.0	18	7	640	3338	79.99	3.60	30.37	99.81
8) 500	22.4	23	10	330	3668	87.90	0.38	27.85	99.92
9) 500	36.9	96	15	505	4173	100.00	0.16	24.50	100.00
10) 500	44.4	23	50				0		
11) 500	43.2	22	30				0		
5500	437.9								

Average rate of water application = $\frac{5500}{437.9 \times 60}$ = 0.21 cc./sec. = 0.0046 cm./sec.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collevted; for example, 220/4173 = 5.27 percent.

Table 53. Electrical conductivity of drainage water collected after subirrigation of distilled water of 500 cc. (11 cm. height) increments maintained at 10 cm. head above soil surface to a 25 cm. long sand column, 45.34 $cm.^2$ cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand with drainage allowed from soil surface. Replicate 2

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos $cm.^{-1}$	mmhos $cm.^{-1}$	percent
1) 500	36.0	23	14	140	140	3.37	200.00	200.00	27.43
2) 500	79.7	22	35	507	647	15.61	80.00	106.00	67.16
3) 500	51.0	28	26	515	1162	28.03	27.50	71.20	81.03
4) 500	47.0	16	12	470	1632	39.37	20.50	56.60	90.47
5) 500	45.0	25	18	515	2167	51.79	11.20	45.71	96.12
6) 500	43.5	28	39	503	2650	63.93	6.40	38.30	99.27
7) 500	45.0	18	5	505	3155	76.10	1.28	32.33	99.90
8) 500	47.1	22	45	528	3683	88.85	0.18	27.72	99.99
9) 500	35.6	96	17	462	4145	100.00	0.01	24.63	100.00
10) 500	43.8	23	15				0		
11) 500	44.5	26	35				0		
5500	518.2								

Average rate of water application = $\frac{5500}{518.2 \times 60}$ = 0.18 cc./sec. = 0.0039 cm./sec.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 140/4145 = 3.37 percent.

Table 54. Electrical conductivity of drainage water collected after subirrigation of distilled water of 500 cc. increments (11 cm. height) maintained at 10 cm. head above soil surface to a 25 cm. long sand column, 45.34 cm.^{2} cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand with drainage allowed from soil surface. Replicate 3

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
1) 500	16.5	11	36.4	93	93	2.07	220.00	220.00	18.69
2) 500	55.4	12	26.1	495	588	13.16	102.00	120.60	64.80
3) 500	48.6	11	18.9	550	1138	25.43	36.00	79.75	82.89
4) 500	39.1	10	49.8	445	1583	35.37	19.60	62.84	90.86
5) 500	44.9	12	23.8	505	2088	46.66	9.20	49.86	95.10
6) 500	36.1	19	33.5	418	2506	56.00	4.50	42.30	96.82
7) 500	44.7	12	4.3	471	2977	66.53	3.15	36.10	98.17
8) 500	47.0	11	52.7	490	3467	77.47	2.20	31.31	99.16
9) 500	68.1	11	25.6	508	3975	88.83	1.60	27.54	99.90
10) 500	51.2	12	18.7	500	4475	100.00	0.22	24.47	100.00
11) 500	52.0	12	92.8	505			0		
12) 500	53.9	11	57.2	491			0		
6000	537.5								

$$\text{Average rate of water application} = \frac{6000}{537.5 \times 60} = 0.186 \text{ cc./sec.} = 0.0061 \text{ cm./sec.}$$

Average water collected = 1/3(4173 + 4145 + 4475) = 12793/3 = 4264.3 cc. = 94.05 cm. height.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 93/4475 = 2.07 percent.

Table 55. Electrical conductivity of drainage water collected after subirrigation of distilled water of 500 cc. (11 cm. height) increments maintained at 10 cm. head above soil surface to a 25 cm. long column, 45.34 $cm.^2$ cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand with gravity drainage allowed. Replicate 1

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos $cm.^{-1}$	mmhos $cm.^{-1}$	percent
1) 500	19.8	11	20.0	386	386	7.19	128.00	128.00	50.40
2) 500	48.7	12	38.1	462	848	15.81	84.00	104.03	89.99
3) 500	74.2	19	59.6	495	1343	25.04	10.80	69.67	95.45
4) 500	72.2	22	30.8	498	1841	34.33	3.65	51.81	96.51
5) 500	56.8	10	45.8	478	2319	43.24	1.95	41.53	98.25
6) 500	55.2	10	37.0	540	2859	53.31	1.50	33.97	99.08
7) 500	39.4	13	8.3	508	3367	62.78	0.90	28.98	99.54
8) 500	38.4	13	19.1	507	3874	72.24	0.44	25.25	99.77
9) 500	46.8	17	32.4	491	4365	81.39	0.23	22.43	99.89
10) 500	52.5	13	32.3	518	4883	91.05	0.14	20.07	99.96
11) 500	48.9	11	52.8	480	5363	100.00	0.08	18.28	100.00
12) 500	63.6	19	6.7	508			0		
13) 500	66.6						0		
6500	683.1								

$$\text{Average rate of water application} = \frac{6500}{683.1 \times 60} = 0.1586 \text{ cc./sec.} = 0.0035 \text{ cm./sec.}$$

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 386/5363 = 7.19 percent.

Table 56. Electrical conductivity of drainage water collected after subirrigation of distilled water of 500 cc. (11 cm. height) increments maintained at 10 cm. head above soil surface to a 25 cm. long column, 45.34 cm.^{2} cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand with gravity drainage allowed. Replicate 2

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
1) 500	11.9	10	56.8	388	388	7.26	128.00	128.00	48.23
2) 500	23.9	13	0.9	487	875	16.38	80.00	101.28	86.06
3) 500	24.2	10	49.1	480	1355	25.36	18.00	71.78	94.46
4) 500	25.9	23	18.0	528	1883	35.24	5.20	53.11	97.12
5) 500	35.8	11	15.2	490	2373	44.41	2.60	42.68	98.38
6) 500	25.0	11	8.1	509	2882	53.95	1.65	35.43	99.18
7) 500	28.7	13	59.0	681	3363	62.94	0.72	30.46	99.51
8) 500	18.8	13	38.4	498	3861	72.26	0.52	26.60	99.76
9) 500	21.0	17	57.0	532	4393	82.22	0.27	23.42	99.90
10) 500	16.4	14	9.1	465	4858	90.92	0.11	21.19	99.95
11) 500	26.7	12	14.0	485	5343	100.00	0.10	19.27	100.00
12) 500	29.6	19	46.8	505			0		
13) 500	39.7	20	44.0				0		
6500	327.6								

Average rate of water application = $\frac{6500}{327.6 \times 60}$ = 0.33 cc./sec. = 0.0073 cm./sec.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example, 388/5343 = 7.26 percent.

Table 57. Electrical conductivity of drainage water collected after subirrigation of distilled water of 500 cc. (11 cm. height) increments maintained at 10 cm. head above soil surface to a 25 cm. long column, 45.34 cm.^{2} cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand with gravity drainage allowed. Replicate 3

Amount of applied water	Time of application of water*	Time between collection of drainage samples		Sample size	Total drainage water	Percent of drainage water**	Conductivity of sample	Conductivity of total drainage water	Percent salts removed
cc.	min.	hrs.	min.	cc.	cc.	percent	mmhos cm.$^{-1}$	mmhos cm.$^{-1}$	percent
1) 500	21.8	11	15.3	360	360	6.16	120.00	120.00	41.81
2) 500	72.6	11	13.4	450	810	13.87	92.00	104.44	81.87
3) 500	123.9	9	14.3	498	1308	22.40	22.80	73.36	92.86
4) 500	121.7	8	48.0	492	1800	30.82	6.00	54.95	95.72
5) 500	84.5	11	44.4	525	2325	39.81	3.60	43.35	97.54
6) 500	62.5	15	0.5	508	2833	48.51	1.90	35.92	98.48
7) 500	64.6	18	29.8	507	3340	57.19	1.28	30.66	99.11
8) 500	54.7	11	10.8	508	3848	65.89	0.73	26.71	99.46
9) 500	68.5	11	23.1	480	4328	74.11	0.56	23.81	99.73
10) 500	72.9	10	13.6	510	4838	82.84	0.30	21.33	99.87
11) 500	93.1	10	44.8	505	5343	91.49	0.16	19.33	99.95
12) 500	91.4	11	9.9	497	5840	100.00	0.10	17.69	100.00
13) 500	137.2	9	91.5	485			0		
14) 500	138.0	14	0.8	518			0		
7000	1207.4								

Average rate of water application = $\frac{7000}{1207.4 \times 60}$ = 0.097 cc. = 0.0021 cm./sec.

Average water collected = 1/3(5363 + 5343 + 5840) = 16546/3 = 5515 cc. = 121.6 cm. height.

*Head of water on soil surface never exceeded 10 cm.

**Percent of drainage water with respect to the total collected; for example 360/5860 = 6.16 percent.

Table 58. Electrical conductivities of drainage water collected after maintaining water table for 36 hours to half the depth of a 25 cm. long sand column, 45.34 cm^2 cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand with gravity drainage allowed. Replicate 1

Amount of applied water	Time of application of water		Time between collection of drainage water samples		Sample size	Total drainage water	Conductivity of sample
cc.	hrs.	min.	hrs.	min.	cc.	cc.	mmhos. $cm.^{-1}$
1) 280	37	13.5	2	5.0	149	149	280.00
2) 155	43	12.4	1	50.5	136	283	178.00
3) 150	45	26.7	-	48.7	120	403	86.80
4) 102	37	18.9	16	28.3	116	519	51.00
5) 113	45	0.7	1	10.8	126	645	31.80
6) 150	36	2.9	1	--	128	773	19.40
7) 125	36	9.7	3	7.3	128	901	9.00
8) 120	43	58.6	1	32.1	138	1039	7.70
9) 120	44	26.6	1	13.4	151	1190	6.00
1315							
10) 170	36	3.0	1	16.8	182		2.50
11) 155	36	13.2	1	0.9	151		1.65
12) 115	36	6.9	13	58.8	178		1.02

Table 59. Electrical conductivities of drainage water collected after maintaining water table for 36 hours to half the depth of a 25 cm. long sand column, 45.34 cm^2 cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand with gravity drainage allowed. Replicate 2

	Amount of applied water	Time of application of water		Time between collection of drainage water samples		Sample size	Total drainage water	Conductivity of sample
	cc.	hrs.	min.	hrs.	min.	cc.	cc.	mmhos $cm.^{-1}$
1)	308	43	3.6	2	10	158	158	280.00
2)	152	45	6.2	-	48.7	136	294	192.00
3)	140	37	25.6	13	9.1	150	444	127.20
4)	170	44	58.0	1	11.4	150	594	43.60
5)	140	36	2.1	1	10.7	152	746	20.00
6)	170	36	9.7	3	8.7	167	913	7.30
7)	160	43	57.0	1	32.5	186	1099	5.00
	1240							
8)	190	44	25.2	1	13.4	172		2.18
9)	170	36	4.8	1	13.8	181		0.60
10)	190	36	5.9	1	0.5	188		0.30
11)	180	36	7.1	13	55.5	186		0.20
12)	210	44	57.7	10	21.8	196		0.12

Table 60. Electrical conductivities of drainage water collected after maintaining water table for 36 hours to half the depth of a 25 cm. long sand column, 45.34 cm^2 cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand with gravity drainage allowed. Replicate 3

	Amount of applied water	Time of application of water		Time between collection of drainage water samples		Sample size	Total drainage water	Conductivity of sample
	cc.	hrs.	min.	hrs.	min.	cc.	cc.	mmhos. $cm.^{-1}$
1)	280	46	30.5	25	0.6	158	158	320.00
2)	150	46	48.1	21	5.4	172	330	160.00
3)	200	49	1.8	22	34.4	166	496	46.00
4)	200	53	5.1	18	51.4	172	668	18.00
5)	180	47	50.5	24	56.1	158	826	9.80
6)	170	50	68.7	24	24.7	167	993	9.50
7)	130	44	42.4	12	34.7	192	1185	6.00
	1310							
8)	220	39	3.5	12	21.0	197		3.20
9)	200	36	0.1	22	36.7	198		2.30
10)	210	45	27.9	12	34.9	210		3.00
11)	210	37	27.3	9	42.1	193		2.25
12)	170	36	0.5	11	29.1	203		1.17

Average amount of collected drainage water to reach a value less than 4.00 mmhos cm^{-1} for electrical conductivity = 1/3(1190 + 1099 + 1185) = 3474/3 = 1158 cc. = 25.5 cm. height.

Average amount of distilled water used = 1/3(1315 + 1240 + 1310) = 3860/3 = 1287 cc. = 28.4 cm. height.

Table 61. Electrical conductivities of drainage water collected after maintaining water tables for 5 days at 2.0 cm. from the bottom of a 25 cm. long sand column, 45.34 $cm.^2$ cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand with gravity drainage allowed. Replicate 1

	Amount of applied water	Time of application of water			Time between collection of drainage water samples		Sample size	Total drainage water	Conductivity of sample
	cc.	days	hrs.	min.	hrs.	min.	cc.	cc.	$mmhos. cm.^{-1}$
1)	205	5	-	2.0	10	53.7	76	76	240.00
2)	75	5	4	49.0	17	58.5	66	142	198.00
3)	70	5	4	33.3	6	32.2	98	240	119.00
4)	80	5	-	30.4	12	24.7	54	294	80.00
5)	80	5	6	36.2	18	9.1	95	389	62.00
6)	110	5	-	4.4	22	58.0	92	481	40.80
7)	90	5	2	9.4	40	9.1	88	569	33.60
8)	95	5	-	9.7	21	35.1	93	662	22.00
9)	105	5	4	31.1	19	12.3	108	770	16.00
10)	110	5	34	1.3	24	10.6	84	854	8.50
11)	70	5	-	18.3	8	37.1	85	939	7.20
12)	60	5	-	9.6	13	28.3	82	1021	5.10
13)	110	5	4	18.0	19	29.5	83	1104	6.00
14)	90	5	-	1.2	10	3.9	91	1195	4.60
15)	80	5	-	58.7	14	6.2	68	1263	5.00
	1430								
16)	170	5	-	22.8	20	42.4	24		2.85

Table 62. Electrical conductivities of drainage water collected after maintaining water tables for 5 days at 2.0 cm. from the bottom of a 25 cm. long sand column, 45.34 cm.^{2} cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand with gravity drainage allowed. Replicate 2

	Amount of applied water	Time of application of water			Time between collection of drainage water samples		Sample size	Total drainage water	Conductivity of sample
	cc.	days	hrs.	min.	hrs.	min.	cc.	cc.	mmhos. cm.$^{-1}$
1)	205	5	-	0.5	10	53.3	64	64	240.00
2)	75	5	4	48.7	17	58.6	80	144	199.20
3)	70	5	4	34.7	6	29.9	100	244	120.00
4)	110	5	-	32.8	12	24.5	127	371	80.00
5)	85	5	6	36.1	18	9.8	130	501	37.20
6)	125	5	-	2.1	22	54.4	113	614	22.40
7)	120	5	2	10.7	23	32.2	110	724	16.80
8)	90	5	-	10.6	21	33.2	104	828	8.80
9)	150	5	4	29.0	19	14.3	118	946	7.50
10)	110	5	34	2.0	24	1.4	126	1072	6.50
11)	120	5	-	19.6	8	36.9	112	1184	4.90
12)	115	5	-	7.6	13	31.4	123	1307	4.80
	1375								
13)	135	5	4	18.6	19	25.8	113		3.90
14)	90	5	0	4.0	10	4.5	46		2.40
15)	40	5	0	58.6	14	9.9	25		3.40

Table 63. Electrical conductivities of drainage water collected after maintaining water tables for 5 days at 2.0 cm. from the bottom of a 25 cm. long sand column, 45.34 cm.^{2} cross section of initially salinized (5 percent $NaHCO_3$) Clayton sand with gravity drainage allowed. Replicate 3

	Amount of applied water	Time of application of water			Time between collection of drainage water samples		Sample size	Total drainage water	Conductivity of sample
	cc.	days	hrs.	min.	hrs.	min.	cc.	cc.	mmhos. cm.$^{-1}$
1)	205	5	5	5.3	16	47.0	52	52	276.00
2)	60	5	-	5.7	12	53.9	46	98	206.00
3)	70	5	1	29.6	9	29.1	70	168	112.00
4)	80	5	-	1.0	11	22.5	106	274	144.00
5)	100	5	1	13.8	11	5.9	96	370	96.00
6)	85	5	0	5.6	12	27.8	82	452	66.00
7)	85	4	13	51.2	12	45.2	117	569	44.80
8)	70	5	-	30.7	13	6.7	58	627	34.00
9)	90	5	4	49.0	12	12.0	60	687	22.00
10)	100	5	-	11.1	12	14.6	80	767	15.00
11)	80	5	-	12.0	13	20.2	82	849	8.00
12)	70	5	-	15.0	11	35.3	83	932	7.00
13)	100	5	1	17.2	12	36.2	81	1013	6.00
14)	80	5	-	13.1	13	38.0	89	1102	5.00
15)	70	5	2	14.2	11	46.0	68	1170	6.20
16)	60	5	-	12.0	12	55.0	62	1232	4.10
	1405								
17)	160	5	-	10.0	11	50.5	26		2.70

Average amount of collected drainage water to reach a value of less than 4.00 mmhos cm.$^{-1}$ for electrical conductivity = 1/3(1263 + 1307 + 1232) = 3802/3 = 1267 cc. = 27.9 cm. height.

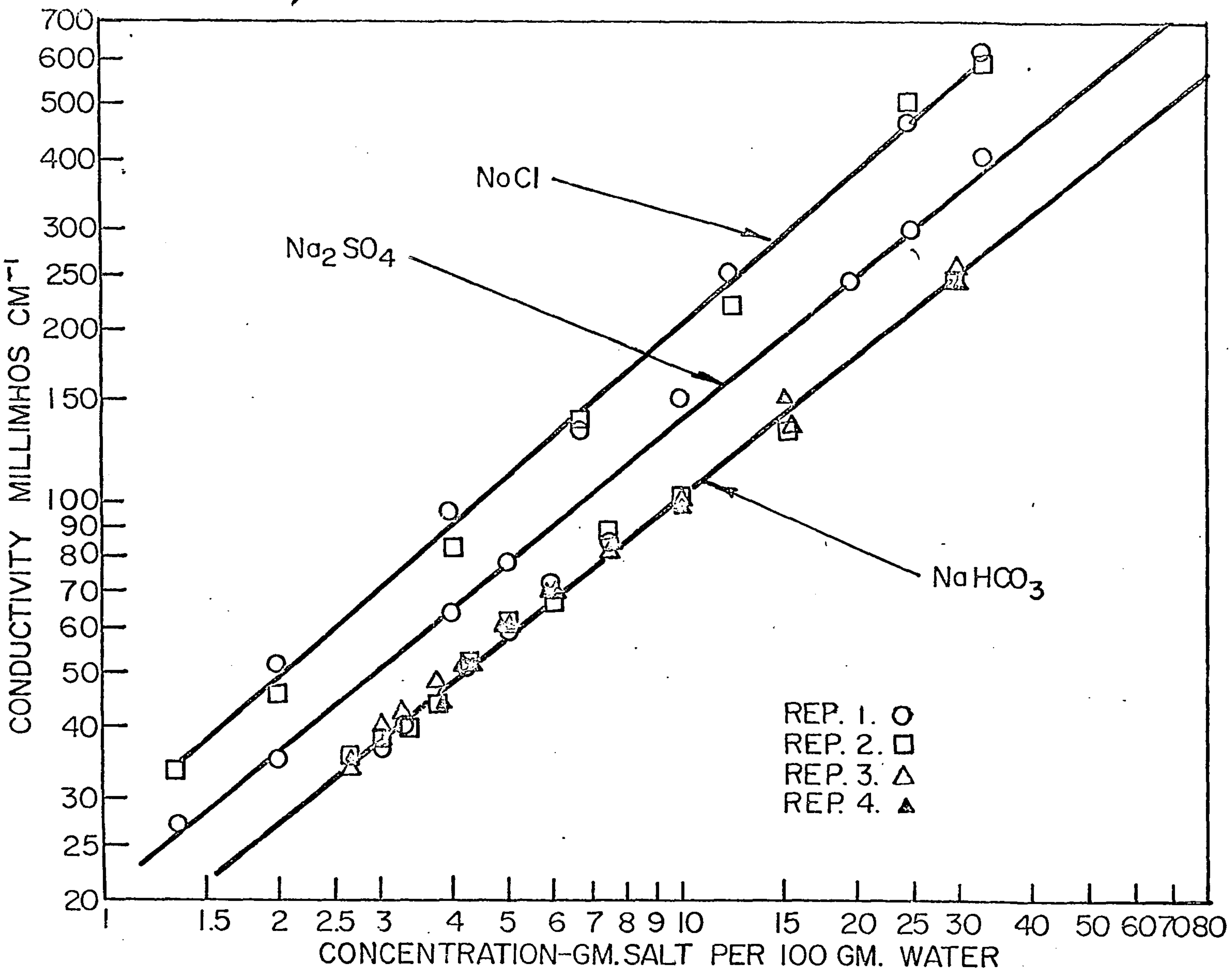
Average amount of distilled water used = 1/3(1430 + 1375 + 1405) = 4210/3 = 1403 cc. = 30.9 cm. height.

APPENDIX B

Table 64. Electrical conductivities in millimhos corresponding to percent salt (NaCl, $NaHCO_3$, and Na_2SO_4) for calibrating the solu-bridge

Percent salt	Conductivity in millimhos $cm.^{-1}$						
	NaCl		$NaHCO_3$				Na_2SO_4
	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Rep. 1
1.33	27.00	33.60					27.00
2.00	52.00	46.00					35.50
2.73			--	35.60	34.40	35.20	
3.00			36.40	38.40	39.60	38.80	
3.33			40.80	44.80	48.00	44.80	
4.00	95.00	83.00					64.00
5.00			59.20	59.60	59.60	60.00	78.00
6.00			70.00	69.20	66.00	69.00	
6.67	132.00	138.00					
7.50			82.00	86.00	80.80	80.00	
10.00			110.00	103.60	103.60	104.00	
12.50	250.00	220.00					
15.00			136.00	132.00	136.00	152.00	
20.00							240.00
25.00	460.00	500.00					295.00
30.00				266.00	252.00	240.00	400.00
33.33	600.00	580.00					

Figure 60. Electrical conductivity in millimhos $cm.^{-1}$ versus concentration of single-salt solutions in percent


NaCl
Na_2SO_4
$NaHCO_3$
REP. 1. ○
REP. 2. □
REP. 3. △
REP. 4. ▲
CONDUCTIVITY MILLIMHOS CM^{-1}
CONCENTRATION-GM. SALT PER 100 GM. WATER
700
600
500
400
300
250
200
150
100
90
80
70
60
50
40
30
25
20
1
1.5
2
2.5
3
4
5
6
7
8
9
10
15
20
25
30
40
50
60
70
80