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EFFECTIVENESS OF MOLE DRAINS
IN LEACHING HEAVY SOILS

by

José Antonio Forero

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Agricultural and Irrigation Engineering

Approved:

Komain Unhanand
Major Professor

Committee Member

Committee Member

Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

1975

To my parents

my wife, and

my son

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José Antonio Forero

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ABSTRACT

Effectiveness of Mole Drains
In Leaching Heavy Soils

by

José Antonio Forero, Master of Science

Utah State University, 1975

Major Professor: Dr. Komain Unhanand
Department: Agricultural and Irrigation Engineering

A field experiment was conducted to determine the effects of leaching by mole drains, 3 inches in diameter, installed 18 inches deep at the spacings of 6, 12, and 24 feet. The water was applied periodically by sprinklers at a rate slightly less than the basic intake rate to avoid ponding. Soil samples, taken before and after leaching from the same location in the experimental area, were analyzed to determine the EC of the saturation extract and the reduction in salt concentration of the soil after leaching. Results of the experiment indicate that, within the limits of the three spacings tested, the combination of mole drains and low application rate of irrigation water leaches the salts more effectively than using the low application rate alone. However, because the initial salt concentration was different from plot to plot, no conclusive result could be drawn as to which mole spacing is most effective in leaching.

(103 pages)

INTRODUCTION

Origin and Nature of the Problem

Optimum crop production requires a favorable soil environment in the plant root zone. To accomplish this condition, adequate levels of moisture, fertility, temperature, and salt balance must be maintained in the soil by means of appropriate drainage practices. Drainage removes the excess water from the soil providing a suitable soil aeration which is necessary for the plant's physiological processes and for the activity of microorganisms in the soil. To reduce the salt concentration in the soil to a desired level, which depends on the tolerance of crop, an adequate amount of water must be passed through the root zone. Therefore, irrigation and drainage management become predominant factors in the leaching process.

In general, drainage and salinity problems are interrelated. When irrigation water is applied, a certain amount of salt is generally added to the soil where they may accumulate to a level that becomes detrimental to plant growth. An adequate salt balance is provided when as much salt is passing out of the soil profile through a drainage system or other means, as is entering.

There are many areas all over the world, where reclamation of saline soils is one of the most important tasks to bring more land under successful agricultural production in order to supply the increasing demands of food and fiber.

Various leaching techniques commonly used for reclamation at present, often require considerable initial investment, time, and a rather large amount of water to be applied. In these respects, the combination of mole drains with low application rate by sprinkler irrigation, may become an economic method for quickly reducing the salt concentration to a suitable level in heavy soils.

Objective

The main objective of the research was to conduct a field study to find the effectiveness in leaching heavy soils by using a combination of mole drains and a low application rate of irrigation water applied by sprinklers.

Three different spacings of mole drains were tested and comparisons of leaching effectiveness were made with that of an area having no mole drains.

REVIEW OF LITERATURE

Salt Problems in Agriculture

Salinization of agricultural lands and research to find efficient ways of controlling it have preoccupied soil scientists, irrigation and drainage experts, and agronomists for many years. Attention has been focused on the problem all over the world, primarily because of the widespread processes of salinization in soils and the heavy losses inflicted thereby on the national economics, and also because of certain difficulties encountered in controlling this phenomenon.

The processes of salinization are brought about by a variety of causes. In reference to irrigated agriculture, Rozanov (1958) indicated that the followings are the major factors contributing to salinity problems:

1. Irrigation and the rise of groundwaters,
2. The effect of the primary salinization of soils, ground and groundwaters on the secondary salinization of irrigated lands,
3. The redistribution of salt accumulations during irrigation,
4. Changes in the salt composition of irrigated soils,
5. The principle laws governing the surface spread of salinized soils in irrigated lands,
6. The system of meliorative measures.

In general, the main salt components of saline soils are formed by combinations of the following ions: sodium, calcium, magnesium, chloride, sulfate, bicarbonate, and nitrate. Thorne and Peterson

(1954) indicated that the major toxic effects of salts in depressing plant crop growth probably come from one or more of three different sources:

1. Direct physical effects of the salts in preventing water uptake,

2. Direct chemical effects of the salts in altering the processes of nutrition and metabolism of plants, and,

3. The indirect effects of salts in disturbing soil structure, permeability, and aeration.

Magistad and Reitemeier (1943) found that plant growth was limited on soils in which the osmotic pressure of the soil solution would be 10 atmospheres based on the moisture content at the 15 atmosphere. Eaton (1941) reported the effects of salts on plants by placing part of a root system in a concentrated solution and the other part in a dilute solution. Under these conditions, he demonstrated that water absorption was almost entirely from the dilute solution.

Salinity is commonly measured in terms of the electrical conductivity of a saturation extract (ECe) expressed in millimhos per centimeter (mmhos/cm) at 25° C. Because of the fact that plants differ in their tolerance to salinity, crops have been classified in broad categories on the basis of their response to salinity. The Soil Conservation Service (1964) has indicated the relationship of ECe to plant yields, as shown in Table 1.

Table 1. Crop response to salinity (S.C.S., 1964)

Salinity (ECe, mmhos/cm at 25° C)	Crop response
0 - 2	Salinity effects mostly negligible
2 - 4	Yields of very sensitive crops may be restricted
4 - 8	Yields of crops restricted
8 - 16	Only tolerant crops yield satisfactorily
Above 16	Only a few very tolerant crops yield satisfactorily

The type of salinity is of prime importance in determining the detrimental effects of salts on crops. Strogonov (1964) reports from his experiments, that the typical anatomical changes of plants are determined not so much by the total salt concentration as by the ratio of the salts in the soil, i.e., the type of soil salinity. He indicates that under saline conditions, the processes of formation of leaf initials in cotton and their differentiation are distorted in the stem apex. At the same time, under conditions of the chloride type of salinity, the initiation of leaf primordia is less inhibited than their differentiation, while under conditions of the sulphate type of salinity, the effect is less pronounced and affects both processes equally. In terms of the anatomical structure of the leaf in cotton, the same author indicates that the typical effect of chloride salinity, as compared to that of the sulphate type, is a decrease in size of the leaf, an increase in size of the epidermical cells, a decrease in the number of stomata per unit area and thickening of the leaf blade due to an excessive development of the palisade and spongy mesophyll layers. His experimental results indicate that the sulphate type of salinity inhibits the extension growth of cells more than cell division. On the other hand, under conditions of the chloride type of salinity, cell division is strongly inhibited while enlargement is stimulated.

Many other effects on plant growth by a number of salt components have been found by means of experimental work. Purves (1965) shows the elongation of etiolated cucumber (Cucumis sativus L.) hypocotyl segments as stimulated by KCl and a number of other potassium salts at a concentration of 0.02 NK. NaCl, LiCl, and RbCl enhanced elongation of the segments, and their dosage response curves were similar to that for KCl. At concentrations of 0.05 M or greater of LiCl the segment growth was inhibited. CsCl was inhibitory at all concentrations tested while NH_4Cl also promoted elongation, but not as effectively as did the alkali cations.

Soluble salts in excess, exchangeable sodium, and the occurrence of drought cause sterility and barrenness of arid-region soils. Saline and alkali soil conditions were among the principal factors involved in the decline of many ancient civilizations, and today they are seriously reducing the value and productivity of millions of acres of farm land all over the world. (Israelsen and Hansen, 1962).

In the United States approximately one third of the irrigated and potentially irrigable lands in the seventeen western states is affected to some extent by salinity and alkali problems, especially in arid and semi-arid climates (U. S. Salinity Laboratory Staff, 1954) where precipitation is insufficient for satisfactory crop growth, and irrigation must be practiced.

Leaching Process

Miscible displacement is a phenomenon that takes place when one flowing fluid displaces another from the space it is occupying and a mixing takes place between the two fluids, which are miscible between them. This process occurs in the soil when water with a salt concentration different from the salt concentration of the soil solution enters the soil. The results of this phenomenon can be observed in the variation of the salt concentration of the soil solution along the soil profile or of the drainage water leaving the soil.

Biggar and Nielsen (1962) indicated that the movement of ionized salt in water was caused simultaneously by diffusion, mixing due to variations in velocity distribution, and by the physical and chemical interaction of the salts and solid matrix during flow. The same authors (1963) expressed the results of their experiment in terms of the ratio of the volume of effluent to the pore volume, V/Vo, where Vo is the volumetric water capacity of the column (pore volume) determined gravimetrically at 105° F and V is the volume of effluent.

Water application rate and the degree of saturation of the soil are determinant factors in leaching efficiency. Laboratory studies conducted by Keller (1964) have indicated that the percent saturation of the soil during sprinkling decreased exponentially with the application rate. Furthermore, Keller and Alfaro (1966) have demonstrated by laboratory experiments that in miscible displacement occurring in the soil, the effect of water flow rate and the degree of soil saturation are interrelated and dependent upon application rate. They concluded that leaching efficiency increases as the water application rate decreases, under unsaturated flow conditions.

Kemper, Sills, and Aylmore (1970) have studied separation of different adsorbed cations as water flows through clays. They developed a theory which predicts that adsorbed divalent cations move upstream and monovalent cations move downstream in a mixed ion system, when solutions of low concentrations are forced through this clay. They obtained some data from small size mica which supports this prediction. Table 2 shows the results of their experiment.

From Table 2 it can be seen that Ca^{2+} tended to move to the upstream half of the plug, while Na^+ was moving towards the downstream side.

Terry and McCants (1970) conducted leaching experiments under controlled water regime conditions on a variety of soils in the field to observe the distribution of certain ions by percolated water. Their studies demonstrated that when NH_4, NO_3, and K were leached, the salt movement was generally in the form of a "normal"

Table 2. Conditions leading to, and extent of, cationic separation by streaming potentials (Kemper, Sills, and Aylmore, 1970)

Pressure difference bars	Flow time days	Flow volume cc	Ca^{2+} μ eq/gm	Na^+	Half of tube
0.12	3	6.0	36.5	38.8	Upstream
			35.4	47.7	Downstream
0.12	6	6.5	36.7	34.2	Upstream
			34.7	41.0	Downstream
0.68	2	17.0	29.2	22.8	Upstream
			26.0	30.7	Downstream
0.68	3	31.0	36.2	24.8	Upstream
			27.9	37.2	Downstream
0.68	4	29.0	40.2	13.8	Upstream
			33.2	33.3	Downstream

distribution. However, the movement of Mg was not as well defined as the other ions. They developed multiple regression equations for predicting the leaching of these ions. These equations utilize the parameters of a normal distribution as the dependent variables and properties of the soil and quantities of percolated water as the independent variables. For mean movement, R^2 ranged from 0.92 to 0.97 and those for the standard deviation from 0.56 to 0.91. The important independent variables were:

1. Quantity of percolated water,

2. Soil porosity as expressed by the weighted porosity index,
3. Cation exchange capacity, and
4. The water content at 0.1 bar suction.

Terkeltoub and Babcock (1971) conducted an experiment in which soil columns containing either Tolo silty clay loam or Hanford sandy loam were prepared with vertically nonuniform salt (Na^+, Ca^{2+}, Mg^{2+}, Cl^-) and moisture distributions and with gypsum ($CaSO_4 \cdot 2\ H_2O$) present in the surface soil. Water containing Na^+, Ca^{2+}, Mg^{2+}, and Cl^-, was applied at both fast and slow rates but always without causing the ponding of water on the soil surface. Glass wool was placed on top of the soil columns to minimize evaporation. After allowing the soils columns to drain for 3 to 4 weeks, each column of soil was subdivided into the original number of portions added to the columns, and the moisture content of each portion was determined. Afterwards, the soluble Ca, Mg, and Na were determined on a 1 to 2.5 air-dry soil to water extract. As a result of this study the slower rates of irrigation leached salt more efficiently than higher rates. Salt movement within the more slowly irrigated columns, occurred at lower soil moisture contents and higher soil moisture suctions than in those more rapidly irrigated. The explanation of this phenomenon is that downward moving soil water enters and leaches salt from the smaller soil pores to a greater extent at lower soil moisture contents. On the other hand, Dyer (1965a) had indicated that as anion exclusion (negative adsorption) limits the presence of salt in the relatively inmobile water adjacent to clay surfaces, a preponderance of the soluble salts are found within the more mobile, downward moving soil water. The same author (1965b) explains that this phenomenon, which is related to leaching efficiency, becomes more substantial at lower soil moisture contents as the soluble salts are concentrated within smaller quantities of mobile water. Finally, Terkeltoub and Babcock (1971) indicated that the increase in salt leaching efficiency with decreased rate of water application was much more pronounced in the Yolo soil, which contains 32 percent clay, than in the Hanford soil, which contains 12 percent clay.

Reclamation of Saline Soils

Most of the best lands all over the world, not subject to salinization, convenient for irrigation and with sufficient water reserves, are already being exploited. As the world's population continuously increases, there is a constant need for melioration and reclamation of salinized soils. Several countries like the U.S.A., the Soviet Union, China, India, Australia, and Egypt, have accumulated valuable and diverse experience in the prevention and control of salinization.

A number of different techniques have been employed in reclaiming saline soils. The method of ponding water on the surface for several months has been the most commonly used practice. However, more efficient methods of leaching saline soils have been found by means of experimental work. Miller, Biggar, and Nielsen (1965) reported that intermittent ponding of a clay-loam soil required less water than continuous ponding in order to obtain the same degree of leaching. On the other hand, it has been shown, (Nielsen, Biggar, and Luthin, 1966) that sprinkling is more efficient than continuous ponding on a silty-clay soil.

Fanning and Carter (1963) investigated the contribution of rainfall in reclaiming saline soils of the nonirrigated portions of the Rio Grande delta (USA), where leaching water is limited to an average annual rainfall of 28 inches. Two practices were studied: a cotton bur mulch and a ridge-furrow. The soils are said to be developed on stratified deposits of alluvium which form a broad delta with little topographic relief. A high water table underlies the delta and fluctuates with seasonal rainfall. Salinity was reduced in the surface 30 inches of soil to a level below that considered detrimental to growth of field crops. The apparent high leaching efficiency by rainfall was attributed to flushing of salts from conducting pores when rains occurred combined with difussion of salts from nonconducting to conducting pores between rains. The ridge-furrow practice facilitated leaching of salts from below the furrows, but less effectively than the mulch system. Both practices proved useful in the management of saline soils of the study area.

Experimental work for reclaiming saline soils was conducted by Carter and Fanning (1964). Twenty-six inches of irrigation water were applied by periodic sprinkling of surface-mulched soil resulting in greater salt removal and higher leaching efficiency than did either flooding or periodic sprinkling of bare soil. Salts were removed from all depths to 5 feet where surface mulches were present. However, flooding and sprinkling bare soil decreased salt concentration in the surface 2 feet of the soil profile, but more salt accumulated below a depth of 3 feet when compared with check soil that received only rainfall. The leaching efficiency decreased from above 90 percent in the surface foot to approximately 33 percent in the fifth foot of surface-mulched soil. The resulting higher leaching efficiency for mulched soil was attributed to the likely reduced evaporation under mulches that restricted upward movement of water.

Experiments on reclamation of saline and alkali soils have been conducted in France (Allemann and Vigneron, 1973) by using subsurface drainage as a means of reclamation. The study soils range from saline to alkali with clayey structure, and some silt and organic matter. Approximately 3 g/l of NaCl were found in the groundwater during the rainy season and prior to reclamation. Flooded conditions existed with fluctuations of several decimeters, prior to reclamation after which the groundwater table lay a few decimeters below the soil surface. The area of the experiment was 30 has and the sources of leaching water were 598 mm/year precipitation and Rhone river water through sprinkler irrigation systems. The total amount of irrigation water applied was 810 mm in 17 irrigations. The drainage system consisted of four types of buried pipe at 150 m of length and spacings of 12, 16, 24, and 36 m. Descriptions of the four types of pipes are given below:

- smooth polyethylene pipes, in 6 m lengths, with side slits of 1.2 mm and an inside diameter of 50 mm.

- corrugated PVC pipes with an inside diameter of 44 mm and perforations about 1 mm wide along the bottom, giving a water inflow area of 20 cm^2 per linear meter of drain. Some of these pipes were equipped with filters.
- clay pipes, 0.5 m in length and inside diameter of 80 mm.
- smooth PVC pipes in 6 m lengths, and 40 mm in diameter.

The following conclusions were drawn from the experiment:

1. When pipes are enveloped with some proper filtering material, the conditions of drainage are improved.

2. Adequate salt removal was achieved by conveniently utilizing the high annual rainfall in the region in combination with sprinkler irrigation and good drainage system.

3. Desalinization does not automatically lead to sodium adsorption by the clays.

4. Drainage practices made feasible the intensification of crops, however, constant concern must be observed to prevent destruction of the soil profile where crops are grown.

The Tulare Lake Basin in southern San Joaquin Valley, California, is a dry lake bottom which has 300,000 acres of irrigated cropland. The main lake bed soil is Tulare clay loam having a dark-gray clay loam surface which is also massive hard calcareous, sticky and plastic. Its subsoil is gray, hard, massive, stratified of fine-textured material and calcareous. The soil is not well drained, moderately saline-alkali, and its runoff and subsoil permeability are slow. Brooks (1966) reports a reclamation operation on a 75-acre field which is representative of the entire dry lake area. Table 3 illustrates the saline-alkali conditions of the soil prior to leaching. The reclamation work carried out consisted of land leveling, installation of drainage facilities, application of soil amendments (gypsum) and leaching excessive soluble salts. The land was prepared for the leaching operation by constructing a 2 to 3 foot levee around the field and a 5 foot deep perimeter drain outside the

Table 3. Average conditions of the 75-acre field, prior to leaching (Brooks, 1966)

Soil sample	-3-	-4-
pH, glass electrode	8.1	8.2
Electrical conductivity, mmhos per cm	8.5	10.4
Total cations, meq per l	102	130
Total salts, ppm	5950	7280
$Ca^{++}Mg^{++}$, meq per l	25.0	37.5
Na^{+}, meq per l	77.0	92.5
PO-4 lb per ac. ft.	Trace	Trace
ESP (exchangeable sodium percent)	24	23
Gypsum requirements - taf	0	0

levee. This drain was connected to an outlet drain from the field. Prior to leaching 5 tons per acre of 65 percent gypsum were applied to control the alkali in the soil. The depth of the ponded water was maintained between 1 and 2 foot pond depth. The EC of the water applied was 0.8 mmhos per centimeter, while the drainage effluent had an EC of 15.1 mmhos per centimeter, which means that net total of 896 tons of salt were leached out from the soil during the 67-day period of leaching.

Oster, Willardson, and Hoffman (1973) conducted an experiment in which they compared the effectiveness of three different techniques for reclaiming a saline Holtville silty-clay soil. The three techniques studied were continuous ponding, intermittent ponding, and sprinkling. Table 4 shows the depths of water applied to the different plots.

They installed twelve salinity sensors in each plot at depths of 53 and 86 cm at three locations on the center line of each plot. The sprinklers were adjusted to operate 30 minutes every 2 hours to avoid ponding of water on the soil surface. The EC for the sprinkler plot did not change for 25 days, likely because of the low water application rate (0.5 cm per hr.) and consequently the lag in the movement of the wetting front.

The leaching efficiency for both soil depths, was found to be in decreasing order, as follows: intermittent ponding, sprinkling, and continuous ponding. The fact that the leaching efficiency for sprinkling was greater than that for the continuous ponding is

Table 4. Accumulated water application record (Oster, Willardson, and Hoffman, 1973)

		Water applied (cm)		
Date	Day	Continuous ponding	Intermittent ponding	Sprinkler
12/27/70	4	14.7	13.0	0
1/20/71	28	34.4	23.4	23.9
2/12/71	51	55.6	33.6	45.7
2/24/71	63	68.9	43.8	54.8
3/8/71	75	82.3	52.7	63.8
3/19/71	86	96.7	62.9	74.1
4/1/71	99	113.2	71.8	87.1

probably a consequence of the condition of no surface ponding in the sprinkled plot rather than due to differences in soil water content of the two treatments (Oster, Willardson, and Hoffman, 1973). These results, on the other hand, support the indication made earlier by Miller, Biggar, and Nielsen (1965) who concluded that salt displacement is most efficient under unsaturated flow conditions.

Mole Drainage

Mole systems have been used successfully for irrigation and drainage practices in heavy soils. The practice of moling started at the beginning of the Eighteenth Century in England (Hudson and

Hopewell, 1950). According to Harrison (1959) the first reported work with mole drainage in the U.S.A. was done in Florida in 1928. The mole drains were constructed by pulling a chisel-shaped implement through the soil, leaving behind a small diameter channel which functioned in a similar manner as a tile drain (Unhanand, 1971).

Mole drainage could become a very suitable system for developing countries from the economical point of view. It requires a very low initial investment to be installed, however, it presents some disadvantages such as its short life, its requirements of machine power for installation, and, the most important one, its suitability only in soils containing large percentage of clay in which the mole channel may remain its shape after being built (Unhanand, 1972).

Cooper (1965) summarizes that a good mole plow should be capable of producing a 3-1/2 inch diameter hole which should be clean and round, at a depth of 26 inches. The mole must be set perfectly parallel with the beam above and since this is the only part that holds the machine in the ground, the minimum diameter must be 3 inches with a length not less than 2 feet 3 inches and preferably several inches longer. Mole draining is only possible in clay soil to retain the shape into which it is pressed by the tool passing through it. Clay swells when wet and shrinks when dry and this explains the fact that a field with a good clay subsoil and poor drainage dries out in spring, so the surface cracks into myriads of small pieces. Once the shrinking process has started, cracks will continue downwards as the moisture recedes. Under these circumstances, air will gradually permeate through the mass of clay, breaking it up into many pieces. Mole drains speed up this process because, as pressure is exerted below, the ground is limited to rise which permits air circulation from the surface downwards and upwards from the moles as well.

When the subsoil is known to be a good clay, a length of 10 chains for the moles appears to be the safety limit and tile drains should be laid across the fall to intercept the moles at decreasing intervals, according to the quality of the subsoil. On the other hand, the minimum depth of the moles should be 2 feet for arable land and about 22 inches for grass to insure a mole life of twenty years or more (Cooper, 1965).

Willardson (1967) reports that installation of mole drains with conventional equipment failed because the dry soil shattered and fell back into the mole opening after the mole plow had passed. This problem occurred as far as 3 feet behind the moving mole blade. To correct this situation, a 1-foot long moling cylinder was constructed by tapering one end of a pipe having a diameter the same size as mole to a bullet shape. The sharp end of this mole cylinder was welded to a 7-foot chain which was then fastened behind the conventional mole blade.

Attempts have been made to add durability to mole drains by providing them with plastic liners. However, Monley (1961) indicated that some plastic liners in common use add little strength, if any, to the load bearing capacity of the drain. Nevertheless, plastic liners may extend the useful life of a drain because they control soil erosion and prevent soil wall particles from caving. A test on a dry clay indicated that no damage was caused to a plastic-lined drain at a depth of 18 inches, by a load of 5,000 pounds applied on the ground surface by means of 9-inch square plate. The same test on a silty clay loam at different soil moisture contents showed no collapsing up to 3,500 pounds of load.

Perez (1969) reports that in 1959, a system of mole drains was installed at the Utah State University Drainage Farm to determine the suitability of this type of drainage. Some of the moles were installed with a thin plastic liner, whereas others were left unlined. The mole spacings used were 20, 30 and 40 feet. The average depth was 22 inches for the moles lined with plastic and 28 inches for the unlined moles. The water table was at a depth of 4 feet at the time the moles were installed; the soil was dry and had a tendency to crumble, so that the power requirements were greater and the moles were less stable.

Both lined and unlined moles were effective in removing water and salt from the soil during the initial period of leaching by continuous flooding. The leaching operation continued until the drainage water had about the same salt content as the water used for flooding. The unlined drains collapsed after the initial period; the lined drains, on the other hand, operated through the flooding and freezing cycles of one winter (Perez, 1969).

Fouss and Donnan (1962) indicated that a 3-inch mole drain with a "zippered" plastic, installed at depths of 30 to 33 inches, cost 10 to 12 cents per linear foot. These low cost mole drainage systems, when compared with costs of 50 cents to $1.50 per foot for conventional, shallow, tile drainage systems, appear to be attractive for leaching practices (Fouss and Donnan, 1962).

Rapp (1968) conducted an experiment to determine the relative performance of lined and unlined mole drains, and shallow tile drains in reclaiming a waterlogged and salinized, shallow, glacial till soil. The study was carried out at Vauxhall, Alberta, (Canada), on a Chin loam soil, moderately saline with a water table depth of about 8 feet. Three types of drains were tested: lined mole drains, unlined mole drains, and tile drains. The plastic-lined mole drains were installed at a depth of 27 inches and 33 foot spacing. The depth for the unlined mole drains was 21 inches, for a 16½ foot spacing and 3 inches in diameter. Clay tile drains, 4 inches in diameter, were laid at 3 foot depths and 33 foot spacing. Soil samples taken before starting the leaching operation were analyzed for EC, Na, and Ca plus Mg. No soil amendments were used during leaching and the total amount of water considering irrigation water and rainfall was as follows: in 1964, 31.8 inches of water were applied and 2.8 inches were received as rainfall, in 1965, the water applied was 12.2 inches and the precipitation was 19.1 inches. According to the results, the unlined mole drains were the most effective in reducing salinity in the 3 foot profiles, followed by the tile drains, lined mole drains and the check.

Unhanand (1972) reports a preliminary investigation to study the possibility of using mole drains as an efficient means of leaching salts from heavy soils. Single and double mole drains were installed in an experimental plot at Utah State University Drainage Farm at 6, 12, and 24 foot spacing. The mole drains were 3 inches in diameter and installed at the depth of 21 inches. Soil samples were taken from the moled and control areas before approximately 15 inches of water were applied to the soil by a sprinkler system and another set of soil samples was collected from the same area bout one year later. All soil samples were analyzed for EC and the results plotted as shown in Figures 1 to 6 to illustrate the reduction in salt concentration in the soil. The precipitation during the year was 24 inches.

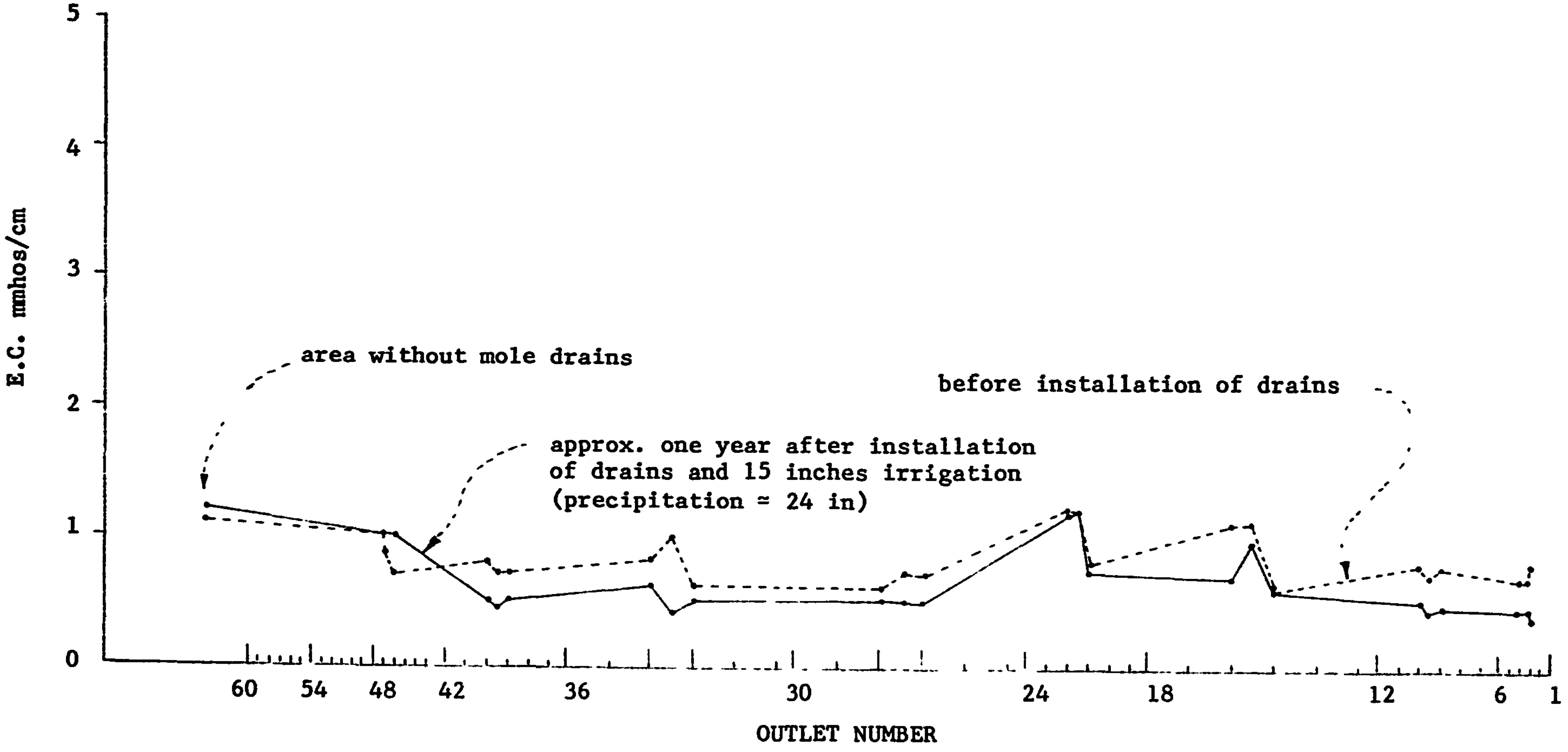


Figure 1. Electrical conductivity of saturation extract of soil samples taken from 6 inches depth along line "A" (redrawn from Unhanand, 1972)

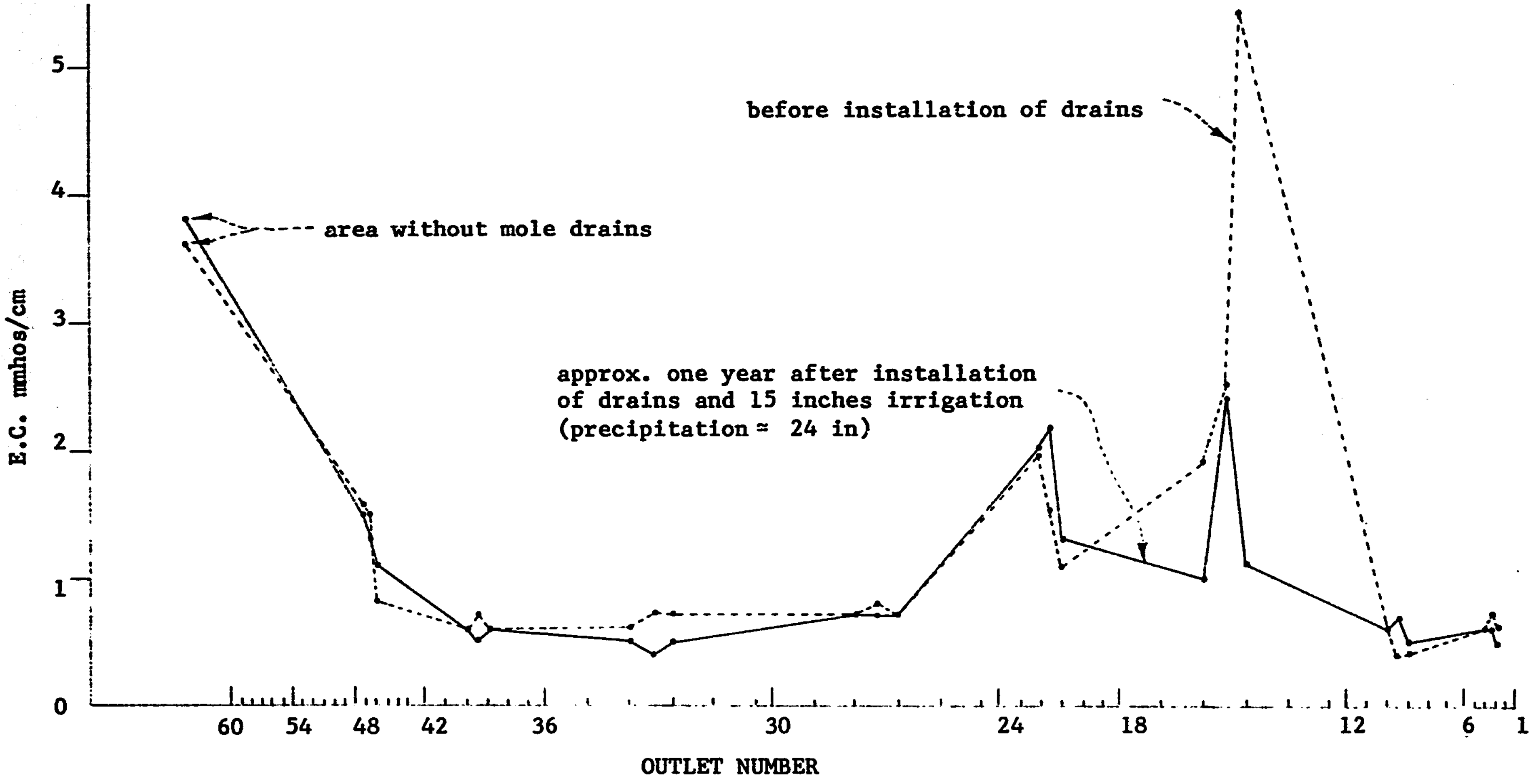


Figure 2. Electrical conductivity of saturation extract of soil samples taken from 12 inches depth along line "A" (redrawn from Unhanand, 1972)

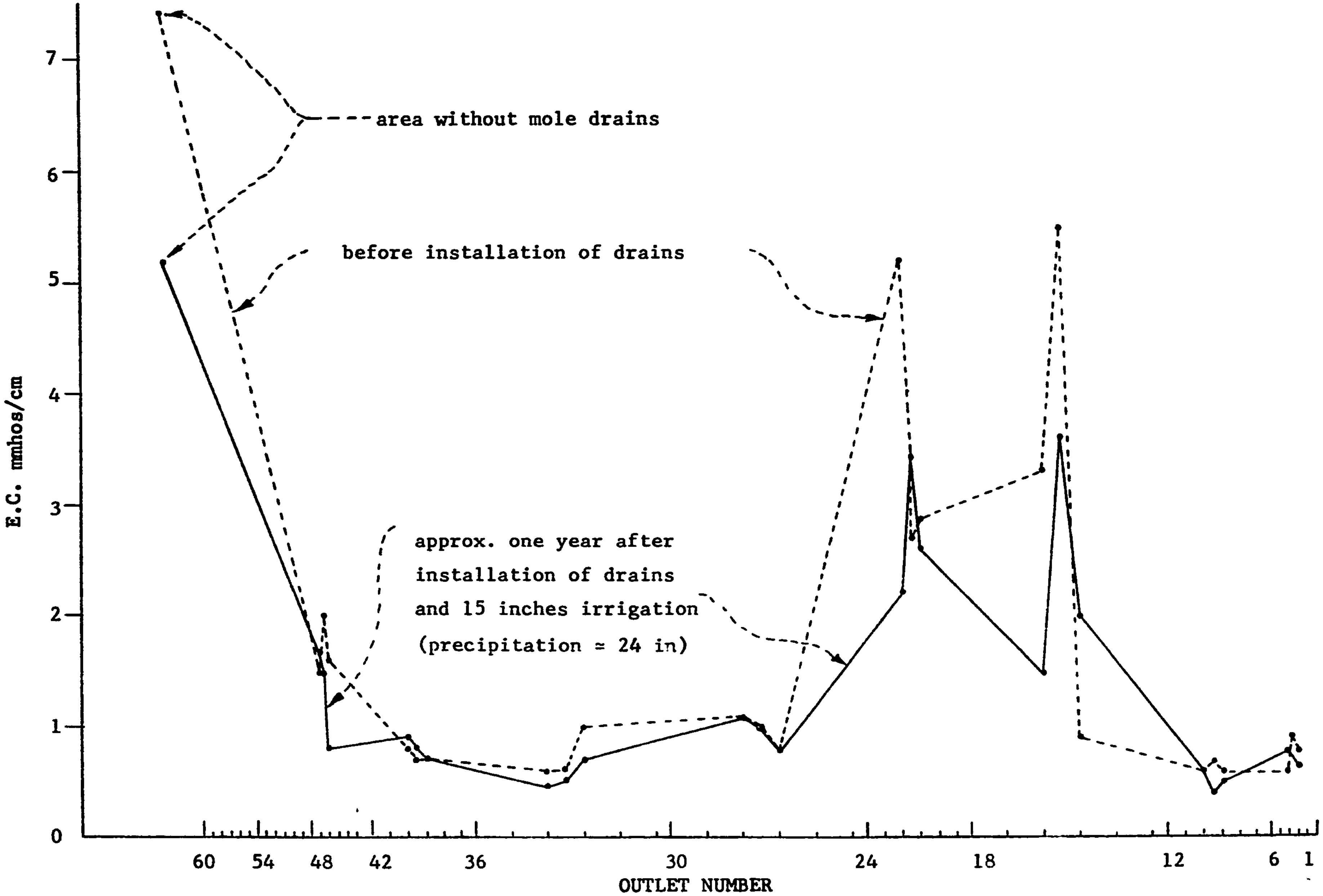


Figure 3. Electrical conductivity of saturation extract of soil samples taken from 18 inches depth along line "A" (redrawn from Unhanand 1972)

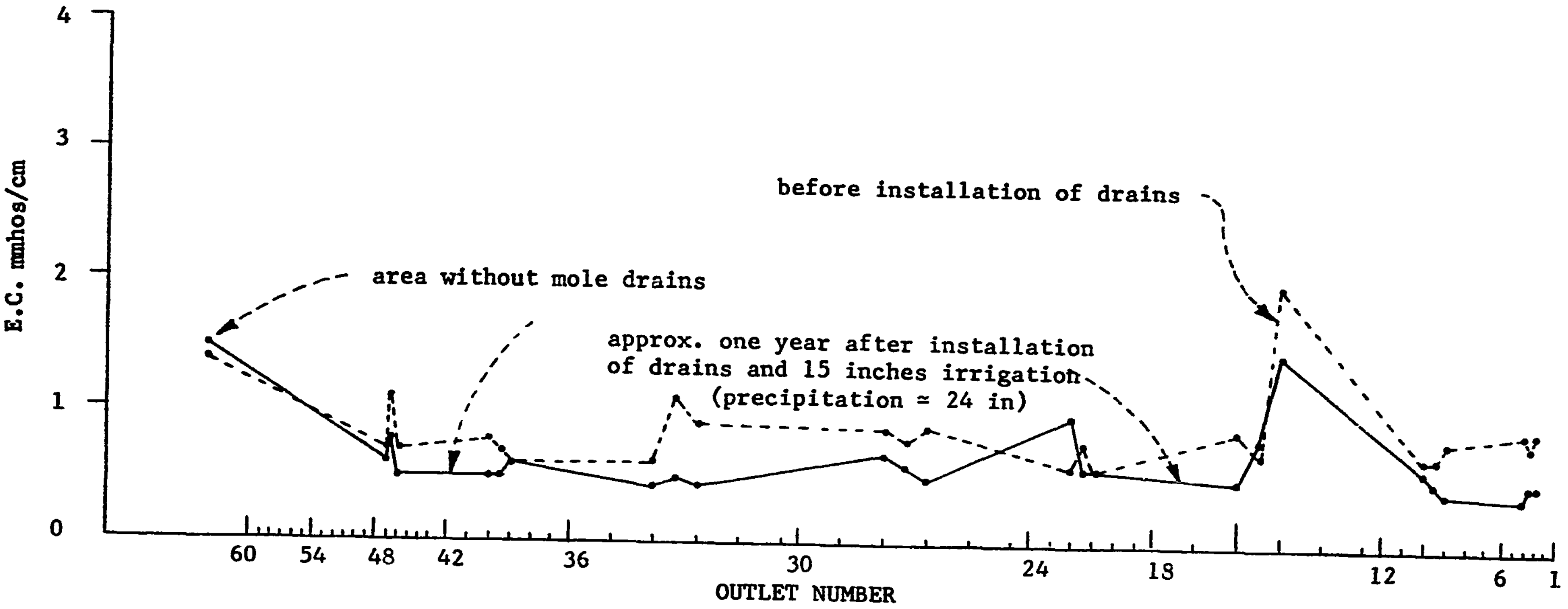


Figure 4. Electrical conductivity of saturation extract of soil samples taken from 6 inches depth along line "B" (redrawn from Unhanand, 1972)

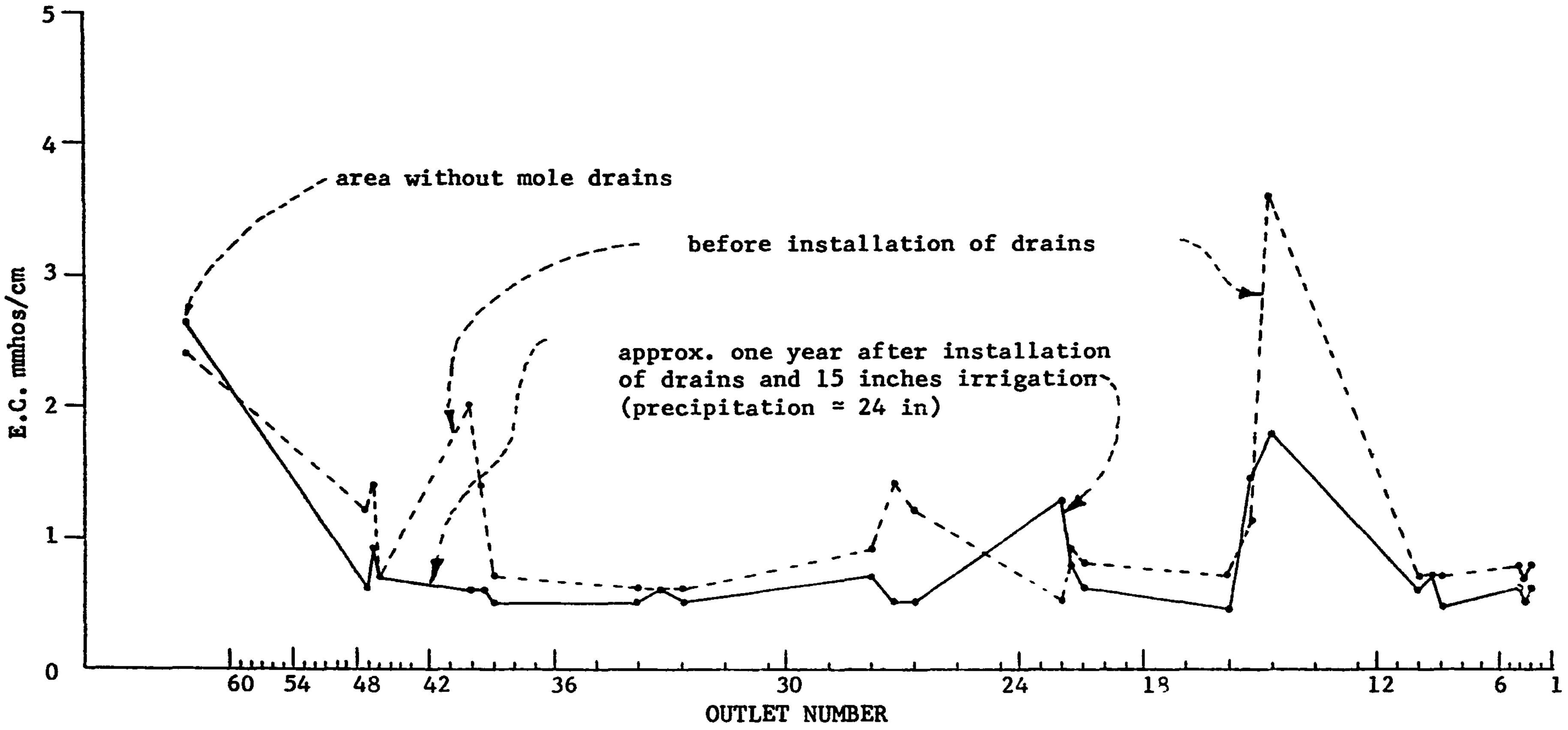


Figure 5. Electrical conductivity of saturation extract of soil samples taken from 12 inches depth along line "B" (redrawn from Unhanand, 1972)

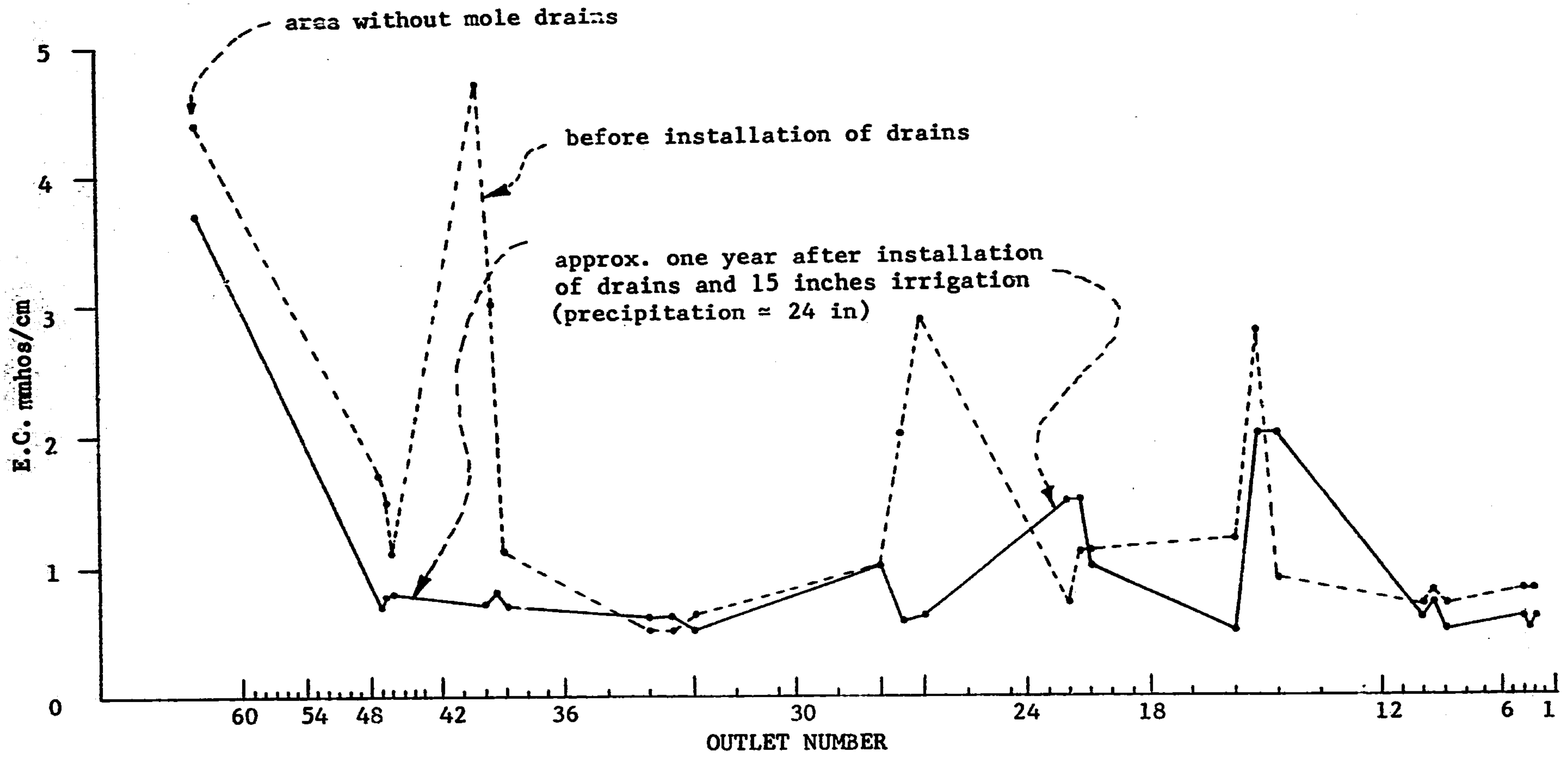


Figure 6. Electrical conductivity of saturation extract of soil samples taken from 18 inches depth along line "B" (redrawn from Unhanand, 1972)

EXPERIMENTAL PROCEDURE

General Description of the Experimental Field

The experimental field is located in the University Drainage Farm. The farm is representative of typical poorly drained lands of Cache Valley which is located in the northern part of Utah and southern Idaho. The valley floor is relatively level and surrounded by mountains except for the low fault notch where the drainage flows to the southwest. The altitude of the valley floor is approximately 4,400 feet and its soil is all transported as a result of stream or lake deposition.

The University Drainage Farm (Figure 7) is characterized by its heavy textured soils and there are many areas with salt accumulations in the soil profile. The salinity is not uniformly distributed and the electrical conductivity ranges as much as 14 mmhos per centimeter from low to high levels. The most important salts encountered in the soil are: sodium, potassium, calcium, magnesium, chloride, bicarbonates and sulfates. The pH reaches values from 8.0 to 8.5 reflecting alkali conditions.

According to the Soil Conservation Service classification (Perez, 1969), the experimental field corresponds to the series Ap 31-Lg 21/ A-13 Ap characterized by its Airport - Salt Lake complex 0-1 percent, 60 percent Airport silt loam at elevated areas and 40 percent Salt Lake silty clay in the depressions. Native pasture, alfalfa, wheat and barley are most of its vegetation; the permeability is slow; the

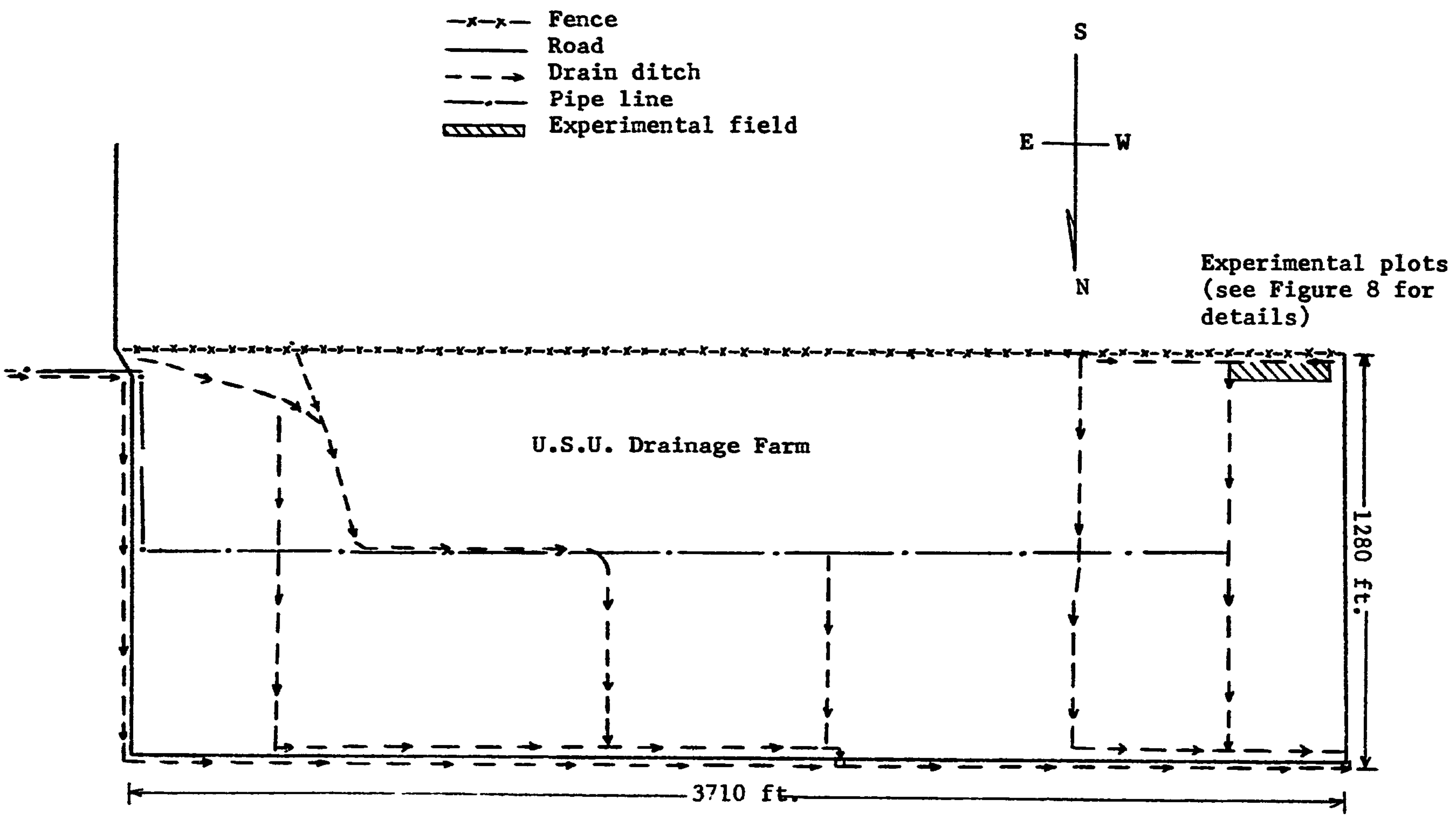


Figure 7. Utah State University Drainage Farm, Logan, Utah, showing the location of the experimental plots

plant roots are shallow because of the high concentration of salt and alkali in the subsoil; the water holding capacity is about 1.8 to 2.0 inches per foot, and the tillage is moderately difficult.

The soil profile of the experimental area, described by the Soil Conservation Service is as follows (Perez, 1969):

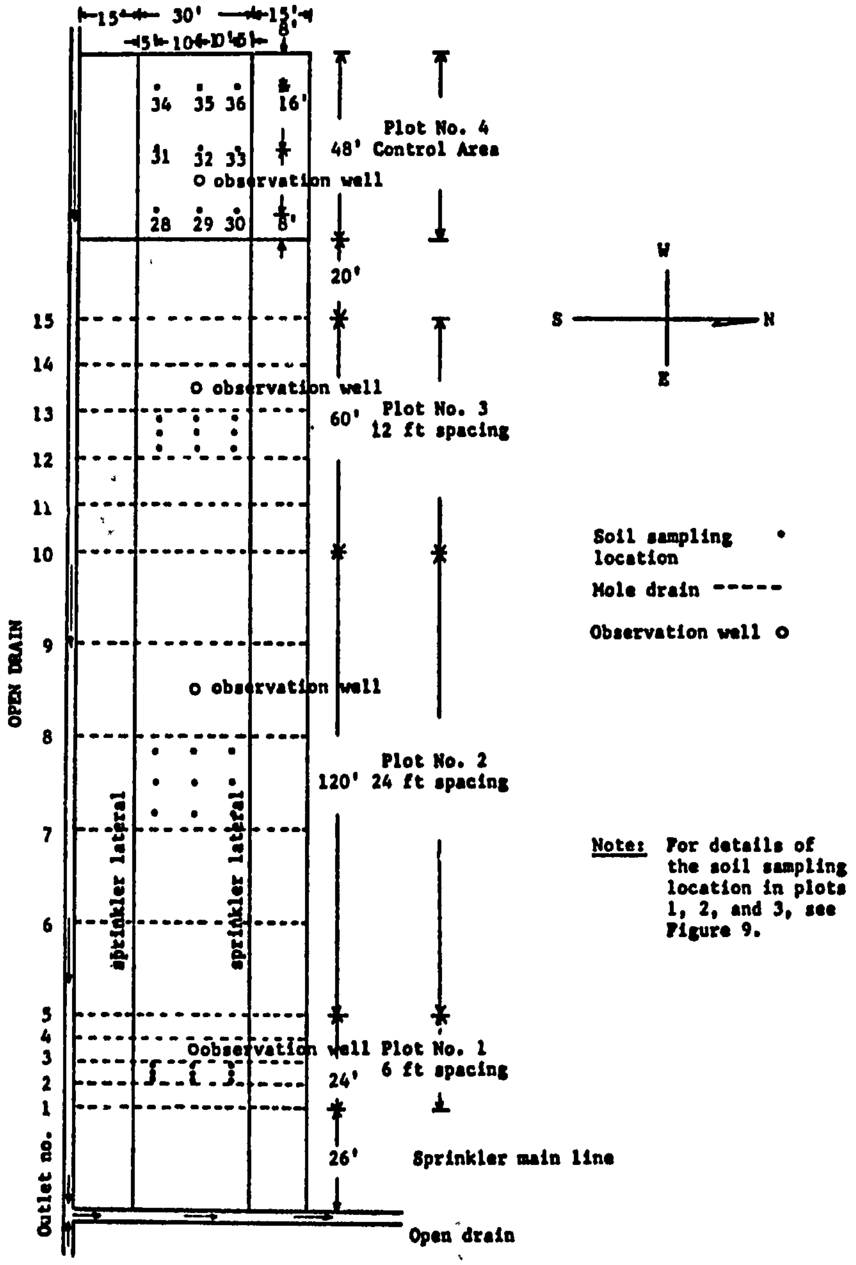
0-2'	dark gray silty clay loam
2-4'	light gray tight clay
4-8'	brown tight clay (some mottles)
8-9'	brown clay (some mottles)
9-11'	green silty loam to silty clay loam

water 11'

Layout of the Experimental Field

The experimental field, 298 feet long by 60 feet wide, was divided into 4 plots. Three of the plots were installed with single mole drains spaced at 6, 12, and 24 feet respectively. The last plot was left unmoled to be used as a control area. The mole drains were numerated from 1 to 15 as shown in Figure 8.

Four observation wells, one per plot were installed at the locations shown in Figure 8 to measure the water table elevation throughout the experiment. The wells were built by augering a hole 3 inch diameter to a depth of 6 feet. Since these were not permanent observation wells and they were built in a heavy textured soil, only a 2½ foot aluminum pipe with a 3-inch diameter was placed in the upper part of each hole. The top of the pipe was about one foot



Note: For details of the soil sampling location in plots 1, 2, and 3, see Figure 9.

Figure 8. Layout of the experimental plots

above ground surface and covered with a can to prevent entry of water from the sprinklers or entry of foreign material.

Two sprinkler lateral lines were laid 30 feet apart as shown in Figure 8. The spacing of the sprinklers was 30 feet. A 1 to 1½ foot levee was constructed around the field to prevent runoff water from adjacent areas to enter the experimental field. The source of water supply is an artesian aquifer located in the Utah State University Drainage Farm. The locations of soil sampling were numerated from 1 to 36 as shown in Figures 8 and 9.

Installation of Mole Drains

Initially the area was covered with native pasture which was removed by disking to a depth of 2-3 inches. Then, the surface was slightly smoothed to facilitate the construction of the mole drains at uniform depth along the mole lines.

The mole drains were built with the single mole plow shown in Figure 10 pulled by a D-4 crawler tractor at a speed of approximately 1½ miles per hour. At the time of the installation of the mole lines, the soil moisture content was about 35 percent by weight at the depth of the mole channels, and approximately 20 percent by weight at the depth of 6 inches from the soil surface. All mole drains were installed at approximately 18 inches depth. Each mole drain was provided with a 3 foot aluminum pipe outlet, 3 inches in diameter. The mole drain spacings were 6, 12, and 24 feet as shown in Figure 8.

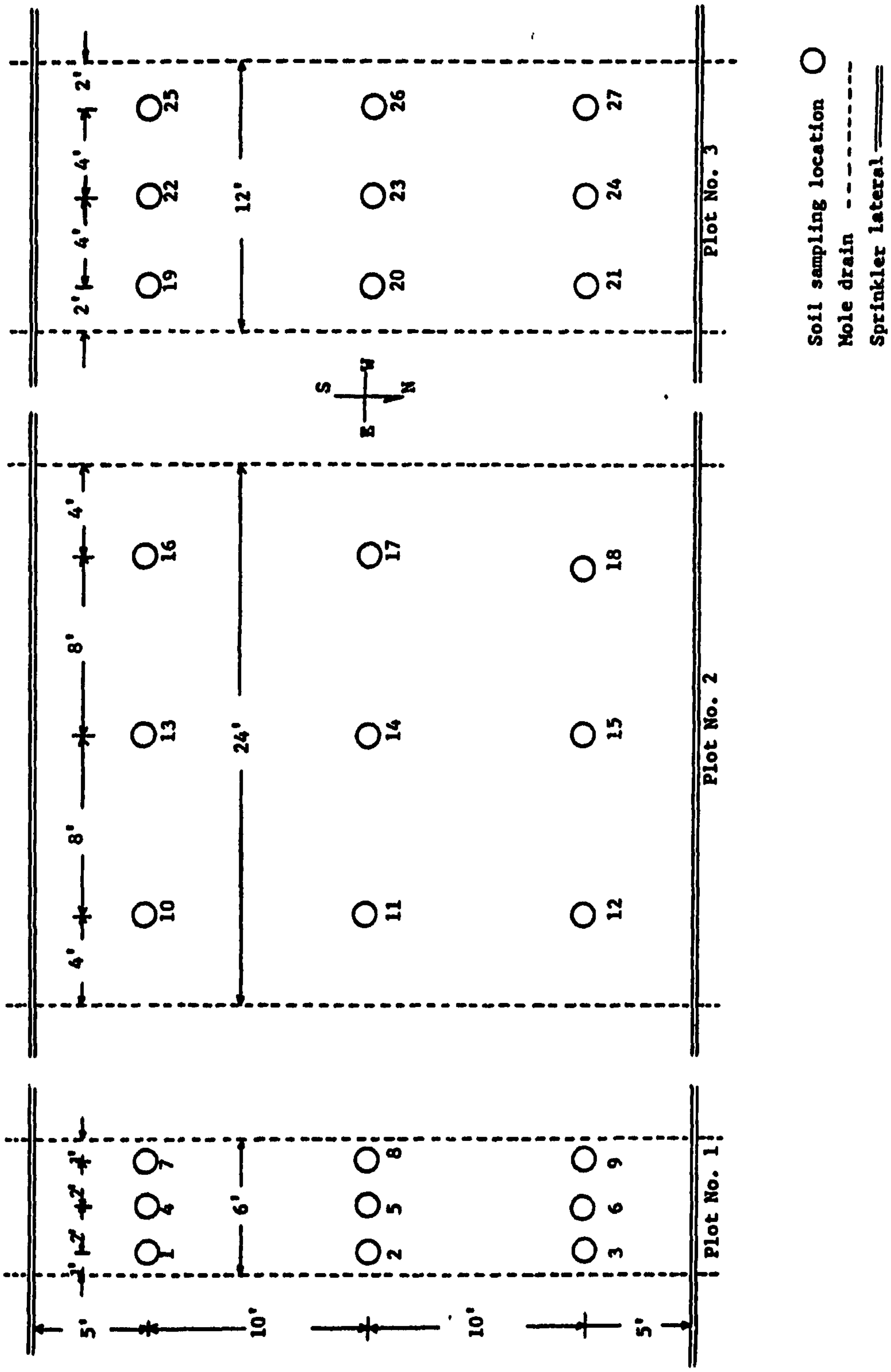


Figure 9. Soil sampling locations

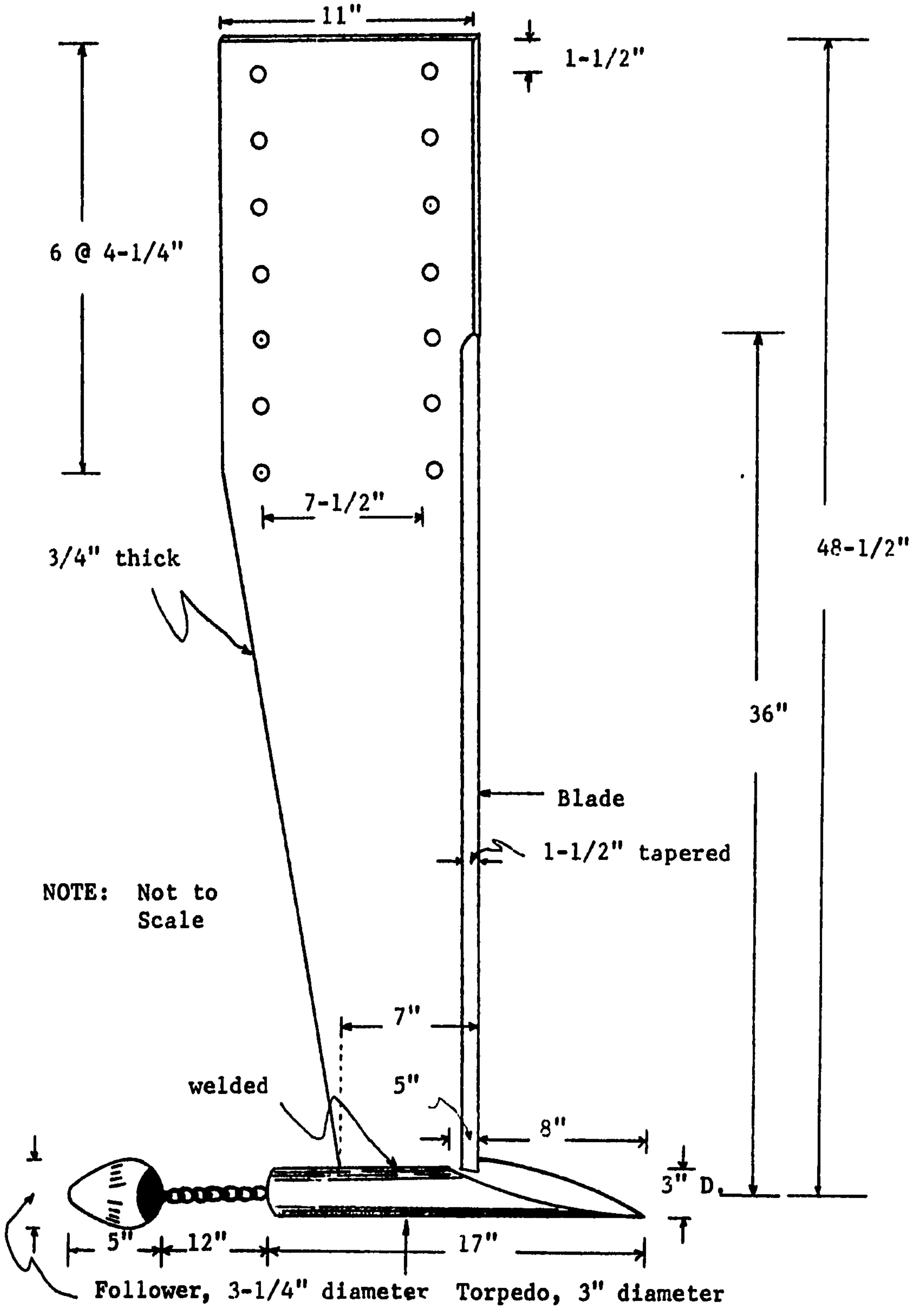


Figure 10. Single mole plow used in the construction of the mole drains

After the mole installation was completed, a disking operation wad made in an attempt to close the slits left by the blade of the mole plow. This practice was made to prevent the possible erosion caused by water entering the mole drains directly through the slits.

Methods of Procedure

Soil samples

Altogether 288 soil samples were taken for EC determinations; half of them before irrigation and the other half after irrigation. These soil samples were taken from 4 depths at each location; from surface, 0 to 6, 6 to 12, and 12 to 18 inches. The samples were also used for the determination of the soluble salts in the soil and other properties. In order to reduce the number of samples for the soluble salt determinations, composite samples for each depth in each experimental plot were prepared by mixing an equal amount of soil from 9 samples taken at the same depth. With this arrangement, there were 4 composite samples for each plot. The total number of composite samples was 32 for both before and after irrigation. The laboratory analysis for EC and soluble salts was based on the standard procedures described in the Handbook 60 of the U.S. Department of Agriculture (U.S. Salinity Laboratory Staff, 1954).

Soil characteristics

Some physical properties of the soil in the experimental field were determined prior to the initiation of the experiment, namely, texture, hydraulic conductivity and infiltration rate.

The results of the soil texture determinations from samples taken at different depths are shown in Table 5.

Table 5. Texture of soil in the experimental field

Plot No.	Depth (inches)	Texture
1	Surface	SiCL - Silty clay loam
	0-6	SiCL - Silty clay loam
	6-12	C - Clay
	12-18	C - Clay
2	Surface	SiCL - Silty clay loam
	0-6	C - Clay
	6-12	C - Clay
	12-18	C - Clay
3	Surface	SiCL - Silty clay loam
	0-6	SiCL - Silty clay loam
	6-12	C - Clay
	12-18	C - Clay
4	Surface	C - Clay
	0-6	C - Clay
	6-12	C - Clay
	12-18	C - Clay

A constant head permeameter was used to make laboratory permeability measurements for undisturbed samples taken at depths of 6, 12, and 18 inches. The hydraulic conductivity for each layer of soil was calculated from the equation

$$K = \frac{VL}{t\ AH}$$

in which K is the hydraulic conductivity, V is the volume of water collected in time t, A is the cross-sectional area of the permeameter, L is the length of the soil sample, and H is the difference of hydraulic head across the soil samples (Figure 11). The results of the hydraulic conductivity measurements are shown in Appendix A.

The infiltration rate was determined by using cylinder infiltrometers. Despite the fact that the infiltration rate varied from place to place, the infiltration characteristics shown in Figures 12 and 13 may be considered as being representative of the entire field. The soil moisture content (by weight) was 35 percent at the start of the infiltration measurements.

The accumulated infiltration was expressed by the equation:

$$D = 0.1\ T^{0.648}$$

where D is the accumulated infiltration in cm and T is the time in minutes. (See Figure 12)

The derivative of D with respect to T multiplied by 60 yields the instantaneous infiltration rate I, in cm/hr.

$$I = 3.89\ T^{-0.352}$$

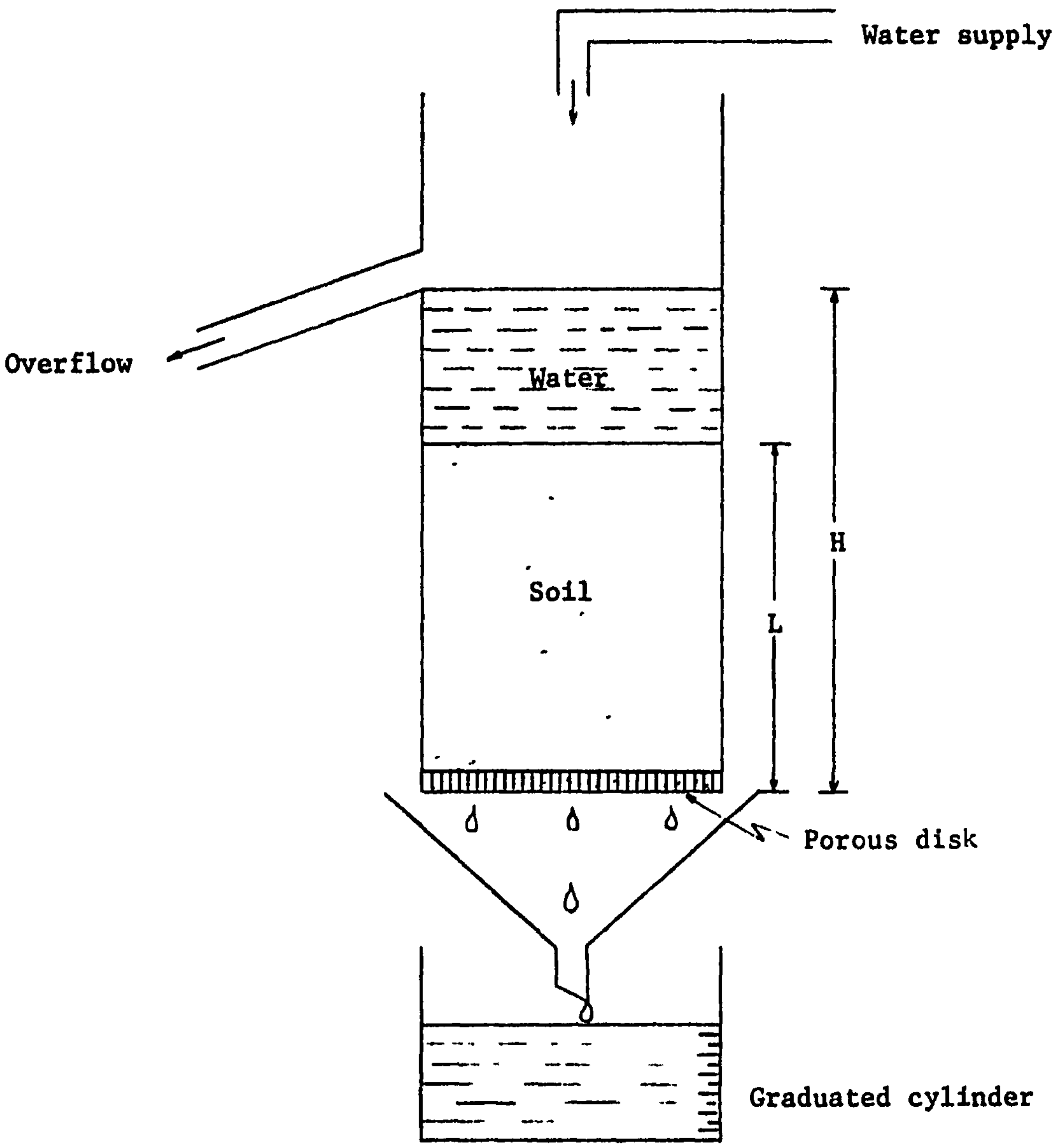


Figure 11. Constant head permeameter

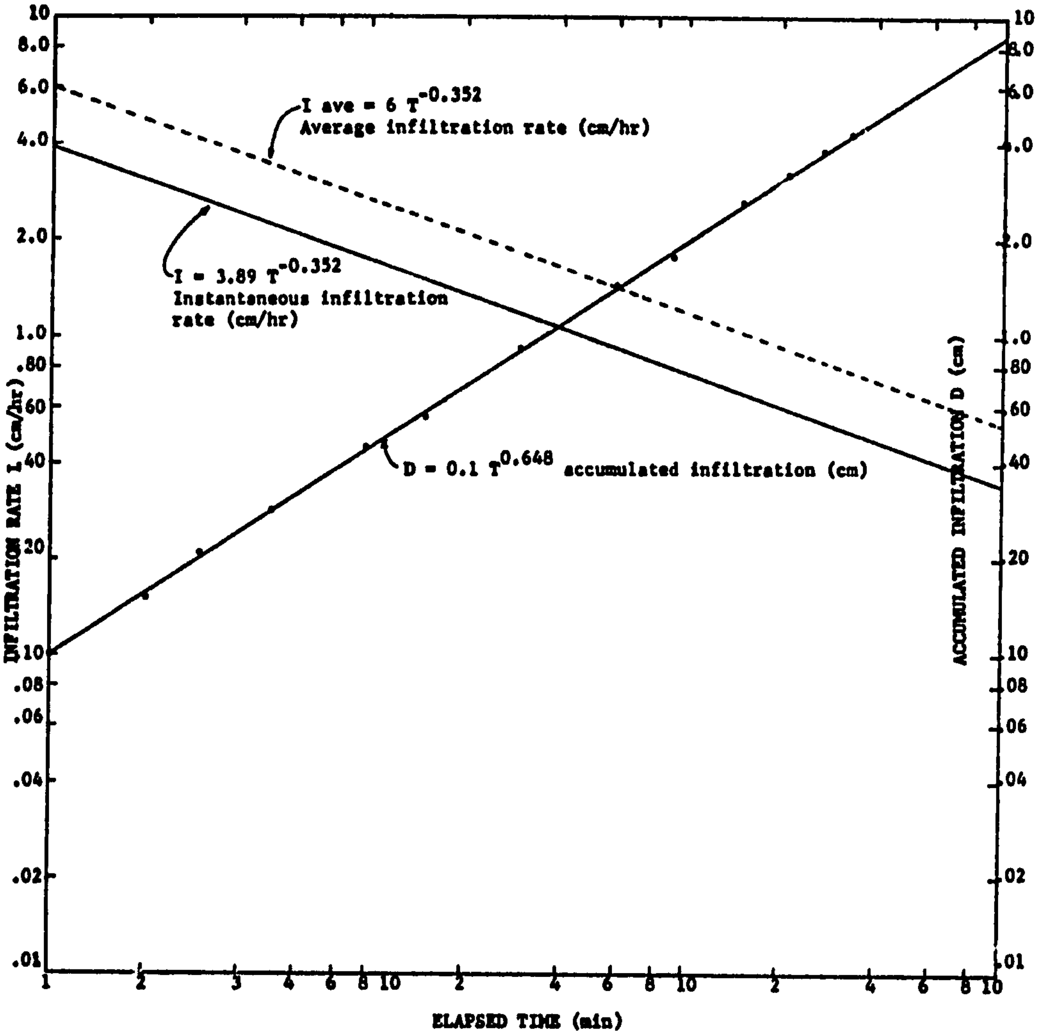


Figure 12. Infiltration characteristics of the soil in the experimental field. (USU Drainage Farm, 1973)

The values of I are plotted in Figure 13 to show the basic infiltration rate which in this case was 0.59 cm/hr. Since ponding of water on the experimental area was undesirable, the application rate in the experiment was limited to this basic infiltration rate. The application rate actually used was found to be less than 0.59 cm/hr (Appendix B).

Irrigation application

The total amount of leaching water was 24.41 cm, 6.4 cm of which was contributed by five rainfalls and 18.01 cm from 14 irrigations.

The water application rate was kept at about the basic intake rate to avoid ponding, with an average of 0.47 cm/hr, whereas the time per irrigation varied from 2.83 to 3 hours. The irrigation interval was 48 hours (Appendix B).

The soil moisture content was checked at depths of 6, 12, and 18 inches before each irrigation and found to vary only slightly from the initial values for any two consecutive irrigations; however, it increased with the number of irrigations which was probably due to a decrease in the soil permeability as the total water applied was increasing. Appendix C illustrates the average values (from 0 to 18 inches) of the soil moisture content determinations.

Readings of the water table elevations in the observation wells were made at 3, 12, 24, and 48 hours after the initiation of every irrigation. Since no significant variations of the water table elevations were found, an assumption was made in that there was no influence of the water table in the leaching process. Besides the water table was about 3.5 feet below the mole drains, throughout the experiment.

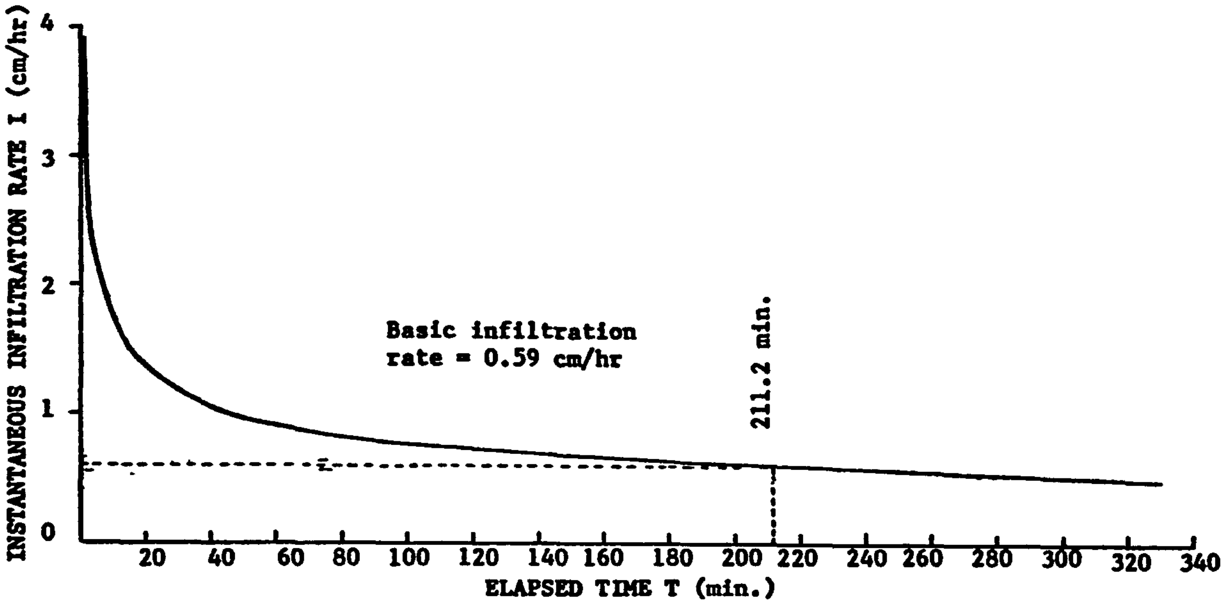


Figure 13. Instantaneous infiltration rate (cm/hr) of the soil in the experimental field. (USU Drainage Farm, 1973)

Electrical conductivity of drainage water

Determinations of the EC of the drainage water at the outlets of the three most central drains of each plot were made after each irrigation. Appendix E shows the EC of the drainage water measured at the outlets indicated 3 hours after each irrigation was completed. The EC values from this appendix are plotted as a function of the cumulative depth of water applied including precipitation as shown in Figure 14, 15, and 16. The EC reduces appreciably with water application in the 6 foot spacing plot, whereas no significant change in EC with the same water application in the 24 and 12 foot spacing plots was observed.

Figure 14 shows that in the 6 foot spacing plot the EC decreases with the depth of water applied until the application depth reaches 20 cm where the EC ceases to decrease. This is an indication that any more water added would be wasteful for it will not reduce effectively the EC of the soil.

Method of data analysis

The data obtained from the electrical conductivity determinations were statistically analyzed by making test comparisons between the leaching effects of the three different mole spacings versus the control plot. To determine the leaching effectiveness for each mole spacing, the following considerations were taken into account as the basis for the statistical analysis:

1. Electrical conductivity of the irrigation water.

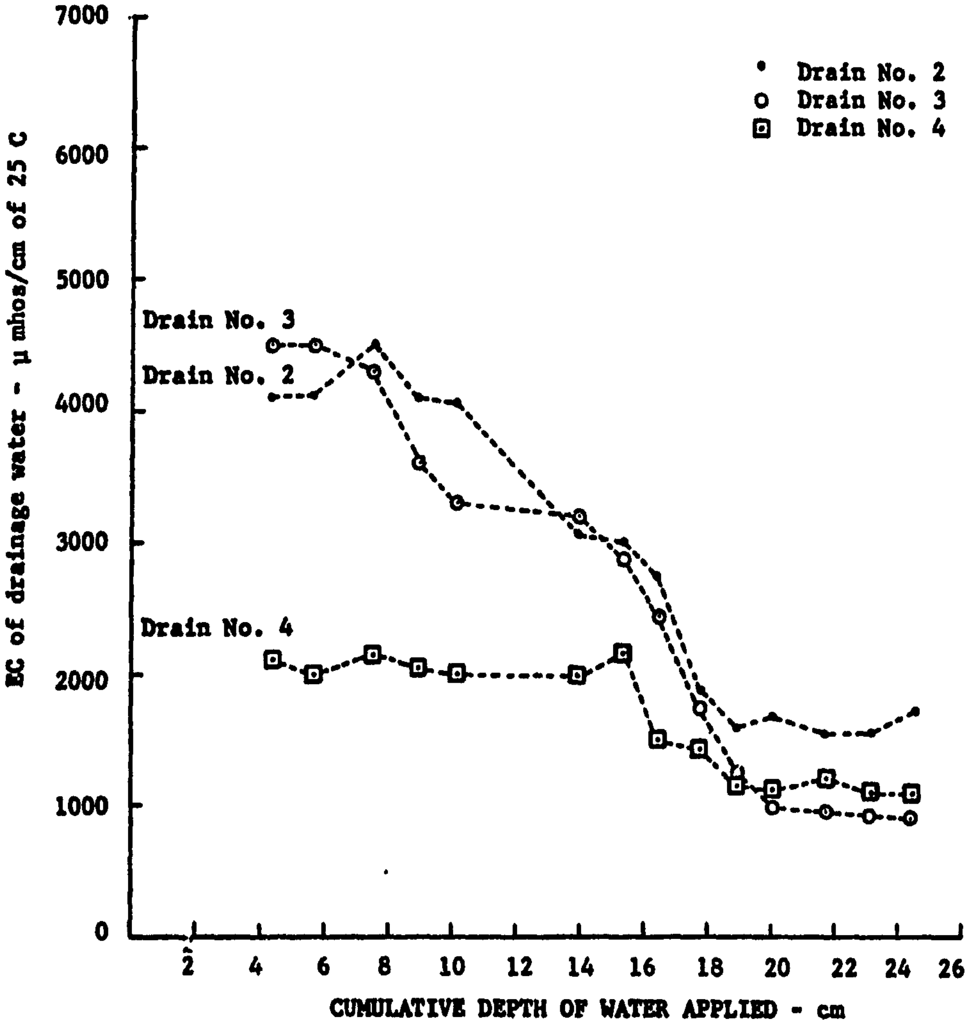


Figure 14. Electrical conductivity of drainage water in µmhos/cm. Plot No. 1. Drain spacing 6 ft. (USU Drainage Farm, 1973)

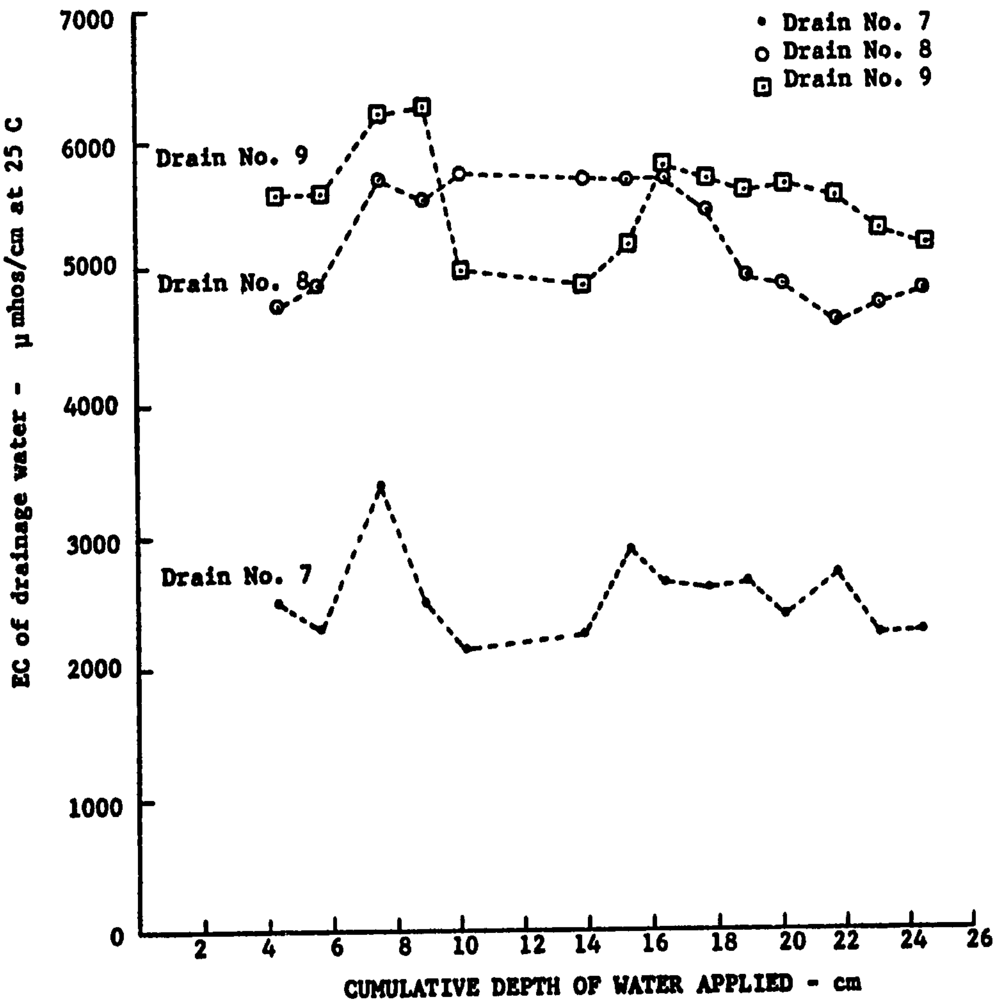


Figure 15. Electrical conductivity of drainage water in μ mhos/cm. Plot No.2. Drain spacing 24 ft. (USU Drainage Farm, 1973)

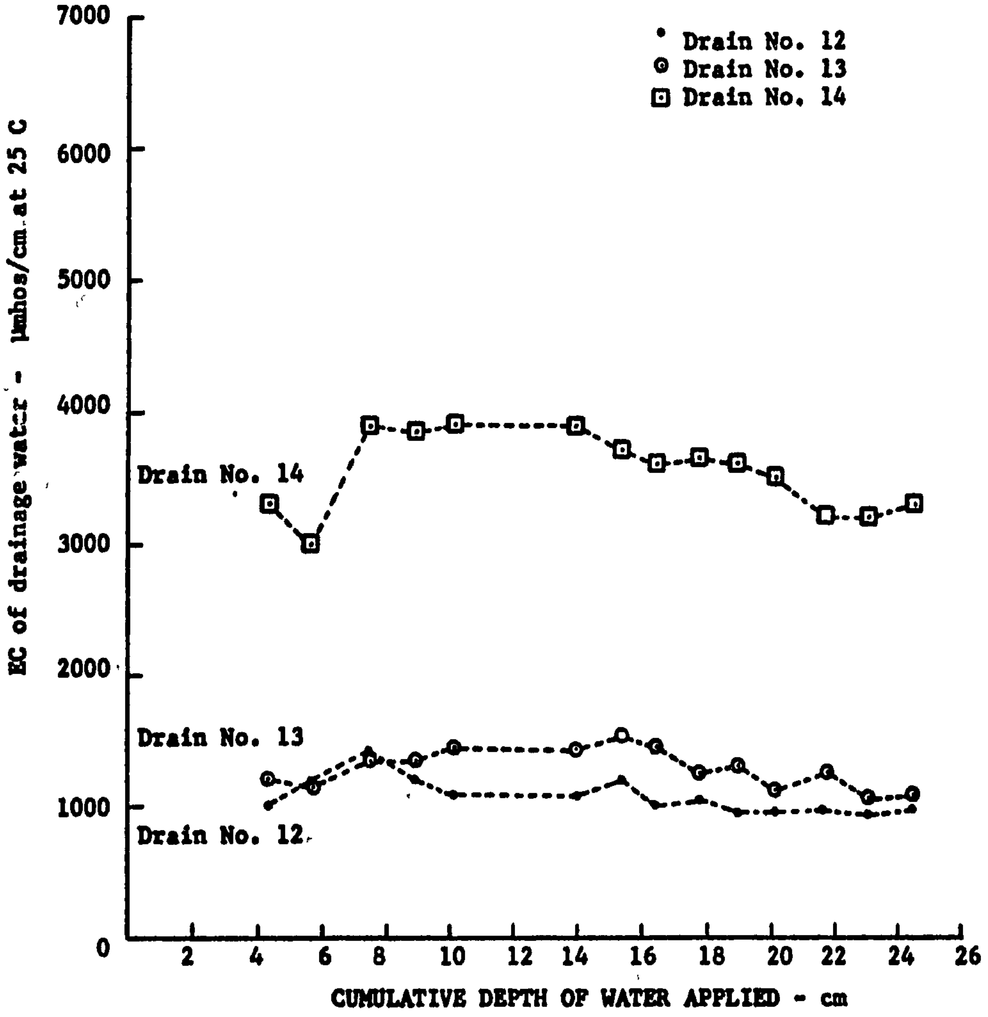


Figure 16. Electrical conductivity of drainage water in μmhos/cm. Plot No. 3. Drain spacing 12 ft. (USU Drainage Farm, 1973)

2. Electrical conductivity of the 1:1 extract of soil samples taken before irrigation.

3. Electrical conductivity of the 1:1 extract of soil samples taken after irrigation.

4. The water table was assumed not to be affecting the leaching process.

5. The water application rate and the depth of water applied over the entire field were considered to be constants throughout the experiment.

6. The infiltration rate, the hydraulic conductivity, and the texture of the soil, were assumed to be the same for the 4 plots.

7. The evaporation losses were considered negligible.

8. The diameter and the shape of the mole drains were relatively constant along the mole lines.

9. The electrical conductivity and soluble salts of the irrigation water did not change during the experiment.

10. The experimental field was relatively flat.

11. In the experiment, four different treatments were tested, namely, the three mole spacings and the control plot with no mole drains. The treatments were assigned at random to the four experimental plots.

The results of the soluble salts determinations were considered as a criteria to identify the type of saline soil on which the experiment was performed, and to observe the changes in concentration of the different soluble salts in the soil, as affected by the leaching process.

RESULTS AND DISCUSSION

Soluble Salts in Soil and Water

The soluble salts concentrations of the soil extract and the irrigation water are shown in Appendix D.

The pH value of the soil was slightly less than 8.5 whereas the electrical conductivity of the 1:1 extract of the soil was less than 4 millimhos per centimeter.

The quality of the irrigation water used in this experiment was classified in relation to the salinity, sodium, and chloride hazards as shown in Table 6. The classification is based on the criteria given by Taylor and Ashcroft (1972).

Table 6. Tentative classification of the irrigation water according to salinity, sodium, and chloride hazards.

Item	Index	Unit of Measurement	Total	Limit	Type of Hazard
Salinity	A	EC mmhos/cm at 25° C	0.495.	<0.75	Low
Sodium	C_2	EC µmhos/cm at 25° C	495.	<750	Low
	S_1	SAR	0.82	<10	
Chloride	1	meq/1	0	<2	generally safe even with sensitive plants

Electrical Conductivity of Solutions

Determinations of electrical conductivity were made for the irrigation water, drainage water, and 1:1 extract of soil samples taken before and after irrigation.

The average EC of the irrigation water used in this experiment was about 495 µmhos/cm which is equivalent to 309.38 parts per million (ppm). The water may be classified as Class I irrigation water, suitable for most plants under most conditions.

Since the total amount of irrigation water applied was 18.01 centimeters and salt in tons per acre-foot of water is equivalent to 0.00136 x ppm, the total amount of salt added to the soil by the irrigation water for the area between the two laterals was 5.1×10^{-2} tons or 5.7×10^{-6} tons of salt per square foot of soil.

The electrical conductivity of the drainage water is shown in Appendix E as mentioned before.

The EC of 1:1 extract of the soil samples taken before and after the irrigation are reported in Appendix F. The results are also plotted as shown in Figures 17, 18, 19 and 20 to observe the reduction in EC of each sample. Even though the leaching effects may be observed from these figures, no conclusions for leaching effectiveness will be drawn from these graphical representations. The discussion and conclusions will be made after the statistical analysis of variance and covariance, presented in the next section.

The 1:1 extract for the various soil samples was prepared by mixing 100 g of soil with 100 g of water including the soil

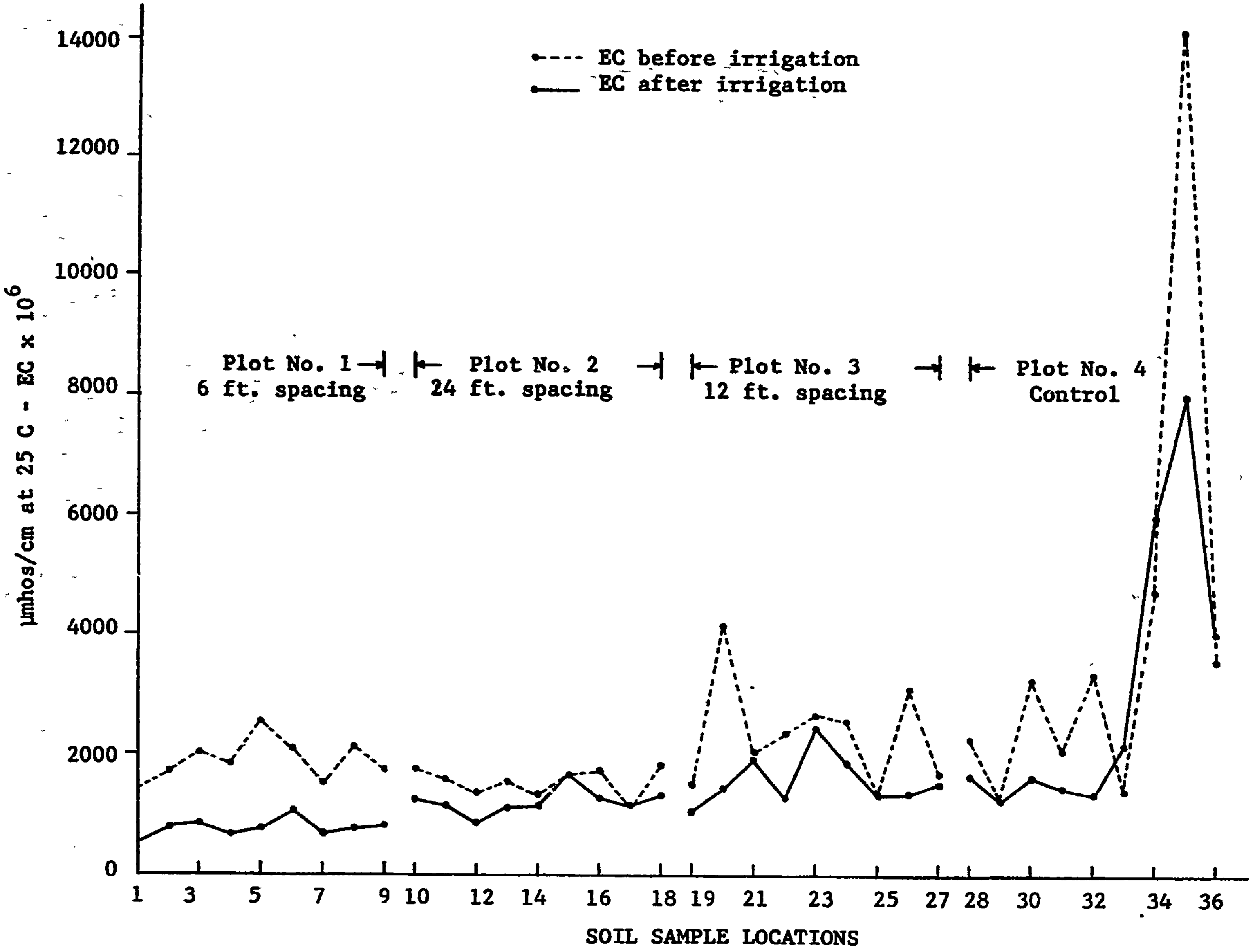


Figure 17. Electrical conductivity of 1:1 extract of soil samples from surface, before and after irrigation (USU Drainage Farm, 1973)

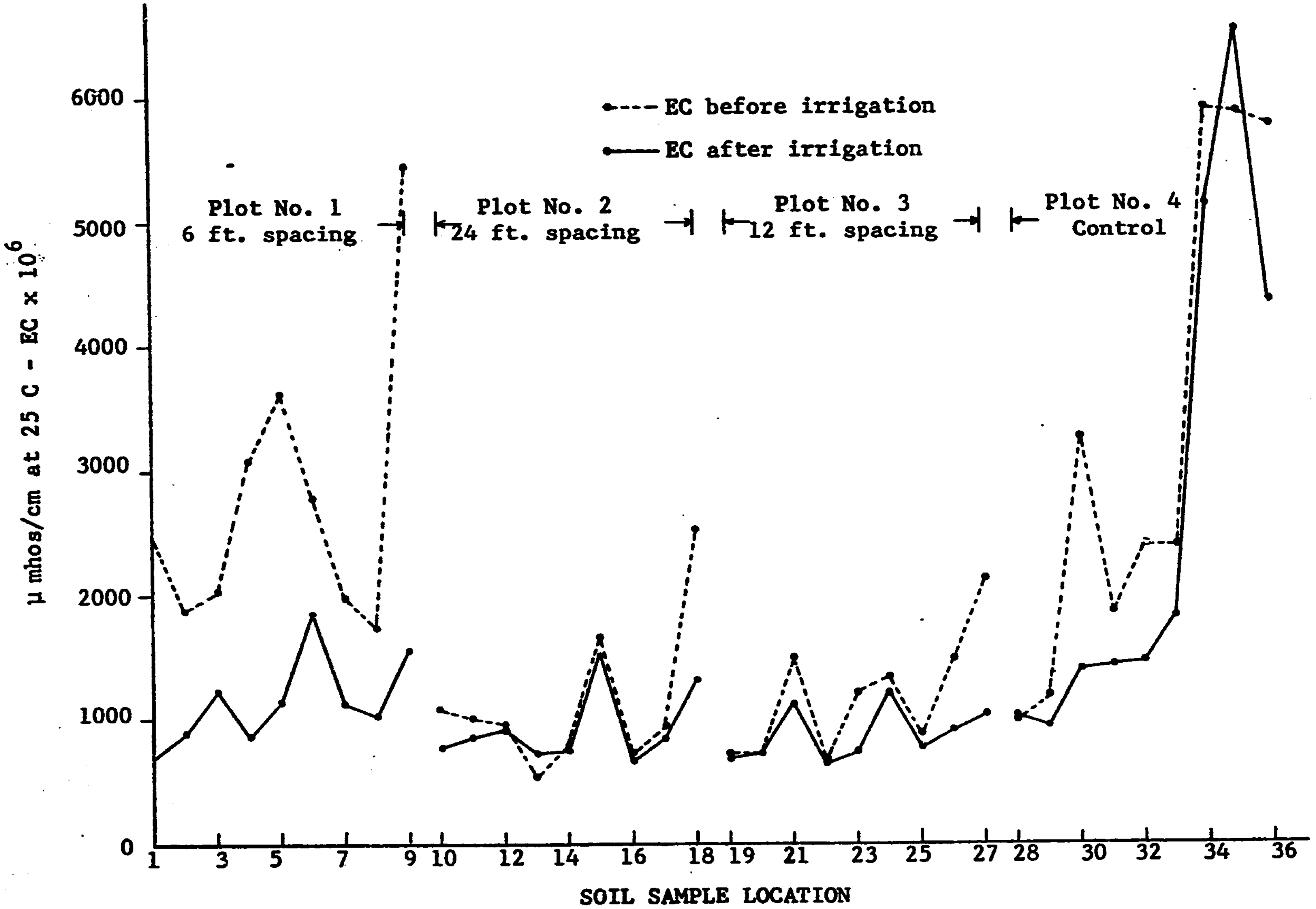


Figure 18. Electrical conductivity of 1:1 extract of soil samples taken from 0-6 inch depth, before and after irrigation (USU Drainage Farm, 1973)

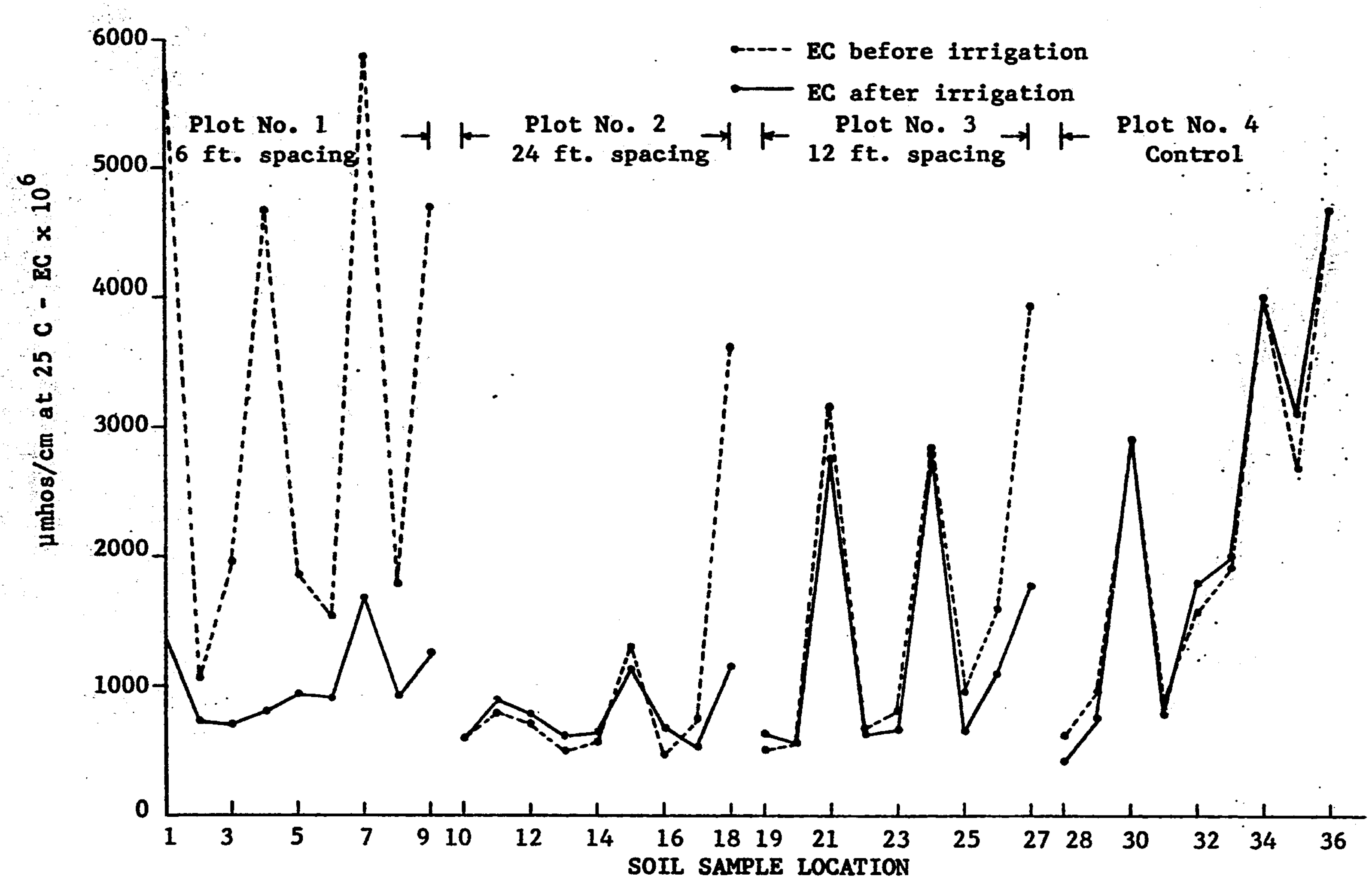


Figure 19. Electrical conductivity of 1:1 extract of soil samples from 6-12 inch depth, before and after irrigation (USU Drainage Farm, 1973)

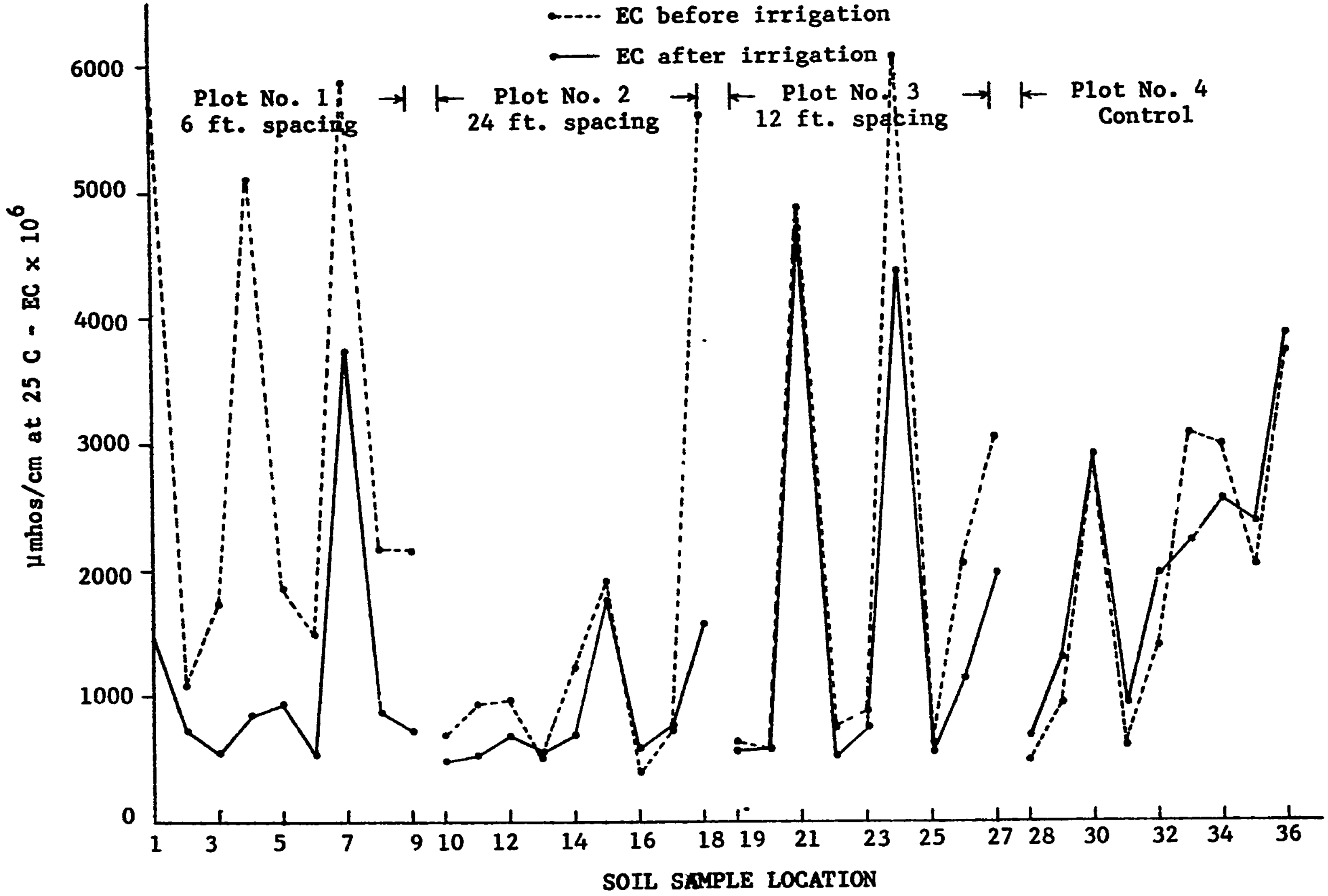


Figure 20. Electrical conductivity of 1:1 extract of soil samples from 12-18 inch depth, before and after irrigation (USU Drainage Farm, 1973)

moisture content by weight of the samples. To convert the EC of the saturation extracts into tons of salt per acre, the soil density was taken into consideration. The bulk densities of the soil at the various depths are presented in Table 7.

Table 7. Bulk density of the soil at various depths

Depth (in)	Bulk density (g/cm^3)
0-6	1.30
6-12	1.26
12-18	1.23

According to the above considerations, the following formula was applied to convert the EC of the soil extracts into ppm.

$$ppm = C_1 \times EC$$

where,

ppm = parts per million for a particular layer of soil

C_1 = conversion factor to express EC in ppm

EC = electrical conductivity of 1:1 extract of soil in μmhos/cm

In this study C_1 is equal to 0.625 (Israelsen and Hansen, 1962).

To compute the salt concentration in tons of salt per acre at each location (Tss), the following equation applies:

$$Tss = C_2 \times \overline{ppm} \times Ds \times bd$$

where,

C_2 = factor to convert ppm into tons of salt per acre foot of soil

$\overline{ppm}$ = average ppm from 0 to 18 inches of soil for each location of sampling

Ds = depth of the soil in feet

bd = bulk density of the soil in g/cm^3

In this study, the EC ranges between 100 and 5000 μmhos/cm and therefore C_2 is equal to 0.00136 (Israelsen and Hansen, 1962). The depth of the soil Ds, is equal to 1.5 feet.

The second part of Appendix F reports the Tss values for the soil before and after irrigation, and the total reduction of salt after irrigation was completed. The total reduction of salt (TRS) was estimated as follows:

$$TRS = Tssb - Tssa + Tsi$$

where,

Tssb and Tssa are the salt concentration of the soil in tons of salt per acre, before and after irrigation respectively, and

Tsi is the amount of salt added by the irrigation water, in tons of salt per acre.

To calculate Tsi the following equation was applied:

$$Tsi = C_1 \times C_2 \times EC \times Di$$

where,

C_1, C_2 remain as expressed previously,

EC is the electrical conductivity of the irrigation water in μmhos/cm.

Di is the total depth of irrigation in feet.

Appendix G reports the average total reduction of salt at the various depths for each plot. In making this computation an assumption was made that the amount of salt added by the irrigation water was uniformly distributed in the 18 inches of soil. Therefore, the Tsi value was divided by 3 which corresponds to the number of layers of soil in this study.

Statistical Analysis

Analysis of variance

The design for this experiment is the commonly known as completely randomized design, since the treatments were assigned completely at random to the experimental units (Ostle, 1972).

Four treatments were tested in this experiment, i.e., plots with 6, 12, and 24 foot mole drain spacings, and the control plot with no mole drains installed.

The soil sampling locations were considered as the experimental units within treatments and they were nine for each treatment. For the purpose of this analysis, the total reduction of salt in tons per acre at each soil sampling location is the observation per experimental unit. The total reduction of salt for each experimental unit is reported in Appendix F.

In other words, in this completely randomized design, ni experimental units were subjected to the ith treatment (i = 1, . . ., t) and there was only one observation per experimental unit. The data obtained from the experiment which will be used in the statistical analysis are reported in Table 8.

Table 8. Total reduction in salt in tons per acre for the four treatments tested

	Treatment No. 1	 2	 3	 4
	Drain spacing (ft.) 6	 12	 24	 Control
	5.881	.233	.529	.237
	1.166	.254	.485	.322
	2.004	.756	.385	1.277
	5.794	.410	.056	.363
	2.608	.594	.526	.371
	1.614	1.225	.476	.954
	4.098	.477	.075	.920
	1.683	1.314	.384	- .521
	4.991	2.553	4.343	.971
Total	29.839	7.816	7.259	4.894

The analysis of variance reported in Table 9 was made according to standard procedures described in Ostle (1972).

Eight hypotheses were tested by means of the cumulative F distribution technique. These hypotheses are:

1. $Ho = \mu_1 = \mu_2 = \mu_3 = \mu_4$
2. $Ho = \mu_1 = \mu_2$
3. $Ho = \mu_1 = \mu_3$

Table 9. Analysis of variance for the experimental data of Table 8

SV	d. f.		SS	MS	Calculated F *	F TAB **	Test Result
Treatments	3		45.321	15.107	9.740	2.904	Reject
6 vs. 12		1	26.945	26.945	17.373	4.152	Reject
6 vs. 24		1	28.325	28.325	18.262	4.152	Reject
6 vs. control		1	34.570	34.570	22.289	4.152	Reject
12 vs. 24		1	.017	.017	.011	4.152	Fail to reject
12 vs. control		1	.474	.474	.306	4.152	Fail to reject
24 vs. control		1	.311	.311	.201	4.152	Fail to reject
6 & 12 & 24 vs. control		1	8.463	8.463	5.456	4.152	Reject
Exp. Error	32		49.641	1.551			
Total	35		94.962				

* Calculated F = MS/MSE

** Tabular F for $\alpha = .05$ and $(V_1, 32)$, where V_1 corresponds to the degrees of freedom of each SV, and 32 are the degrees of freedom of the experimental error

4. $H_o = \mu_1 = \mu_4$
5. $H_o = \mu_2 = \mu_3$
6. $H_o = \mu_2 = \mu_4$
7. $H_o = \mu_3 = \mu_4$
8. $H_o = \dfrac{\mu_1 + \mu_2 + \mu_3}{3} = \mu_4$

where μ is the observation mean of each treatment and the subscripts 1, 2, 3, and 4, designate the treatments using 6, 12, and 24 foot mole drain spacing and control plot respectively. The tabular value of F in each case corresponds to an α-level of 0.05 for the degrees of freedom (df) of each source of variation (SV) and the degrees of freedom of the experimental error.

The result of the test of hypothesis is shown in Table 9. Hypotheses numbers 1, 2, 3, 4, and 8 were rejected because the calculated F values were greater than those from the cumulative F distribution table (Ostle, 1972). The analysis indicates that there is not enough evidence to reject the hypotheses numbers 5, 6, and 7. The discussion of these results is given in the last section of this chapter.

Covariance analysis

The analysis of covariance is made to determine whether the differences in the values of total reduction of salt after irrigation, were resulted from the mole drain spacing or from the initial salt concentration in the soil. Assigning the initial values of salt concentration as X and the average total reduction of salt after irrigation as Y, it is possible to adjust the Y-values according to the associated X-values and then analyze and interpret the experimental data.

The mathematical model associated with the completely randomized design may be expressed as:

$$Y_{ij} = \mu + \Gamma_i + \beta(X_{ij} - \bar{X}) + \epsilon_{ij}$$

where, $i = 1, \ldots, k$ = treatment number, and $j = 1, \ldots, n$ = experimental unit number; μ is the true mean effect; Γi is the true effect of the ith treatment, β is the regression coefficient; $\bar{X}$ is the average of X values; and Θ_{ij} is the true effect of the jth experimental unit subjected to the ith treatment.

Table 10 shows the experimental data used in the analysis of covariance and the results of this analysis are reported in Table 11. The computations were made according to standard procedures described in Ostle, 1972.

To test the hypotheses of no differences among the true effects of the four treatments (6, 12, and 24 foot mole drain spacings and control plot) after adjusting for the effect of the initial salt concentration differences from plot to plot, F calculated is compared to the tabular value of F. By the method of analysis of covariance F calculated was found to be 12.100. The tabular value of F is 2.912 (Ostle, 1972) with degrees of freedom $V_1 = 3$ and $V_2 = 31$, and α-level of 0.05. Since the calculated F is greater than the tabular F, the hypothesis is rejected. This indicates that the results of leaching in this experiment are influenced not only by the mole drain spacing but also by the different levels of initial salt concentrations of the four plots.

Further discussion of the results of covariance analysis is given in the next section.

Table 10. Initial salt concentrations (X) of the soil samples and total reductions of salt (Y) after irrigation in tons per acre

	Treatment							
	1 6 ft spacing		2 12 ft spacing		3 24 ft spacing		4 Control plot	
	X	Y	X	Y	X	Y	X	Y
	7.526	5.881	1.010	.233	1.281	.529	1.130	.237
	2.168	1.166	1.011	.254	1.462	.485	1.669	.322
	3.093	2.004	5.063	.756	1.427	.385	4.875	1.277
	6.888	5.794	1.131	.410	.824	.056	1.818	.363
	3.979	2.608	1.568	.594	1.399	.526	2.923	.371
	3.154	1.614	5.423	1.225	2.625	.476	3.952	.954
	7.311	4.098	1.303	.477	.858	.075	6.990	.920
	2.946	1.683	2.747	1.314	1.301	.384	5.741	-.521
	6.660	4.991	4.873	2.553	6.265	4.343	7.642	.971
Total	43.725	29.839	24.129	7.816	17.442	7.259	36.740	4.894

Table 11. Analysis of covariance for the experimental data of Table 10.

Source of Variation	Degrees of Freedom	Sum of Squares and Products			Deviations About Regression		
		$\sum x^2$	$\sum xy$	$\sum y^2$	$\sum y^2 - \frac{(\sum xy)^2}{\sum x^2}$	Degrees of Freedom	Mean Square
Among treatments . . .	3	47.215	31.125	45.321	. . . . .	. . . . .	. . . .
Among soil samples treated alike . . .	32	136.063	60.729	49.641	22.536	31	.727
Total	35	183.278	91.854	94.962	48.927	34	. . . .
Difference for testing among adjusted treatment means					26.391	3	8.797

Discussion of Results

The graphical representation shown in Figures 17, 18, 19, and 20, indicates that leaching is more effective in the moled plots than in the unmoled control plot. The figures also indicate different levels of effectiveness of leaching as affected by different mole drain spacings. However, in order to interpret the data statistically, the analysis of variance was made to test whether there was a significant difference in leaching effectiveness between the moled and unmoled areas, and to test if the mole drain spacing influences the leaching effectiveness. The results of the analysis of variance, reported in Table 8, show that:

1. There are differences in leaching effectiveness from one treatment to another (test of hypothesis number 1).

2. The 6-foot mole drain spacing is the most effective of the four treatments in leaching, as proved by the test of the hypothesis numbers 2, 3, and 4.

3. There is no significant difference in leaching effectiveness between the plots using 12 and 24-foot mole drain spacings, and the control plot (hypotheses 5, 6, and 7).

4. In the moled plots, regardless of mole spacing, leaching was more effective than in the unmoled plot (hypothesis 8).

Because the initial salt concentration was different from plot to plot, the covariance analysis was performed to determine whether the reduction of salt after irrigation was influenced by the initial salt concentration. Results of this analysis indicate that the leaching effectiveness as determined by the total reduction of salt after irrigation is affected by the level of initial salt concentration. Appendixes F and G and Figures 17, 18, 19, and 20, seem to support the above results for they show in general that the higher the initial salt concentration in the moled plots, the higher the reduction of salt after irrigation. Since the initial salt concentration was affecting the reduction of salt after irrigation, no conclusion could be made as to which mole drain spacing is the most effective in leaching. Nevertheless, because the results show more reduction in salt concentration in the moled plots, than in the unmoled plot, and the fact that the average initial salt concentration in the moled plots was lower than that of the unmoled, it can be concluded that leaching is more effective in the moled area.

SUMMARY AND CONCLUSIONS

An investigation was made to determine the effectiveness of mole drains in leaching heavy soils with sprinkler irrigation at an application rate of 0.47 cm/hr. Three mole drain spacings of 6, 12, and 24 feet and a control plot (unmoled) were used in this study. The effectiveness of leaching was determined by the total reduction of salt concentration in the soil measured in terms of electrical conductivity of the saturation extract of soil samples.

The results may be summarized as follows:

1. Leaching was more effective in the moled plots than in the unmoled plot.

2. The 6 feet mole drain spacing appeared to be most effective in leaching. However, this result is not conclusive because this plot exhibited higher initial salt concentration in the soil than the other moled plots and the influence of the level of initial salt concentration on the reduction of salts in the soil is not known.

3. No significant difference in leaching effects was found between the plots using 12 and 24 feet mole drain spacing and the unmoled plot.

In conducting this study one major problem was encountered; the non-uniformity of the salt concentration in the experimental area as indicated by the different levels of the initial salt concentration which varied from plot to plot as well as within a plot. Because a natural field with uniform salt distribution is difficult if not impossible to find, a laboratory study by means of a physical model may be used to overcome such a problem.

In reclaiming poorly drained lands (normally heavy soils) a drainage system is necessary to maintain a suitable salt condition and adequate salt balance in the soil. Mole drains in combination with a low application rate of water could provide a means for permanent land reclamation. The low cost of mole drains compared to that of tile drains allows for a closer drain spacing and furthermore, because leaching is effective with a low application rate, a more efficient use of water may be obtained. Under these conditions the land reclamation work may become economically feasible in many unproductive areas where the major problem appears to be the high initial investment demanded by the conventional techniques of land reclamation.

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APPENDIXES

Appendix A

Results of the Laboratory Hydraulic Conductivity Measurements

Table 12. Results of the laboratory hydraulic conductivity measurements

Plot No.	Depth of sample (inches)	Hydraulic conductivity (feet per day)
1	6	3.91
	12	3.14
	18	0.36
2	6	4.05
	12	3.44
	18	0.55
3	6	3.10
	12	2.91
	18	0.63
4	6	3.22
	12	2.53
	18	0.25

Appendix B

Irrigation and Precipitation During the Experiment

Table 13. Irrigation and precipitation during the experiment

Date	Precipitation		Irrigation				Total Water Applied (cm)
	No	Amount (cm)	No	App. rate (cm/hr)	Time of app. (hr)	Amount (cm)	
9-8-73	1	2.70					2.70
9-11-73	2	0.20					0.20
9-15-73			1	0.46	3.00	1.38	1.38
9-17-73			2	0.44	3.00	1.32	1.32
9-19-73			3	0.61	3.00	1.83	1.83
9-21-73	3	1.00					1.00
9-21-73			4	0.47	0.87	0.41	0.41
9-23-73			5	0.43	3.00	1.28	1.28
9-25-73	4	1.00					1.00
9-26-73	5	1.50					1.50
9-28-73			6	0.43	3.00	1.30	1.30
9-30-73			7	0.46	3.00	1.38	1.38
10-2-73			8	0.39	2.83	1.10	1.10
10-4-73			9	0.45	2.83	1.26	1.26
10-6-73			10	0.46	2.83	1.29	1.29
10-8-73			11	0.46	2.83	1.30	1.30
10-10-73			12	0.51	2.83	1.44	1.44
10-12-73			13	0.49	2.83	1.39	1.39
10-14-73			14	0.47	2.83	1.33	1.33
Total water applied = irrigation + precipitation							24.41
Average application rate				0.47 cm/hr			

Appendix C

Soil Moisture Content (by weight) Before Each Irrigation

Table 14. Soil moisture content (by weight) before each irrigation

Date	Plot No.	Irrigation No.	Soil moisture content by weight % *
9-15-73	1	1	34.72
	2		37.02
	3		39.74
	4		41.02
9-17-73	1	2	36.36
	2		37.43
	3		40.03
	4		40.75
9-19-73	1	3	37.36
	2		35.44
	3		39.61
	4		40.27
9-21-73		4	**
9-23-73	1	5	39.18
	2		40.04
	3		38.17
	4		41.29

* Average from 0 to 18 inches depth

**Not measured because of rain prior to the 5th irrigation

Table 14. Continued

Date	Plot No.	Irrigation No.	Soil moisture content by weight %
9-28-73	1	6	38.46
	2		39.55
	3		40.10
	4		41.15
9-30-73	1	7	39.11
	2		40.12
	3		39.98
	4		39.37
10-2-73	1	8	40.41
	2		41.18
	3		39.23
	4		40.49
10-4-73	1	9	41.78
	2		40.11
	3		41.99
	4		40.17
10-6-73	1	10	40.48
	2		39.09
	3		41.70
	4		41.77

Table 14. (Continued)

Date	Plot No.	Irrigation No.	Soil moisture content by weight %
10-8-73	1	11	42.03
	2		41.90
	3		39.99
	4		42.96
10-10-73	1	12	40.41
	2		41.98
	3		43.35
	4		44.04
10-12-73	1	13	41.07
	2		40.35
	3		42.93
	4		45.30
10-14-73	1	14	39.88
	2		42.36
	3		46.92
	4		48.50

Appendix D

Soluble Salts in the Soil and Water

Table 15. Soluble salts in the soil and water

a. Soil samples before irrigation						
Plot No.	Depth (inches)	pH	ECe mmhos/cm	SP Sat. %	Cl me/100g	SO_4 me/100g
1	Surface	8.3	1.6	70	.09	.72
	0-6	8.2	2.5	71	.23	.73
	6-12	8.5	3.9	74	.28	2.24
	12-18	8.4	4.2	73	.29	2.74
2	Surface	8.3	3.1	79	.46	1.07
	0-6	8.6	4.9	78	1.10	2.32
	6-12	8.6	4.9	78	1.11	2.54
	12-18	8.5	5.5	85	1.35	3.10
3	Surface	8.0	3.4	80	.70	1.14
	0-6	8.3	2.3	75	.51	.77
	6-12	8.4	1.3	82	.20	.39
	12-18	8.3	1.1	88	.66	.35
4	Surface	8.3	2.6	78	.37	.73
	0-6	8.4	3.0	79	.76	1.23
	6-12	8.4	3.2	69	.74	1.28
	12-18	8.4	3.3	70	.70	1.32

Table 15. (Continued)

Plot No.	Depth (inches)	pH	ECe mmhos/cm	SP Sat. %	Cl me/100g	SO_4 me/100g
			b. Soil samples after irrigation			
1	Surface	8.0	1.1	65	.030	.20
	0-6	8.1	1.6	66	.040	.23
	6-12	8.4	2.0	73	.100	1.04
	12-18	8.3	3.0	74	.160	1.78
2	Surface	8.1	1.9	79	.190	.58
	0-6	8.7	1.9	77	.120	.72
	6-12	8.7	2.6	83	.400	.45
	12-18	8.5	3.4	81	.650	2.01
3	Surface	7.9	1.9	79	.170	.40
	0-6	8.1	1.8	73	.290	.57
	6-12	8.1	2.2	74	.470	.96
	12-18	8.3	1.8	85	.640	.96
4	Surface	8.3	1.7	85	.220	.47
	0-6	8.4	2.3	80	.500	.86
	6-12	8.3	3.6	71	.700	1.51
	12-18	8.4	3.5	65	.720	1.56
			c. Irrigation water			
					me/l	me/l
		7.6	.495	--	0	6.5

Table 15. (Continued)

d. Soil samples before irrigation							
Plot No	Depth from (inches)	Ca me/100g	Mg me/100g	Na me/100g	K me/100g	Carb me/100g	Bicarb me/100g
1	Surface	.09	.18	.94	.09	0	.70
	0-6	.07	.26	1.54	.07	0	.62
	6-12	.07	.33	2.77	.06	0	.34
	12-18	.13	.45	2.92	.05	0	.25
2	Surface	.13	.20	2.27	.11	0	.78
	0-6	.06	.25	3.76	.06	0	.53
	6-12	.08	.34	3.76	.05	0	.35
	12-18	.10	.48	4.10	.06	0	.29
3	Surface	.28	.87	1.74	.18	0	.43
	0-6	.09	.28	1.24	.06	0	.32
	6-12	.07	.19	.78	.04	0	.28
	12-18	.06	.16	.69	.04	0	.30
4	Surface	.07	.17	1.70	.10	0	.55
	0-6	.06	.20	2.23	.06	0	.44
	6-12	.07	.25	2.01	.05	0	.24
	12-18	.09	.26	1.98	.04	0	.23

Table 15. (Continued)

e. Soil samples after irrigation							
Plot No	Depth from (inches)	Ca me/100g	Mg me/100g	Na me/100g	K me/100g	Carb me/100g	Bicarb me/100g
1	Surface	.08	.16	.45	.06	0	.39
	0-6	.05	.14	.86	.05	0	.42
	6-12	.07	.13	1.33	.04	0	.39
	12-18	.15	.28	1.96	.04	0	.35
2	Surface	.10	.17	1.03	.09	.04	.61
	0-6	.07	.06	1.51	.04	0	.70
	6-12	.04	.10	2.27	.04	0	.43
	12-18	.06	.24	2.96	.05	0	.30
3	Surface	.22	.55	.79	.11	0	.39
	0-6	.08	.29	.95	.06	0	.32
	6-12	.11	.36	1.22	.05	0	.25
	12-18	.13	.25	1.11	.05	0	.33
4	Surface	.07	.15	1.33	.10	0	.88
	0-6	.04	.13	1.63	.06	.05	.46
	6-12	.05	.25	2.28	.06	0	.34
	12-18	.07	.28	2.03	.05	0	.22
Irrigation water							
		me/l	me/l	me/l	me/l	me/l	me/l
		2.05	1.48	1.09	0.148	0	4.0

Appendix E

Electrical Conductivity of the Drainage Water From Experimental Plots

Table 16. Electrical conductivity of the drainage water from experimental plots

Cumulative water app. cm *	EC in µmhos/cm at 25° C								
	Plot No. 1 6 ft spacing			Plot No. 2 24 ft spacing			Plot No. 3 12 ft spacing		
	Drain No.			Drain No.			Drain No.		
	2	3	4	7	8	9	12	13	14
4.28	4100	4500	2100	2500	4750	5600	1000	1200	3300
5.60	4120	4500	2000	2300	4900	5600	1200	1150	3000
7.43	4500	4300	2150	3400	5700	6200	1430	1400	3900
8.84	4100	3600	2050	2500	5550	6250	1200	1350	3850
10.12	4050	3300	2000	2140	5750	5000	1090	1450	3900
13.92	3070	3200	1980	2250	5700	4900	1080	1420	3900
15.30	3000	2890	2160	2890	5700	5200	1190	1530	3700
16.40	2750	2450	1500	2650	5700	5800	1000	1430	3600
17.66	1870	1750	1400	2600	5450	5700	1050	1250	3650
18.95	1600	1250	1150	2650	4950	5600	950	1300	3600

Appendix F

Total Reduction in Salinity as Measured by the Electrical Conductivity and in Tons of Salt per Acre at the Various Depths and Locations in the Moled and Control Areas

Table 17. Total reduction in salinity as measured by the electrical conductivity and in tons of salt per acre at the various depths and locations in the moled and control areas

Part 1. Reduction in EC

Drain spacing (ft)	Sampling Location No.	Sample No.	Depth (cm)	µmhos/cm at 25° C EC x 10^6		
				Before irrigation	After irrigation	Total reduction
6	1	1	Surface	1463	535	928
		2	0-6	2478	695	1783
		3	6-12	5750	1391	4359
		4	12-18	5888	1464	4424
	2	5	Surface	1716	773	943
		6	0-6	1887	883	1004
		7	6-12	1059	722	337
		8	12-18	1067	719	348
	3	9	Surface	2022	845	1177
		10	0-6	2027	1222	805
		11	6-12	1978	704	1274
		12	12-18	1748	548	1200
	4	13	Surface	1812	647	1165
		14	0-6	3086	852	2234
		15	6-12	4680	799	3881
		16	12-18	5120	849	4271

Table 17. (Continued)

Drain spacing (ft)	Sampling Location No.	Sample No.	Depth (cm)	µmhos/cm at 25° C EC x 10^6 Before irrigation	After irrigation	Total reduction
	5	17	Surface	2560	796	1764
		18	0-6	3624	1132	2492
		19	6-12	1878	945	933
		20	12-18	1859	934	925
	6	21	Surface	2092	1090	1002
		22	0-6	2791	1852	939
		23	6-12	1542	911	631
		24	12-18	1504	533	971
	7	25	Surface	1504	680	824
		26	0-6	1984	1127	857
		27	6-12	5873	1676	4197
		28	12-18	5873	3715	2158
	8	29	Surface	2122	779	1343
		30	0-6	1744	1018	726
		31	6-12	1575	929	646
		32	12-18	2178	866	1312
	9	33	Surface	1728	807	921
		34	0-6	5462	1556	3906
		35	6-12	4688	1255	3433
		36	12-18	2165	739	1426

Table 17. (Continued)

Drain spacing (ft)	Sampling Location No.	Sample No.	Depth (cm)	µmhos/cm at 25° C EC x 10^6 Before irrigation	After irrigation	Total reduction
24	10	37	Surface	1769	1269	500
		38	0-6	1089	771	318
		39	6-12	602	594	8
		40	12-18	682	491	191
	11	41	Surface	1600	1136	464
		42	0-6	1000	849	151
		43	6-12	774	895	- 121
		44	12-18	945	531	414
	12	45	Surface	1361	843	518
		46	0-6	960	928	32
		47	6-12	723	784	- 61
		48	12-18	976	684	292
	13	49	Surface	1573	1114	459
		50	0-6	544	727	- 183
		51	6-12	484	606	- 122
		52	12-18	505	557	- 52
	14	53	Surface	1333	1132	201
		54	0-6	800	760	40
		55	6-12	566	637	- 71
		56	12-18	1250	690	560

Table 17. (Continued)

Drain spacing (ft)	Sampling Location No.	Sample No.	Depth (cm)	μmhos/cm at 25° C EC x 10^6		
				Before irrigation	After irrigation	Total reduction
24	15	57	Surface	1667	1644	23
		58	0-6	1667	1539	128
		59	6-12	1313	1128	185
		60	12-18	1914	1805	109
	16	61	Surface	1765	1266	499
		62	0-6	715	655	60
		63	6-12	475	670	- 195
		64	12-18	401	595	- 194
	17	65	Surface	1129	1123	6
		66	0-6	941	856	85
		67	6-12	743	533	210
		68	12-18	733	780	- 47
	18	69	Surface	1858	1326	532
		70	0-6	2527	1306	1221
		71	6-12	3610	1158	2452
		72	12-18	5616	1586	4030
12	19	73	Surface	1509	1042	467
		74	0-6	724	712	12
		75	6-12	505	624	119
		76	12-18	649	571	78

Table 17. (Continued)

Drain spacing (ft)	Sampling Location No.	Sample No.	Depth (cm)	µmhos/cm at 25° C EC x 10^6		
				Before irrigation	After irrigation	Total reduction
24	20	77	Surface	4156	1419	2737
		78	0-6	732	729	3
		79	6-12	556	553	3
		80	12-18	590	587	3
12	21	81	Surface	2024	1931	93
		82	0-6	1490	1129	361
		83	6-12	3156	2749	407
		84	12-18	4877	4706	171
	22	85	Surface	2333	1274	1059
		86	0-6	671	653	18
		87	6-12	671	622	49
		88	12-18	766	528	238
	23	89	Surface	2682	2417	265
		90	0-6	1206	745	461
		91	6-12	813	766	47
		92	12-18	894	766	128
	24	93	Surface	2555	1882	673
		94	0-6	1341	1214	127
		95	6-12	2824	2794	30
		96	12-18	6064	4361	1703

Table 17. (Continued)

Drain spacing (ft)	Sampling Location No.	Sample No.	Depth (cm)	µmhos/cm at 25° C EC x 10^6 Before irrigation	After irrigation	Total reduction
12	25	97	Surface	1383	1376	7
		98	0-6	865	778	87
		99	6-12	941	654	287
		100	12-18	613	565	48
	26	101	Surface	3119	1376	1743
		102	0-6	1490	909	581
		103	6-12	1578	1095	483
		104	12-18	2063	1137	926
	27	105	Surface	1686	1511	175
		106	0-6	2131	1037	1094
		107	6-12	3922	1788	2134
		108	12-18	3053	1987	1066
Control*	28	109	Surface	2259	1677	582
		110	0-6	991	1012	- 21
		111	6-12	606	416	190
		112	12-18	491	688	- 197
	29	113	Surface	1288	1229	59
		114	0-6	1193	925	268
		115	6-12	954	750	204
		116	12-18	954	1306	352

Table 17. (Continued)

Drain spacing (ft)	Sampling Location No.	Sample No.	Depth (cm)	µmhos/cm at 25° C EC x 10^6 Before irrigation	After irrigation	Total reduction
Control *	30	117	Surface	3265	1632	1633
		118	0-6	3265	1404	1861
		119	6-12	2902	2902	0
		120	12-18	2902	2902	0
	31	121	Surface	2089	1431	658
		122	0-6	1866	1439	427
		123	6-12	865	786	79
		124	12-18	619	933	- 314
	32	125	Surface	3353	1315	2038
		126	0-6	2424	1458	966
		127	6-12	1578	1797	- 219
		128	12-18	1412	1975	- 563
	33	129	Surface	1404	2175	- 771
		130	0-6	2394	1828	566
		131	6-12	1916	1983	- 67
		132	12-18	3066	2247	819
	34	133	Surface	4706	5992	-1286
		134	0-6	5922	5136	786
		135	6-12	4034	3995	39
		136	12-18	2980	2568	412

Table 17. (Continued)

Drain spacing (ft)	Sampling Location No.	Sample No.	Depth (cm)	µmhos/cm at 25° C EC x 10^6 Before irrigation	After irrigation	Total reduction
Control *	35	137	Surface	14118	8036	6082
		138	0-6	5877	6530	- 653
		139	6-12	2682	3107	- 425
		140	12-18	2024	2370	- 346
	36	141	Surface	3552	4018	- 466
		142	0-6	5788	4353	1435
		143	6-12	4666	4664	2
		144	12-18	3720	3859	- 139

* No mole drains installed

Table 17. (Continued)

Part 2. Total Reduction of Salt in Tons/Acre

Drain spacing (ft)	Sampling Location No.*	Tons of salt per acre* Before irrigation	After irrigation	Added by irrigation	Total reduction
(1)	(2)	(3)	(4)	(5)	(6)
6	1	7.526	1.894	0.249	5.881
	2	2.168	1.251		1.166
	3	3.093	1.338		2.004
	4	6.888	1.343		5.794
	5	3.979	1.620		2.608
	6	3.154	1.789		1.614
	7	7.311	3.462		4.098
	8	2.946	1.512		1.683
	9	6.660	1.918		4.991
Average	Plot No. 1	4.859	1.792		3.316
24	10	1.281	1.001		.529
	11	1.462	1.226		.485
	12	1.427	1.291		.385
	13	.824	1.017		.056
	14	1.399	1.122		.526
	15	2.625	2.398		.476
	16	.858	1.032		.075
	17	1.301	1.166		.384
	18	6.265	2.171		4.343

*Average from depths 0-6, 6-12, and 12-18 inches

Table 17. (Continued)

Part 2. Total Reduction of Salt in Tons/Acre

Drain spacing (ft)	Sampling Location No.*	Tons of salt per acre*			
		Before irrigation	After irrigation	Added by irrigation	Total reduction
(1)	(2)	(3)	(4)	(5)	(6)
Average	Plot No. 2	1.938	1.380	0.249	.807
12	19	1.010	1.026		.233
	20	1.011	1.006		.254
	21	5.063	4.556		.756
	22	1.131	.970		.410
	23	1.568	1.223		.594
	24	5.423	4.447		1.225
	25	1.303	1.075		.477
	26	2.747	1.682		1.314
	27	4.873	2.569		2.553
Average	Plot No. 3	2.680	2.061		.868
Control	28	1.130	1.142		.237
	29	1.669	1.596		.322
	30	4.875	3.847		1.277
	31	1.818	1.704		.363
	32	2.923	2.801		.371
	33	3.952	3.247		.954
	34	6.990	6.319		.920
	35	5.741	6.511		- .521

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*Average from depths 0-6, 6-12, and 12-18 inches

Table 17. (Continued)

Part 2. Total Reduction of Salt in Tons/Acre

Drain spacing (ft)	Sampling Location No.**	Tons of salt per acre* Before irrigation	After irrigation	Added by irrigation	Total reduction
(1)	(2)	(3)	(4)	(5)	(6)
Control	36	7.642	6.920	0.249	.971
Average	Plot No. 4	4.082	3.787		.544

* Average from depths 0-6, 6-12, and 12-18 inches

**Corresponds to total depth from 0 to 18 inches

Col. (6) = Cols (3) - (4) + (5)

Appendix G

Total Reduction of Salt as Determined by the Electrical Conductivity and Estimated in Tons of Salt Per Acre at Various Depths for the Entire Moled and Control Areas

Table 18. Total reduction of salt as determined by the electrical conductivity and estimated in tons of salt per acre at various depths for the entire moled and control areas

Drain spacing (ft)	Depth (in)	Average mhos/cm at 25° C EC x 10^6		
		Before irrigation	After irrigation	Total reduction
6	0-6	2786.98	1148.52	1638.46
	6-12	3224.75	1036.91	2187.84
	12-18	3044.66	1151.87	1892.79
24	0-6	1138.11	932.35	205.76
	6-12	1032.26	778.36	253.90
	12-18	1446.93	857.62	589.31
12	0-6	1183.34	878.34	305.00
	6-12	1662.74	1294.00	368.74
	12-18	2174.07	1689.24	484.83
Control	0-6	3302.17	2676.07	626.10
	6-12	2244.89	2266.66	- 21.77
	12-18	2018.80	2094.22	- 75.42

Table 18. (Continued)

Drain spacing (ft)	Depth (in)	Tons of salt per acre			
		Before irrigation	After irrigation	Added by irrigation	Total reduction
6	0-6	1.540	.635	.083	.988
	6-12	1.727	.555	.083	1.255
	12-18	1.592	.602	.083	1.073
Total	0-18	4.859	1.792	.249	3.316
24	0-6	.629	.515	.083	.197
	6-12	.553	.417	.083	.219
	12-18	.756	.448	.083	.391
Total	0-18	1.938	1.380	.249	.807
12	0-6	.654	.485	.083	.252
	6-12	.890	.693	.083	.280
	12-18	1.136	.883	.083	.336
Total	0-18	2.680	2.061	.249	.868
Control	0-6	1.824	1.479	.083	.428
	6-12	1.202	1.214	.083	.071
	12-18	1.055	1.095	.083	.043
Total	0-18	4.081	3.788	.249	.542

VITA

José Antonio Forero

Candidate for the Degree of

Master of Science

Thesis: Effectiveness of Mole Drains in Leaching Heavy Soils

Major Field: Agricultural and Irrigation Engineering

Biographical Information:

Personal Data: Born at Tocaima, Cundinamarca, Colombia, June 14, 1944, son of Juan and Amparo Forero; married to former Beatriz Guerrero in 1970; one child -- Erick Ricardo Forero.

Education: Received Bachelor of Science degree in Agronomical Engineering from Pedagogical and Technological University of Colombia, Colombia, 1968; completed requirements for the Master of Science degree at Utah State University, Logan, Utah, in 1974.

Professional Experience: 1968 to 1969, Irrigation Engineer at Magdalena 1 Project, Colombia, for the Colombian Institute of the Agrarian Reform--INCORA; 1969-1972, Irrigation Engineer for the Colombian Agricultural Institute--ICA, Colombia.