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Long-Term Effects of Variable Water Quality on Some Soil Physical Characteristics Under Field Conditions

A Thesis submitted in partial satisfaction of the requirements for the degree of

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in

Soil Science

by

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I. INTRODUCTION

Careful water management is essential to a stable and efficient agriculture. Major efforts by a number of agencies are being directed toward water management and conservation activities such as irrigation, drainage, salinity control, flood prevention and erosion control. Where the rate of water entry into the soil is limiting, the entire water economy of the rooting zone of plants may be affected.

The rate of water entry into the soil fluctuates widely between soil type, and also wide differences can be found within a single soil type, depending upon the soil moisture level and management practices employed. Knowledge of infiltration processes as related to soil properties and mode of water supply is needed for efficient soil water management. Comprehensive reviews of infiltration processes were published by Davidson (1940), Parr and Bertrand (1960) and by Philip (1969).

Many workers have investigated methods of determining infiltration rates of water into soil. Many of these methods have been developed to meet a specific need and in many cases the method was not widely adaptable. A review of infiltration rate equipment by Parr and Bertrand (1960) showed the great diversity of methods and brought out the fact that no one method yet developed meets all needs.

The role of infiltration in the hydrologic cycle was pointed out by Horton (1933). He stressed that the importance of infiltration rate varied between the maximum value when the soil was dry and minimum value after wetting and packing.

However, since then, many researchers have investigated methods of determining infiltration rates in soil and factors influencing infiltration rates, like variation with time, initial wetness and suction, texture, structure and uniformity of profile.

To maintain the passage of sufficient quantities of water into and through plant zones to replenish water lost during evapotranspiration and maintain salinity control, it is important to maintain a favorable hydraulic conductivity of the soil matrix. The hydraulic conductivity is not an invariant property, but may be markedly influenced by tillage, microbial activities, irrigation and cropping practices, and by the composition of the irrigation water. The study described in the following pages has limited to the evaluation of this latter factor.

While a great deal of progress has been made in soil-water movement very little has been done on the long-term effects on variable water quality on the dynamic nature of soil structure under field conditions. The soil solid phase is not rigid, as generally assumed, but rather the particles are being rearranged with respect to one another depending on the stability of soil aggregates. The amount of water contained in the pores and the potential or activity of this water are two factors of prime importance in soil-water relationship.

Objectives of the current study have been to investigate the long-term effects of variable water quality on the following soil physical properties under field conditions:

1. Infiltration rates, and hydraulic conductivity, and soil-water characteristics

2. Distribution of clay

3. To deduce the mechanisms responsible for the observed water transmission

II. LITERATURE REVIEW

A. Water Flow Theory

One of the basic physical relationships used to describe the flow of water in soil is a flux equation, Darcy's Law, relating the flux of water, V, to the driving force:

$$V = -(K\rho/\eta)\nabla\Phi \tag{1}$$

Where K is the permeability of the soil or porous medium, ρ is the fluid density, η is the fluid viscosity, and $\nabla\Phi$ is the driving force per unit mass of water. The soil water potential, Φ, is the work per unit mass of water required to transfer the water reversibly from the reference state to the point in question in the soil.

Darcy's Law may also be written in terms of the hydraulic gradient:

$$V = -K\nabla H \tag{2}$$

where V is the volumetric flux of water ($cm^3\ cm^{-2}\ sec^{-1}$) i.e., the volume of water passing through unit cross section of soil per unit time, and ∇H is the hydraulic gradient (dimensionless when expressed as cm of H_2O per cm of sample) or the space rate of change of hydraulic head H in the direction of flow. The constant K varies markedly with the water content of the media. It has been designated as the hydraulic conductivity when used to describe the flow characteristics of saturated media, and as capillary conductivity when used for unsaturated flow (Richard, 1952a).

Also, the existing infiltration theories are based upon proportionality of flow-rate (the flux) to the potential gradient (Darcy's Law) as discussed above.

In vertical flow the total potential head (H) is taken to include the gravitation head (Z) and the pressure head (h), disregarding osmotic or thermal effects.

$$H = h + Z \tag{3}$$

where Z is the vertical coordinate, decreasing in the downward direction.

The flow equation thus becomes:

$$q = K(\Theta)\frac{d}{dz}(h+z) \tag{4a}$$

or

$$q = K(\Theta)\frac{dh}{dz} + K(\Theta) \tag{4b}$$

Equation (4b) explains the initial decrease of infiltration rate with time and the eventual establishment of a constant rate (often called the "final infiltration capacity"). As the length of the wetted soil $(Z)_w$ increases, the pressure (or suction) gradient $(\frac{dh}{dz})_{tz}$ at any particular depth in the transmission zone decreases in magnitude and after a while becomes negligible.

Eventually the gravitational head gradient remains the only effective drawing force. In a uniform soil, therefore, as time $\to \infty$, $q \to K_s$ (where Ks, is the saturated hydraulic conductivity).

Combined with the equation of continuity, Eq (4b) becomes

$$\frac{\partial \Theta}{\partial t} = - \frac{\partial}{\partial z} [K(\Theta)\frac{h}{dz}] - \frac{\partial K(\Theta)}{dz} \qquad (5a)$$

or

$$\frac{\partial \Theta}{\partial t} = \frac{\partial}{\partial z} (D \frac{\partial \Theta}{\partial z}) - \frac{\partial K(\Theta)}{\partial z} \qquad (5b)$$

Where D is diffusivity and Θ is volumetric water content. It is assumed that the hydraulic gradient is the only driving force which causes water to flow. However, the dynamic changes of salt concerntration, due to mass movement of salt and water contents fluctuations, may create an additional driving force due to osmotic gradient. Also, variation in salt concentration and composition may affect the hydraulic conductivity function, K (Θ), due to density and electrical changes. Thus, in applying equations (5a) and (5b) to a given salinity control situation the mutual salt-water flow effects must be considered.

The osmotic efficiency coefficient (σ), ranges between 0 to 1 and is interpreted as the degree of semipermeability of the soil. The value of σ will be 0 when salt concentration gradients will cause no water to flow and will be 1 for complete solute restriction when the osmotic gradients are as effective in causing water to flow as the equivalent hydraulic gradients. The greater the restriction of the solute relative to the solvent, the greater will be the value of σ , Kemper and Evans (1963).

Letey (1968) reviewed experimental information on water movement in response to salt concentration gradients in unsaturated soils. He concluded that at low suction, σ is very small and water flow due osmotic gradients is negligible. At higher suctions the total amount of water concentration gradients is still very low but becomes large relative to the flow due to pressure gradients.

Letey (1968) suggested that an approximate value of σ at soil water suction between 0.25 and 1 bar is about 0.03, whereas at suctions less than 0.25 bar can be assumed to be zero. No data are available at higher suctions. It seems, therefore, that under most salinity control conditions, salt concentration effects on macroscopic water flow can be neglected in practice. This implies that transient water flow under these conditions may be adequately described by equation.

$$\frac{\partial \Theta}{\partial t} = \frac{\partial}{\partial z} \left(K(\Theta) \frac{\partial h}{\partial z}\right) + \frac{\partial K}{\partial z} \qquad (6)$$

or equations (5a) and (5b).

Most of the expressions for infiltration of water into the soil that have been worked out, both empirically and from physical considerations based on equations described above, apply only to soils that are homogeneous and remain homogeneous during the flow process. They do not, therefore, apply to many situations that have been described above

B. Solution Composition Indices

Due to the effects of sodium in the soil and in the plant growth, sodium is considered to be one of the major factors governing water quality. The presence of sodium in irrigation water also influences the physical properties of the soil, particularly permeability, by affecting the swelling and dispersion of the clay. If the ratio of sodium to total cations in the irrigation water is high, and the same ratio in the soil is initially low, the increase of Na present on the exchange complex causes a reduction in the permeability. This reduction in permeability is contingent also upon electrolyte concentration and various soil properties.

There are several proposals existing for classifying the salt composition of irrigation waters.

A value which has come into wide use in predicting the sodium hazard is the sodium adsoprtion ratio (SAR) proposed by U. S. Salinity Laboratory (1954). It is defined by the relation:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} \qquad (7)$$

with all concentrations expressed in meq/1.

Using a modified Langelier index in combination with the SAR for evaluation of sodium hazard, Bower (1961, 1963) proposed, for water with high carbonate and without residual sodium bicarbonate, the empirical equation for calculating exchangeable sodium percentage (ESP_c):

$$ESP_c = 2\ SAR\ [1 + (8.4 - pH_c^*)]\ \cdot \qquad (8)$$

In the Bower equation the term "(8.4 - pHc)" is analogous to Langelier's saturation index except that 8.4, the approximate pH reading of a non-sodic soil in equilibrium with $CaCO_3$, is substituted for the actual pH value ($_pH_a$) of the water. The saturation index is defined by Langelier as the actual pH of water ($_pH_a$) minus the pH (obtained by calculation) which the water will have when it is in equilibrium with $CaCO_3$ ($_pH_c^*$). The relation of the calculated pH ($_pH_c^*$) is given by the following equation:

$$_pH_c^* = (_pK_2 - {_pK_c}) + {_p(Ca^{++} + Mg^{++})} + {_pAlk}. \qquad (9)$$

where the last two terms of the above equation, $_p(Ca^{++} + Mg^{++})$ and $_pAlk$ are the negative logarithms of the molal concentration of Ca^{++} plus Mg^{++}, and of the equivalent concentration of titratable base ($CO_3^{--} + HCO_3^-$), respectively, while $_pK_2$ and $_pK_c$ are the negative logarithms of the second dissociation constant for H_2CO_3 and the solubility constant of $CaCO_3$, respective, both corrected for ionic strength.

Values of $({}_pK_2 - {}_pK_c)$ are highly related to and are obtained from total cation concentration,(Bower, 1965). Wilcox (1966) tabulated tables for calculating ${}_pH_c^*$ values of waters. Using the above equation (9) on a series of well waters from West Pakistan, a good correlation between calculated and determined ESP was obtained by Bower (1961, 1963).

The bicarbonate anion is important in irrigation water for its tendency to precipitate calcium, and to a lesser degree also magnesium, from the soil as calcium carbonate and magnesium carbonate. This brings about a change in the ratio between Na and total cations in irrigation water, and therefore the sodium hazard is more pronounced. Eaton (1950) introduced the term "residual sodium carbonate" (RSC):

$$RSC = (CO_3^{--} + HCO_3^{-}) - (Ca^{++} + Mg^{++}) \qquad (10)$$

Wilcox (1955, 1967) concluded that water with more than 2.5 meq/liter of residual sodium carbonate is not suitable for irrigation. Water containing 1.25 - 2.5 meq/liter is considered marginal, and water with less than 1.25 is probably safe. Arany (1956 unpublished paper) showed that in evaluation of the effect of residual sodium carbonate the soil type must be considered. Water with the same RSC is dangerous for soils with an alkaline pH, but has an ameliorative effect on soils with an acid pH.

Taking into account the ratio between sodium and total cations, Doneen (1949, 1963) used the term "permeability index" (PI):

$$PI = \frac{100 \times \sqrt{Na^{+} + HCO_3^{-}}}{(Ca^{++} + Mg^{++} + Na^{+})} \qquad (11)$$

with all concentrations expressed in meq/l.

C. Factors Affecting Soil Water Flow

1. Infiltration Rates

The rate of infiltration in the hydrologic cycle was pointed out by Horton (1933). He stressed the importance of infiltration by rainfall-runoff data, and that for a given soil, the infiltration rate varied between the maximum value when soil was dry and maximum value after wetting and packing. Horton (1940) also presented an approach toward a physical interpretation of infiltration rate. He suggested the following factors affecting infiltration rate: (1) soil type and soil profile (2) biologic and micro-structure within the soil and (3) vegetal cover.

Some individuals are of the opinion that infiltration rate is governed solely by the soil mass and hence is largely independent of surface conditions or microstructures at or close to the surface. Horton, however, is of the opinion that infiltration is governed mainly by conditions at or near the soil surface.

Hillel (1964, 1971) indicated that the decrease of infiltration rate from an initially high rate can in some cases result (at least in part) from gradual deterioration of soil structure and the consequent partial sealing of the profile by formation of dense surface crust, from the detachment and migration of pore-blocking particles, from swelling of clay, or from entrapment of air bubbles or the bulk compression of soil air if it is. Also, the decrease in infiltration rate results in part from the inevitable decrease in matric suction gradient (constituting one of the forces drawing water into the soil) which occurs as infiltration proceeds.

Fletcher (1944) used a modification of Poulovassilis' approximation in a study of some properties of water that influence infiltration. Factors such as surface tension, viscosity, pore space, depth of wetting, head of water, wettability of the solid by the solution, and density of the solution, appear in the resultant equation. The temperature was indirectly included in the equation since it enters into values of both surface tension and viscosity. The relationship between infiltration rate and each of the various factors in the equation were as follows: (1) infiltration rate increased linearly with surface tension; (2) infiltration rate decreased hyperbolically with viscosity; (3) pore size increased infiltration rate parabolically; (4) depth of wetting and head of water decreased infiltration rate hyperbolically; (5) temperature increased infiltration rate linearly. Fletcher in his study presented brief experimental evidence to support the value that the use of this approach may be valid and based on experimental fact.

Baver (1956) pointed out the irrigation effects on soil structure. The break-down of aggregation during irrigation leads to crust formation, which produces unfavorable air and water relations for plant growth. Sometimes a puddling action takes place under flood type of irrigation. This puddling action increases the "cloddiness" of the soil and obviates the beneficial effects of any tillage operations under irrigation. In general, Baver concluded, the finer the condition of the soil surface before irrigation, the coarser are the clods after water is applied. Puddling action is accentuated in the presence of sizeable amounts of exchangeable sodium in the soil.

Permeable structure is favored by high proportion of divalent exchangeable cations, a minimum electrolyte concentration, sufficient reactive clay for aggregation (but not excessive clay content), and organic matter in a form which contributes to the bonding together of aggregates. Other bonding agencies, particularly lime and oxides of iron, aluminum, and silicon, also contribute to aggregate formation.

Reitermeir and Christiansen (1946) studied the effect of organic matter, gypsum, and drying on the infiltration rate and permeability of soil treated with water of high sodium content. It was found that incorporating gypsum into the soil at a rate of 5 tons per acre, or organic matter in the form of chopped alfalfa at the same rate, were both highly effective in that they both approximately doubled the infiltration rate during a two-year experiment.

As discussed above, a great deal of progress has been made in the problem of salt-water movement. However, the dynamic nature of soil matrix has been neglected. The soil solid phase is not rigid, as generally assumed, but rather the particles are continually being rearranged with respect to one another.

Pore size distribution undergoes marked change in soil and since large pores are nearly readily destroyed, decreases in this size range are almost apparent. Water conductivities are very sensitive to changes in soil structure, and intake rates are highly variable from place-to-place and time-to-time. We must be able to characterize the durability of soil structure, or lack of it, as well as describe the pore size distribution at any given time.

While there are exceptions, aggregated structure is less developed in arid soils than in those from humid regions. Aggregates tend to be much smaller, and many irrigated soil approach a single-grain structure, particularly those of coarse texture.

The dynamic nature of the surface soil structure arises because of resultant processes tending to improve structure and those tending to destroy it,(Baver, 1956). Beneficial processes include microbiological activity, alternative freezing and thawing, alternative wetting and drying (provided rewetting is slow), proper tillage (frequently to the detriment of soil physical condition just below tillage depth), and, possibly the physical incorporation of crop residues. Destructive processes include compressive or shear forces due to traffic load or tillage tending to break down soil structural units and the disruptive action of water, or stacking,(Yoder, 1936).

Beutner et al (1940), Berton et al (1958), Borst et al (1945), and Hornter and Lloyd (1940) observed that final infiltration rates varied with the season of the year. They observed higher infiltration rates during summer than during cooler seasons of the year.

Musgrave (1955) summarized the major factors that affect intake of water by soil as follows: (1) surface conditions and the amount of the protection against the impact of rain; (2) internal characteristics of the soil mass, including pore size, depth of the permeable portion, degree of swelling of the clay and colloids, content of organic matter, and degree of aggregation; (3) soil moisture content and degree of saturation; (4) duration of rainfall or application of water; (5) season of the year and temperature of soil and water.

However, the direct or indirect effects of soil microorganisms should not be overlooked in infiltration studies. The influence of earthworms on infiltration rates was studied by Hopp and Slater (1948). They found the earthworms increased infiltration rates on fine-textured soil by a factor of 4. Also, it has been found under some conditions there is clogging of the small soil pores by products of microbial metabolisms such as slimes, gums, and microbial tissues.

2. Hydraulic Conductivity

The ionic species which directly affect water transmission are Na^+, Ca^+, and Mg^{++}. Ions like CO_3^{--} and HCO_3^- affect it indirectly by precipitating Ca^{++} and Mg^{++}; thereby increasing the Na^+ concentration (Eaton, 1949). The presence of Na^+ in the percolating solution or on the exchange complex has long been recognized as leading to potential hydraulic conductivity decreases. Ca^{++} and Mg^{++}, in contrast to sodium, are known to promote flucculation, thereby increasing the flow rate. The beneficial effect of CA^{++} ion on water flow was reported by a number of workers such as Doneen (1949), Greancen (1949),USSL Staff (1954), Quirk (1955) and others. Fireman (1944) noticed that when Ca^{++} was the principal ion adsorped on the exchange complex, a reasonable flow can be maintained. Studying a Hesperia sandy loam soil, he found a high and constant permeability when a water containing 800 ppm calcium chloride was used. However, when this was replaced by distilled water, the permeability dropped to less than one hundredth of that of calcium chloride containing water. He concluded that the chemical composition of the percolating solution and checmical changes it brings about are of utmost importance in soil permeability. For a Yolo clay loam Greancen (1949) found that 60 ppm $CaCl_2$ gave a reasonable flow rate, while 600 ppm NaCl were needed to give the same flow. Bodman (1950) studied the effect of long continued irrigation with salt free water and water synthesized by adding sodium and calcium chloride, and found that the velocity depends on the salt concentration of the irrigation water rather than the base status of the soil.

One of the most complete and widely-cited works on the effect of composition of the percolating solution on soil hydraulic conductivity was reported by Quirk and Schofield (1955). They studied the permeability of soil after being saturated with a single ion-containing solution,i.e., K^+, Na^+, Ca^+, and Mg^{++}, and using successive dilute solutions. They found that K^+ and Na^+ produce similar decreases while little effect was noticed when Ca^{++} was used. They introduced the term "threshold permeability" which gives a 10-15% decrease in permeability. Beyond the threshold permeability, factors become operative that can cause drastic reduction in permeability. They also worked with mixed ions system and noticed that high electrolyte water can give good permeability even with a high exchangeable sodium percentage (ESP) soil.

Swelling and dispersion of soil colloidal material alter the geometry of the soil pores and thus affect the intrinsic permeability of the soil. It may be deduced from the double layer theory that both swelling and particle dispersion increases as soil solution concentration and Ca/Na ration decrease (Bresler, 1972).

McNeal (1965) studied the effect of solution composition on the hydraulic conductivity of fragmented soils. He observed soil hydraulic conductivity decreases of several hundred folds as the salt concentration of percolating solution decreased from 800 to 3.13 meq/l at constant SAR. Soil with 2:1 layer silicates dominating the clay fraction exhibited the greatest hydraulic conductivity decrease and conditions of moderately high ESP (25-35). Soils high in expandable minerals such as montmorillonite had more labile structure, with pronounced hydraulic conductivity decrease at ESP values of 15-20. However, soils high in kaolinite and sesquioxides, or amorphous materials, had a structure more stable than the average, with the kaolinite soil essentially unaffected by the presence of exchangeable sodium over the ESP range of 0-100 and over the total salt concentration range of 3.13 to 800 meq/l.

The U. S. Salinity Laboratory Staff (1954) have proposed the term Sodium Adsorption Ratio (SAR), is an expression for the relative activity of Na ions in exchange reactions in soils. The soil solution cationic composition in SAR terms is commonly used to describe the cationic composition effect on soil hydraulic conductivity. It has been shown by many investigations (e.g. Quirk, 1957: Naghshine-Pour et al., 1970) that the hydraulic conductivity decreases as the

SAR, or the associated Exchangeable-Sodium-Percentage (ESP) decreases, and the solution concentration increases. This was found to be true as long as SAR had a value of at least 10. For lower values of SAR the effects of the electrolyte was negligibly small.

3. Water Retention and Release

Some of the water that infiltrates dry soil is held to the soil colloids by forces of adsorption. Additional water is held in tiny soil capillaries by surface tension. As these forces of attraction are satisfied, the water will move into an adjacent volume of soil. Thus, the affinity of the soil for water is satisfied in each successive volume as water penetrates the soil. When there is insufficient water to satisfy the affinity of the soil, the movement to adjacent layers becomes low.

According to Hillel (1971) and Taylor (1972) as each increment of water is lost from the soil, the work that must be done to remove the next increment increases. The influence of water content upon the work required to remove a small increment of water is different for each soil. These relations -- called water characteristic curves -- are used to evaluate soil physical changes in this study.

The water is usually retained in the soil and in the capillaries by forces of attraction at the solid-liquid interface, by surface tension, or by attraction to the adsorbed ions. The water will be released when the forces causing it to be removed exceed retentive forces. The energy of retention of water in soil-water and plant-water system (the water potential) is dependent upon temperature, pressure, soil matrix and composition of the system. Each of these factors influences the water potential independently of the others. The influence of the last two factors on soil water potential will be discussed in relation to our study.

a. Influence of the Soil Matrix.-- The kinds and amounts of colloids influence the soil water characteristics; e.g., soils high in the smectite (2:1 expanding) clays retain more than do sandy soils. The number and kinds of ions adsorbed on the colloids (which, in turn, are fundtions of the kinds and amounts of ions in solution) exert a marked influence on the nature of the colloidal matrix. According to Taylor (1972) these factors are usually considered to be a part of the soil matrix; if any one of them changes, the soil water characteristic will be expected to change.

Fine soils retain water more strongly than do coarse soils. The amount or degree of aggregation also influences the water characteristic curve. Water characteristic curves determined with sieved samples frequently are different from those determined with relatively undisturbed cores of the same soil. This effect is usually more pronounced in moist soils.where the shape of the characteristic curve is determined largely by pore water.

The degree of aggregation has a distinct effect on the pore size distribution in the soil and, consequently, at high water contents, aggregation has a pronounced influence on the water characteristic curve. The effect of aggregation decreases as the water is removed from soils because many pores are emptied and film water become more important in influencing the shape of water characteristic curve. The amount of water held in films is a function of specific surface and consequently is largely determined by soil texture and not by soil aggregation.

Taylor (1972) found that an increase in bulk density 1.10 to 1.35 g/cm^3 resulted in an increase in water potential from -27 to -23 joules/kg for Millville silt loam at 23 percent water from -46 to -41 joules/kg at 19.7 percent water, and from -58 to -52 joules/kg at 17.5 percent water. He fruther points out that although these increases are relatively small, they are significant with respect to the measurement of water potential. In some of the common measuring methods, disturbed soil samples are used. This practice may result in water potential measurements that are different from those of field soil samples. It may account for some of the variation encountered in repeated measurements using samples from the same soil.

b. Influence of Solutes.-- It has long been known that dissolved solutes influence the rate and amount of water uptake by plants. This influence has been generally attributed to their effect in reducing the water potential. For the most part, this is still correct but we now know that solutes as well as water may be taken up and their influence may be more directly related to the relative rates of adsorption rather than to the direct influence on the water potential. In this discussion we are concerned about the direct influence of solute upon water potential in an equilibrium condition.

In the absence of a sealed system with a rigid semipermeable membrane that is in contact with pure water, no pressure will develop. Nevertheless, the amount of work that is required to remove a unit of pure water from the solution is made greater because of the solute.

The actual amount of additional work is expressed by the decrease in water potential. A unit concentration difference of each kind of solute influences the potential differently.

In summary, the amount of water contained in the soil pores and the potential or activity of this water are two factors of prime importance in soil-water relations. In equilibrium, the total potential of the water is uniform throughout the system. In order for water to move, whether within the soil or into the plant, there must exist differences in the potential of the free energy. The mechanisms responsible for the sorption and retention of water by soil are not yet completely understood quantitatively (Gardner, 1960).

The total potential of the soil water is made up of a number of terms in addition to the matric potential term (capillary term). These terms take into account the short range adsorptive forces emanating from the soil particles, such as the chemical and van der Waals forces, and longer range forces arising from the interaction of water, dipoles with electrostatic field associated with the charged surface of the soil particles. Other components of the total potential may be the osmotic potential, pressure potential and gravitational potential.

4. Proposed Mechanisms Influencing Water Transmission

A number of mechanisms have been suggested to account for the decrease in water transmission in soil when low electrolye waters are used. However, the exact events responsible for hydraulic changes which occur when salt solutions are passed through soils are not well known.

Some researchers, like Bodman and Harradine (1939, 1950), Burges and

Gardner (1945), and Reeve and Bower (1960) regard reduction of hydraulic conductivity as due to the dispersion of fine silt particles, followed by their movement into and a deposition in conducting voids thus decreasing permeability.

However, a number of investigators have suggested that in-situ swelling of soil colloids, rather than their dispersion and disposition in pores, is responsible for low hydraulic conductivity values and low-salt, and high Na conditions. Carman (1939), Smith and Stallman (1955), and Mielenz and King (1955) have the opinion that swelling as a major cause of such hydraulic conductivity decreases.

The third possible mechanism proposed by Emerson (1954), Quirk and Schofield (1955), and Reeves and Tamaddoni (1965) indicates that the process takes place as follows: first swelling, then dispersion of particles, translocation of particles, and finally decrease in permeability.

However, Bresler (1971) regards hydraulic conductivity to be affected not only by intrinsic permeability, but also by the properties of the soil solution, such as fluid density and viscosity which are also affected by the composition and concentration of solutes. Investigations have confirmed that the hydraulic conductivity behaves accordingly, i.e., greater hydraulic conduction in the presence of concentrates solution or high Ca/Na ratio.

III. MATERIALS AND METHODS

A. General Information

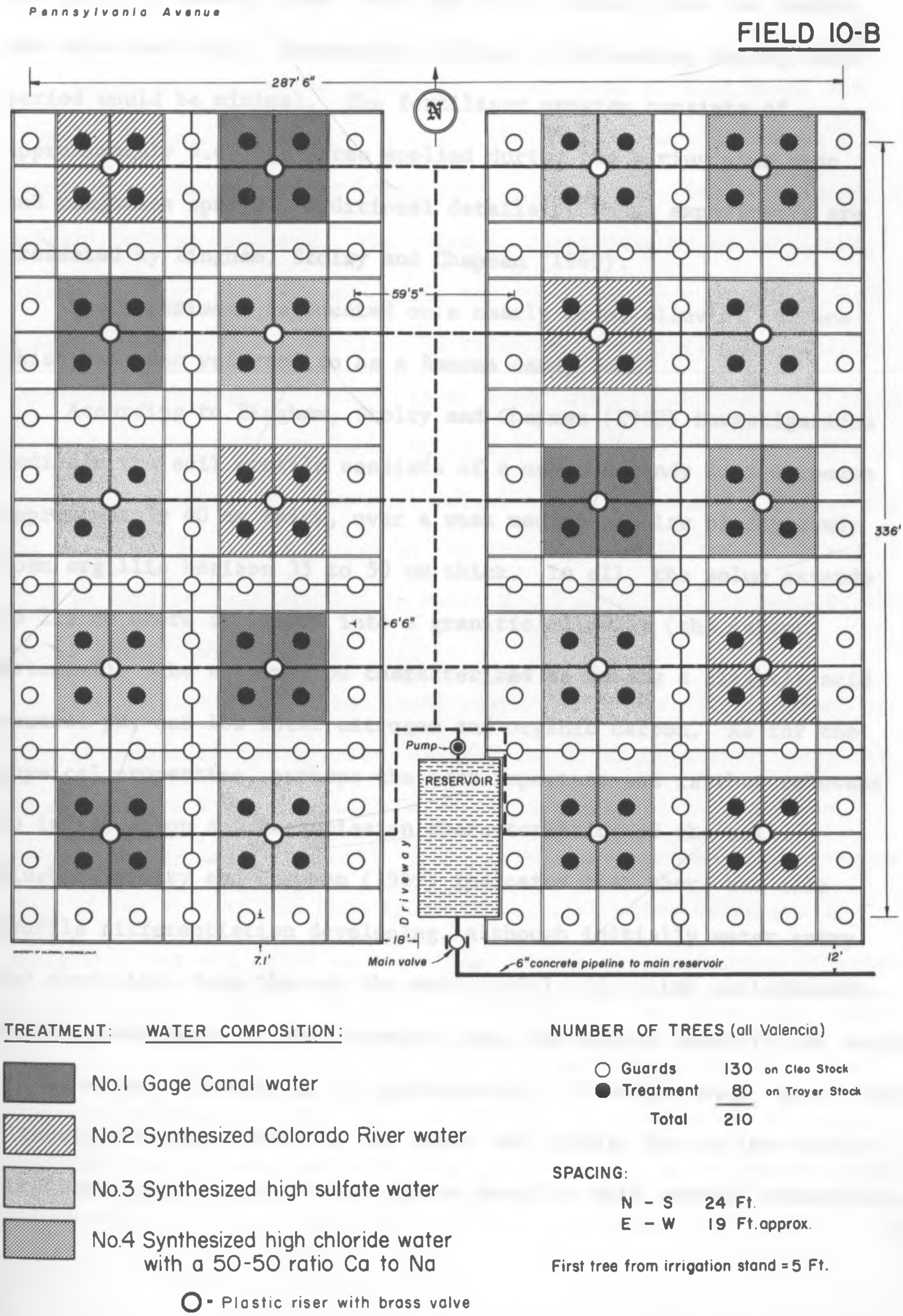
1. Experimental Site

The location of the experimental site is within the University of California, Riverside campus. (Fig. 1)

Originally the land was dry farmed with barley 1928. In 1928 fig and olive trees were set out. The land was cleared in 1954 and permitted to remain bare for approximately 2 1/2 years prior to planting the orange trees in June 1957. The planting design consists of 7.2 x 5.7 m. spacing with 4-tree plots replicated 5-fold for each of the 4 water treatments under investigation. Each 4-tree plot is surrounded with a guard row of trees. There are 80 trees under treatment.

The trees were furrow irrigated until the Spring, 1964 at which time they were placed on uniform flood basin irrigation using Gage Canal water. The uniform irrigation continued for one year, and then differential irrigation treatments with variable water quality started in the end of Spring of 1965. The application consists of 7.5 cm of water per plot whenever average soil suction for each treatment (replicated five-fold) reaches between 0.4 and 0.5 bars. Usually four irrigations are necessary during the normal year, beginning in late May and at 4 to 5 week intervals thereafter. The usual orchard management practices are being carried out for fertilizers and pest control. The weeds in the basins are controlled with herbicides and no heavy machineries are used in these basins. The harvesting of

Fig. 1 Schematic sketch of irrigation water quality experiment with Valencia orange trees.



Pennsylvania Avenue
FIELD 10-B
287' 6"
59'5"
6'6"
336'
Pump
RESERVOIR
Driveway
18'
7.1'
Main valve
6" concrete pipeline to main reservoir
12'
TREATMENT:
WATER COMPOSITION:
No.1 Gage Canal water
No.2 Synthesized Colorado River water
No.3 Synthesized high sulfate water
No.4 Synthesized high chloride water with a 50-50 ratio Ca to Na
- Plastic riser with brass valve
NUMBER OF TREES (all Valencia)
Guards 130 on Cleo Stock
Treatment 80 on Troyer Stock
Total 210
SPACING:
N - S 24 Ft.
E - W 19 Ft. approx.
First tree from irrigation stand = 5 Ft.

the fruit is usually done once per year (summer) when the basins are relatively dry. Compaction induced by harvesting during this period would be minimal. The fertilizer program consists of approximately 0.68 kg N/tree applied during the spring plus zinc and manganese sprays. Additional details of these experiments are presented by Bingham, Stolzy and Chapman (1969).

The experiment is located on a nearly level alluvial terrace which has been referred to as a Ramona sandy loam.

According to Bingham, Stolzy and Chapman (1969) investigations indicate the soil profile consists of a massive sandy loam epipedon approximately 40 cm thick, over a weak medium angular blocky sandy loam argillic horizon 35 to 50 cm thick. In all, the solum extends to 125 cm where it blends into a granitic alluvium (the parent material). The soil may be characterized as having a slightly acid neutral pH, and low total nitrogen and organic carbon. As for the physical properties, perhaps the most important one is that relevant to infiltration and transmission characteristics of the soil. Bingham, Stolzy and Chapman (1969) indicated that there was some profile differentiation developing, although initially water entry and conduction down through the soil profile was quite satisfactory. Field measurements of infiltration using the entire water filled basin showed rates of intake to be approximately 1.3 cm per hour, never less. Although the Ramona soil is not ideal for citrus due to its massive structure, good citrus production is possible with careful management.

2. Irrigation Treatments

Salts applied in the irrigation waters used in this study are given in Table 1. Water No. 1 (T_1), the local water, serves as a "control" as it is a water being used in Riverside, San Bernardino, and Redlands citrus orchards. The water is considered to be excellent, quite free from salinity or sodium hazard. The other waters were synthesized from Water No. 1. The Water No. 2 (T_2) is comparable in composition to that of Colardo River water used in Southern California. It has moderate salinity level, EC of 1.3 mmho/cm, with a favorable cation and anion composition. The most saline water is Water No. 3 (T_3) which has an EC of 2.5 mmho/cm with $SO_4^=$ as the predominant anion. Water No. 4 (T_4) is more or less similar to Water No. 2 except Cl^- is considerably higher than in Water No. 2.

The water from the Gage Canal supply (Water No. 1) is pumped into a large reservoir (of appoximately 280,000 liter capacity) centrally located at the experimental site where variable quality water is synthesized by adding specific salts in the appropriate concentrations (Fig. 2 and 3). It had been found circulating water overnight is sufficient for all salts to dissolve. Checks for uniformity of water composition was done by Bingham et al. (1969). They found the blending and mixing procedure quite satisfactory, even though the water was prepared in batches. The above waters provide a range of salinity concentration for evaluation as well as waters which are predominantly Cl^- or $SO_4^=$. Additional data on the irrigation waters are given in Table 2.

The water quality indices calculated from four water treatments

TABLE 1

SALT APPLICATION PER 149.5 CUBIC METERS WATER

Treatment	Salt Applied in Kg/149.5 m^3 Water	
T_1	Gage Canal water only (No salts added)	
T_2	Calcium chloride	21.8
	Sodium sulfate	36.3
	Epsom salts	36.3
	Gypsum	3.6
T_3	Sodium bicarbonate	31.8
	Sodium sulfate	70.4
	Epsom salts	78.5
	Gypsum	104.4
T_4	Calcium chloride	38.6
	Sodium chloride	28.1

TABLE 2

COMPOSITION OF IRRIGATION WATER AND INDICES

WATER	EC mmho/cm	Composition						Indices		
		Ca^{++}	Mg^{++}	Na^{+}	HCO_3^-	Cl^-	$SO_4^=$	SAR	ESP_c	PI
		meq/l								
1	0.5	2.9	0.7	1.5	2.9	0.7	1.6	1.12	4.26	41.13
2	1.3	5.2	2.6	5.0	2.8	2.7	7.2	2.53	10.83	21.82
3	2.5	9.7	4.9	10.0	5.6	0.7	18.3	3.70	19.46	16.06
4	1.3	6.6	0.7	5.2	2.9	8.1	1.6	2.72	11.53	22.77

Calculated Indices

SAR = Sodium Adsorption Ratio

ESP_c = Calculated Exchangeable Sodium Percentage according to Bower (1961, 1963)

PI = Doneen's Permeability Index

Fig. 2 Details of blender used for mixing salts.

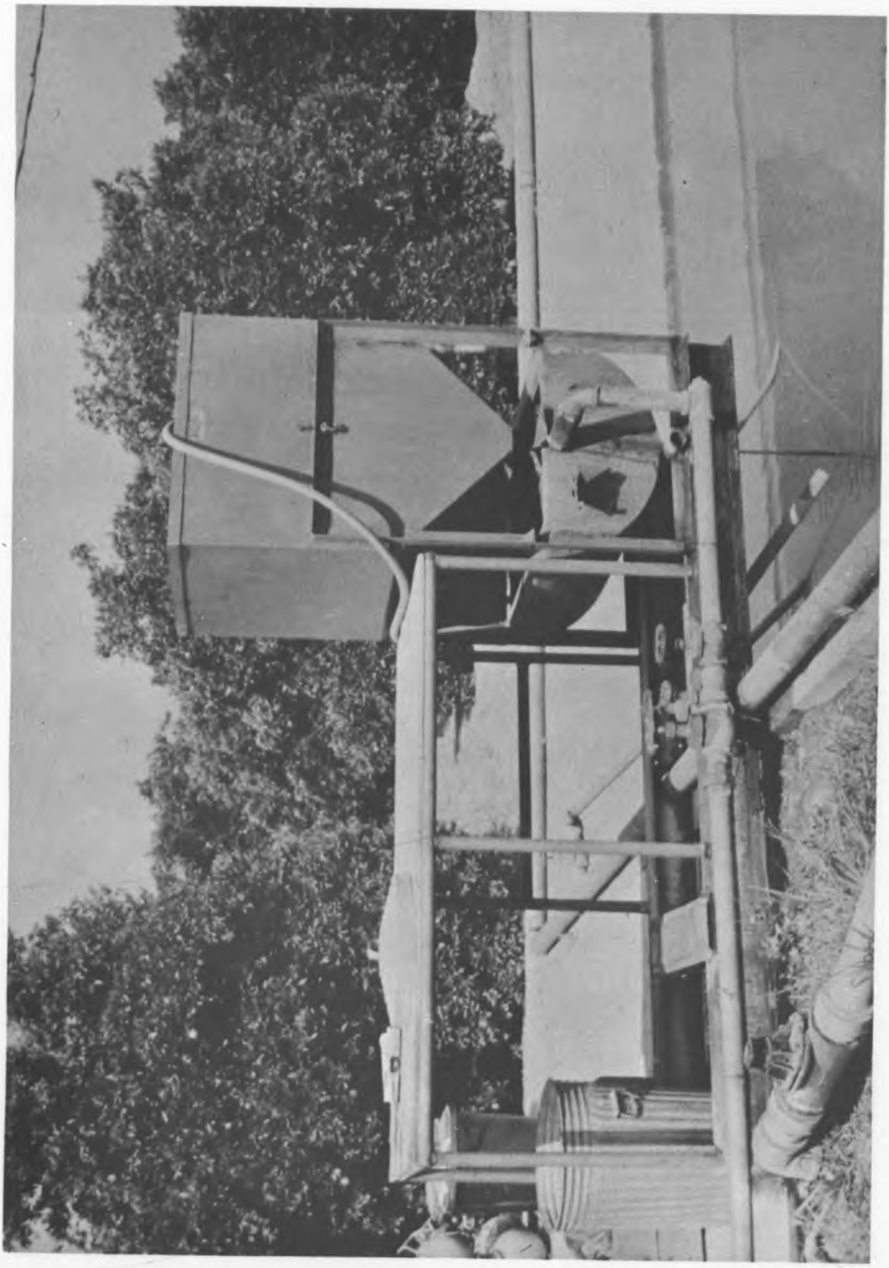
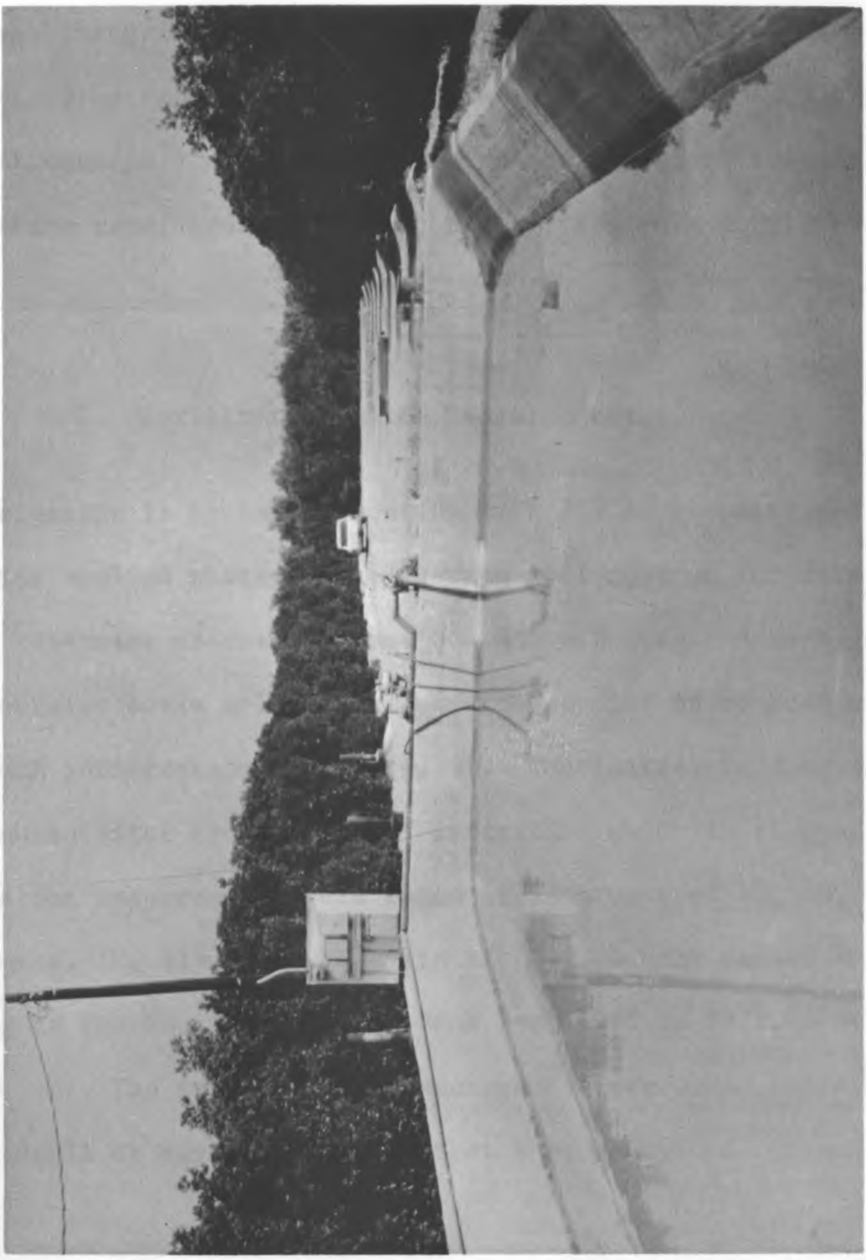


Fig. 3 Reservoir (of approximately 280,000 liters capacity) centrally located at the experimental site where variable water quality is synthesized by adding specific salts in the appropriate concentrations.



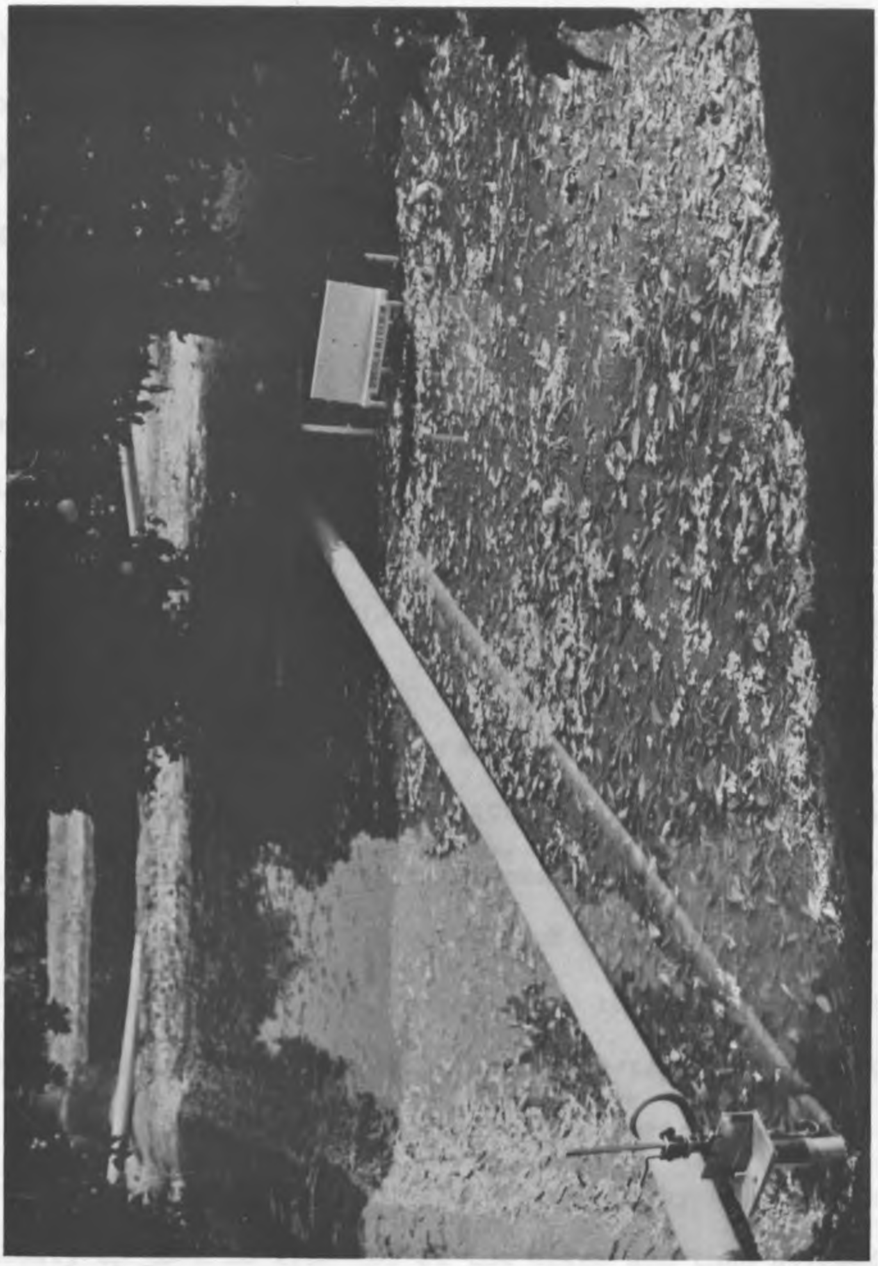
are sodium-adsorption ratio, SAR (U. S. Salinity Laboratory Staff, 1954): Exchangeable-Sodium-Percentage, ESP (Bower, 1961, 1963); and permeability index, PI (Doneen, 1963) cited in Irrigation in Arid Zones edited by Yaron (1969). Studies have been carried out to find the relationships of these indices with soil physical changes, i.e., infiltration rate, hydraulic conductivity, and bulk densities.

B. Methods of Study

1. Infiltration Rates Measurements

Irrigation is by basin flooding with 7.5 cm of water per irrigation applied whenever the average soil suction for five replicates in each treatment reaches between 0.4 and 0.5 bars. A hook-gauge device with a vernier scale able to measure thousandths of an inch was used to measure infiltration rate (Fig. 4). The initial reading is taken five minutes after application of irrigation water is stopped. The infiltration measurements were taken at intervals of 10, 40, and 160 minutes. We also checked again after a 24 hour period for water standing in the basin. This was done from 1965 to 1972, a seven year period. The infiltration measurements were taken twice every year in April or May, and in August or September.

Fig. 4 Details of infiltration rate measurement. Hook gauge instrument in lower left hand corner of picture.



2. Saturated Hydraulic Conductivity of Soil Cores and Bulk Density

Soil cores were obtained in brass sleeves that fitted into a sampling tube (sampler) connected to extendable iron tubings. The size of the sleeves used to take the undisturbed cores was 7.5 cm in height and 5.4 cm in diameter.

The samples were taken from all four irrigated treatments and the non-irrigated treatment (in replicate numbers 1, 3 and 5) at intervals of 15 cm (6") down to 300 cm (10') depth. Care was taken to avoid compaction. After the samples had been taken, the sleeves served as the core containers.

The samples from the field which could not be analysed the same day were stored in a refrigerator at a temperature of $10^{o}C$ to reduce mocrobial activity. At this temperature microbial activities are assumed to be at a minimum and the effect could be regarded as negligible to hydraulic conductivity measurements.

In the laboratory, the bottom of each core was capped with a cheese cloth filter, the exposed top was connected to a brass ring of 5.4 cm in diameter and 3 cm in height with vinyl plastic electrical tape (Scotch brand), and then placed in a large plastic tray. The cores were saturated with water at room temperature ($25^{o}C$) by raising the water level slowly up to 1 cm from top of the cores and then allowed to stand for 24 hours.

Then the cores were carefully mounted vertically and supported on a porous outflow surface. A shallow water level of 1 cm depth was maintained over the soil surface by a siphon tube from a constant-level reservoir (Fig. 5).

The saturation and the conductivity tests were conducted with water of the same qualities as those which were used in the corresponding treatments (T_1, T_2, T_3 and T_4),except Gage Canal water (T_1) which is regarded as good water with low salinity value, were used for non-irrigated treatment (T_5) samples.

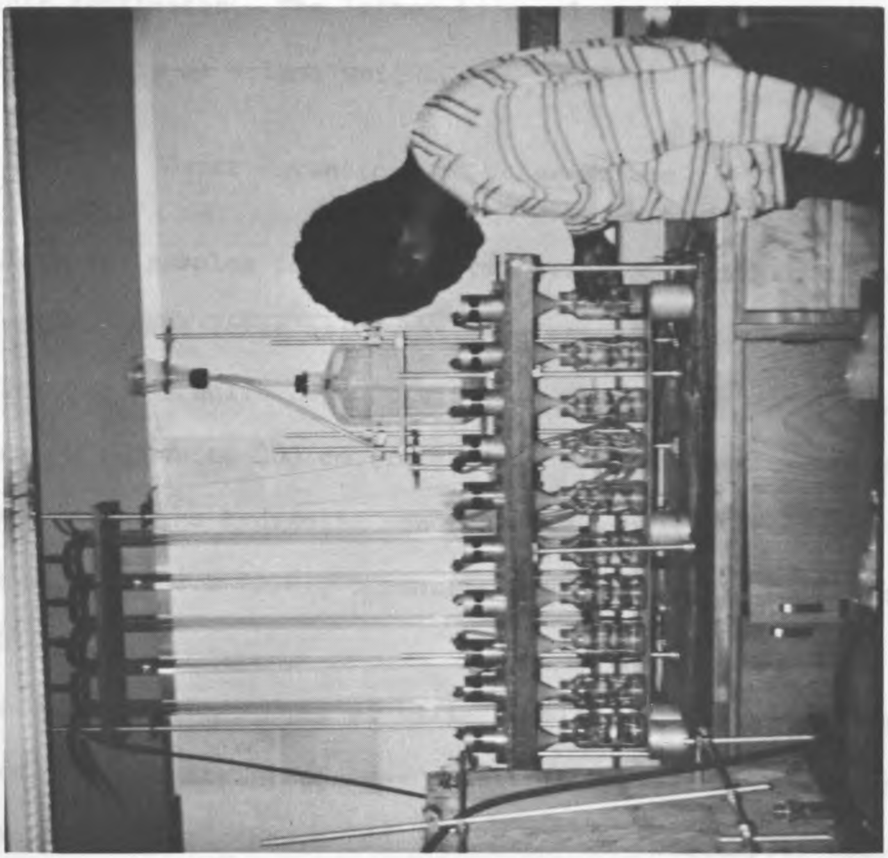
The hydraulic conductivity was calculated by using the equation:

$$K = (Q/At) \quad (\Delta L/\Delta H) \qquad (12)$$

where Q is the volume of water passing through the core in time (t), A is the area of the core, and K is the average hydraulic conductivity in the soil interval (ΔL), over which there is a hydraulic head difference of ΔH. The hydraulic conductivity (K) will be in centimeters per hour if t is expressed in hours, Q in cm^3, A in cm^2, and ΔH and ΔL are both in the same units.

The cores used for determination of hydraulic conductivity were also used to determine bulk density. The mass for each core was determined after drying to a constant weight at 105°C and the volume was that of the sample as taken in the field. The bulk density (ρ_b) of each core was calculated by using the following relationship:

Fig. 5 Laboratory apparatus used to determine hydraulic conductivity of undisturbed samples from the field using corresponding variable water quality used in each treatment in the field.



$$\rho_b = M_s / V_t$$

where ρ_b = Bulk density

M_s = wt. of oven-dry soil core

V_t = field volume of sample

Bulk density is expressed as pounds per cubic foot or grams per cubic centimeter. The latter is equal numerically to apparent specific gravity or volume weight.

3. Water Retention and Water Relase

Soil core samples for the determination of water retention and water release were taken using the same procedure used to sample the cores for the hydraulic conductivity and the bulk density at intervals of 15 cm (6") down to 300 cm (10'). The samples were taken about 30 cm (1') from where the hydraulic conductivity samples were taken in replicate 1, 3 and 5 (i.e., 3 profiles per treatment in the Spring of 1972).

Previous in the Summer of 1971, samples were taken at depths of 15-30 cm, in four irrigated treatments (five replicates per treatment were sampled). The storage and saturation of the samples with water were as used with hydraulic conductivity samples, except that no sleeve connections were done to the cores.

After the samples were saturated and allowed to equilibrate for 24 hours at room temperature (25°C), they were placed in a pressure plate apparatus (Fig 6). The apparatus accomodated 20 samples, 5.4 cm in diameter on a single plate. After placing cores on a ceramic plate, the pressure plate was closed and adjusted for the desired suction value.

The suctions applied to the cores were: 0.1, 0.3, 0.5, 0.7, 1.0, 3.0, 5.0, 7.0, 10.0, and 15.0 bars. The approach to hydraulic equilibrium was followed by connecting the outflow tube from each plate to the lower end of a graduated buret and recording the buret readings occasionally. When equilibrium was attained, the outflow tubes were clamped off, and the air pressure released in the pressure plate cell. In this study two kinds of ceramic plates were used, one for lower tensions up to 1 bar and the other one for higher tensions up to 15 bars.

Soil water retention (in volumetric water content, (cm^3/cm^3) in each sample was calculated using the following equation:

$$\theta = \frac{W_{t(i)} - W_{t(OD)}}{(V_s)\ (\rho_w)} \tag{14}$$

where θ = Volumetric water content

$W_{t(i)}$ = Weight of the soil sample in grams at corresponding soil water suction

$W_{t(OD)}$ = Oven-dry weight of the sample in grams

V_s = Volume in the soil in cm^3 as from the field

ρ_w = Density of water expressed in grams/cm^3

Fig. 6 Details of set up in the laboratory to determine soil water characteristic of undisturbed soil core samples from the field using pressure plate apparatus.

Soil water release data was determined from the same samples used for determination of soil water retention by the following equation:

$$W_{(\tau)} = \frac{W_{t(o)} - W_{t(\tau)}}{(V_{s(o)})\ (\rho_w)}$$

where $W_{(\tau)}$ = Soil water release equivalence to volume fraction of water occupying space in soil and now, at suction value τ is release by soil.

$W_{t(o)}$ = Initial weight of soil in grams at suction 0.1 bar

$W_{t(\tau)}$ = Soil subsequent weighing in grams at corresponding value of suction

$V_s(o)$ = Volume of the soil as from the field in cm^3

ρ_w = Density of water expressed in $grams/cm^3$

4. Soil Particle Size Analyses

Disturbed soil samples were taken in the same sites as for hydraulic conductivity, water retention and water release samples (30 cm apart from any of the two profiles). The sampling was done at intervals of 15 cm down to 300 cm depth. The hydrometer method was used for the particle size analysis (Day, 1965).

Fifty grams of Calgon [sodium hexametaphosphate, $(NaPO_3)_6$] was dissolved in water and the solution was diluted to a volume of one liter. The hydrometer used for particle size analysis was first calibrated by adding 100 ml of Calgon solution to a sedimentation cylinder and distilled water was added to make exactly 1 liter. The suspension was mised thoroughly with a plunger and brought to the temperature of the sedimentation cabinet which was maintained at constant temperature (30°C). The hydrometer was lowered into the solution carefully and the scale reading, R_L, at the upper edge of the meniscus surrounding the stem.

Forty grams of soil (sieved through a 2 mm sieve) was weighed from each soil sample for analysis and an equal quantity for determination of the oven-dry weight. The latter was dried overnight in an oven at 105°C., and then reweighed.

Organic matter was destroyed with hydrogen peroxide (H_2O_2) for samples at 0-60 cm depth. Below this depth organic matter contents were well below one percent and was assumed to have no influence on dispersion.

For dispersion, samples were placed in 600-ml beaker. Ten ml of Calgon solution and approximately 400 ml of distilled water were added and the sample allowed to soak at least 10 minutes.

The suspension were transferred to dispersion cups using a stream of distilled water from a wash bottle to complete the transfer. The suspensions were mixed for 5 minutes by a malt mixer. The samples were transferred to sedimentation cylinders with the aid of a jet of water from a wash bottle and then distilled water was added to bring the volume to 1000 ml. The cylinders were placed into a constant temperature bath accomodating 10 cylinders and allowed to equilibrate.

The hydrometer reading (R) were taken at various times (3, 10, 30, 90, 270 and 720 minutes). For each reading (R), the concentration (C) of the suspension was calculated in grams per liter, from the equation:

$$C = R - R_L \tag{16}$$

and the summation percentage values from the equation:

$$P = 100\ (C/_{Co}) \tag{17}$$

where Co is the oven-dry weight of soil in grams per liter of suspension. The corresponding particle sizes, or "diameters" were calculated by equation:

$$X\ (\text{microns}) = \theta\ /(t)^{1/2} \tag{18}$$

where t is the sedimentation time in minutes and θ is a sedimentation parameter obtained from the table given by Day (1965). The hydrometer readings were used to calculate the amount of material in the silt (20-50μ) and clay (<2μ) fraction.

The suspension of each sample was poured directly from the sedimentation cylinder into the 47 micron sieve. The effluent was discarded. The residue on the sieve was worked by running water onto it directly from the tap. When most of the fine material appeared to have been washed through, the contents were transferred to tared evaporating dish by using water from a wash bottle and then dried overnight in an oven at 105°C. They were then removed, cooled and weighed to the nearest 0.01g. The sands were transferred from the dish onto a set of sieves and shaken for five minutes. The separates remaining on the sieves were then calculated as the amounts of very coarse sand(2-1 mm), coarse sand (1 - .5 mm); medium sand (.5 - .25 mm) fine sand (.25 - .10 mm) and very fine sand (.10 - .050 mm).

5. Thin Section Evaluation

After analyzing the particle size data investigations of thin section were undertaken to observe the soil constitutents in their natural undisturbed state. Core samples for thin sections were taken in replicate numbers 1, 3 and 5, from treatments 1, 2, 3, 4 and the non-irrigated treatment, at depths of 60-75 cm (24" - 30"), and 150-165 cm (60" - 66") which had big differences in regard to clay contents within treatments. The samples were air-dried and mounted thin section were prepared by a commercial firm.

In the study of clay translocation which was one of the objectives of these studies, the thin section slides were studied using a petrograph microscope in both plain and crossed polarized light. The features of the several common types of clay arrangement are summarized below according to Cady (1965).

> "In residual materials, clay is often arranged in forms pseudomorphic after rock mineral or in crystal aggregated in definite bodies such as the vermicular or accordion-like kaolin books. Regular, intact arrangement of these materials generally is diagnostic for residual material.
>
> The clay becomes rearranged by pressure applied differentially to produce shear. Root pressure, wetting and drying and mass movement can produce pressure orientation. Pressure orientation can be inferred when smooth faces with no separate coating are seen on structural units. But, otherwise cannot be served in plain

light. In crossed polarized light, a recticular pattern of orientation appears, consisting of bright lines showing aggregate birefringance often intersecting at regular angles. The effect is that of a network in a plain pattern. Pressure oriented clay may appear around rigid bodies, such as quartz grains, or along root channels, and it is often strongly developed on ped faces. Pressure can also orient the mica flakes and any other small platy grains.

Translocated clay has several features that distinguish it from residual clay, it occurs in separate bodies, usually with distinct boundary, and it is located on present or former pore walls or ped faces. Also translocated clay is more homogeneous than matrix clay and it is usually finer. It is often of different composition from the matrix, especially if it came from another horizon. It shows lamination, indicating deposition in successive increments. And, finally, these bodies of translocated clay will show birefringence and extinction, indicating that they are oriented aggregates. If they are straight, they will have parallel extinction; if curved, a dark band will be present wherever composite c axis and composite a and b axis are parallel to the vibration planes the stage is rotated.

Swelling, slump, and movement in soils may cause clay skins to become distorted and broken. Pores may collapse, and the lining then becomes an oblong block or oriented clay. New faces and openings develop, and the old clay skins are found as isolated fragments in the matrix; ultimately they may be re-incorporated into the matrix and disappear."

IV. RESULTS AND DISCUSSION

A. Infiltration Rates

The infiltration rate values were calculated from the field data for the following year 1967, 1969, 1970 and 1971, only for the fall period of each year started. The values were taken at minute rate intervals consisting of the following sets of time: 0-10, 10-40 and 40-160 minutes for all the treatments (T_1, T_2, T_3 and T_4) studied.

Due to a lack of consistency, the data for 1965 and 1966 were not taken at the same intervals as described above. Also, in 1968 measurements for one treatment was not completed, thus data were not included in the analysis.

The results obtained in this study indicated that there was great variation of the infiltration rates between each year and in each treatment's infiltration rate measurement, especially at the 0-10 minute interval (Fig. 7). Although there was great variation, Treatment 1 generally had the highest infiltration rate.

Analysis of variance of the average infiltration rate indicated that Treatment 3 had the lowest and Treatment 1 had the highest infiltration rate. Statistically, the infiltration rate of Treatment 1 is different from the infiltration rate of Treatment 3, but the infiltration rates in Treatments 2 and 4 do not differ from the infiltration rates in Treatment 3 at the 1% significance level (Table 3).

The analyses for 10-40 and 40-160 minute rate intervals showed

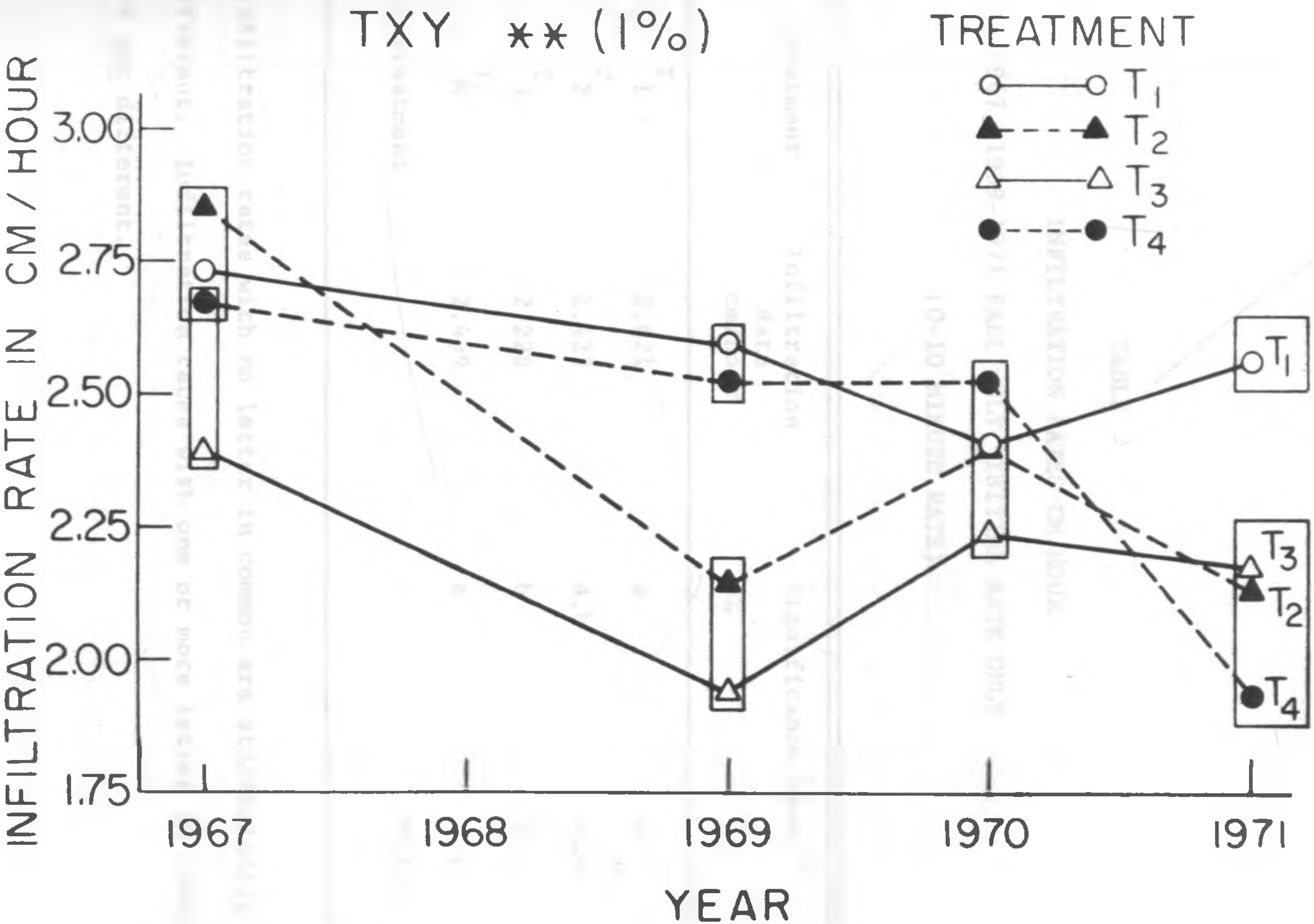


Fig. 7 Infiltration rate in cm/hour;Initial rate (0-10 minute rate interval) 1967, 1969-1971 (Fall Only). Infiltration rates with no box in common are statistically different. Infiltration rates with one or more boxes in common are not different.

TABLE 3

INFILTRATION RATES CM/HOUR

1967, 1969-1971 FALL ONLY, INITIAL RATE ONLY

(0-10 MINUTE RATE)

Treatment	Infiltration Rate cm/hour	Significance Level[1] 5%	1%
T_1	2.621	a	x
T_2	2.423	a,b	x,y
T_3	2.228	b	y
T_4	2.459	a	x,y
Treatment			**(1%)

[1] Infiltration rates with no letter in common are statistically different. Infiltration rates with one or more letter in common are not different.

showed that there were decreases in the infiltration rate in all treatments, even on Treatment 1 which was the control treatment (Fig. 8). Statistically, there were no differences between the treatments at 5% and 1% levels (Tables 4 and 5).

The average infiltration rate data for all the treatments at 0-10, 10-40 and 40-160 minute rate intervals were analyzed. This analysis was done to check if, on the average, infiltration rates were changing with time. The analysis showed that the downward linear trend ($D_1L.T$) was statistically significant at 1% level for all treatments combined into the 0-10, 10-40, and 40-160 minute intervals. Refer to Fig. 9, and Tables 6-8 for year infiltration rates ranks. The downward trend was statistically significant at 5% level only at the 10-40 minute rate interval, but not significant at 0-10 and 40-160 minute rate intervals for Fall 1967, 1969-1971.

The variation in infiltration rates determined in the Spring (April-May and Fall (Sept-Oct) for the years 1967, 1969 and 1972 has also been determined. Infiltration measurements for 1972 were done after heavy soil sampling of each of the treatments used (T_1, T_2, T_3 and T_4). This occurred at the end of the spring period. It is possible that infiltration measurements for the Fall of 1972 might have been affected due to the soil sampling. The spring infiltration measurements were normally conducted after heavy rainfall; the fall infiltration measurements were done after summer, a dry period season (Fig. 10).

TABLE 4

INFILTRATION RATES CM/HOUR

1967, 1969-1971 FALL ONLY, 10-40 MINUTE RATE ONLY

Treatment	Infiltration Rate cm/hour	Significance Level[1]	
		5%	1%
T_1	1.237	a	x
T_2	1.191	a	x
T_3	1.184	a	x
T_4	1.191	a	x

[1]Infiltration rates with no letter in common are statistically different. Infiltration rates with one or more letters in common are not different.

TABLE 5

INFILTRATION RATES CM/HOUR

1967, 1969-1971 FALL ONLY, 40-160 MINUTE RATE ONLY

Treatment	Infiltration Rate cm/hour	Significance Level[1]	
		5%	1%
T_1	0.574	a	x
T_2	0.559	a	x
T_3	0.538	a	x
T_4	0.584	a	x

[1] Infiltration rates with no letter in common are statistically different. Infiltration rates with one or more letters in common are not different.

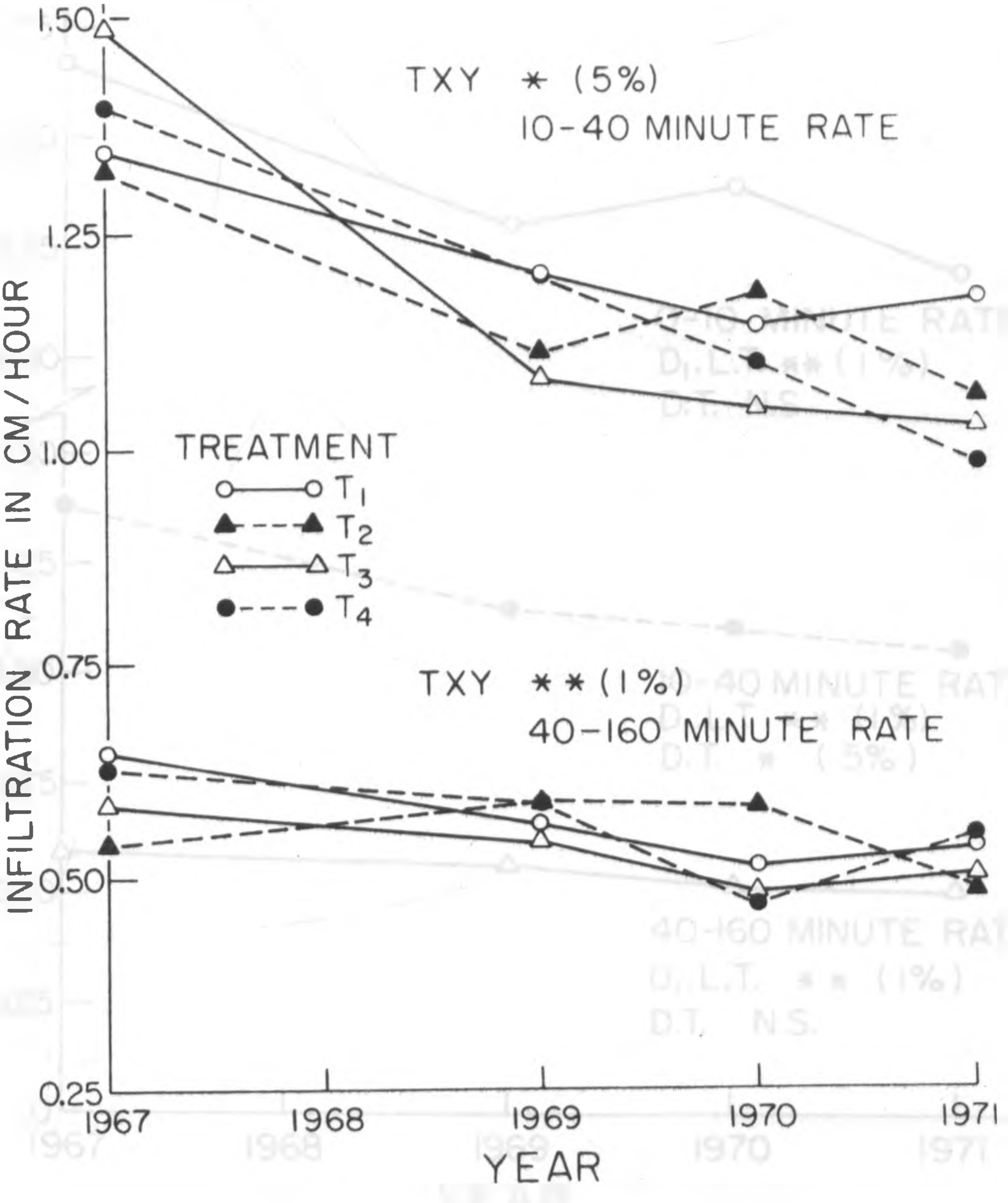


Fig. 8 Infiltration rate in cm/hour. Above, 10-40 minute rate interval, and below 40-160 minute rate interval, 1967, 1969-1971. (Fall only)

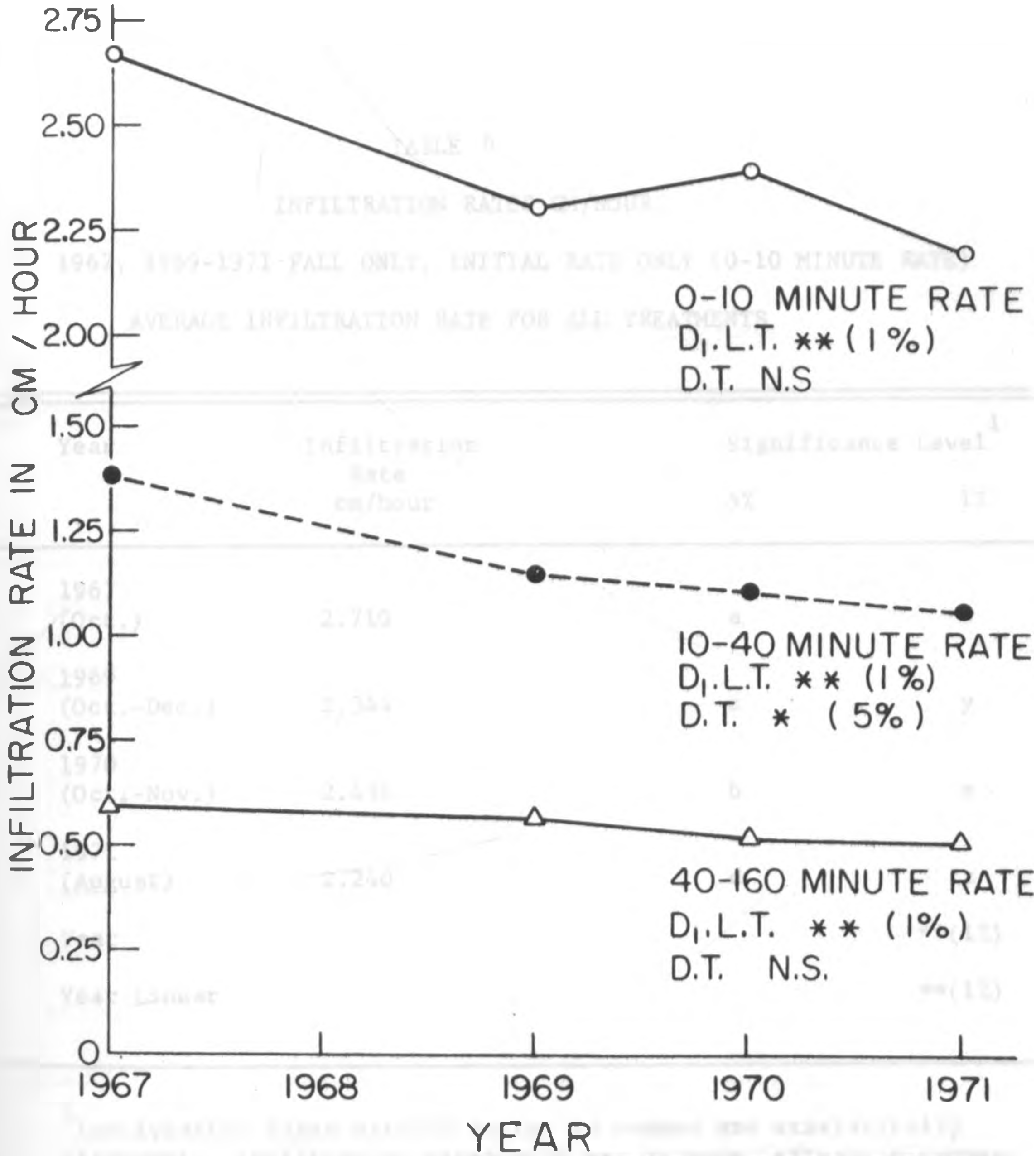


Fig. 9 Average infiltration rates for four treatments. 0-10, 10-40, 40-160 minute rate intervals. D_1. L. T. (Downward Linear Trend), and D.T. (Downward Trend) 1967, 1969-1971, (Fall only).

TABLE 6

INFILTRATION RATES CM/HOUR

1967, 1969-1971 FALL ONLY, INITIAL RATE ONLY (0-10 MINUTE RATE)

AVERAGE INFILTRATION RATE FOR ALL TREATMENTS

Year	Infiltration Rate cm/hour	Significance Level[1] 5%	1%
1967 (Oct.)	2.710	a	w
1969 (Oct.-Dec.)	2.344	c	y
1970 (Oct.-Nov.)	2.436	b	x
1971 (August)	2.240	d	z
Year			**(1%)
Year Linear			**(1%)

[1] Infiltration rates with no letter in common are statistically different. Infiltration rates with one or more letters in common are <u>not</u> different.

TABLE 7

INFILTRATION RATES CM/HOUR

1967, 1969-1971 FALL ONLY, 10-40 MINUTE RATE ONLY

AVERAGE INFILTRATION RATE FOR ALL TREATMENTS

Year	Infiltration Rate cm/hour	Significance Level[1] 5%	1%
1967 (Oct.)	1.410	a	x
1969 (Oct.-Dec.)	1.171	b	x
1970 (Oct.-Nov.)	1.138	c	y
1971 (August)	1.082	d	z
Year (Y)			**(1%)
Year Linear			**(1%)

[1] Infiltration rates with no letter in common are statistically different. Infiltration rates with one or more letters in common are not different.

TABLE 8

INFILTRATION RATES CM/HOUR

1967, 1969-1971 FALL ONLY, 40-150 MINUTE RATE ONLY

AVERAGE INFILTRATION RATE FOR ALL TREATMENTS

Year	Infiltration Rate cm/hour	Significance Level[1] 5%	1%
1967 (Oct.)	0.610	a	w
1969 (Oct.-Dec.)	0.582	b	x
1970 (Oct.-Nov.)	0.536	c	y
1971 (August)	0.528	d	z
Year (Y)			**(1%)
Year Linear			**(1%)

[1]Infiltration rates with no letter in common are statistically different. Infiltration rates with one or more letters in common are not different.

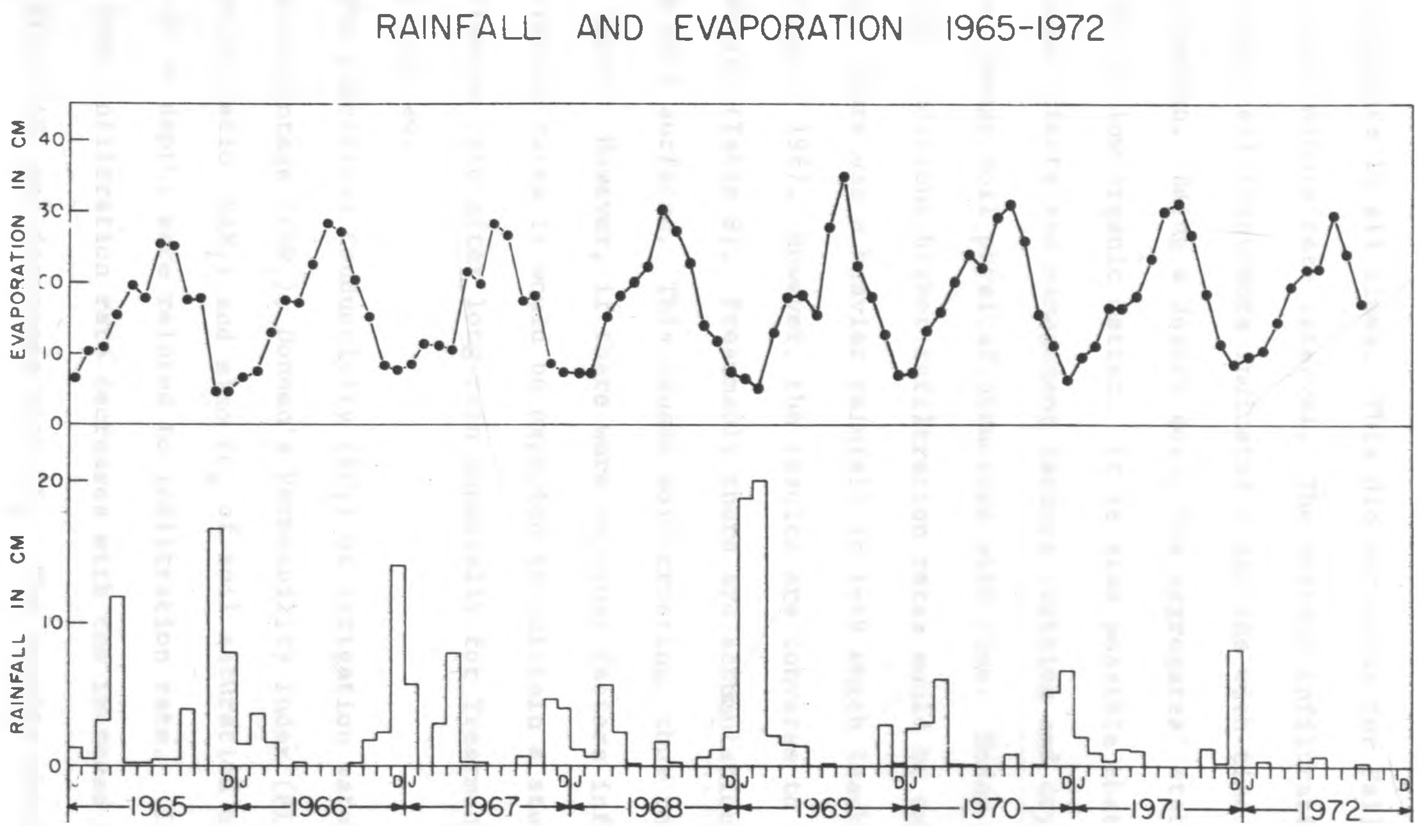


Fig. 10 Distribution of rainfall and evaporation at Citrus Experimental Station at University of California, Riverside Campus.

The infiltration rates in Spring are higher than infiltration rates in the Fall (Fig. 11). On the average, these took place for all treatments in all times. This did not occur for Fall of 1972 at the 0-10 minute rate interval. The average infiltration rate results for all treatments indicated a decline with time regardless of the season. Being a desert soil, the aggregates' stability is poor due to low organic matter. It is also possible that there are treatment effects and management factors (wetting and drying) which seem to change soil physical structure with time. Under normal soil physical conditions higher infiltration rates would be expected during Spring. There was a heavier rainfall in 1969 which leached salts than in Spring of 1967. However, the results are converse to the above explanation (Table 9). Presumably there are accumulations of salts on the soil surfaces. This causes soil crusting, thus reducing initial water entry. However, if there were no other factors influencing the infiltration rates it would be expected to maintain a steady infiltration rate after long rain especially for Treatment 1, but this is not so.

The Electrical Conductivity (EC_1) of irrigation water, Exchangeable Sodium Percentage (ESP), Doneen's Permeability Index (PI) Sodium

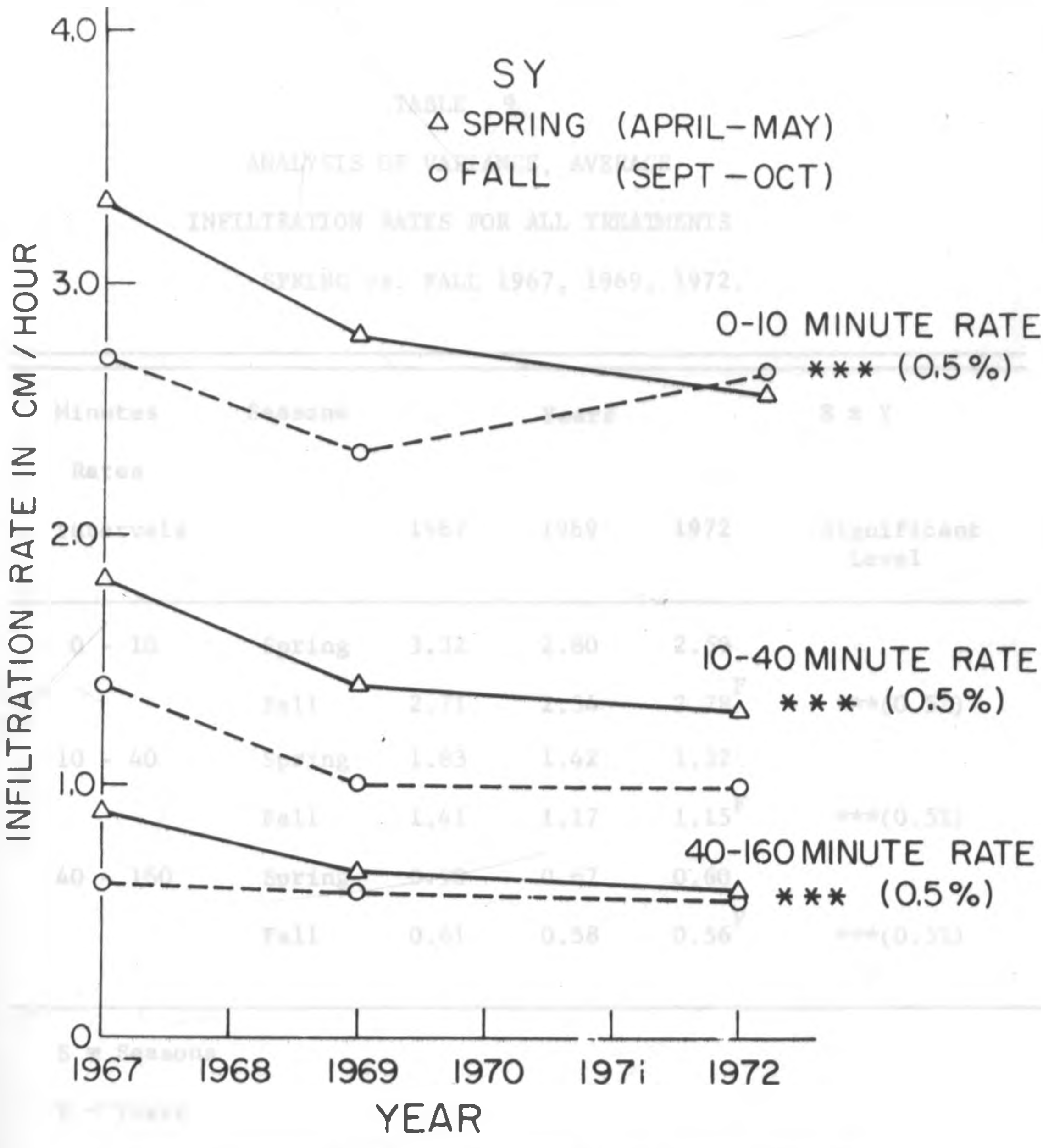


Fig. 11 Average infiltration rates for four treatments, 0-10, 10-40, 40-160 minute rates intervals, Spring (April-May) versus Fall (Sept-Oct), 1967, 1969-1972.

TABLE 9

ANALYSIS OF VARIANCE, AVERAGE
INFILTRATION RATES FOR ALL TREATMENTS
SPRING vs. FALL 1967, 1969, 1972.

Minutes Rates Intervals	Seasons	Years 1967	1969	1972	S x Y Significant Level
0 - 10	Spring	3.32	2.80	2.59	
	Fall	2.71	2.34	2.78[F]	***(0.5%)
10 - 40	Spring	1.83	1.42	1.32	
	Fall	1.41	1.17	1.15[F]	***(0.5%)
40 - 160	Spring	0.90	0.67	0.60	
	Fall	0.61	0.58	0.56[F]	***(0.5%)

S = Seasons

Y = Years

F = Infiltration measurements taken after soil sampling in all treatments, Fall 1972.

S x X = Analysis of variance of seasons and years.

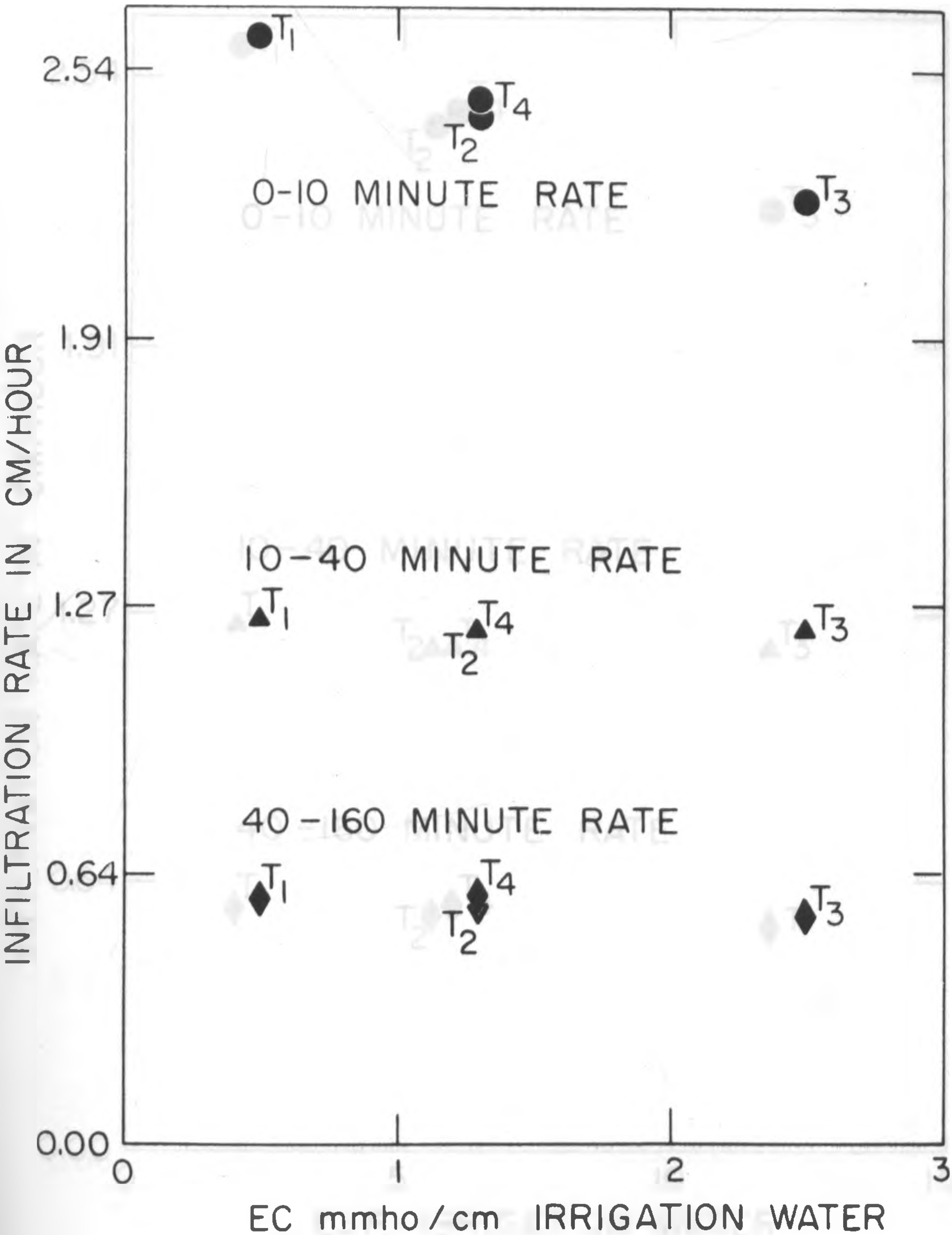


Fig. 12 Relationship between infiltration rate in cm/hour and Electrical Conductivity (EC_i) in mmho/cm irrigation water. 0-10, 10-40, and 40-160 minute rate intervals, 1967, 1969-1970. Fall only (Sept-Oct).

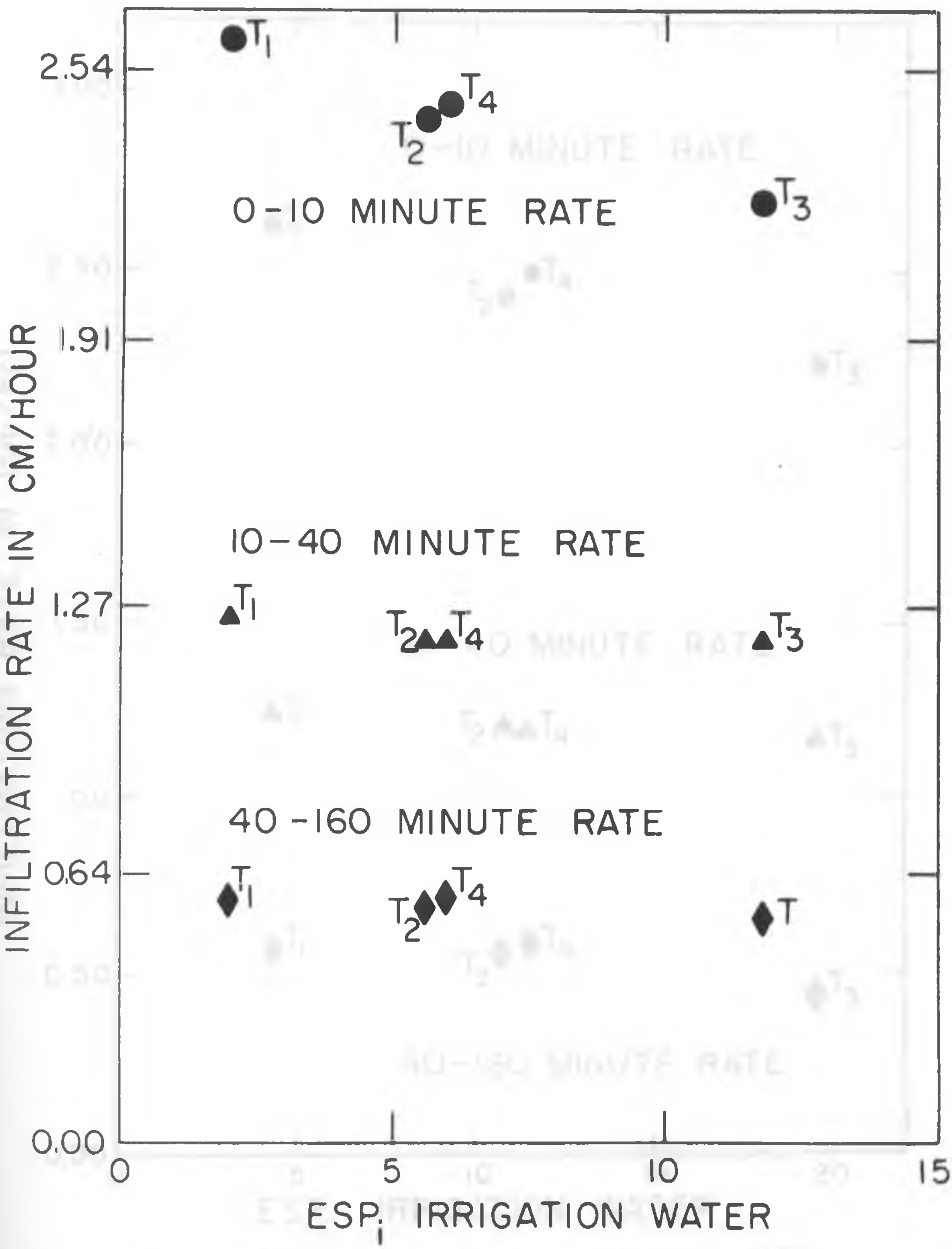


Fig. 13 Relationship between infiltration rate in cm/hour and Exchangeable Sodium Percentage (ESP_c) irrigation water. 0-10, 10-40, and 40-160 minute rate intervals, 1967, 1969-1970. Fall only (Sept-Oct).

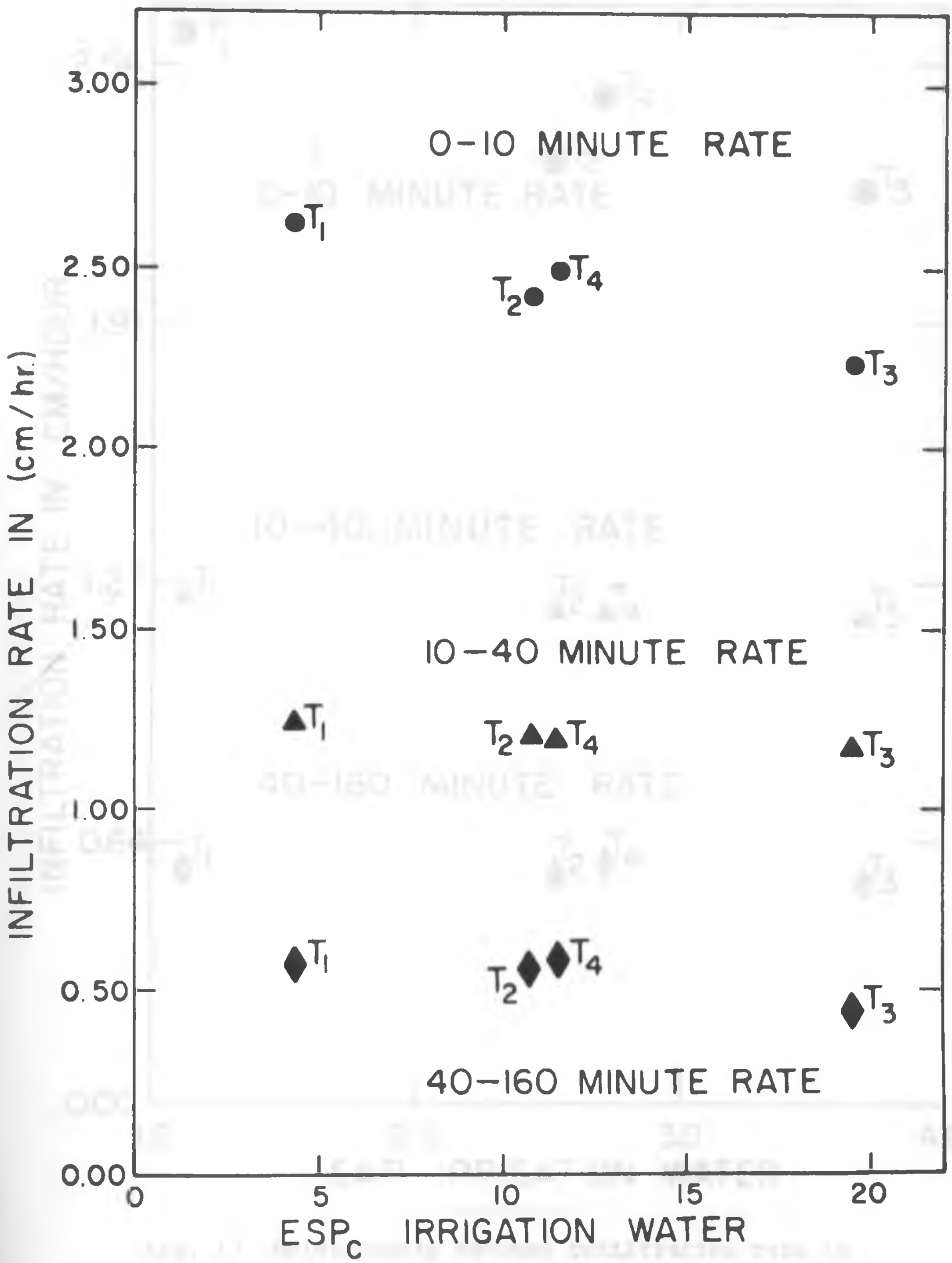


Fig. 14 Relationship between infiltration rate in cm/hour and Doneen's permeability index (PI_i) irrigation water. 0-10, 10-40 and 40-160 minute rate intervals 1967, 1969-1970. Fall only (Sept-Oct).

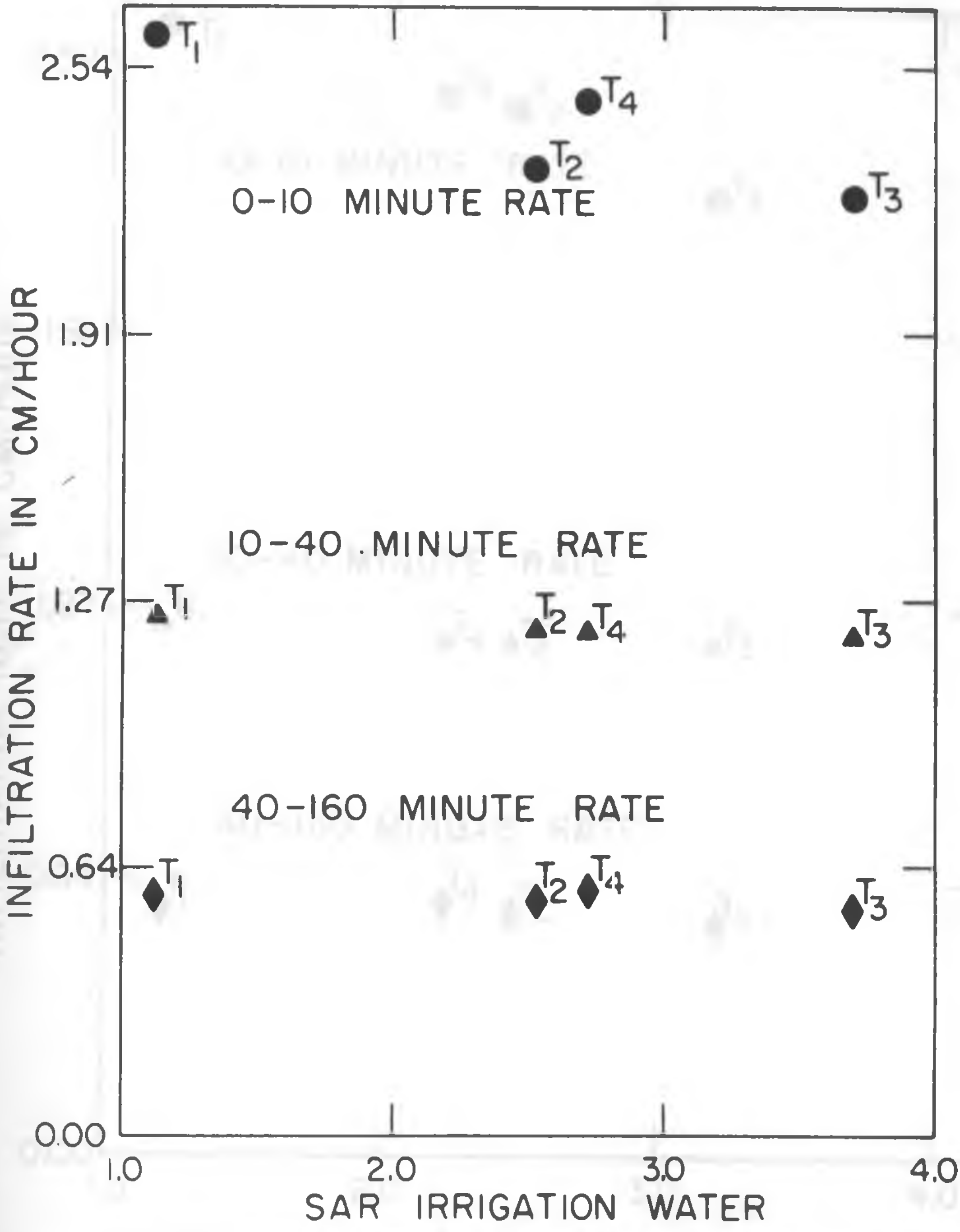


Fig. 15 Relationship between infiltration rate in cm/hour and Sodium Adsorption Ratio (SAR_i) irrigation water. 0-10, 10-40 and 40-160 minute rate intervals 1967, 1969-1970, Fall only (Sept-Oct).

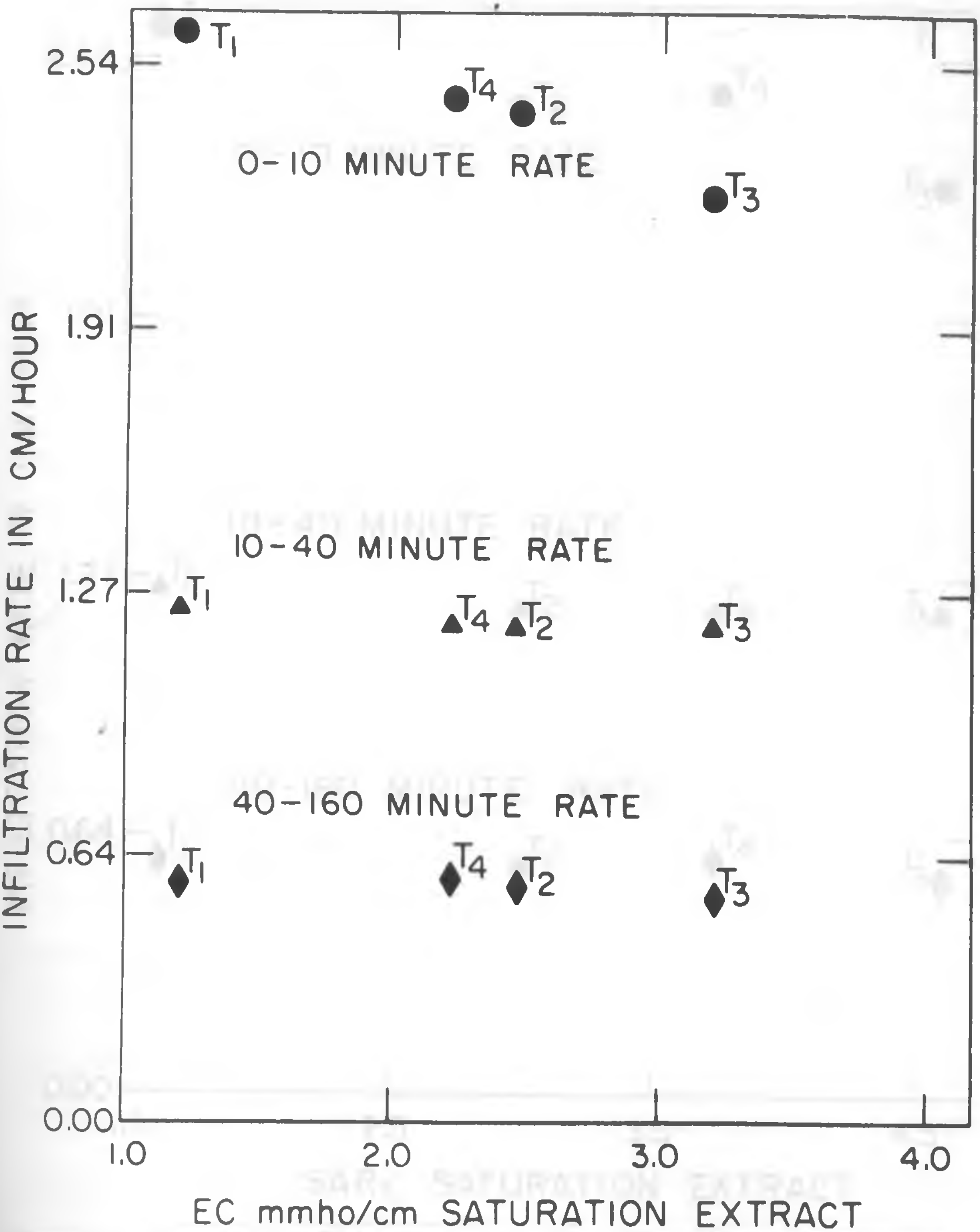


Fig. 16 Relationship between infiltration rate in cm/hour and Electrical Conductivity (EC_s) in mmho/cm Saturation Extract, 0-10, 10-40 and 40-160 minute rate intervals. 1967, 1969-1970, Fall only (Sept-Oct).

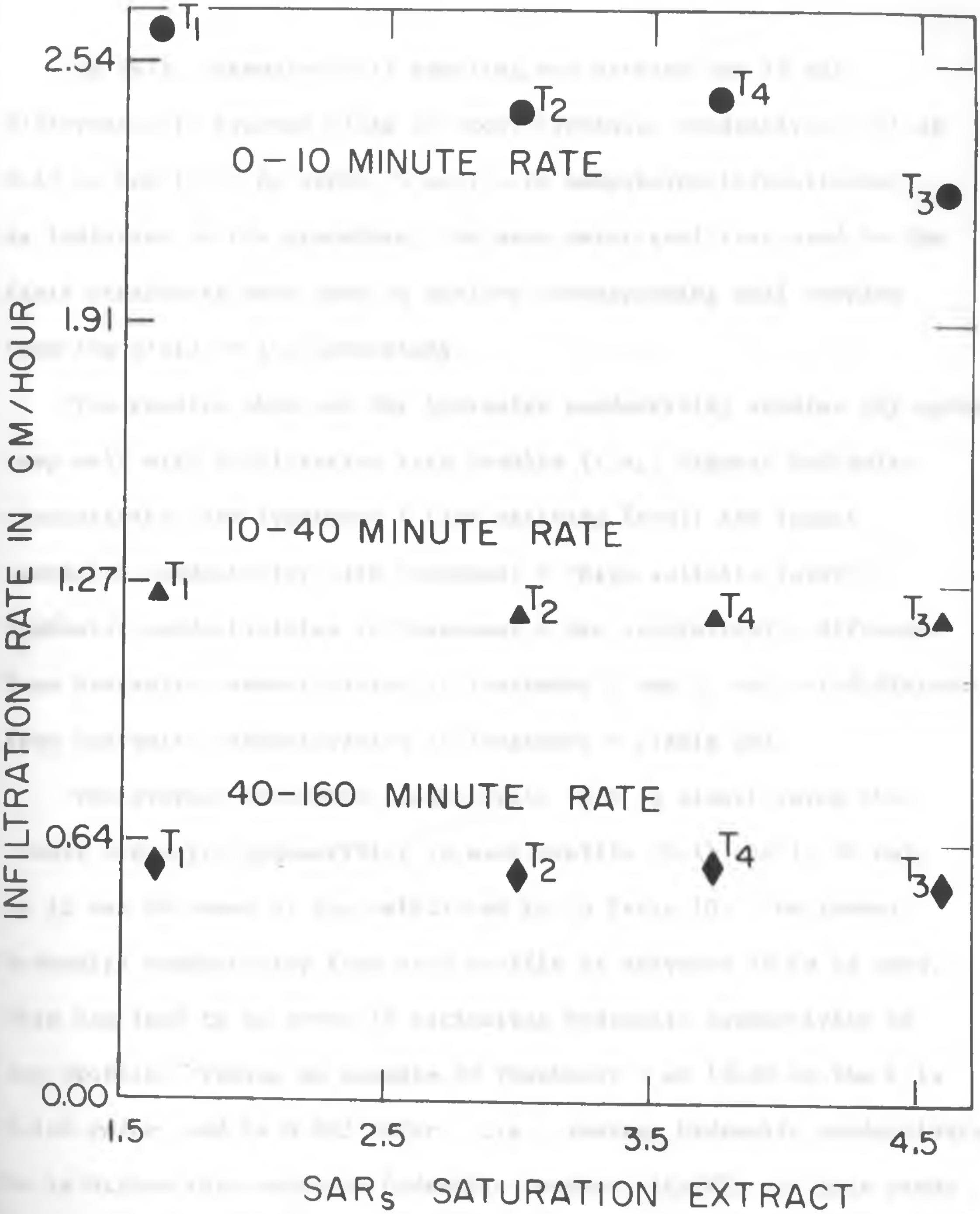


Fig. 17 Relationship between infiltration rate in cm/hour and Sodium Adsorption Ratio (SAR_s) of Saturation Extract. 0-10, 10-40, and 40-160 minute rate intervals. 1967, 1969-1970, Fall only (Sept-Oct).

B. Hydraulic Conductivity (K)

In 1971, intensive soil sampling was carried out in all differentially treated plots to study hydraulic conductivity (K) at 0-15 cm and 15-30 cm depth (4 soil core samples/depth/replicate). As indicated in the procedure, the same water qualities used in the field treatments were used to analyze corresponding soil samples from the field in the laboratory.

The results obtained for hydraulic conductivity studies (K) agreed very well with infiltration rate results [i.e., highest hydraulic conductivity with Treatment 1 (low salinity level) and lowest hydraulic conductivity with Treatment 3 (high salinity level)]. Hydraulic conductivities in Treatment 1 are statistically different from hydraulic conductivities in Treatment 2 and 3, but not different from hydraulic conductivities in Treatment 4 (Table 10).

The average hydraulic conductivity (Ka) is almost twice the lowest hydraulic conductivity in each profile (0-15 and 15-30 cm), as it can be shown by the calculated Ka in Table 10. The lowest hydraulic conductivity from each profile is elevated if Ka is used. This can lead to an error in estimating hydraulic conductivity of any profile. Taking an example of Treatment 3 at 15-30 cm the K is 0.134 cm/hr. and Ka 0.243 cm/hr. (i.e., average hydraulic conductivity Ka is higher than measured hydraulic conductivity K). In this study no attempt has been made to use Ka in the interpretations of the data.

TABLE 10

ANALYSIS OF VARIANCE, SATURATED HYDRAULIC CONDUCTIVITY$^{(K)}$ IN CM/HOUR

SUMMER 1971

Treatment	Hydraulic Conductivity in Cm/Hr 0-15 cm	15-30 cm	Ka 0-30 cm	Significant Level 5%	1%
T_1	2.360	0.464	0.776	a	x
T_2	1.331	0.139	0.252	b	y
T_3	1.311	0.134	0.243	b	y
T_4	2.126	0.275	0.487	a	x,y

$$Ka = \frac{(L_1 + L_2)\ K_1 K_2}{L_1\ K_2 + L_2\ K_1}$$

Ka = Average hydraulic conductivity 0 - 30 cm

K_1 = Hydraulic conductivity 0 - 15 cm

K_2 = Hydraulic conductivity 15-30 cm

L_1 = Length of the upper layer (0-15 cm)

L_2 = Length of the lower layer (15-30)

a, b are for 5% (0-15 cm and 15-30 cm)

x, y are for 1% (0-15 cm and 15-30 cm)

Hydraulic conductivities with no letter in common are statistically different. Hydraulic conductivities with one or more letters in common are <u>not</u> different.

Studies in the saturated hydraulic conductivities in lower depths (0-300 cm) have been done at 15 cm intervals, 3 replicates per irrigated and non-irrigated treatments. Results are tabulated im Appendix 1, Table 25. Depending on the desired depth, the water movement is governed by lowest K in each profile and this varies with depth and treatment. Treatment 1 has the highest K of all irrigated treatments at 0-150 cm depth and lowest K at 150-300 cm depth.

Also saturated hydraulic conductivity (K) was correlated with EC_i in mmho/cm and indices calculated from irrigation water composition (SAR_i, ESP_c, PI_i). Hydraulic conductivity decreased with the increase of SAR_i and ESP_c, but K increased with the increase of PI. These indices seem to respond very well with saturated K especially at 0-15 cm depth with low bulk densities (see Figs. 18-21 and Table 11 in Section C). Researchers such as McNeal (1965) and others, found similar results with disturbed samples. They observed that hydraulic conductivity decreases several hundred folds as ESP_c increases.

C. Bulk Density

The same 160 core samples used for determination of K in 1971, were used for determination of bulk density for 0-15 cm and 15-30 cm depth. The summary of the results of K, bulk density, and water composition indices are tabulated in Table 11. Further analysis of variance have been included in Table 12 for the two depths sampled. At both depths, Treatment 1 has the lowest bulk densities and Treatment 2 the highest at 0-15 cm depth. The next depth (15-30 cm) Treatment 3 has highest bulk density and Treatment 1 the lowest.

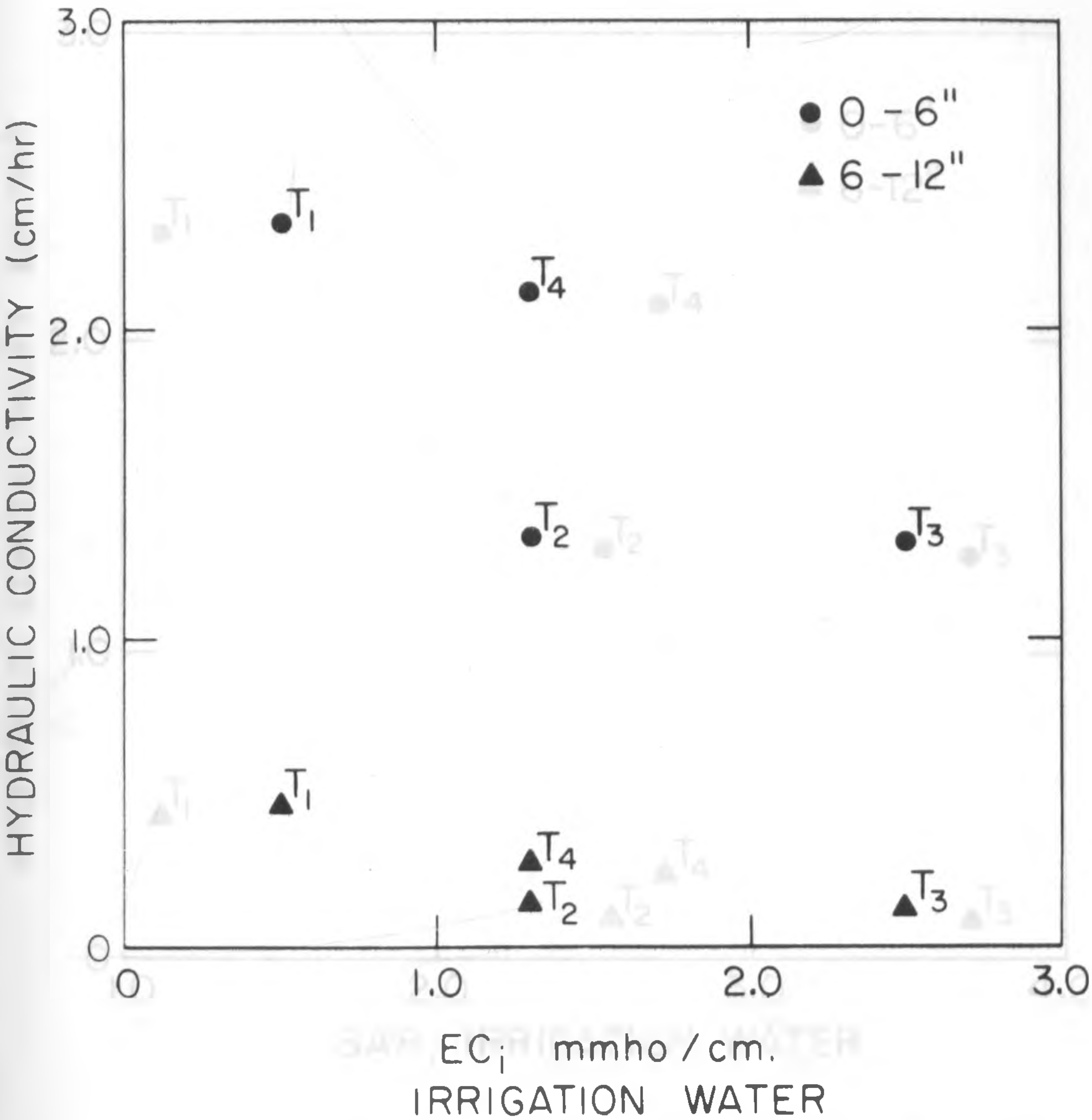


Fig. 18 Relationship between hydraulic conductivity in (cm/hr) and Electrical Conductivity (EC_i) in mmho/cm Irrigation Water. Treatments T_1, T_2, T_3 and T_4. Depth 0-15 cm (0-6") and 15-30 cm (6"-12"). Summer 1971.

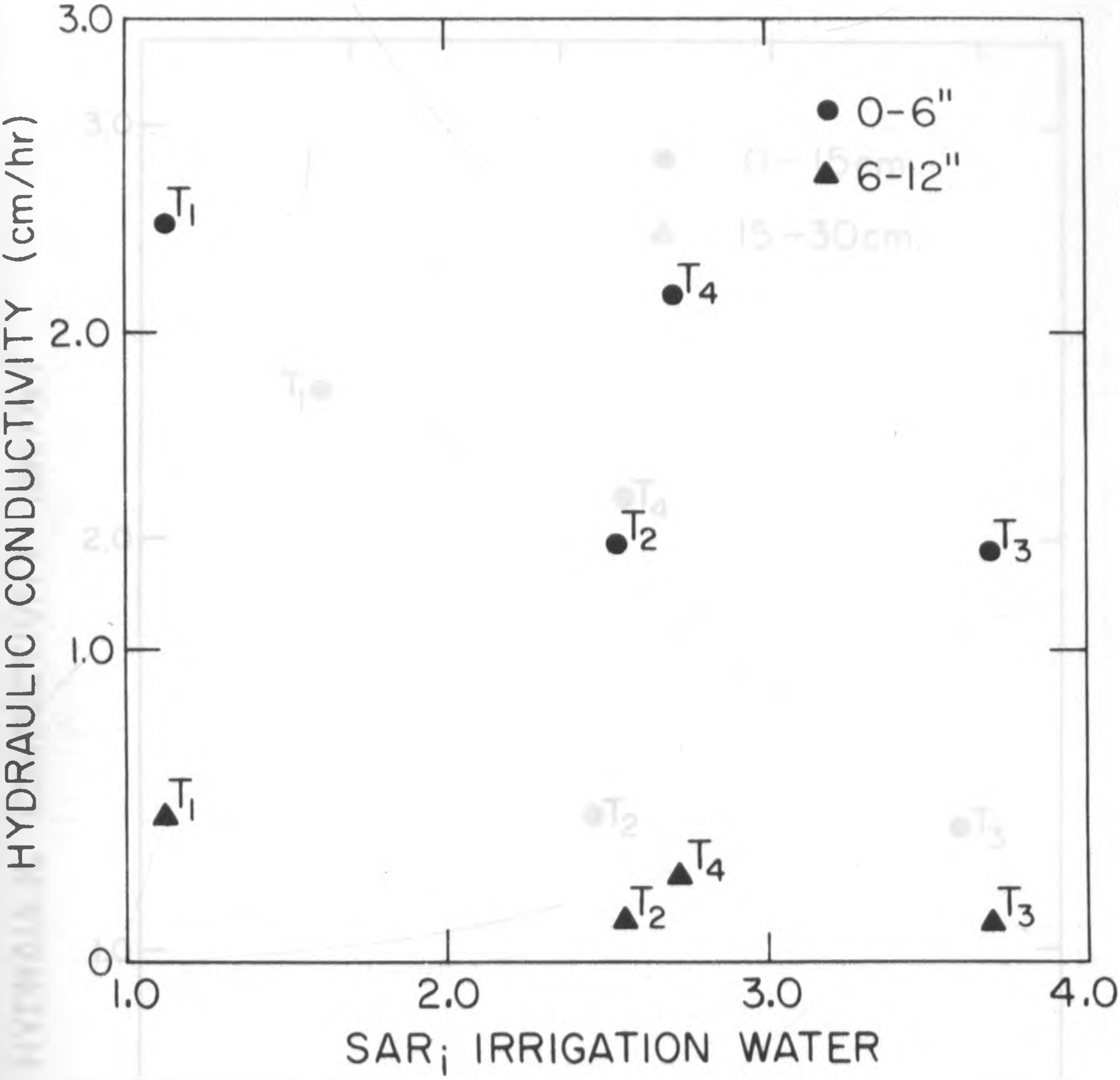


Fig. 19 Relationship between hydraulic conductivity in cm/hour and Sodium Adorption Ratio (SAR_i) of irrigation water. Treatments T_1, T_2, T_3 and T_4, and depths 0-15 cm (0-6") and 15-30 cm (6"-12"). Summer 1971.

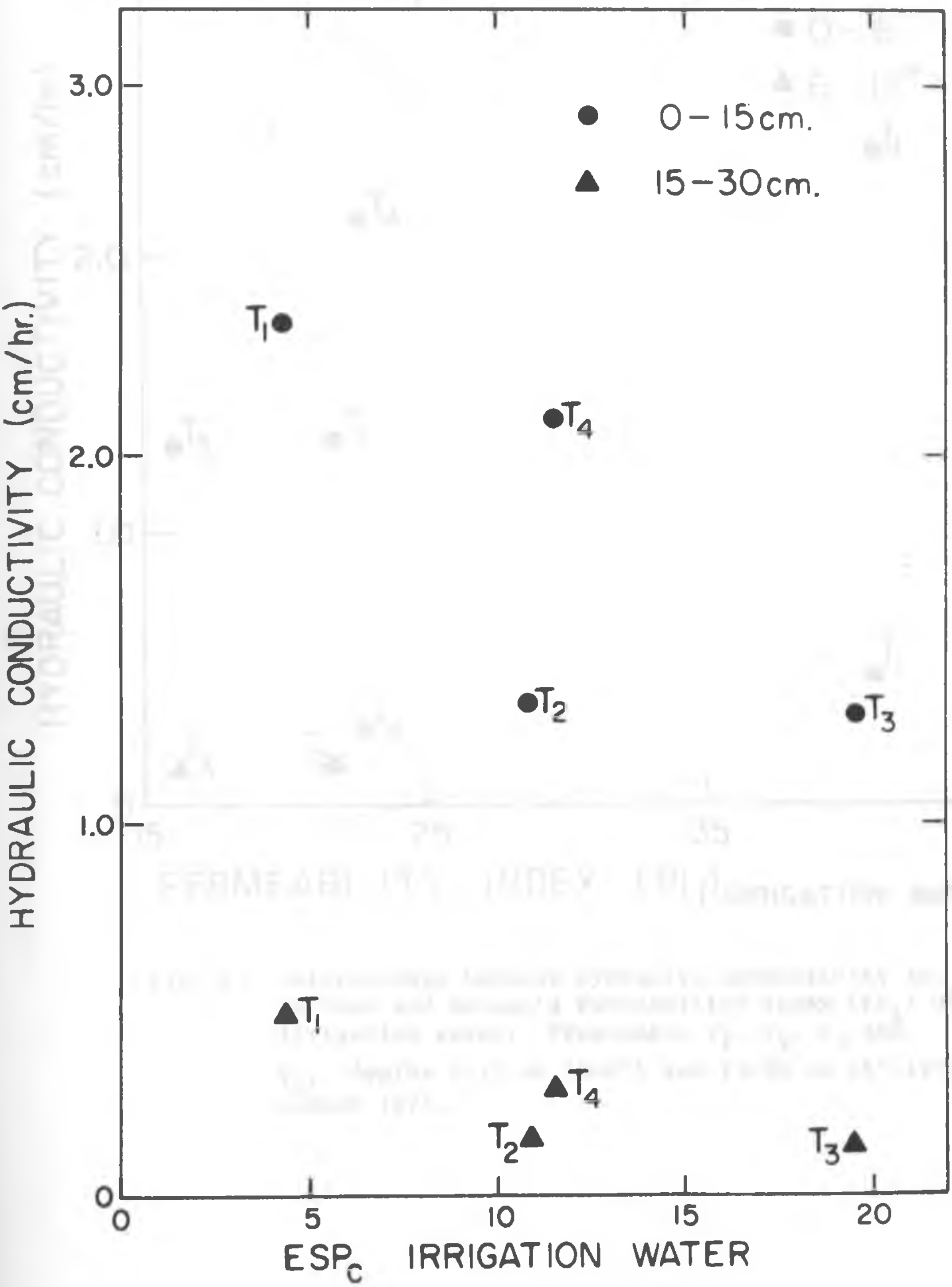


Fig. 20 Relationship between hydraulic conductivity in cm/hour and Exchangeable Sodium Percentage (ESP_c) of irrigation water. Treatments T_1, T_2, T_3 and T_4; depths 0-15 cm (0-6") and 15-30 cm (6"-12"), Summer 1971.

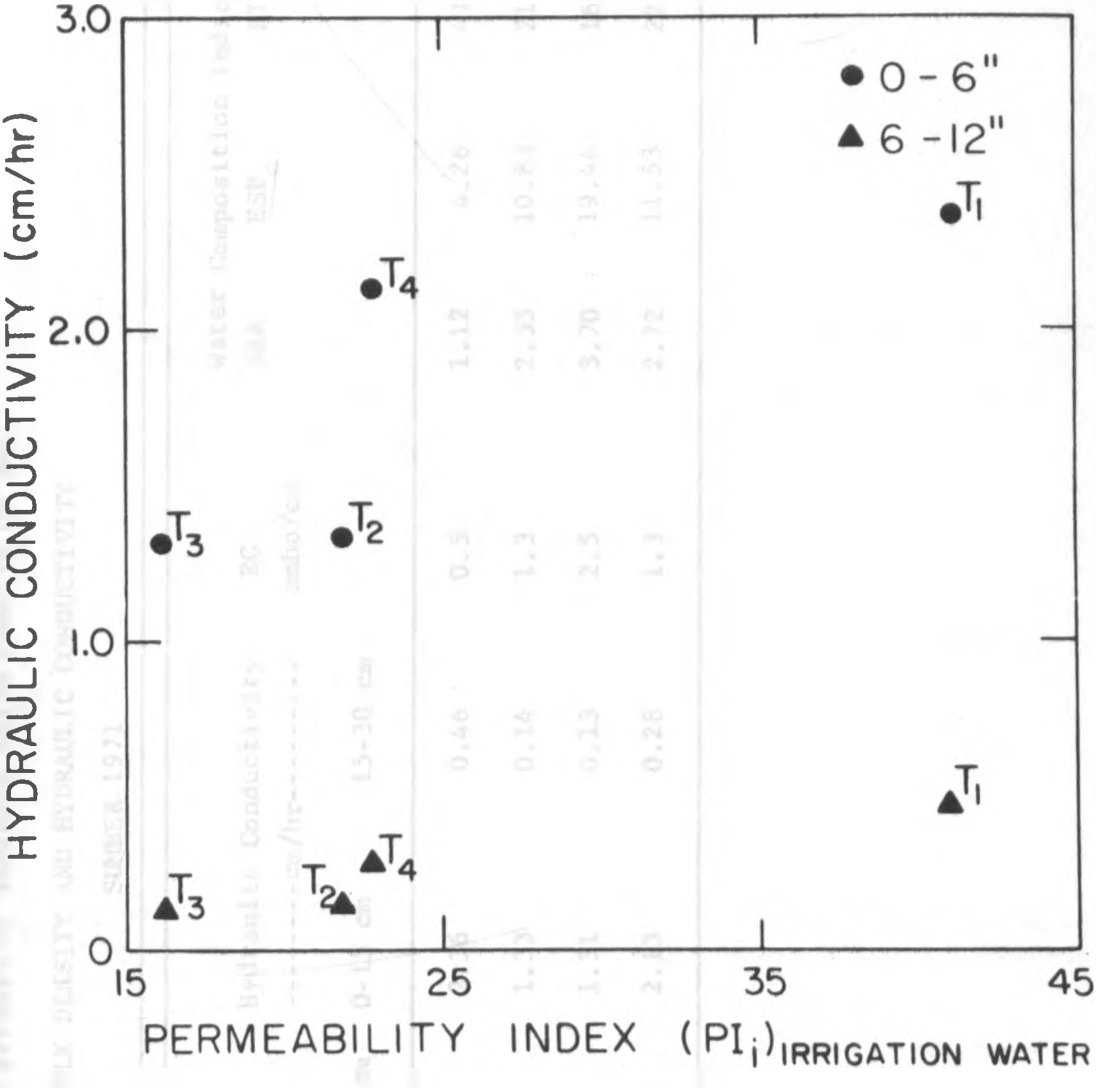


Fig. 21 Relationship between hydraulic conductivity in cm/hour and Doneen's Permeability Index (PI_i) of irrigation water. Treatments T_1, T_2, T_3 and T_4; depths 0-15 cm (0-6") and 15-30 cm (6"-12") Summer 1971.

TABLE 11

THE EFFECTS OF VARIABLE WATER QUALITY ON SOIL

BULK DENSITY AND HYDRAULIC CONDUCTIVITY

SUMMER 1971

Water Treat.	Bulk Density ------gm/cm^3--------		Hydraulic Conductivity --------cm/hr---------		EC mmho/cm	Water Composition Indices		
	0-13 cm	15-30 cm	0-15 cm	15-30 cm		SAR	ESP_c	PI
1	1.58	1.78	2.36	0.46	0.5	1.12	4.26	41.13
2	1.69	1.85	1.33	0.14	1.3	2.53	10.83	21.82
3	1.68	1.84	1.31	0.13	2.5	3.70	19.46	16.06
4	1.64	1.82	2.13	0.28	1.3	2.72	11.53	22.77

TABLE 12

ANALYSIS OF VARIANCE, BULK DENSITY IN GM/CM^3

SUMMER 1971

Treatment	Bulk Density 0-15 cm	Bulk Density 15-30 cm	Mean 0-30 cm	Significance Level[1] 5% (0-30 cm)	Significance Level[1] 1% (0-30 cm)
T_1	1.468	1.789	1.629	c	y
T_2	1.638	1.865	1.751	a	x
T_3	1.585	1.853	1.719	b	x
T_4	1.521	1.773	1.647	c	y

[1] Bulk densities with no letter in common are statistically different. Bulk densities with one or more letters in common are not different.

The bulk densities of Treatments 1 and 4 are different from Treatments 2 and 3 at 1% significant level. However, the analysis of bulk densities in 1972, in which soil cores were sampled at 15 cm intervals down to 300 cm depth, indicated that bulk densities in all irrigated treatments and the non-irrigated treatment (T_5) were not statistically different at the 5% and 1% levels. However, both were not significant at averaged intervals of 0-150 cm and 150-300 cm (Table 13). However, Treatments 1 and 5 had the lowest bulk densities at 0-150 cm and Treatment 1 had the highest bulk density at 150-300 cm.

The bulk densities data at 0-15 and 15-30 cm in Summer 1971 were related to EC_i and irrigation water composition indices (Fig. 22-25). The results showed a bulk density increase with an increase of EC_i, SAR_i, ESP_c and a decrease as PI_i increases. The bulk densities in all treatments (T_1, T_2, T_3 and T_4) are sensitive to the above indices.

In 1972 further studies were conducted to estimate the area covered by water 24, 48 and 72 hours after irrigation (Fig. 26-28). After 24 hours of irrigation, large areas in all the treatments were still covered with water (Fig. 26). The big difference appears 48 hours after irrigation. No water patches were present on any of the replicates of Treatment 1. Whereas there were some water patches on Treatments 2, 3 and 4 (Fig. 27). A tensiometer in Treatment 3 (Fig. 28), indicates 0.48 bars at 45 cm (18") depth 72 hours after irrigation. Thus, no water has reached this layer.

As shown with qualitative and quantitative studies in the field and in the laboratory, movement of irrigation water is controlled by

TABLE 13

BULK DENSITY CM/CM^3, ANALYSIS OF VARIANCE,

JUNE 1972

Treatment	---------Bulk Density--------- in gm/cm^3		Significance Level[1] (0-150 cm and 150-300 cm)	
	0-150 cm	150-300 cm	5%	1%
T_1	1.77	1.83	a	x
T_2	1.80	1.80	a	x
T_3	1.83	1.76	a	x
T_4	1.83	1.76	a	x
T_5	1.76	1.78	a	x

[1] Bulk densities with no letter in common are statistically different. Bulk densities with one or more letters in common are not different.

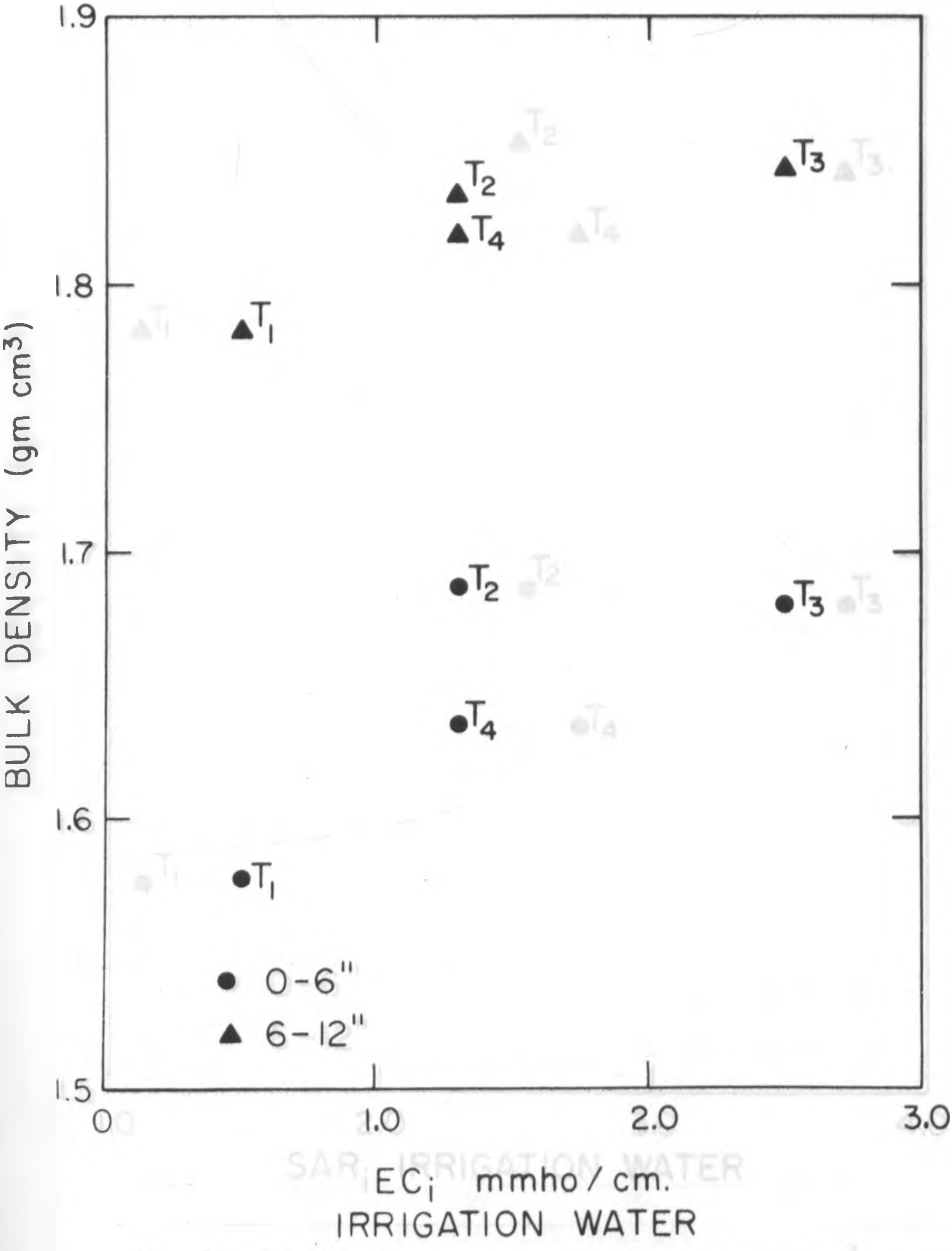


Fig. 22 Relationship between Bulk Density in gm/cm^3 and Electrical Conductivity (EC_i) in mmho/cm of irrigation water. Treatments T_1, T_2, T_3 and T_4. Depth 0-15 cm (0-6") and 15-30 cm (6"-12"). Summer 1971.

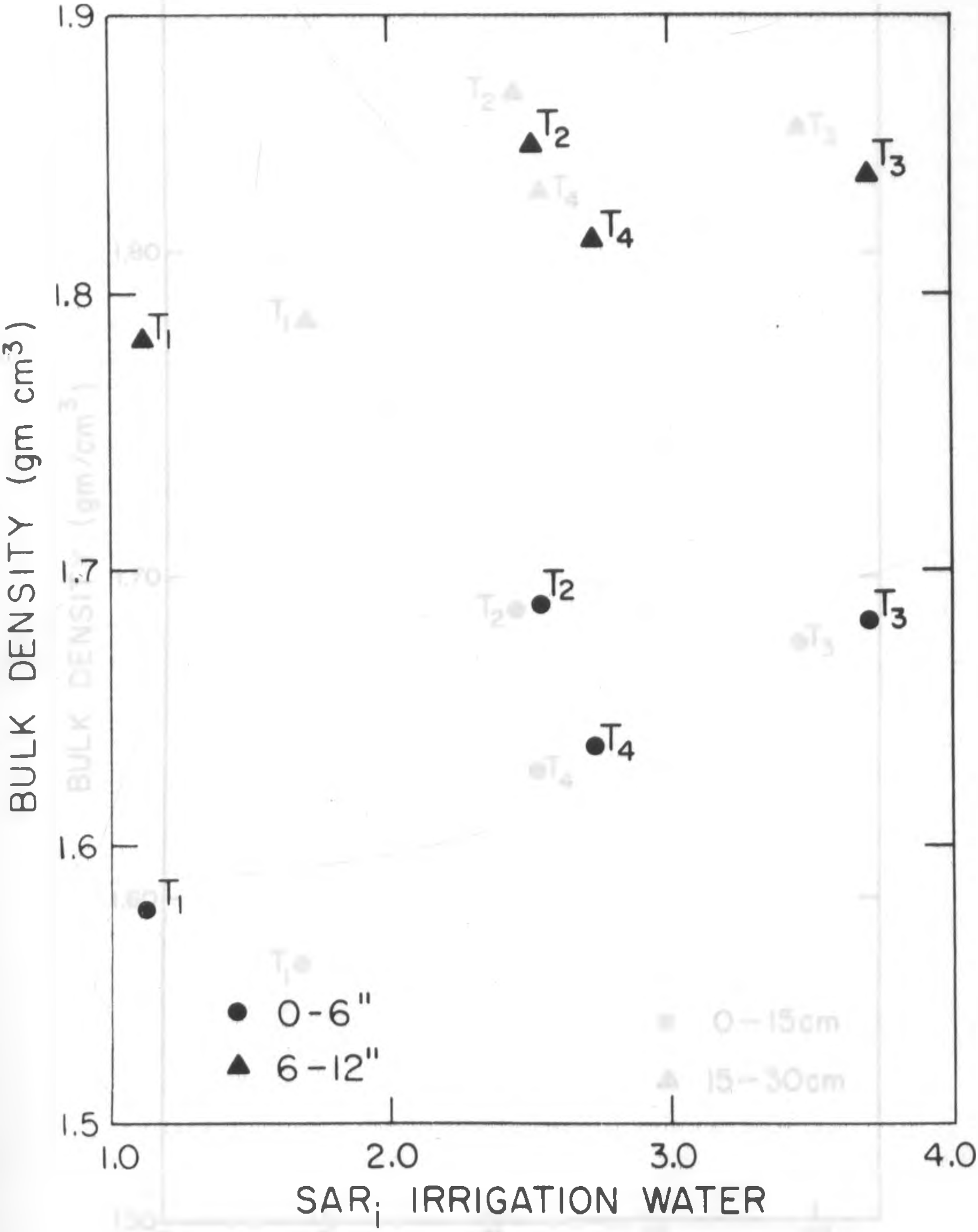


Fig. 23 Relationship between Bulk Density in gm/cm^3 and Sodium Adsorption Ratio (SAR_i) of irrigation water. Treatments T_1, T_2, T_3 and T_4. Depth 0-15 cm (0-6") and 15-30 cm (6"-12"); Summer 1971.

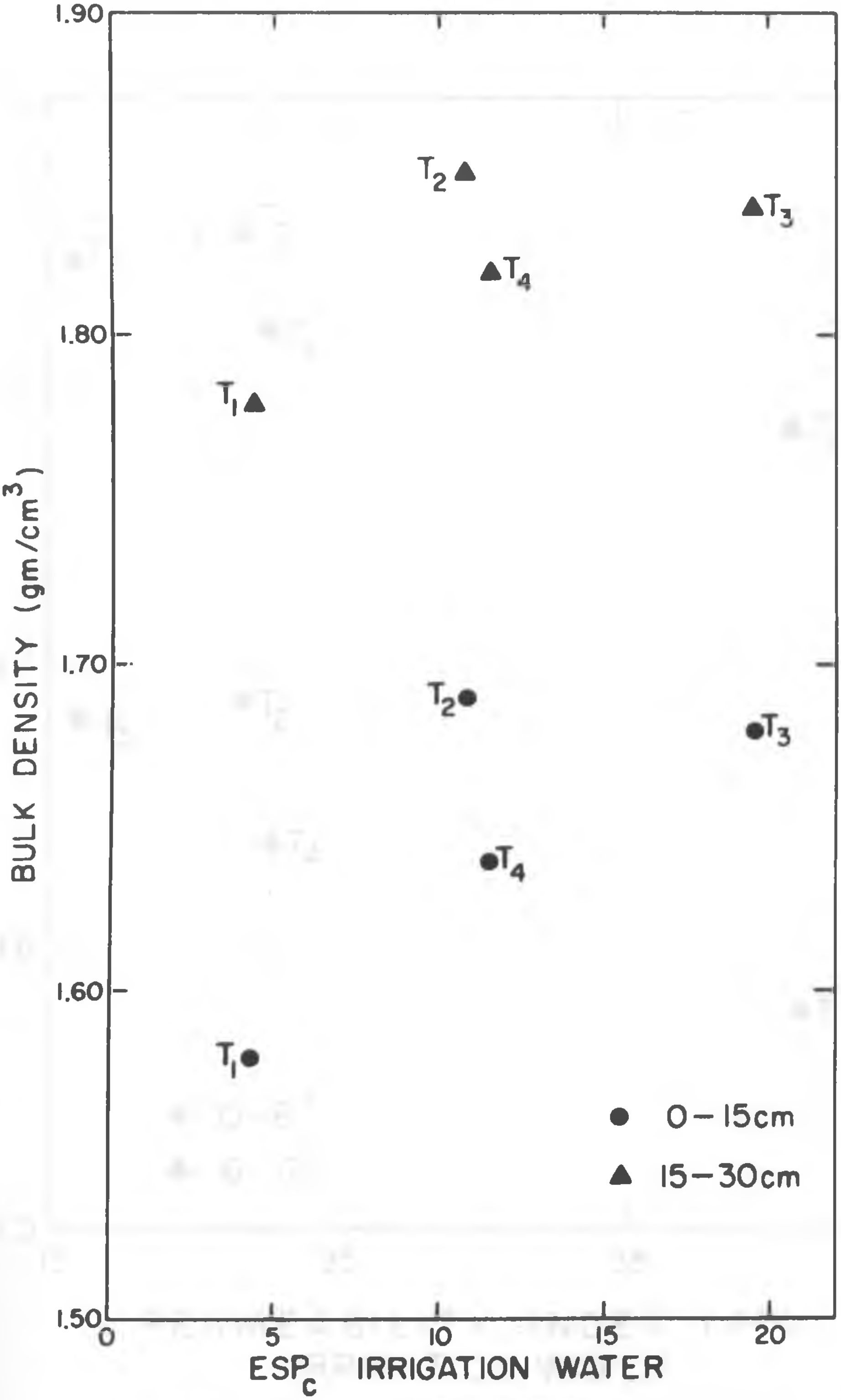


Fig. 24 Relationship between Bulk Density in gm/cm^3 and Exchangeable Sodium Percentage (ESP_c) of irrigation water. Treatments T_1, T_2, T_3, and T_4. Depth 0-15 cm (0-6") and 15-30 cm(6"-12"); Summer 1971.

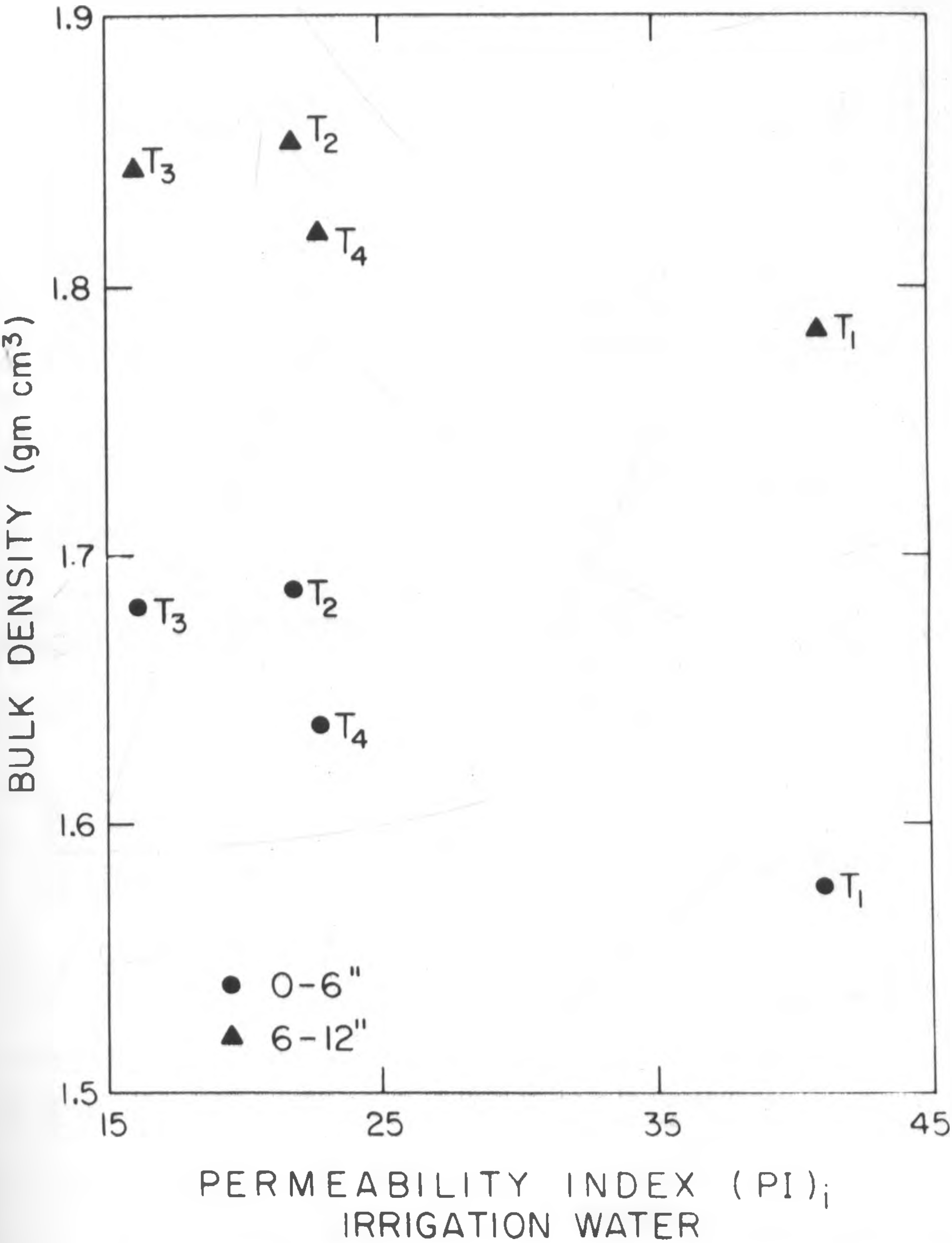
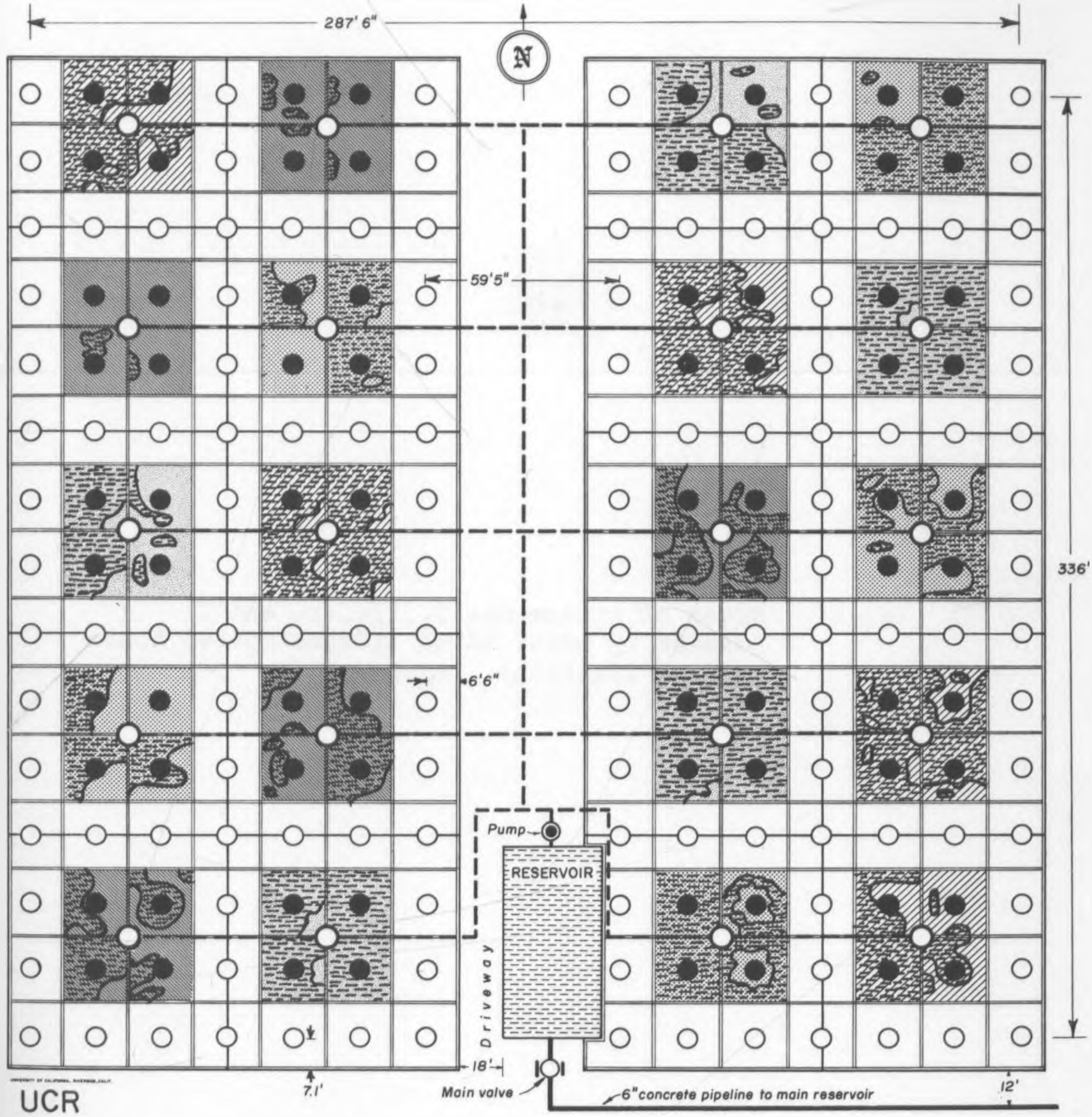


Fig. 25 Relationship between Bulk Density in gm/cm^3 and Doneen's Permeability Index (PI_i) of irrigation water. Treatments T1, T2, T3 and T4. Depths 0-15 cm (0-6") and 15-30 cm (6"-12"); Summer 1971.

Fig. 26 Areas of treatments T_1, T_2, T_3, and T_4 covered by water after irrigation (24 hours after irrigation). Spring 1972.

Pennsylvania Avenue

AREA COVERED BY WATER AFTER 24 HRS **FIELD 10-B**



TREATMENT: WATER COMPOSITION:

No.1 Gage Canal water

No.2 Synthesized Colorado River water

No.3 Synthesized high sulfate water

No.4 Synthesized high chloride water with a 50-50 ratio Ca to Na

○ - Plastic riser with brass valve

NUMBER OF TREES (all Valencia)

○ Guards	130	on Cleo Stock
● Treatment	80	on Troyer Stock
Total	210	

SPACING:

N – S 24 Ft.
E – W 19 Ft. approx.

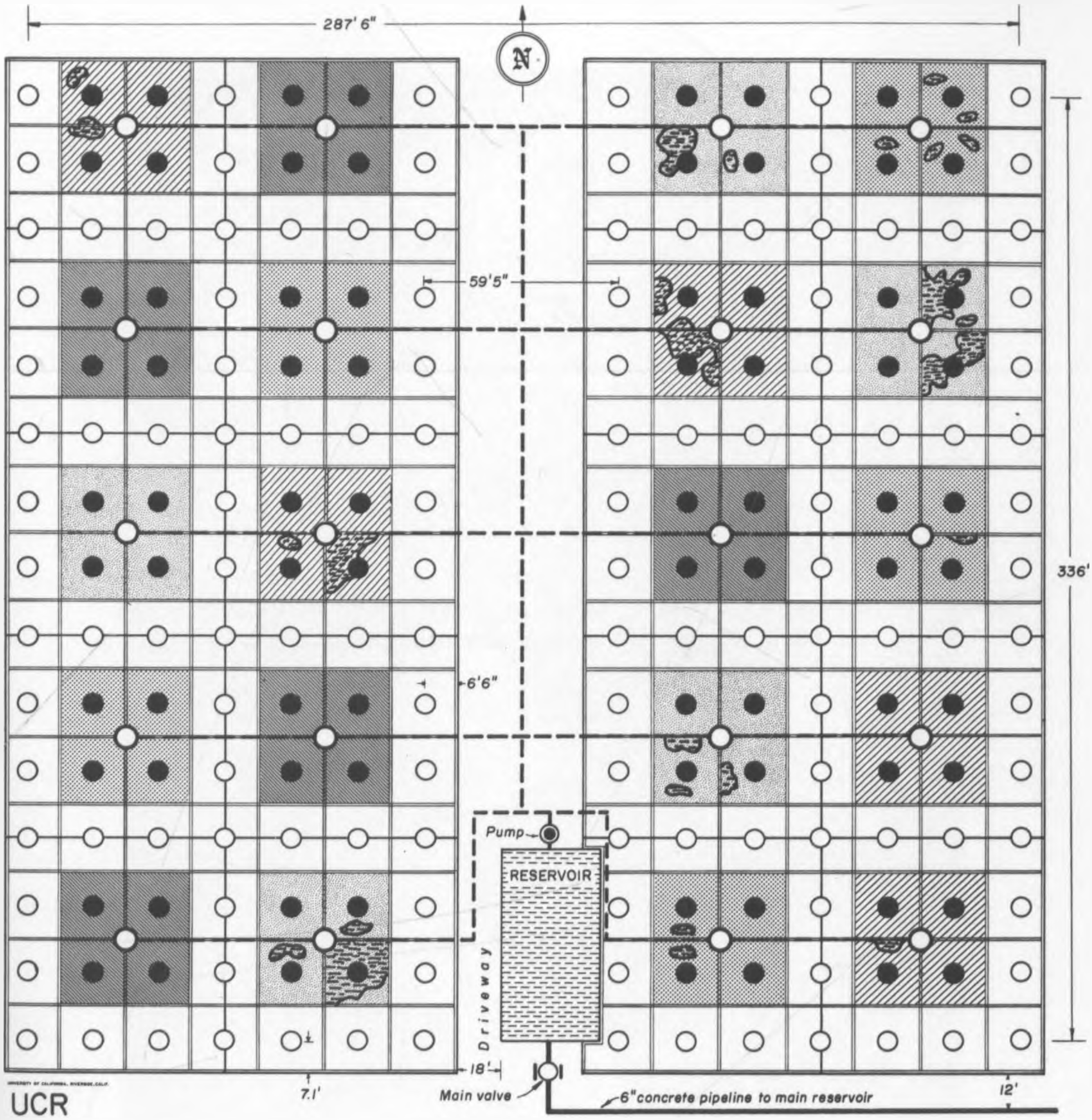
First tree from irrigation stand = 5 Ft.

Area covered by water

Fig.27 Areas of treatments T_1, T_2, T_3 and T_4 covered by water after irrigation (48 hours after irrigation). Spring 1972.

Pennsylvania Avenue

AREA COVERED BY WATER AFTER 48 HRS — FIELD 10-B



TREATMENT: **WATER COMPOSITION:**

- No.1 Gage Canal water
- No.2 Synthesized Colorado River water
- No.3 Synthesized high sulfate water
- No.4 Synthesized high chloride water with a 50-50 ratio Ca to Na

○ - Plastic riser with brass valve

NUMBER OF TREES (all Valencia)

○ Guards	130	on Cleo Stock
● Treatment	80	on Troyer Stock
Total	210	

SPACING:

N – S 24 Ft.
E – W 19 Ft. approx.

First tree from irrigation stand = 5 Ft.

Area covered by water

Fig. 28 Treatment 3. Tensiommeter indicated 48 centibars (0.48 bar) 72 hours after irrigation. Spring 1972.


MORE THAN 72 HRS.
AFTER IRRIGATION

the layer below 0-15 with low hydraulic conductivities and high bulk densities, especially the first and the second day after irrigation. During this period larger quantities of water may evaporate especially in the summer when evaporation can be as high as 1.27 cm/day or 0.5"/day (see Appendix 2).

D. Clay Distribution and Migration

Initially soil particle analysis was done in 1957. The data were not tested to see if there was statistical differences within the treatments. The statistical analysis of variance on these data were conducted at the end of 1971. However, the analyses showed that there were no statistically significant differences in replication, treatments, and depth X treatment (D X T) with sand, silt and clay contents in percentage, although statistically there were significant differences with depth. Sand contents increased with depth whereas silt and clay contents decreased with depth; (Table 14 and 15, and Appendix 3).

Further studies were conducted in Spring 1972 to investigate the effects of variable water quality on soil texture distribution. Non-irrigated treatment (T_5) located at the middle portion of the experiment (Fig. 1) was used as the control treatment to evaluate the effects of irrigation on clay distribution. Disturbed samples were sampled at intervals 15 cm down to 300 cm. Soil particle analysis of 3 replicates/treatment showed big differences on clay distributions of the irrigated and non-irrigated treatments. The actual results obtained are shown in Fig. 29..

For each treatment, a polynomial curve with first, second, third and fifth degree terms was fitted to the average percent clay at each depth. The fourth degree term was not significant. Multiple range,

TABLE 14

CITRUS IRRIGATION EXPERIMENT, FIELD 10-B

(INITIAL CONDITION)

1957

CLAY CONTENTS IN PERCENTAGE

Depth in cm	Treatments T_1	T_2	T_3	T_4	Mean/Depth	Significance Level[1] 5%	1%
30	13.40	13.60	13.50	13.00	13.40	a	x
60	13.60	13.80	13.80	13.00	13.55	a	x
90	12.40	12.60	12,20	12.40	12.40	b	y
120	8.40	8.20	7.60	8.40	8.15	c	z
R = Replication							N.S.
T = Treatment							N.S.
D = Depth							**(1%)
D x T = Depth x Treatment							N.S.

[1]Clay contents in percentage with no letter in common are statistically different. Clay contents with one or more letters in common are not different.

TABLE 15

DUNCAN'S MULTIPLE RANGE TEST OF MEAN DIFFERENCES, 1972 TREATMENTS (T_1, T_2, T_3, T_4) VS. 1972 NON-IRRIGATED TREATMENTS (T_5)

CLAY CONTENT IN PERCENTAGE

Depth	Treatment					Significance Level[1]									
						5%					1%				
	T_1	T_2	T_3	T_4	T_5	T_1	T_2	T_3	T_4	T_5	T_1	T_2	T_3	T_4	T_5
0-30	14.23	13.27	14.60	15.13	11.57	a	a	a	a	a	z	z	z	z	z
30-60	16.37	17.37	18.03	18.37	13.57	a,b	a	a	a	b	z	z	z	z	z
60-90	16.00	16.17	16.83	17.23	13.67	a	a	a	a	a	z	z	z	z	z
90-120	13.83	13.83	14.00	14.13	12.60	a	a	a	a	a	z	z	z	z	z

T_5 = Non-irrigated treatment

[1] Clay content with no letters in common are statistically different. Clay content with one or more letters in common are not different.

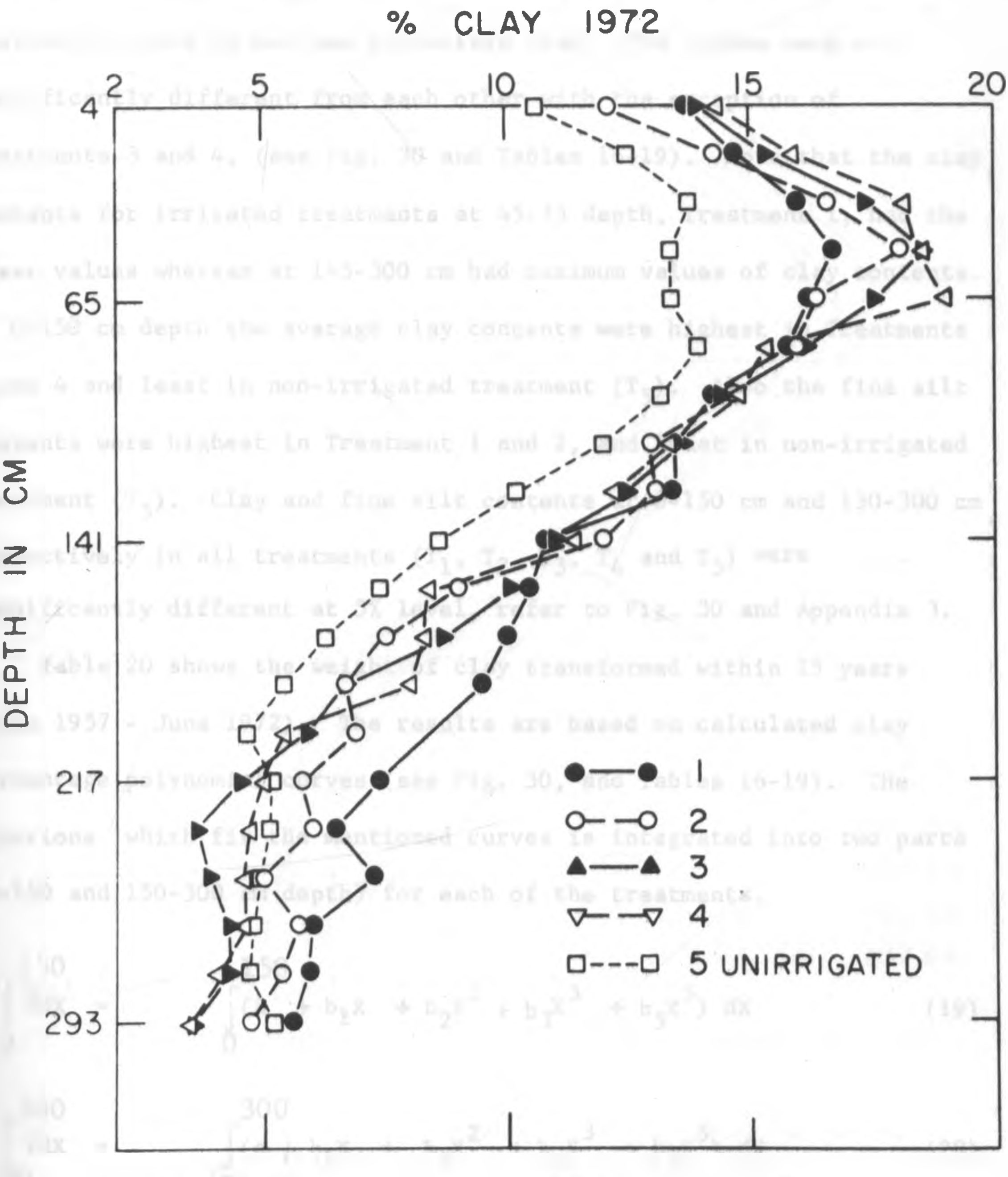


Fig. 29 The influence of variable water quality on clay distribution in percentage. Treatments T_1, T_2, T_3 and T_4 and unirrigated treatment, depth 0-300 cm (0-10 ft) Spring 1972.

tests between treatments were done on the regression coefficients, the intercept and the height of the curves at 49.53 cm (the point of maximum or close to maximum percentage clay). The curves were all significantly different from each other with the exception of Treatments 3 and 4, (see Fig. 30 and Tables 16-19). Note that the clay contents for irrigated treatments at 45-75 depth, Treatment 1, had the least values whereas at 145-300 cm had maximum values of clay contents. At 0-150 cm depth the average clay concents were highest in Treatments 3 and 4 and least in non-irrigated treatment (T_5). Also the fine silt contents were highest in Treatment 1 and 2, and least in non-irrigated treatment (T_5). Clay and fine silt contents at 0-150 cm and 150-300 cm respectively in all treatments (T_1, T_2, T_3, T_4 and T_5) were significantly different at 5% level, refer to Fig. 30 and Appendix 3.

Table 20 shows the weight of clay transformed within 15 years (June 1957 - June 1972). The results are based on calculated clay percentage polynomial curves (see Fig. 30, and Tables 16-19). The equations which fit the mentioned curves is integrated into two parts (0-150 and 150-300 cm depth) for each of the treatments.

$$\int_0^{150} \bar{Y}dX = \int_0^{150} (a + b_1X + b_2X^2 + b_3X^3 + b_5X^5)\, dX \qquad (19)$$

$$\int_{150}^{300} \bar{Y}dX = \int_{150}^{300} (a + b_1X + b_2X^2 + b_3X^3 + b_5X^5)\, dX \qquad (20)$$

The terms are already defined in Tables 16-19 and further calculations are shown in Table 20, (see computer output Appendix 5).

Results indicate the treatments irrigated with high salinity water

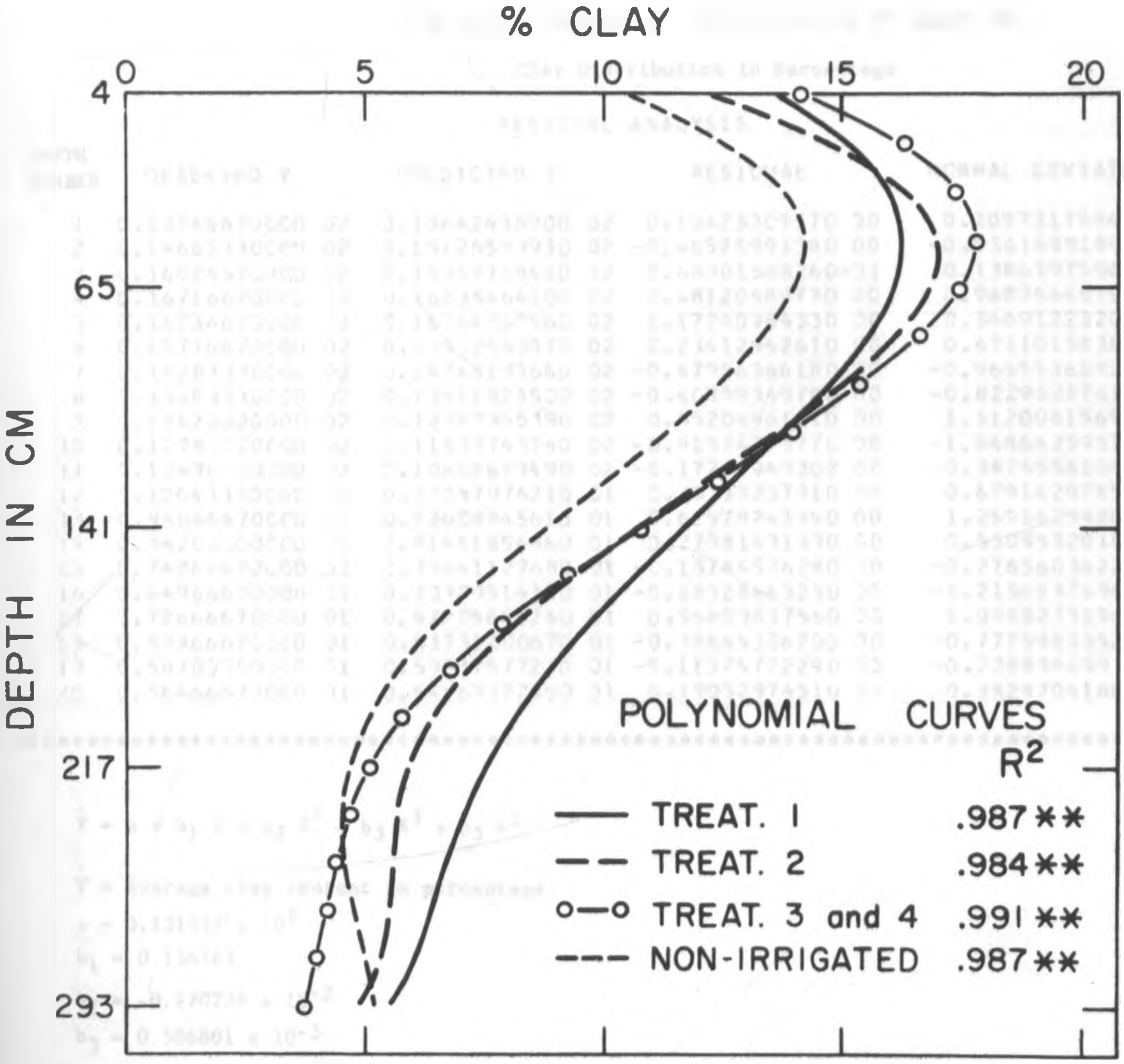


Fig. 30 Fitted Clay Polynomial curves from the actual analysis data. Treatments: T_1, T_2, T_3, T_4 and non-irrigated treatments, Spring 1972. Multiple range test done on the regression coefficients, intercepts, and the point of maximum or close to maximum % clay (49.53 cm), ** (1%).

Table 16 Treatment 1. Relationships of Depth and Clay Distribution in Percentage

RESIDUAL ANALYSIS

DEPTH NUMBER	OBSERVED Y	PREDICTED Y	RESIDUAL	NORMAL DEVIATE
1	0.1374667000D 02	0.1364243690D 02	0.1042330957D 00	0.2097317594
2	0.1466333000D 02	0.1512858993D 02	-0.4652599338D 00	-0.9361689189
3	0.1602667000D 02	0.1595776841D 02	0.6890158826D-01	0.1386397596
4	0.1671667000D 02	0.1623546410D 02	0.4812058977D 00	0.9682544579
5	0.1623667000D 02	0.1606426056D 02	0.1724094433D 00	0.3469122320
6	0.1577667000D 02	0.1554254057D 02	0.2341294261D 00	0.4711015838
7	0.1428333000D 02	0.1476319366D 02	-0.4798636618D 00	-0.9655536892
8	0.1340333000D 02	0.1381232350D 02	-0.4089934978D 00	-0.8229528761
9	0.1342000000D 02	0.1276795539D 02	0.6520446101D 00	1.3120061569
10	0.1078000000D 02	0.1169874374D 02	-0.9187437377D 00	-1.8486425957
11	0.1049000000D 02	0.1066267949D 02	-0.1726794930D 00	-0.3474556104
12	0.1004333000D 02	0.9705797621D 01	0.3375323791D 00	0.6791629785
13	0.9486667000D 01	0.8860884561D 01	0.6257824395D 00	1.2591629480
14	0.8420000000D 01	0.8146185686D 01	0.2738143139D 00	0.5509532018
15	0.7426667000D 01	0.7564112768D 01	-0.1374457678D 00	-0.2765603622
16	0.6496667000D 01	0.7099951432D 01	-0.6032844323D 00	-1.2138937694
17	0.7266667000D 01	0.6720568624D 01	0.5460983756D 00	1.0988273196
18	0.5986667000D 01	0.6373120067D 01	-0.3864533067D 00	-0.7775983352
19	0.5870000000D 01	0.5983757723D 01	-0.1137577229D 00	-0.2288966591
20	0.5646667000D 01	0.5456337255D 01	0.1903297451D 00	0.3829704188

****

$\bar{Y} = a + b_1 X + b_2 X^2 + b_3 X^3 + b_5 X^5$

$\bar{Y}$ = Average clay content in percentage

$a = 0.131557 \times 10^2$

$b_1 = 0.134163$

$b_2 = -0.170276 \times 10^{-2}$

$b_3 = 0.506801 \times 10^{-5}$

$b_5 = -0.131020 \times 10^{-10}$

X = Depth in cm = [(Depth number)(6) -4.5] 2.54

$R^2 = 0.987162$ ** (1%)

Table 17 Treatment 2. Relationships of Depth

and Clay Distribution in Percentage

RESIDUAL ANALYSIS

DEPTH NUMBER	OBSERVED Y	PREDICTED Y	RESIDUAL	NORMAL DEVIATE
1	0.1214333000D 02	0.1207446155D 02	0.6886844967D-01	0.1045963749
2	0.1434667000D 02	0.1480508194D 02	-0.4584119434D 00	-0.6962292271
3	0.1659333000D 02	0.1639829968D 02	0.1950303155D 00	0.2962091363
4	0.1811667000D 02	0.1704526440D 02	0.1071405602D 01	1.6272348591
5	0.1637667000D 02	0.1693160882D 02	-0.5549388227D 00	-0.8428328127
6	0.1598333000D 02	0.1623499686D 02	-0.2516668617D 00	-0.3822278784
7	0.1459667000D 02	0.1512267163D 02	-0.5260016339D 00	-0.7988834416
8	0.1303333000D 02	0.1374900352D 02	-0.7156735246D 00	-1.0869542822
9	0.1314333000D 02	0.1225303824D 02	0.8902917640D 00	1.3521618616
10	0.1200333000D 02	0.1075604484D 02	0.1247285162D 01	1.8943581134
11	0.9036667000D 01	0.9359063819D 01	-0.3223968192D 00	-0.4896514838
12	0.7486667000D 01	0.8140455137D 01	-0.6537881370D 00	-0.9929636779
13	0.6693333000D 01	0.7153446269D 01	-0.4601132689D 00	-0.6988131749
14	0.6940000000D 01	0.6423680263D 01	0.5163197371D 00	0.7841787211
15	0.5820000000D 01	0.5946763789D 01	-0.1267637885D 00	-0.1925269526
16	0.6050000000D 01	0.5685815187D 01	0.3641848128D 00	0.5531184656
17	0.4990000000D 01	0.5569012523D 01	-0.5790125231D 00	-0.8793955901
18	0.5743333000D 01	0.5487141634D 01	0.2561913659D 00	0.3890996281
19	0.5440000000D 01	0.5291144182D 01	0.1488558180D 00	0.2260799977
20	0.4680000000D 01	0.4789665704D 01	-0.1096657038D 00	-0.1665586364

****

$\bar{Y} = a + b_1 X + b_2 X^2 + b_3 X^3 + b_3 X^5$

$\bar{Y}$ = Average clay content in percentage

$a = 0.111914 \times 10^{2}$

$b_1 = 0.242974$

$b_2 = -0.297162 \times 10^{-2}$

$b_3 = 0.919173 \times 10^{-5}$

$b_5 = -0.248545 \times 10^{-10}$

X = Depth in cm = [(Depth number)(6) -4.5] 2.54

$R^2 = 0.983832$ ** (1%)

Table 18 Treatments 3 and 4. Relationships of

Depth and Clay Distribution in Percentage

RESIDUAL ANALYSIS

DEPTH NUMBER	OBSERVED Y	PREDICTED Y	RESIDUAL	NORMAL DEVIATE
1	0.1417333500D 02	0.1413209111D 02	0.4124389358D-01	0.0706492330
2	0.1557167000D 02	0.1627469512D 02	-0.7030251181D 00	-1.2042554923
3	0.1781000000D 02	0.1743658120D 02	0.3734187982D 00	0.6396523069
4	0.1857666500D 02	0.1777807234D 02	0.7985926558D 00	1.3679590771
5	0.1831667000D 02	0.1745519837D 02	0.8614716284D 00	1.4756683839
6	0.1576000000D 02	0.1661778788D 02	-0.8577878786D 00	-1.4693582595
7	0.1462000000D 02	0.1540756016D 02	-0.7875601564D 00	-1.3490608221
8	0.1348833500D 02	0.1395621712D 02	-0.4678821222D 00	-0.8014644155
9	0.1232167000D 02	0.1238353525D 02	-0.6186524735D-01	-0.1059728337
10	0.1120000000D 02	0.1079545749D 02	0.4045425137D 00	0.6929660570
11	0.9230001500D 01	0.9282185205D 01	-0.5218370495D-01	-0.0893887170
12	0.8545000000D 01	0.7916270110D 01	0.6287298901D 00	1.0769905709
13	0.7360000000D 01	0.6750706177D 01	0.6092938234D 00	1.0436973222
14	0.5631667000D 01	0.5817021578D 01	-0.1853545784D 00	-0.3175053968
15	0.4758333500D 01	0.5123370615D 01	-0.3650371150D 00	-0.6252948000
16	0.4153333500D 01	0.4652625641D 01	-0.4992921413D 00	-0.8552685927
17	0.4235000000D 01	0.4360468996D 01	-0.1254689960D 00	-0.2149236544
18	0.4461666500D 01	0.4173484930D 01	0.2881815697D 00	0.4936441517
19	0.4216666500D 01	0.3987251537D 01	0.2294149632D 00	0.3929791729
20	0.3535000000D 01	0.3664432678D 01	-0.1294326777D 00	-0.2217132916

$\bar{Y} + a + b_1 X + b_2 X^2 + b_3 X^3 + b_5 X^5$

$\bar{Y}$ + Average clay content in percentage

$a = 0.134242 \times 10^2$

$b_1 = 0.195410$

$b_2 = -0.254944 \times 10^{-2}$

$b_3 = 0.769781 \times 10^{-5}$

$b_5 = -0.193414 \times 10^{-10}$

X = Depth in cm = [(Depth number)(6) - 4.5] 2.54

$R^2 = 0.990741$ ** (1%)

Table 19 Non-Irrigated Treatment. Relationships of Depth and Clay Distribution in Percentage

RESIDUAL ANALYSIS

DEPTH NUMBER	OBSERVED Y	PREDICTED Y	RESIDUAL	NORMAL DEVIATE
1	0.1060333000D 02	0.1035463610D 02	0.2486938962D 00	0.5189530148
2	0.1248667000D 02	0.1247784774D 02	0.8822256826D-02	0.0184095261
3	0.1376333000D 02	0.1370331322D 02	0.6001678422D-01	0.1252378590
4	0.1339333000D 02	0.1417838783D 02	-0.7850578261D 00	-1.6381910932
5	0.1338000000D 02	0.1404657996D 02	-0.6665799634D 00	-1.3909616879
6	0.1393000000D 02	0.1344584136D 02	0.4841586390D 00	1.0103005711
7	0.1317333000D 02	0.1250685736D 02	0.6664726432D 00	1.3907377414
8	0.1203333000D 02	0.1135133715D 02	0.6819928474D 00	1.4231239675
9	0.1016333000D 02	0.1009030407D 02	0.7302592598D-01	0.1523842162
10	0.8640000000D 01	0.8822385830D 01	-0.1823858305D 00	-0.3805870512
11	0.7423333000D 01	0.7632104775D 01	-0.2087717749D 00	-0.4356469687
12	0.6263333000D 01	0.6588163163D 01	-0.3248351635D 00	-0.6778380571
13	0.5363333000D 01	0.5741758416D 01	-0.3784254156D 00	-0.7896655820
14	0.4586667000D 01	0.5124823373D 01	-0.5381563735D 00	-1.1229783953
15	0.5210000000D 01	0.4748366562D 01	0.4616334376D 00	0.9632969198
16	0.5050000000D 01	0.4600737450D 01	0.4492625499D 00	0.9374824163
17	0.4853333000D 01	0.4645921707D 01	0.2074112934D 00	0.4328080329
18	0.4813333000D 01	0.4821831464D 01	-0.8498464442D-02	-0.0177338640
19	0.4733333000D 01	0.5038595578D 01	-0.3052625781D 00	-0.6369956706
20	0.5233333000D 01	0.5176849884D 01	0.5648311620D-01	0.1178641048

****

$\bar{Y} = a + b_1 X + b_2 X^2 + b_3 X^3 + b_5 X^5$

$\bar{Y}$ = Average clay content in percentage

$a = 0.966606 \times 10^1$

$b_1 = 0.189522$

$b_2 = -0.233522 \times 10^{-2}$

$b_3 = 0.707174 \times 10^{-5}$

$b_5 = -0.173310 \times 10^{-10}$

X = Depth in cm = [(Depth number)(6) - 4.5] 2.54

$R^2 = 0.987092$ **(1%)

TABLE 20

THE INFLUENCE OF WATER ON CLAY TRANSFORMATION

JUNE 1957 - JUNE 1972 (15 YEARS)

Treat.	Depth in Cm	Area (A) Clay % Integrated From Curves	(A) % Clay[1] /15 Yrs./1 m^2/ Depth	Average % Clay Due to Irrig. Water /15 Yrs./1 m^2/cm	Average Bulk Density per Depth in gm/cm^3	Weight of Clay Due to Irrig. Water in Kg/15 Yrs./ 1 m^2/Depth[2]	Weight of Total Clay in Kg/15 Yrs./ 1 m^2/300 cm Depth
T_1	0-150	2183.63	366.61	2.444	1.77	64.8882	126.6507
	150-300	1146.31	337.49	2.250	1.83	61.7625	
T_2	0-150	2185.24	368.22	2.455	1.80	66.2850	92.5830
	150-300	954.85	146.03	0.974	1.80	26.2980	
T_3	0-150	2281.42	464.40	3.096	1.83	84.9852	89.1564
	150-300	832.46	23.64	0.158	1.76	4.1712	
T_4	0-150	2281.42	464.40	3.096	1.83	84.9852	89.1564
	150-300	832.46	23.64	0.158	1.76	4.1712	
T_5	0-150	1817.02	—	—	1.76	—	—
	150-300	808.82	—	—	1.78	—	—

1 Δ (A) % Clay = $(A)\,T_{(i)} - (A)\,T5_{(j)}$

i = Corresponding treatment numbers 1,2,3,4,5

j = Corresponding treatment depths (0-150 cm) and (150-300 cm)

2 Wt of Clay/Depth = (ρ_b) x (V) x (Average % Clay/15Yrs./1 m^2/cm)

ρ_b = Bulk density in gm/cm^3

V = Total volume in 1 m^2/150 cm depth have less clay transferred below 0-150 cm depth, whereas Treatment 1 (low salinity) has more clay transferred at lower depth (150-300 cm). In general, Treatment 1 has more clay transformed than all other irrigated treatments 0-300 cm depth. There is very little data available on the effects of irrigation water on clay transformation. More studies have been conducted on the influence of rainfall on clay formation.

Goddard et al (1973) studied the relationship between rainfall frequency and amount to the formation and profile distribution of clay particles. They found that the distribution of clay within the soil profile is related to the amount and distribution of rainfall (leachable water), depth of leaching, and natural drainage class. According to an abstract by Barshad (1957) on factors affecting the frequency distribution of clay mineral in soil, the chemical, moisture and other environmental factors influence clay formation.

> "An extensive survey of the clay minerals and the other mineral colloids of many soils led to the conclusions that the chemical environment that exists in a soil during its development determines the kind of clay minerals that are being formed and that the frequency distribution of the clay minerals and the other mineral colloids, exclusive of those inherited from the parent material, are determined by the chemical environment occurring during soil formation. Furthermore, the chemical environment also determines the nature and extent of the alteration that biotite and muscovite undergo during breakdown to colloidal dimensions.
>
> Because the chemical environment of a soil is determined by the factors of soil formation, a good correlation exists between these factors and the frequency distribution of the clay minerals.

Any of the factors of soil formation that function to maintain a neutral or an alkaline environment and to accumulate $CaCO_3$ also induce the formation and accumulation of montmorillonite — whether this formation is through synthesis or through the alteration of micas and vermiculites. Thus, highly basic parent materials, such as serpentines and periodotites, that tend to maintain a neutral to basic environment regardless of degree of leaching, induce montmorillonite formation. Also under low rainfall condictions montmorillonite always accumulates regardless of the nature of the parent materials. Furthermore, conditions that impose on the soil a base accumulating environment, such as poor drainage, high water table, or its position in the profile as deep horizons, also induce montmorillonite formation. If potassium is high in such an environment, the mica minerals are either synthesized or accumulated.

Any of the factors, however, that function to maintain a highly base-depleting environment, such as high rainfall, good drainage and a high permeability, or the position of a soil in the profile as surface horizons, are conducive to kaolinite and halloysite formation. Acidic parent materials with high permeability, such as pumice and volcanic ash, or very dense basic rocks, such as basalts that have an extremely low water holding capacity, are particularly responsive to kaolinite and halloysite formation even at moderate precipitation.

Any of the factors that function to maintain an intermediate environment, i.e., between a highly accumulating and a highly depleting one, induce the formation of vermiculite either by synthesis or by the alteration of the micas. Soils found presently in such environments have the broadest frequency distribution of clay minerals. This is believed to reflect an environment that has responded readily to change in the course of soil development, particularly with respect to changes in rainfall and temperature."

The initial soil particle analysis done in 1957 and final analysis in Spring 1972 indicate that there might have been some changes in clay migration and dispersion to account for these big differences in clay contents in the two depths (0-150 cm and 150-300 cm). (See Appendix 3 for further soil particle analysis)

E. Thin Section Studies

By definition cutans are pedological features, those formed by deposition or diffusion of plasmic material are plasma concentrations, while those formed in situ modification of the plasma are plasma separations. Buol and Holes' (1961) definition of a clay skin which is "the assemblage of optically oriented clay (less than 0.002 mm) with included coarser particles, formed on the walls of interstices in the soil and exhibiting abrupt internal and external boundaries" is based on microscopic characteristics in thin section. Apparently material of less than 2 microns equivalent diameter is accepted as "clay". Some materials may not be recognizable as "optically oriented" by microscopic methods, for example, opaque forms of manganese and iron oxides; anisotropic clay mineral may occur as very weakly iron oxides; anisotropic clay mineral may occur as very weakly oriented "skins," and skins of clay size materials, such as manganese oxides, may be optically disoriented. The definition, therefore, is of a particle group of cutans composed dominantly of optically oriented clay minerals, (Brewer 1964).

Although the definition is strongly genetic, cutans are recognized by their location (distribution pattern) as evidenced by a change in concentration, texture, structure, or fabric and by their shape, which conforms to the shape of the natural surfaces with which they are associated. The definition has been made broad so that cutans can be recognized in the field to the extent that data allow; for example, all the phenomena that have been identified as "clay skin" are cutans irrespective of their methods of formation. The natural surfaces within the soil are, surface of soil peds, skeleton grains, voids, and even other pedological features that occur as individuals such as nodules.

Since the results in the clay distribution indicated larger differences in clay contents at 60-75 cm and 150-165 cm, core sample for the thin section studies were sampled at the same sites where hydraulic conductivity and bulk density, soil water retention and release, and soil particle analysis samples were collected (in replicate number 1, 3 and 5 of each treatment). Care was taken to take samples from undisturbed soil.

After thin section preparations were done, the identification of the above mentioned phenomenon were investigated by using a petrographic microscope. The results obtained were as follows (Figs.31-40):
(i) At 60-65 cm depth: non-irrigated treatment had the largest pores and abundant, more clay on particles and grains, and clay not dispersed. However, control treatment had relatively larger pores and more oriented clay around solid particles but not in voids (pores spaces) than other irrigated treatments. Treatments 3 and 4 were mostly compacted matrices with small and few pores with dispersed clay. However, Treatment 2 was in between with some solid particles and voids with oriented clay film.
(ii) At 150-165 cm depth: The results were reverse of what had been obtained at depth 60-65 cm. Treatment 1 had compacted matrix with

Fig. 31 Treatment 1 at 60-75 cm (24-30") depth. Thin section under crossed polarizers. Coarse texture not compacted. The black areas are voids (pores). There are oriented clay films around solid particles but not in voids (pore spaces).

Fig. 32 Treatment 1 at 150-165 cm (60-66") depth. Thin section under crossed polarizers. Compacted matrix with dispersed clay and with few pores.

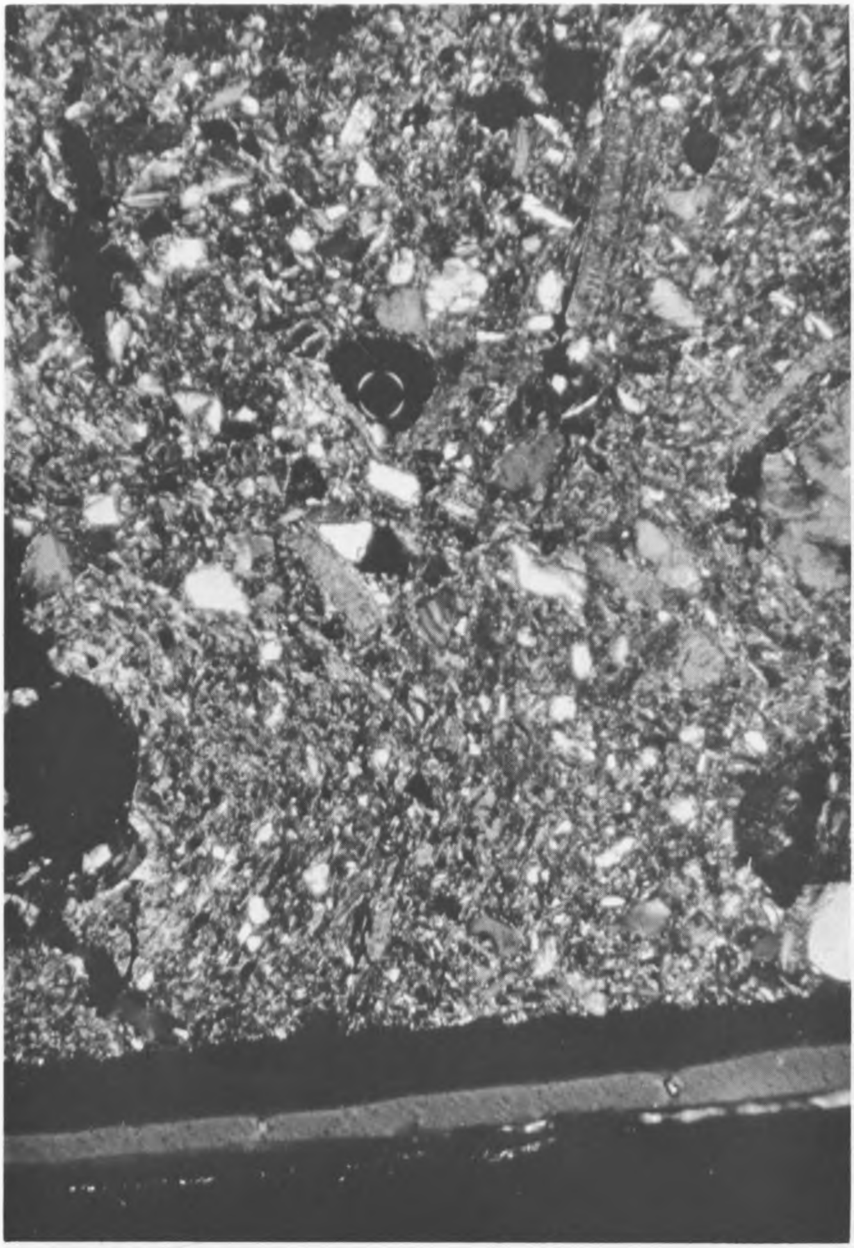


Fig. 33 Treatment 2 at 60-75 cm (24-30") depth. Thin section under crossed polarizers. Larger grains, some solid particles and voids with oriented clay films. Top left side dispersed clay.

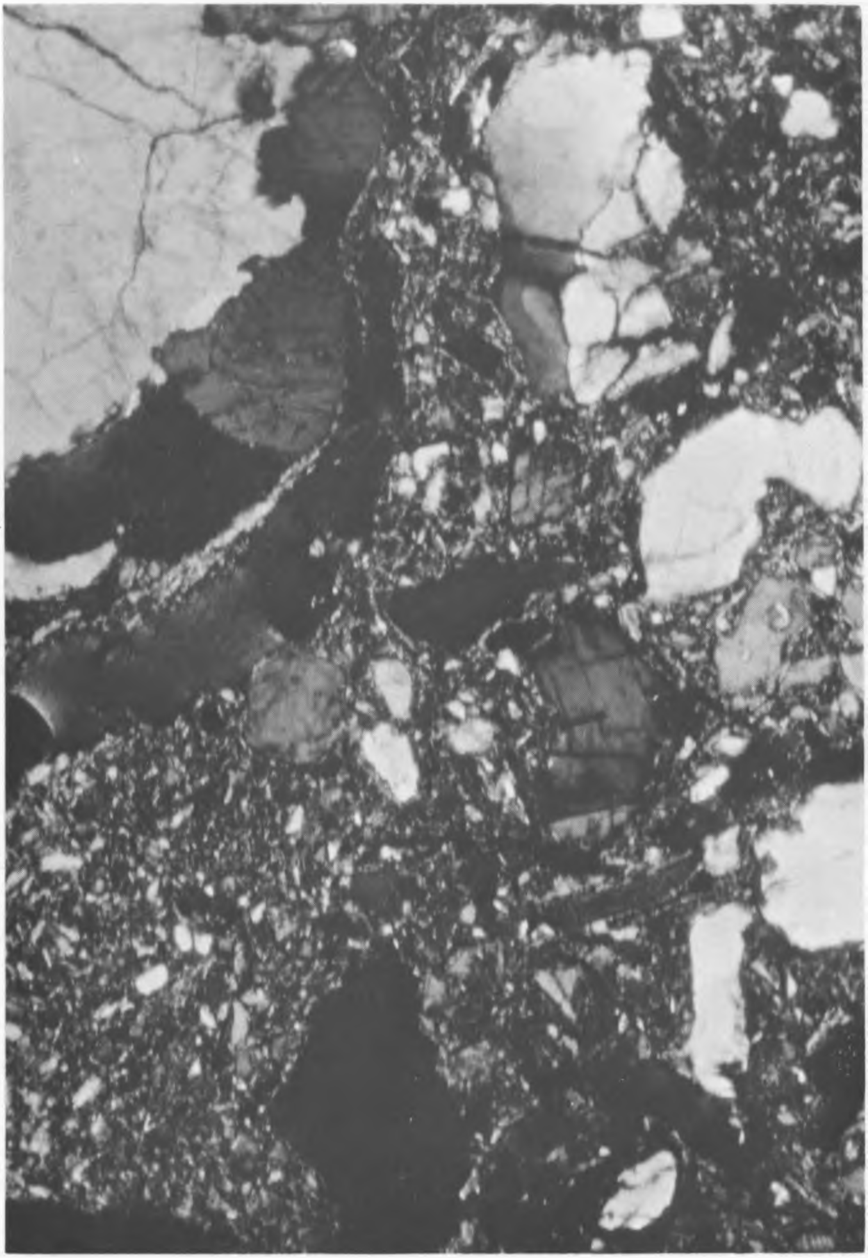


Fig. 34 Treatment 2 at 150-165 cm (60-66") depth. Thin section under crossed polarizers. Coarse texture, with micas no clay film orientation and no carbonate on the section.

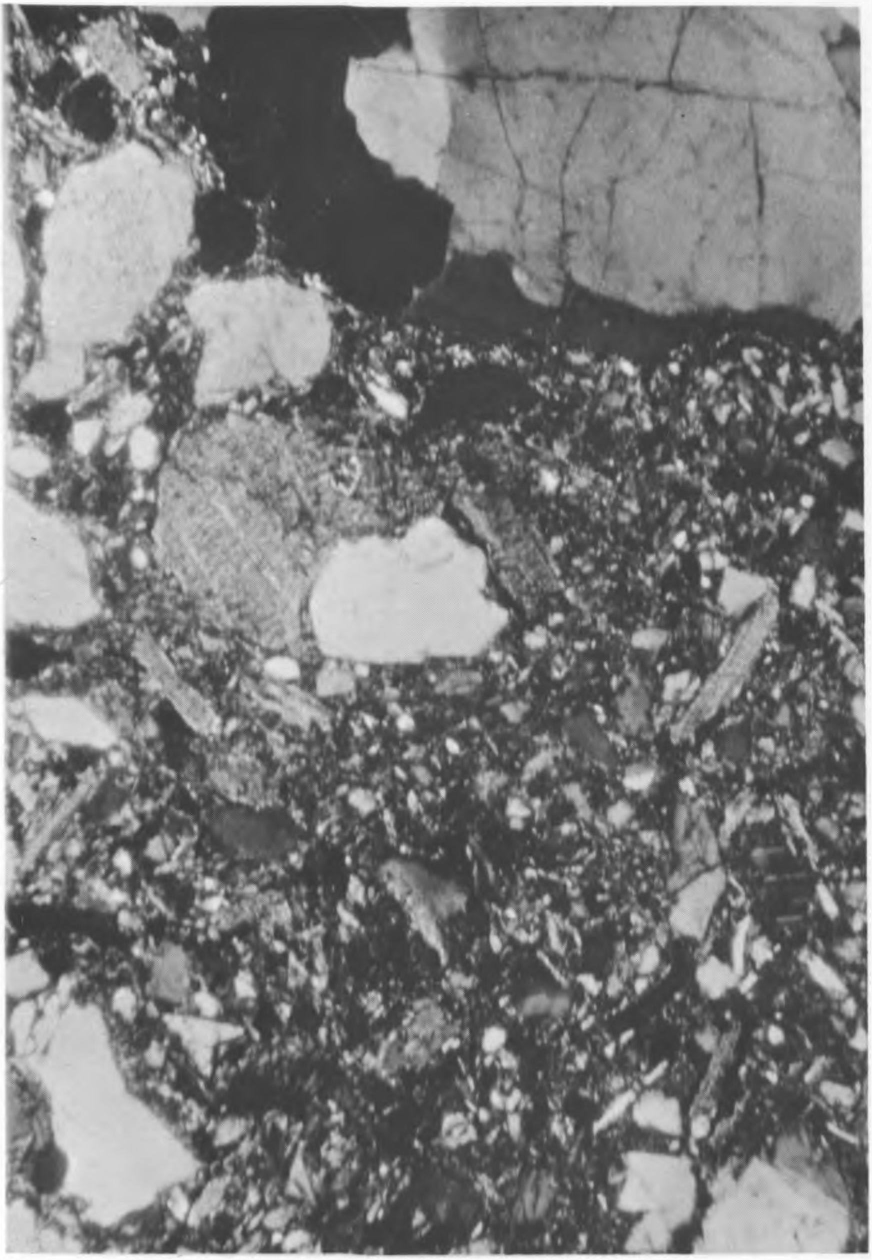


Fig. 35 Treatment 3 at 60-75 cm (24-30") depth. Thin section under crossed polarizers. Few and small voids (pores), dense compact matrix with dispersed clay.

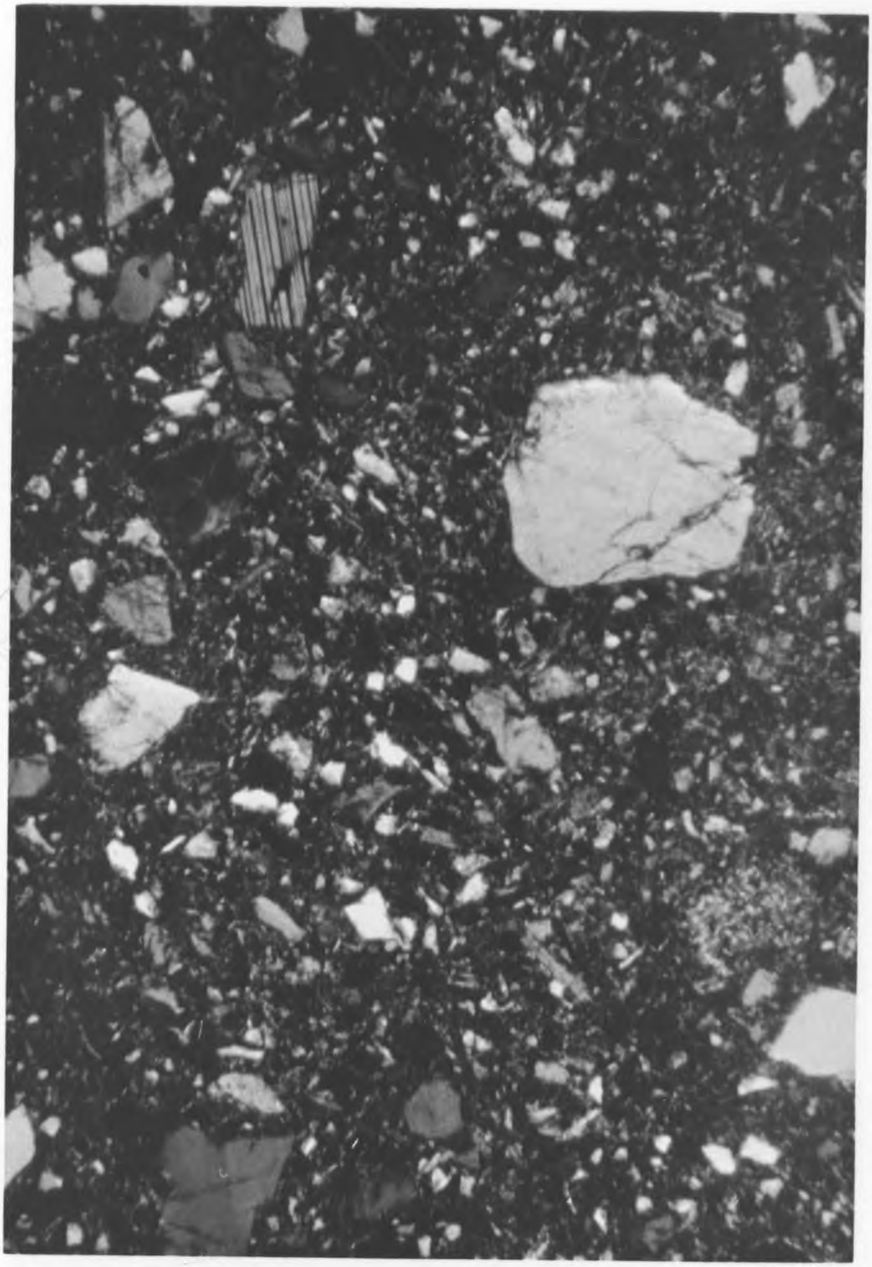


Fig. 36 Treatment 3 at 150-165 cm (60-66") depth. Thin section under crossed polarizers. Large voids (pores), coarse texture with less clay. Slightly thin layer of clay film on solid particles and clay not dispersed.

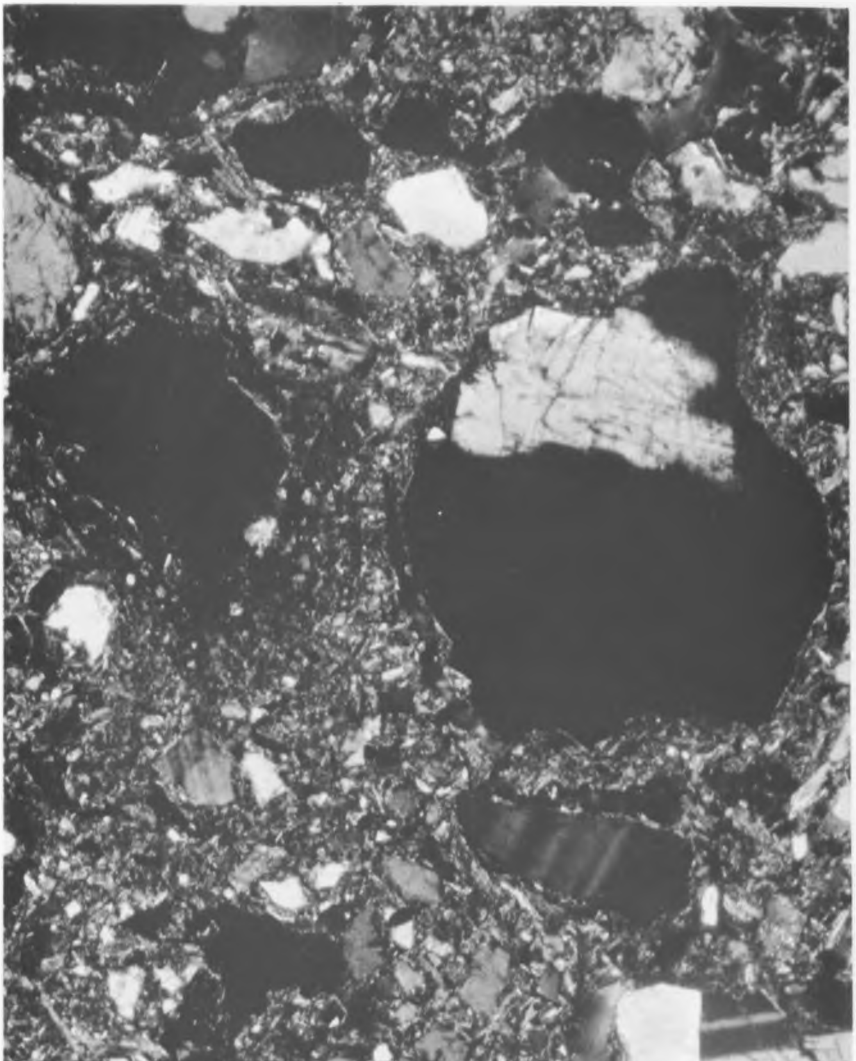


Fig. 37 Treatment 4 at 60-75 cm (24-30") depth.
Thin section under crossed polarizers.
Few and small voids (pores), matrix fine and compact with dispersed clay.

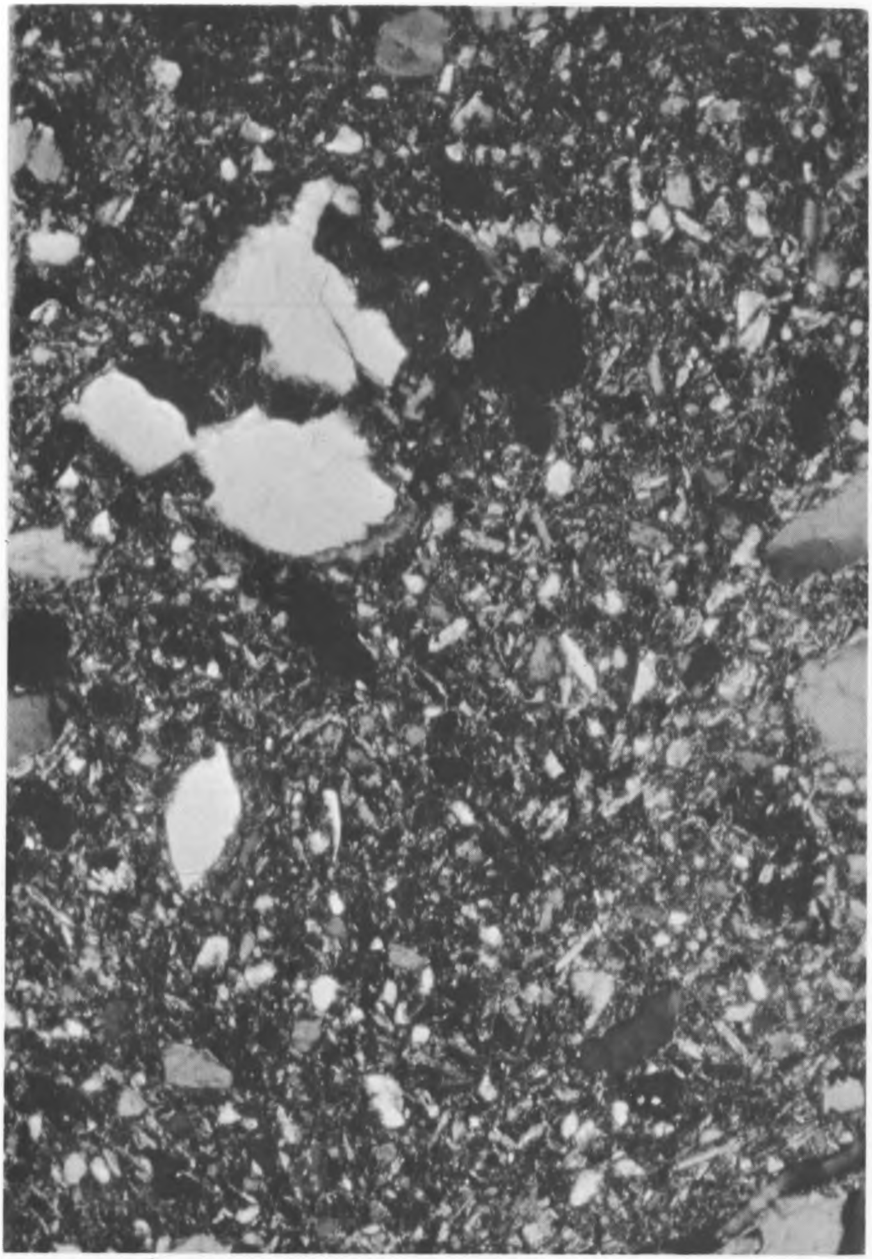


Fig. 38 Treatment 4 at 150-165 cm (60-66"). Thin section under crossed polarizers. Void (pore) in centre otherwise compact with fine and coarse texture, no clay films.

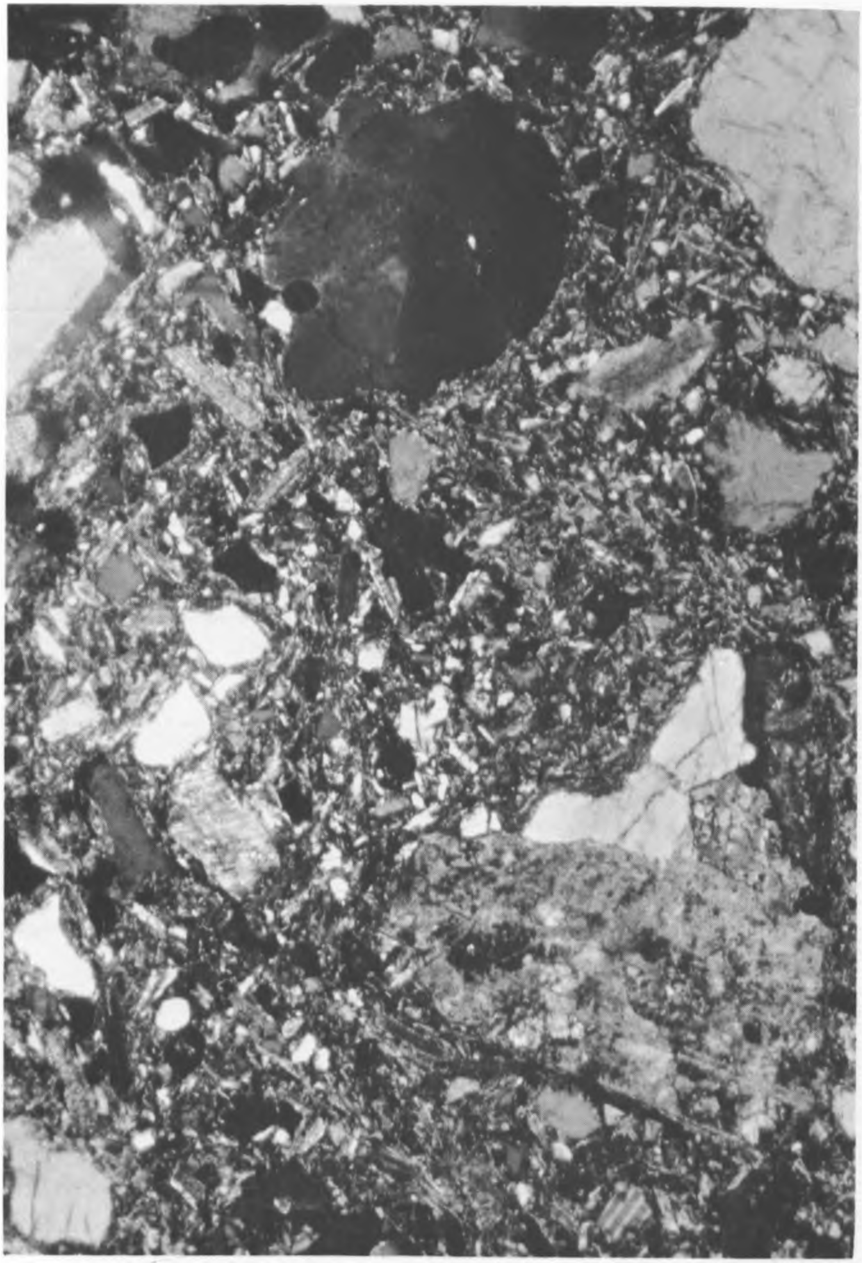


Fig. 39 Non-irrigated treatment (T_5) at 60-75 cm (24-30") depth. Thin section under crossed polarizers. Voids (pore spaces) abundant more oriented clay on particles and grains. Clay not dispersed.

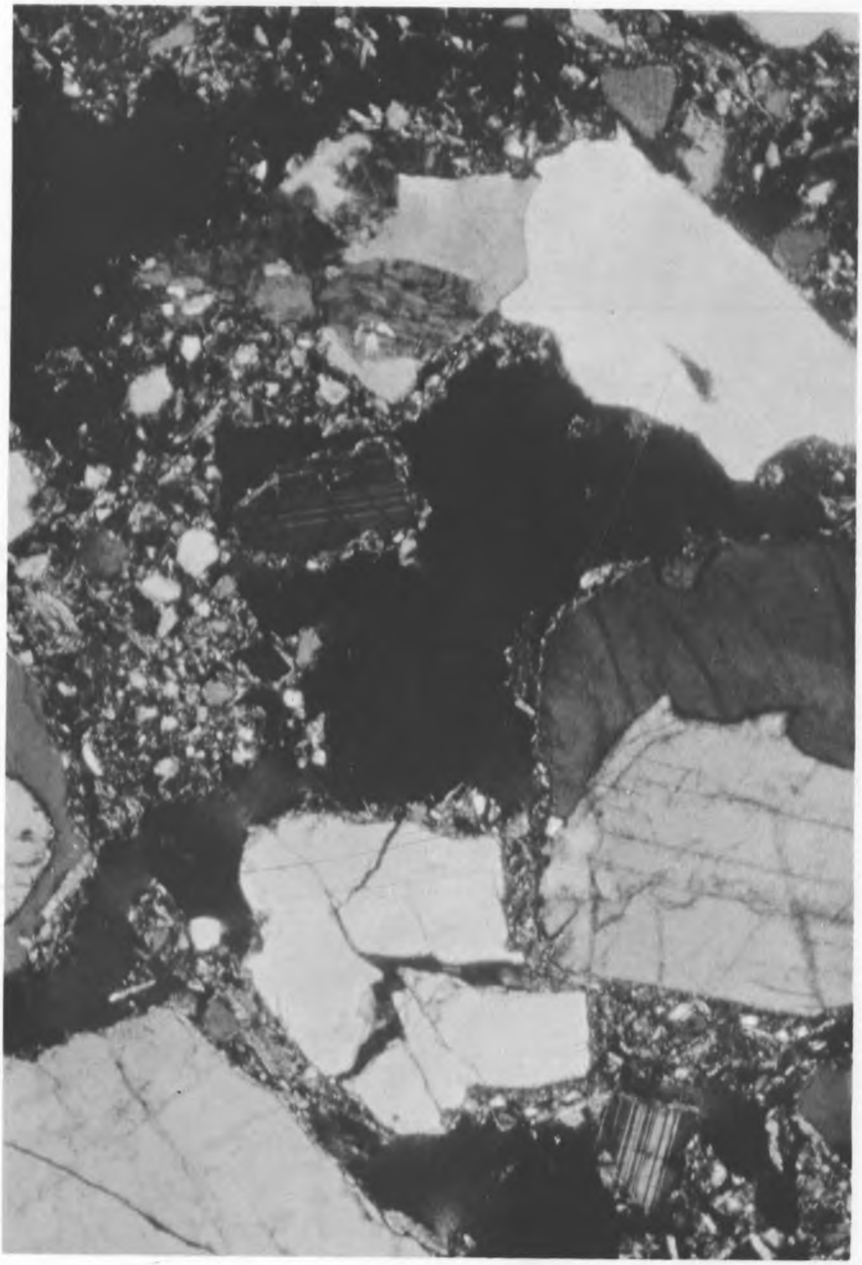
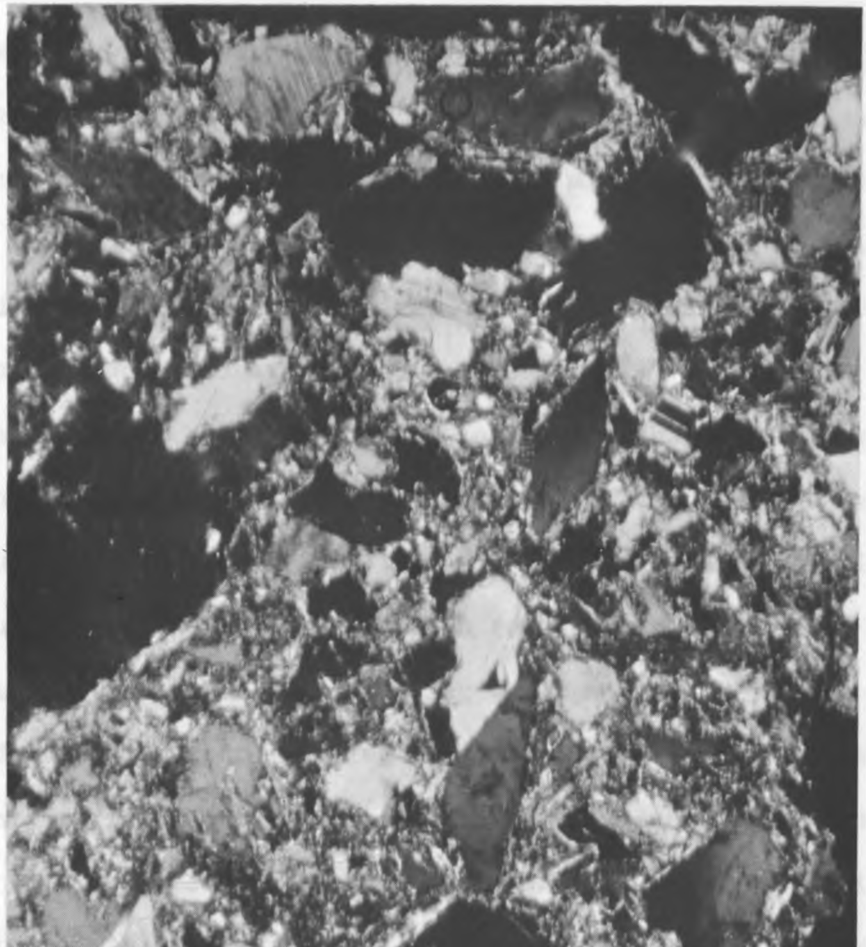


Fig. 40 Non-irrigated treatment (T_5) at 150-165 cm (60-66") depth. Thin section under crossed polarizers. Coarse texture with voids (pores) and slightly thin clay films on solid particles.



dispersed clay and with few pores. Treatment 3 had large pores, coarse texture with less clay. Slightly thin layer of clay film on solid particles and clay not dispersed. Non-irrigated treatment (T_5) had coarse texture with relatively large pores, slightly clay film on solid particles and no clay dispersion. However, Treatment 4 thin section showed pore in the center otherwise compact matrix with fine coarse texture, no clay film and no clay dispersion. Treatment 2 results indicated coarse texture, with mica, no clay film orientation, no clay dispersion and no carbonate on the section.

However, from the above results in appears that under treatment with high salinity levels, clay is not translocated to lower depth, but only to upper horizon (45-75 cm). Where it dispersed and blocks the pores thus reducing clay translocation (especially Treatment 3 and 4, and possibly Treatment 2) and reducing water movement. In the non-irrigated treatment where wetting and dry processes do not take place except only during the rainy season, the matrix seems to be more stable than for the irrigated treatments. In Treatment 1 where Gage Canal water (water with low salinity) is used, the soil matrix of this treatment is different from non-irrigated and irrigated treatments. It appears, also that using low salinity water, clay migrated from upper horizon to deeper zones. The way in which the water is introduced to soil either flooding or sprinkler can affect structure, especially desert soils with low organic matter. From the data obtained in this study it could be speculated that using low salinity water in the long run, and depending on the aggregate stability, could be as bad as using high salinity water if the clay migrates to a lower depth. This process will block all the pores, thus clay will start building up at that layer and thus impede drainage.

F. Soil Water Retension and Release

Further studies were carried out to investigate the influence of variable water quality on soil water retention and release under field conditions.

As indicated by Slayter (1967) the water status of soil continually affects soil properties through its influence on weathering and profile development.

The amount of water retained at relative low values of matric suction (say, between 0 and 1 bar of suction) depends primarily upon the capillary effect and the pores-size distribution, and hence is strongly affected by structure of the soil. On the other hand, water retention in the higher suction rainge is due increasingly to adsorption and is thus influenced less by structure and more by the texture and specific surface of the soil material. According to Gardner (1968), the water content at suction of 15 bars (often taken to be the lower limit of soil moisture availability to plants) is fairly well correlated with the surface area of a soil and would represent, roughly, about 10 molecular layers of water if it were distributed uniformly over the particle surfaces.

As described in the procedure (Material and Methods, Section 3) undisturbed core samples from the field were used to study water characteristics as influenced by variable water quality. The results obtained in this study indicated that the relationship between volumetric water content at 15 bars and depth had a similar pattern as the relationship between clay content distribution and depth (Fig. 41). The non-irrigated treatment had the lowest volumetric content in all depths. In the irrigated treatments, Treatment 1 had the lowest volumetric water content at 0-70 cm. Whereas Treatment 3 had the highest volumetric water content at 0-125 cm depth. However, it was interesting to note that at about 120-260 cm Treatment 1 had the highest volumetric water content at 15 bars.

The Multiple Range Test between treatments (T_1, T_2, T_3, T_4, and T_5) was done at 49.53 cm and 186.69 cm. Volumetric water contents at 15 bars suction were found to be statistically different at the 1% level for all treatments except for Treatments 2 and 4. Also coefficient of determination (or squared regression coefficients) for actual data to fitted polynomial curves were very high for all treatments.

Soil water release characteristics (of undisturbed samples) for the 0-150 cm depth are given in Fig. 42. Treatment 3 retained more water than all other treatments (T_1, T_2,T_3 ,T_4 , non-irrigated treatment T_5), where the non-irrigated treatment (T_5) had the lowest value. All treatments were statistically different at 1% level. The bulk densities were very high, especially Treatments 2, 3 and 4; however, these values for all treatments were not statistically different from each other.

The results obtained for the 150-300 cm depth are given in Fig 43. At 150-300 cm depth, Treatment 1 retained more water than all other treatments, and non-irrigated treatment (T_5), the least. The volumetric water content for all treatments were significantly different at 1% level. Treatments 1 and 2 had the highest average bulk densities and Treatment 3, 4 and non-irrigated treatment had slightly lower bulk

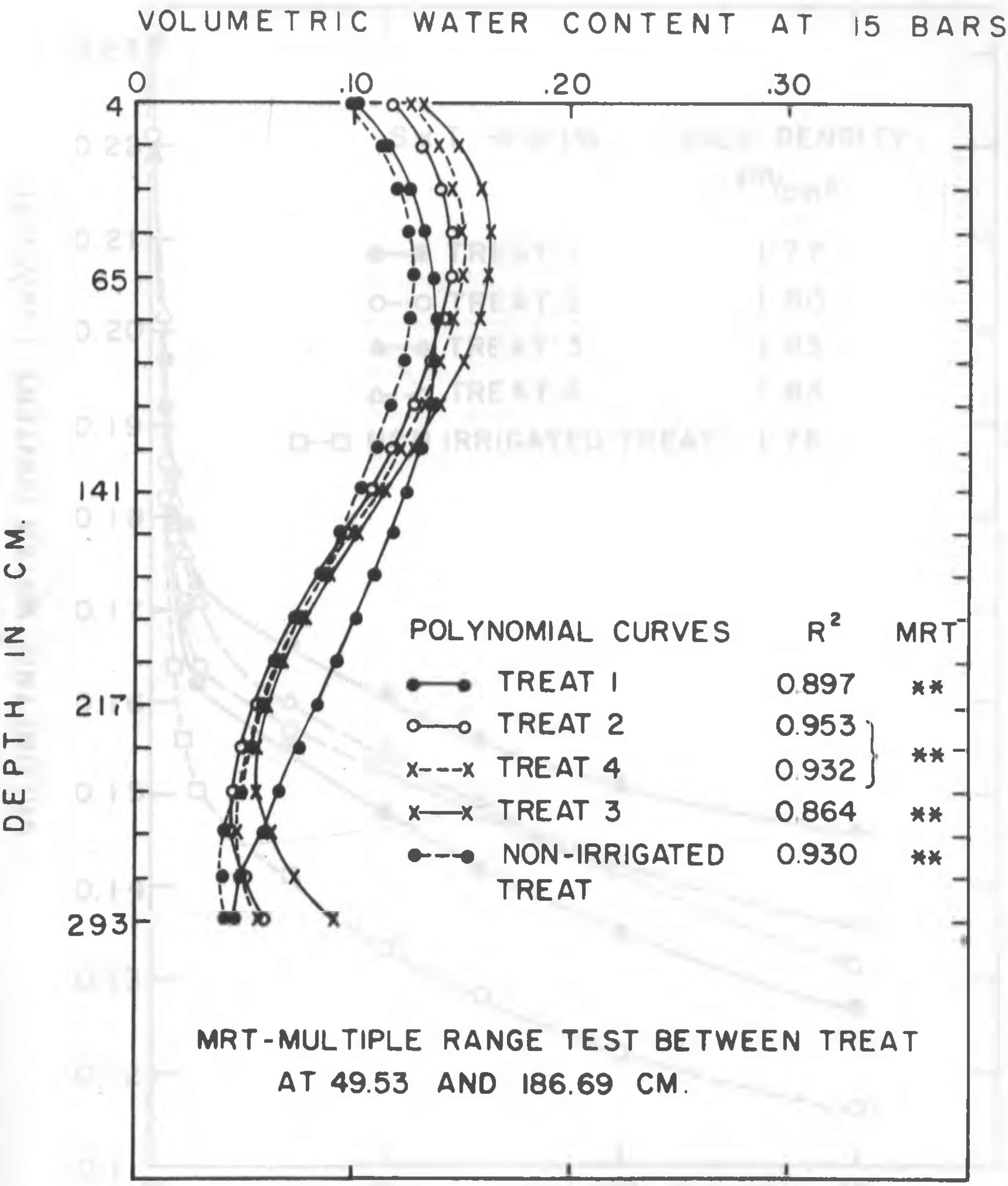


Fig. 41 Relationship between depth in cm and volumetric water content (cm^3/cm^3) at 15 bars (Clay fitted Polynomial Curves from actual data). Treatments: T_1, T_2, T_3, T_4 and Non-irrigated treatment. Depth 0-300 cm; Spring 1972. Multiple range tests between treatments at 49.53 and 186.69 cm, ** (1%).

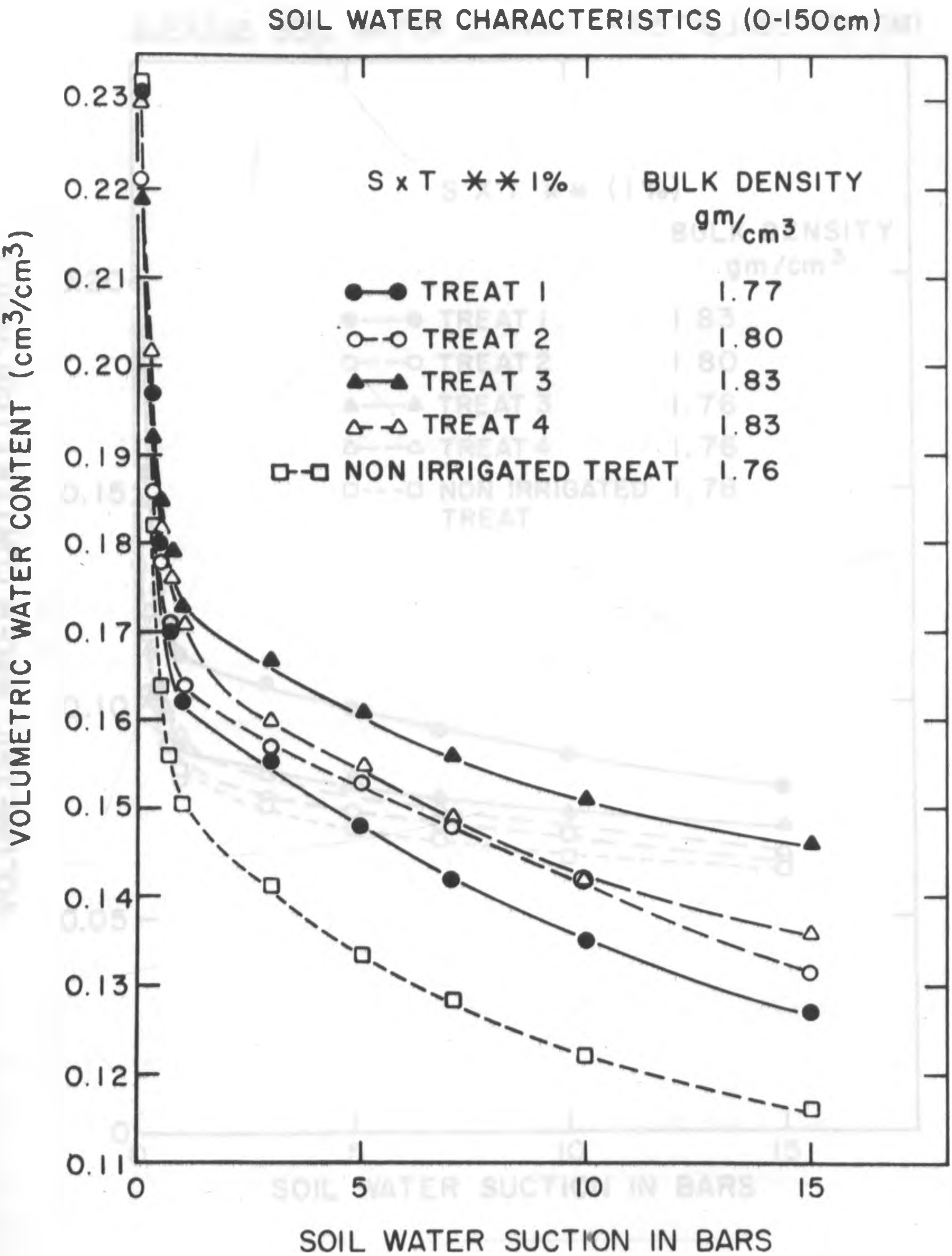


Fig. 42 Relationship between average Volumetric water content (cm^3/cm^3) and Soil Suction in bars. Treatments T_1, T_2, T_3, T_4 and non-irrigated treatments; depth 0-150 cm (0-5 ft); Spring 1972. Analysis of variance

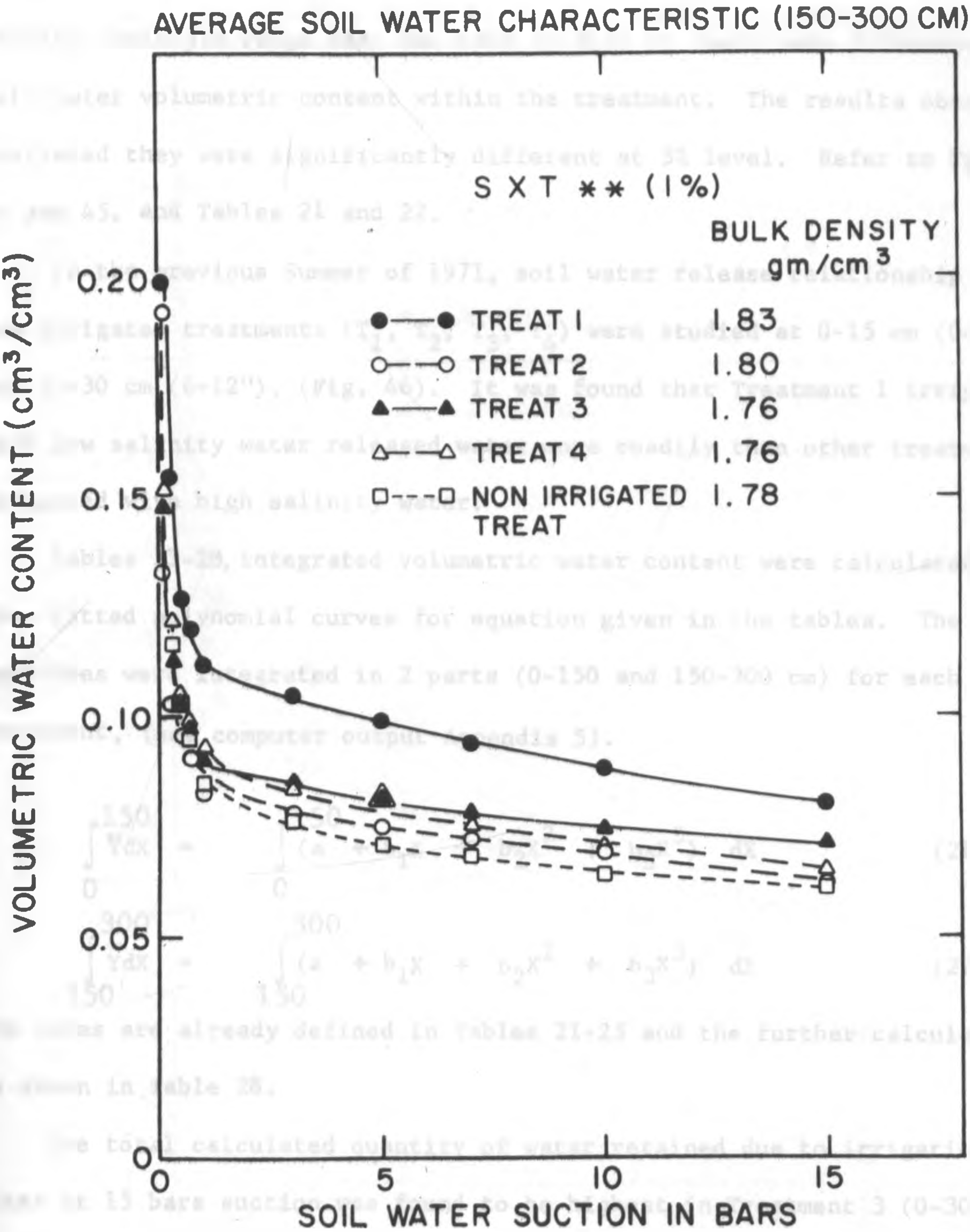


Fig. 43 Relationship between average Volumetric Water Content (cm^3/cm^3) and Soil suction in bars. Treatments T_1, T_2, T_3, T_4 and Non-irrigated treatment; depth 150-300 cm (5-10 ft). Spring 1972. Analysis of variance, soil suction(s) X Treatment (T), **(1%).

densities.

Similar depth (45-60 and 135-150 cm) which thin section were studied, multiple range test was used to find if there were differences with water volumetric content within the treatment. The results obtained indicated they were significantly different at 5% level. Refer to Figs. 44 and 45, and Tables 21 and 22.

In the previous Summer of 1971, soil water release relationship in the irrigated treatments (T_1, T_2, T_3, T_4) were studied at 0-15 cm (0-6") and 15-30 cm (6-12"), (Fig. 46). It was found that Treatment 1 irrigated with low salinity water released water more readily than other treatments irrigated with high salinity water.

Tables 23-28, integrated volumetric water content were calculated from fitted polynomial curves for equation given in the tables. The equations were integrated in 2 parts (0-150 and 150-300 cm) for each treatment, (see computer output Appendix 5).

$$\int_{0}^{150} \bar{Y} dX = \int_{0}^{150} (a + b_1 X + b_2 X^2 + b_3 X^3) \, dX \qquad (21)$$

$$\int_{150}^{300} \bar{Y} dX = \int_{150}^{300} (a + b_1 X + b_2 X^2 + b_3 X^3) \, dX \qquad (22)$$

The terms are already defined in Tables 21-25 and the further calculation as shown in Table 28.

The total calculated quantity of water retained due to irrigation water at 15 bars suction was found to be highest in Treatment 3 (0-300 cm depth).

In summary, the soil moisture characteristic curves are strongly affected by soil texture, in general, the greater the clay content, the greater the water content at any particular suction, and the more gradual

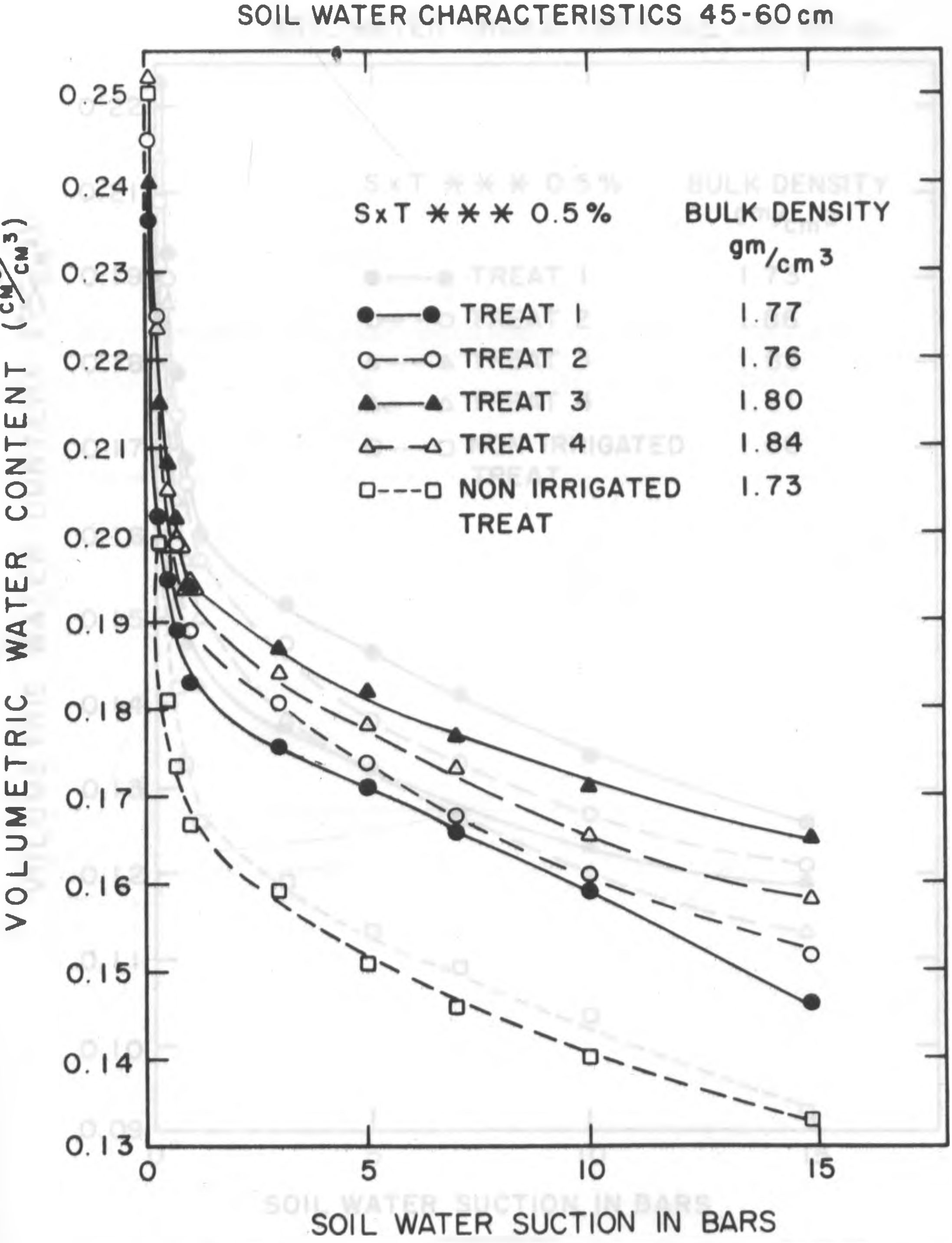


Fig. 44 Relationship between Volumetric water content (cm /cm) and soil water suction in bars. Treatments T_1, T_2, T_3, T_4 and non-irrigated treatment; depth 45-60.cm (1 1/2 - 2 ft); Spring 1972. Analysis of variance soil water suction (x) X Treatments(T). *** (0.5%).

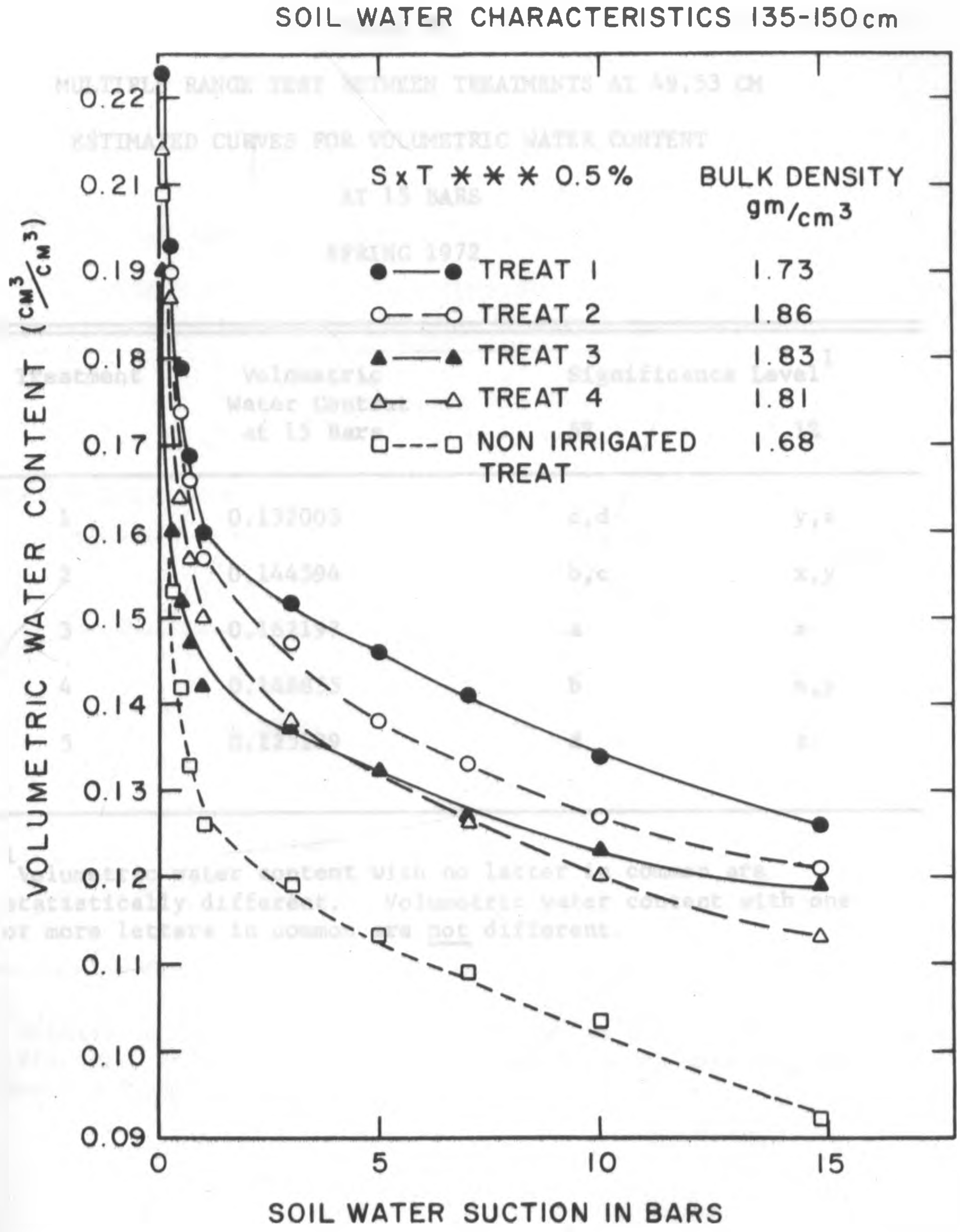


Fig. 45 Relationship between volumetric water content (cm^3/cm^3) and soil water suction in bars. Treatments; T_1, T_2, T_3, T_4 and non-irrigated treatment; depth 135-150 cm (4 1/2 - 5 ft); Spring 1972. Analysis of variance; soil water suction(s) X Treatments(T) ***(0.5%).

TABLE 21

MULTIPLE RANGE TEST BETWEEN TREATMENTS AT 49.53 CM

ESTIMATED CURVES FOR VOLUMETRIC WATER CONTENT

AT 15 BARS

SPRING 1972

Treatment	Volumetric Water Content at 15 Bars	Significance Level[1] 5%	1%
1	0.132003	c,d	y,z
2	0.144594	b,c	x,y
3	0.162197	a	x
4	0.148855	b	x,y
5	0.125229	d	z

[1] Volumetric water content with no letter in common are statistically different. Volumetric water content with one or more letters in common are <u>not</u> different.

TABLE 22

MULTIPLE RANGE TEST BETWEEN TREATMENTS AT 186.69 CM

ESTIMATED CURVES FOR VOLUMETRIC WATER CONTENT

AT 15 BARS

SPRING 1972

Treatment	Volumetric Water Content at 15 Bars	Significance Level[1]	
		5%	1%
1	0.10144	a	x
2	0.07384	b	y
3	0.07596	b	y
4	0.07769	b	y
5	0.07544	b	y

[1] Volumetric water content with no letter in common are statistically different. Volumetric water content with one or more letters in common are <u>not</u> different.

Table 23 Treatment I. Relationships of Depth and Volumetric Water Content at 15 Bars

RESIDUAL ANALYSIS

DEPTH NUMBER	OBSERVED Y	PREDICTED Y	RESIDUAL	NORMAL DEVIATE
1	0.10283820000D 00	0.1012955322D 00	0.1542667840D-02	0.1366166996
2	0.11031810000D 00	0.1147992033D 00	-0.4481103328D-02	-0.3968408050
3	0.12051290000D 00	0.1249443861D 00	-0.4431486118D-02	-0.3924467681
4	0.15223660000D 00	0.1320027411D 00	0.2023385888D-01	1.7918847792
5	0.13078750000D 00	0.1362459289D 00	-0.5458428925D-02	-0.4833915155
6	0.12864890000D 00	0.1379456101D 00	-0.9296710120D-02	-0.8233048110
7	0.13043550000D 00	0.1373734453D 00	-0.6937945294D-02	-0.6144156014
8	0.13800280000D 00	0.1348010950D 00	0.3201704962D-02	0.2835389148
9	0.13063630000D 00	0.1305002199D 00	0.1360800600D-03	0.0120510769
10	0.12603810000D 00	0.1247424806D 00	0.1295619410D-02	0.1147384053
11	0.12596230000D 00	0.1177995376D 00	0.8162762424D-02	0.7228838469
12	0.11129040000D 00	0.1099430515D 00	0.1347348512D-02	0.1193194687
13	0.11549180000D 00	0.1014446879D 00	0.1404711708D-01	1.2439948032
14	0.77046570000D-01	0.9257609245D-01	-0.1552952245D-01	-1.3752747347
15	0.75333420000D-01	0.8360894067D-01	-0.8275520673D-02	-0.7328695738
16	0.57662670000D-01	0.7481488818D-01	-0.1715221818D-01	-1.5189786027
17	0.89369600000D-01	0.6646559556D-01	0.2290400444D-01	2.0283494701
18	0.61784640000D-01	0.5883272340D-01	0.2951916597D-02	0.2614179752
19	0.50455050000D-01	0.5218793229D-01	-0.1732882295D-02	-0.1534618496
20	0.44275620000D-01	0.4680288283D-01	-0.2527262827D-02	-0.2238111780

****

$\bar{Y} = a + b_1 X + b_2 X^2 + b_3 X^3$

$\bar{Y}$ = Volumetric water content at 15 bars

$a = 0.973630 \times 10^{-1}$

$b_1 = 0.106230 \times 10^{-2}$

$b_2 = -0.796113 \times 10^{-5}$

$b_3 = 0.127915 \times 10^{-7}$

X = Depth in cm [Depth number)(6) -4.5] 2.54

$R^2 = 0.897011$ ** (1%)

Table 24 Treatment 2. Relationships of Depth and Volumetric Water Content at 15 Bars

RESIDUAL ANALYSIS

DEPTH NUMBER	OBSERVED Y	PREDICTED Y	RESIDUAL	NORMAL DEVIATE
1	0.1167878000D 00	0.1167358699D 00	0.5193011745D-04	0.0056326725
2	0.1312506000D 00	0.1309434067D 00	0.3071933324D-03	0.0333201526
3	0.1402900000D 00	0.1400416885D 00	0.2483115121D-03	0.0269334539
4	0.1471598000D 00	0.1445935598D 00	0.2566240247D-02	0.2783508219
5	0.1413746000D 00	0.1451618649D 00	-0.3787264871D-02	-0.4107909580
6	0.1366742000D 00	0.1423094483D 00	-0.5635248253D-02	-0.6112350488
7	0.1402900000D 00	0.1365991543D 00	0.3690845693D-02	0.4003327175
8	0.1232961000D 00	0.1285938274D 00	-0.5297727443D-02	-0.5746253841
9	0.1373974000D 00	0.1188563121D 00	0.1854108793D-01	2.0110849206
10	0.9256244000D-01	0.1079494526D 00	-0.1538701260D-01	-1.6689737475
11	0.1106411000D 00	0.9643609343D-01	0.1420500657D-01	1.5407658175
12	0.8930826000D-01	0.8487907899D-01	0.4429181011D-02	0.4804172859
13	0.5640525000D-01	0.7384125367D-01	-0.1743600367D-01	-1.8912204177
14	0.5821311000D-01	0.6388546189D-01	-0.5672351894D-02	-0.6152595468
15	0.5712839000D-01	0.5557454806D-01	0.1553841938D-02	0.1685396295
16	0.5821309000D-01	0.4947135659D-01	0.8741733414D-02	0.9481842875
17	0.4266550000D-01	0.4613873188D-01	-0.3473231876D-02	-0.3767289318
18	0.5170480000D-01	0.4613951834D-01	0.5565281660D-02	0.6036460249
19	0.4881223000D-01	0.5003656039D-01	-0.1224330388D-02	-0.1327987004
20	0.5640522000D-01	0.5839270243D-01	-0.1987482429D-02	-0.2155750492

****

$\bar{Y} = a + b_1 X + b_2 X^2 + b_3 X^3$

$\bar{Y}$ = Volumetric water content at 15 bars

$a = 0.112320$

$b_1 = 0.120639 \times 10^{-2}$

$b_2 = -0.125137 \times 10^{-4}$

$b_3 = 0.265022 \times 10^{-7}$

X = Depth in cm = [(Depth number)(6) -4.5] 2.54

R^2 = 0.953394 ** (1%)

Table 25 Treatment 3. Relationships of Depth and Volumetric Water Content at 15 Bars

RESIDUAL ANALYSIS

DEPTH NUMBER	OBSERVED Y	PREDICTED Y	RESIDUAL	NORMAL DEVIATE
1	0.1249079000D 00	0.1311009849D 00	-0.6293084936D-02	-0.3627171275
2	0.1438483000D 00	0.1475651710D 00	-0.3716870997D-02	-0.2142308240
3	0.1784023000D 00	0.1576782524D 00	0.2072404765D-01	1.1944804670
4	0.1652448000D 00	0.1621968803D 00	0.3047919722D-02	0.1756742039
5	0.1572857000D 00	0.1618777061D 00	-0.4592006061D-02	-0.2646713440
6	0.1211832000D 00	0.1574773810D 00	-0.3629418098D-01	-2.0919026524
7	0.1605830000D 00	0.1497525563D 00	0.1083044369D-01	0.6242387420
8	0.1812859000D 00	0.1394598833D 00	0.4182601666D-01	2.4107433429
9	0.1111274000D 00	0.1273560134D 00	-0.1622861335D-01	-0.9353752696
10	0.1189250000D 00	0.1141975976D 00	0.4727402378D-02	0.2724752373
11	0.8318853000D-01	0.1007412874D 00	-0.1755275743D-01	-1.0116955070
12	0.9224135000D-01	0.8774373406D-01	0.4497615941D-02	0.2592309418
13	0.7155454000D-01	0.7596158879D-01	-0.4407048790D-02	-0.2540108856
14	0.5353063000D-01	0.6615150290D-01	-0.1262087290D-01	-0.7274344478
15	0.6027311000D-01	0.5907012768D-01	0.1202982321D-02	0.0693367874
16	0.7010376000D-01	0.5547411440D-01	0.1462964560D-01	0.8432149070
17	0.5822659000D-01	0.5612011434D-01	0.2106475656D-02	0.1214118047
18	0.6352276000D-01	0.6176477879D-01	0.1757981206D-02	0.1013254866
19	0.7629249000D-01	0.7316475903D-01	0.5127730968D-02	0.2955491410
20	0.8230388000D-01	0.9107670634D-01	-0.8772826337D-02	-0.5056430036

****

$\bar{Y} = a + b_1 X + b_2 X^2 + b_3 X^3$

$\bar{Y}$ = Volumetric water content at 15 bars

$a = 0.125904$

$b_1 = 0.142340 \times 10^{-2}$

$b_2 = -0.157087 \times 10^{-4}$

$b_3 = 0.356279 \times 10^{-7}$

X = Depth in cm = [(Depth number)(6) -4.5] 2.54

$R^2 = 0.864436$ ** (1%)

Table 26 Treatment 4. Relationships of Depth and Volumetric Water Content at 15 Bars

RESIDUAL ANALYSIS

DEPTH NUMBER	OBSERVED Y	PREDICTED Y	RESIDUAL	NORMAL DEVIATE
1	0.1095457000D 00	0.1254849306D 00	-0.1593923063D-01	-1.3707193611
2	0.1495872000D 00	0.1377486060D 00	0.1183859399D-01	1.0180786235
3	0.1637225000D 00	0.1453695846D 00	0.1835291537D-01	1.5782879996
4	0.1584377000D 00	0.1488545043D 00	0.9583195740D-02	0.8241220824
5	0.1380419000D 00	0.1487100027D 00	-0.1066810269D-01	-0.9174203728
6	0.1295098000D 00	0.1454427177D 00	-0.1593291772D-01	-1.3701764719
7	0.1244619000D 00	0.1395592871D 00	-0.1509738712D-01	-1.2983236956
8	0.1331279000D 00	0.1315663487D 00	0.1561551329D-02	0.1342880776
9	0.1357909000D 00	0.1219705402D 00	0.1382035983D-01	1.1885037132
10	0.1128351000D 00	0.1112784994D 00	0.1556600598D-02	0.1338623317
11	0.9667444000D-01	0.9999686415D-01	-0.3322424147D-02	-0.2857171220
12	0.9215093000D-01	0.8863227219D-01	0.3518657808D-02	0.3025925462
13	0.8630145000D-01	0.7769136132D-01	0.8610088677D-02	0.7404382006
14	0.6011804000D-01	0.6768076933D-01	-0.7562729325D-02	-0.6503688758
15	0.5835018000D-01	0.5910713398D-01	-0.7569539830D-03	-0.0650954556
16	0.6398332000D-01	0.5247709308D-01	0.1150622692D-01	0.9894961916
17	0.4076067000D-01	0.4829728441D-01	-0.7536614408D-02	-0.6481230822
18	0.4466716000D-01	0.4707434575D-01	-0.2407185747D-02	-0.2070097475
19	0.3879714000D-01	0.4931491488D-01	-0.1051777488D-01	-0.9044926947
20	0.6491876000D-01	0.5552562960D-01	0.9393130400D-02	0.8077771127

****

$\bar{Y} = a + b_1 X + b_2 X^2 + b_3 X^3$

$\bar{Y}$ = Volumetric water content at 15 bars

$a = 0.121634$

$b_1 = 0.105361 \times 10^{-2}$

$b_2 = -0.113581 \times 10^{-4}$

$b_3 = 0.238557 \times 10^{-7}$

X = Depth in cm = [(Depth number)(6) -4.5] 2.54

$R^2 = 0.932211$ ** (1%)

Table 27 Non-Irrigated Treatment. Relationships of Depth and Volumetric Water Content at 15 Bars

RESIDUAL ANALYSIS

DEPTH NUMBER	OBSERVED Y	PREDICTED Y	RESIDUAL	NORMAL DEVIATE
1	0.9544128000D-01	0.1001856734D 00	-0.4744393388D-02	-0.4859503847
2	0.1142846000D 00	0.1122347584D 00	0.2049841609D-02	0.2099575725
3	0.1220976000D 00	0.1204562491D 00	0.1641350899D-02	0.1681174042
4	0.1327168000D 00	0.1252287230D 00	0.7488076473D-02	0.7669755833
5	0.1325015000D 00	0.1269307577D 00	0.5570742325D-02	0.5705902009
6	0.1310726000D 00	0.1259409306D 00	0.5131669447D-02	0.5256176160
7	0.1071299000D 00	0.1226378192D 00	-0.1550791917D-01	-1.5884178801
8	0.9393001000D-01	0.1174000010D 00	-0.2346999103D-01	-2.4039429787
9	0.1086618000D 00	0.1106060537D 00	-0.1944253652D-02	-0.1991425949
10	0.1208335000D 00	0.1026345545D 00	0.1819894547D-01	1.8640495905
11	0.1053311000D 00	0.9386408118D-01	0.1146701982D-01	1.1745236431
12	0.8797753000D-01	0.8467321111D-01	0.3304318890D-02	0.3384489659
13	0.7235157000D-01	0.7544052182D-01	-0.3088951823D-02	-0.3163897266
14	0.6259557000D-01	0.6654459083D-01	-0.3948920829D-02	-0.4044731200
15	0.5627336000D-01	0.5836399564D-01	-0.2090635637D-02	-0.2141359514
16	0.5350826000D-01	0.5127731375D-01	0.2230946246D-02	0.2285074398
17	0.4464658000D-01	0.4566312269D-01	-0.1016542688D-02	-0.1041206472
18	0.4181969000D-01	0.4185999995D-01	-0.8030994631D-04	-0.0082258460
19	0.3355443000D-01	0.4036652304D-01	-0.6812093038D-02	-0.6977370892
20	0.4706237000D-01	0.4144126947D-01	0.5621100531D-02	0.5757482026

****

$\bar{Y} = a + b_1 X + b_2 X^2 + b_3 X^3$

$\bar{Y}$ = Volumetric water content at 15 bars

$a = 0.965310 \times 10^{-1}$

$b_1 = 0.994255 \times 10^{-3}$

$b_2 = -0.925872 \times 10^{-5}$

$b_3 = 0.178258 \times 10^{-7}$

X = Depth in cm = [(Depth number)(6) - 4.5] 2.54

$R^2 = 0.929682$ ** (1%)

TABLE 28

THE INFLUENCE OF IRRIGATION WATER ON SOIL WATER CHARACTERISTICS

(VOLUMETRIC WATER CONTENT AT 15 BARS SUCTION)

JUNE 1957 - JUNE 1972 (15 YEARS)

Treat.	Depth in Cm	Area (A) Volumetric Water Content	$\Delta(A)$[1] Volumetric Water Content /15 Yrs./1 m^2/cm	Average Volumetric Water Content (θ) Retained Due to Irrig. Water /15 Yrs./1 m^2/cm	Quantity of Water(Q)[2] Retained Due to Irrig. at 15 Bars Suction in Liters /15 Yrs./1 m^2/ Depth	Quantity of Water Retained Due to Irrig. at 15 Bars in Liters /15 Yrs./1 m^2/ 300 cm Depth
T_1	0-150	19.22	1.71	0.011400	34.200	96.000
	150-300	12.05	3.09	0.020600	61.800	
T_2	0-150	19.70	2.19	0.014600	43.800	51.201
	150-300	9.33	0.37	0.002467	7.401	
T_3	0-150	21.74	4.23	0.028200	84.600	122.601
	150-300	10.86	1.90	0.012667	38.001	
T_4	0-150	20.34	2.83	0.018867	56.601	70.401
	150-300	9.65	0.69	0.004600	13.800	
T_5	0-150	17.51	—	—	—	—
	150-300	8.96	—	—	—	—

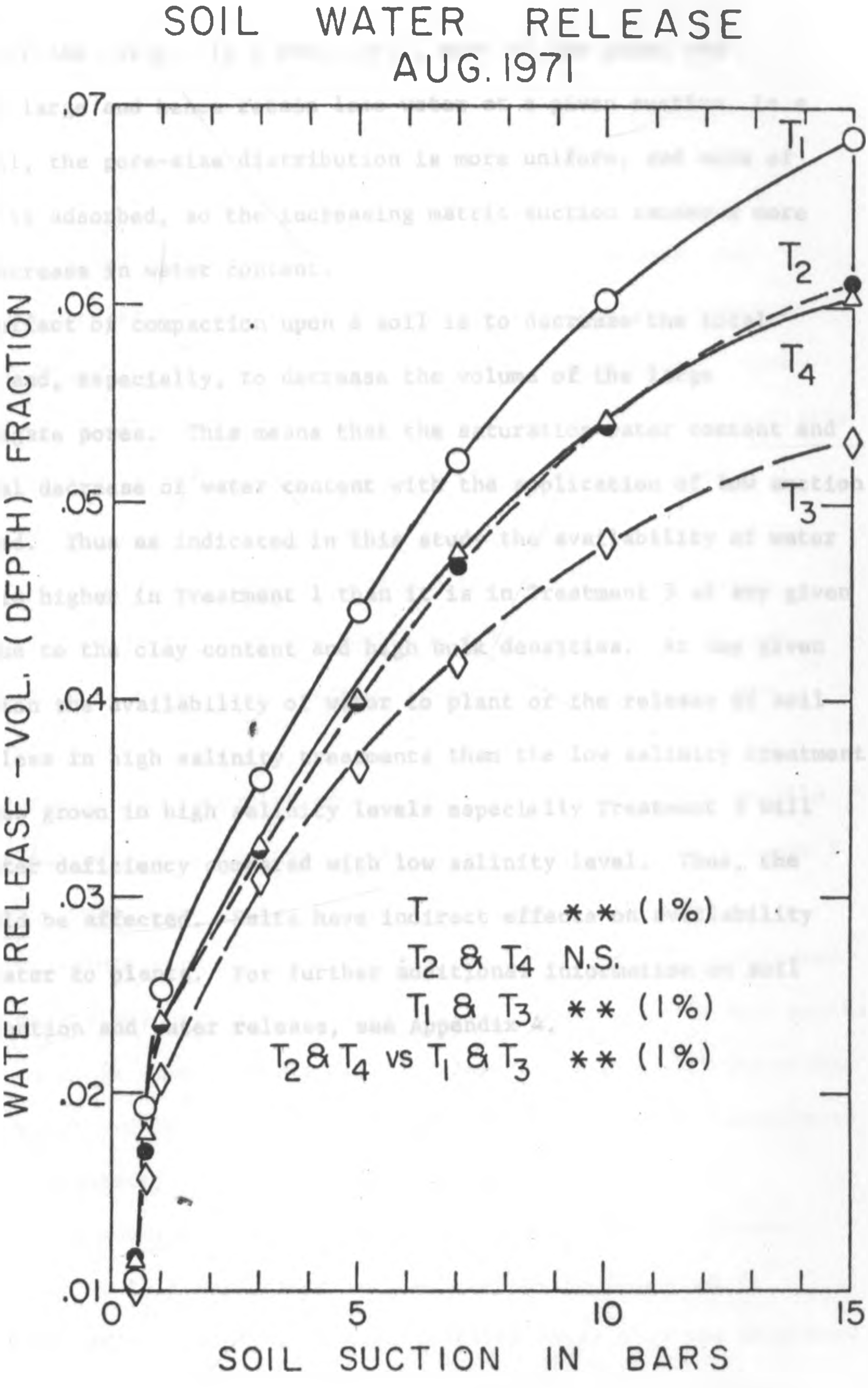
1 $\Delta(A) = (A)_{T(i)} - (A)_{T_{5(j)}}$

i = Corresponding treatments numbers 1,2,3,4,5

j = Corresponding treatment depths (0-150 cm) and (150-300 cm)

2 $Q = [(\theta)/(15 \text{ Yrs.})/1\ m^2/\text{cm}] \times (\text{Depth})$

Fig. 46 The relationship between average water release - volume (depth) fraction and soil suction in bars for treatments T_1, T_2, T_3, and T_4 at depth 0-30 cm, August 1971.


SOIL WATER RELEASE
AUG. 1971
WATER RELEASE -VOL. (DEPTH) FRACTION
SOIL SUCTION IN BARS
.07
.06
.05
.04
.03
.02
.01
0
5
10
15
T1
T2
T4
T3
T ** (1%)
T2 & T4 N.S.
T1 & T3 ** (1%)
T2 & T4 vs T1 & T3 ** (1%)

the slope of the curve. In a sandy soil, most of the pores are relatively large and hence retain less water at a given suction. In a clayey soil, the pore-size distribution is more uniform, and more of the water is adsorbed, so the increasing matric suction causes a more gradual decrease in water content.

The effect of compaction upon a soil is to decrease the total porosity, and, especially, to decrease the volume of the large interaggregate pores. This means that the saturation water content and the initial decrease of water content with the application of low suction are reduced. Thus as indicated in this study the availability of water to plant is higher in Treatment 1 than it is in Treatment 3 at any given suction due to the clay content and high bulk densities. At any given high suction the availability of water to plant or the release of soil water is less in high salinity treatments than the low salinity treatment.

Plants grown in high salinity levels especially Treatment 3 will suffer water deficiency compared with low salinity level. Thus, the yield would be affected. Salts have indirect effects on availability of soil water to plants. For further additional information on soil water retention and water release, see Appendix 4.

V. GENERAL CONCLUSIONS

The soil solid phase is not rigid, as generally assumed, but rather the particles are continually being rearranged with respect to one another depending on the stability of the soil aggregates. Thus the amount of water contained in the pores and the potential or activity of this water are two factors of prime importance in soil-water relationships.

The infiltration rate data indicate higher infiltration rates in Spring than in Fall. However, there is a linear decrease of infiltration rates with time (years). Bulk density increases under these conditions.

The variation of hydraulic conductivity with depth in the profile has been examined and is related to irrigation treatments. Treatment 1 (low salinity water Gage Canal) produced the highest hydraulic conductivity values with samples from the 0-150 horizon. Non-irrigated treatment maintained high values of hydraulic conductivity in both depths.

Soil particle size analysis data indicate a transfer of clay within a profile which may be a result of irrigation treatments and managements (flooding irrigation). Soil with low stability of aggregate is affected by introducing water very fast (wetting and drying process). Clay was found to be translocated in lower depths in Treatment 1 whereas irrigated treatments with high salinity water clay was dispersed near the surface layer and blocks most of the big pores. In general, Treatment 1 has more clay transformed at 0-300 cm depth.

Soil matrix in non-irrigated treatment was found to be more stable compared with other irrigated treatments. It has big pores and no clay dispersion was noticed. These results have been confirmed by thin section studies in all treatments.

The variation of saturated hydraulic conductivity was found to correlate to clay content and bulk density values.

The relationship between soil water characteristics at 15 bars and clay content with depth in the treatments' profiles studied was found to be well correlated.

Soil water retention values (at 0.1, 0.3, 0.5, 0.7, 1, 3, 5, 7, 10 and 15 bars of suction) were found to be highest in Treatment 3 and lowest in non-irrigated treatment (T_5) and Treatment 1 at 0-150 cm depth. Also at 150-300 cm depth Treatment 1 had the highest water retention values and non-irrigated had the least values. The rest of the treatments were in between.

At 0-150 cm depth Treatment 1 and non-irrigated treatment (T_5) released more water than other treatments (from 0.1 to 15 bars of suction). Also, at 150-300 cm depth non-irrigated treatment with high content of coarse textures drains water initially at low suction and very little water is left.

Infiltration rates, hydraulic conductivity decreased as ESP_c and SAR_i increased and as PI decreases. The soil bulk density increased as ESP_c and SAR_i increased and as PI decreased.

In California alone it is estimated that 2 million acres have been already compacted to the point where yields are reduced and tillage costs are increased and that 2 to 3 million additional acres are rapidly chemical properties of soils over half a century have indicated that bulk density increases and pore space and water holding capacity decreases over extended periods of cultivation.

However, the data obtained in this study indicate movement, and dispersion of clay, and increase in bulk density in the profile in a short period of time (6 years) and thus a decrease in infiltration rates due to irrigation practice (flooding) and irrigation water quality. As indicated above, many soils under irrigated agriculture in California, are problem soils because of decreasing infiltration rates.

This study may show that changes in physical properties of many irrigated soils are not mechanically induced but result from additions of irrigated water.

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APPENDICES

APPENDIX 1. SATURATED HYDRAULIC CONDUCTIVITY OF ALL TREATMENTS (0-300 CM DEPTH) T_1, T_2, T_3, T_4 AND NON-IRRIGATED TREATMENT (T_5) SPRING 1972.

TABLE 29

SATURATED HYDRAULIC CONDUCTIVITY OF TREATMENTS (0-300 CM DEPTH)

T_1, T_2, T_3, T_4 AND NON-IRRIGATED TREATMENT (T_5)

SPRING 1972

Depth in Cm	Treatments				
	T_1	T_2	T_3	T_4	T_5
	K in cm/hr				
0-15	1.35	1.09	0.90	0.85	1.50
15-30	0.37	0.22	0.15	0.30	0.52
30-45	1.88	0.93	0.20	0.96	2.00
45-60	0.44	0.85	0.80	0.42	1.57
60-75	1.00	0.65	0.55	0.24	0.81
75-90	1.78	0.81	0.50	0.56	0.70
90-105	1.57	0.86	0.27	0.21	1.12
105-120	1.00	0.98	0.19	0.10	0.71
120-135	0.22	0.40	0.37	0.32	1.15
135-150	0.40	0.59	1.90	0.20	0.60
150-165	0.19	0.30	1.20	1.13	1.96
165-180	0.37	0.53	4.70	1.39	2.10
180-195	0.20	0.82	6.06	2.51	1.28
195-210	0.28	2.26	5.09	5.04	6.28
210-225	0.58	1.74	5.03	3.87	4.30
225-240	1.61	2.03	3.40	6.46	5.79
240-255	2.06	3.34	7.71	4.50	9.82
255-270	1.24	1.55	3.59	6.82	8.02
270-285	7.82	4.92	12.78	10.54	13.07
285-300	6.15	7.91	10.52	5.89	9.11

APPENDIX 2. GENERAL INFORMATION ON AREA COVERED BY WATER

Fig. 47 General details of four basins of each replicate 10 minutes after irrigation.

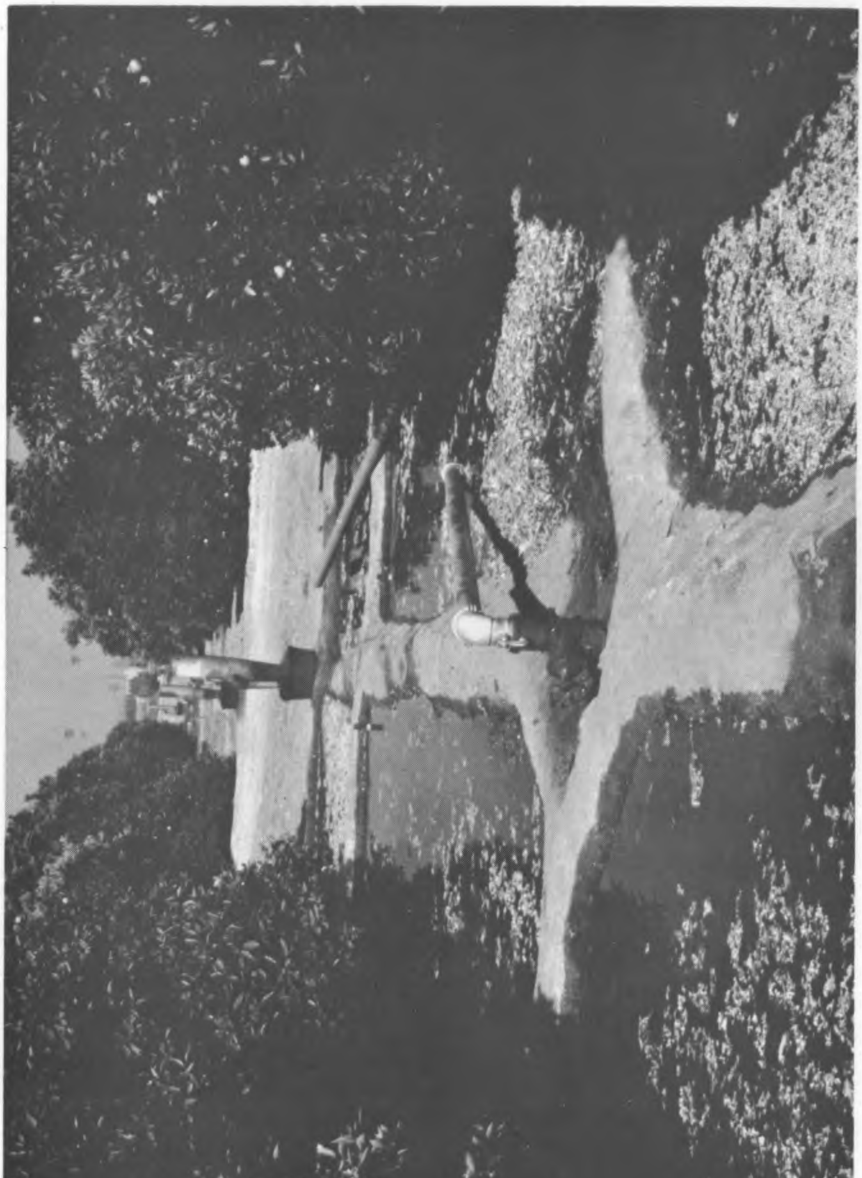


Fig. 48 Treatment 3. Details of areas covered by water 24 hours after irrigation.

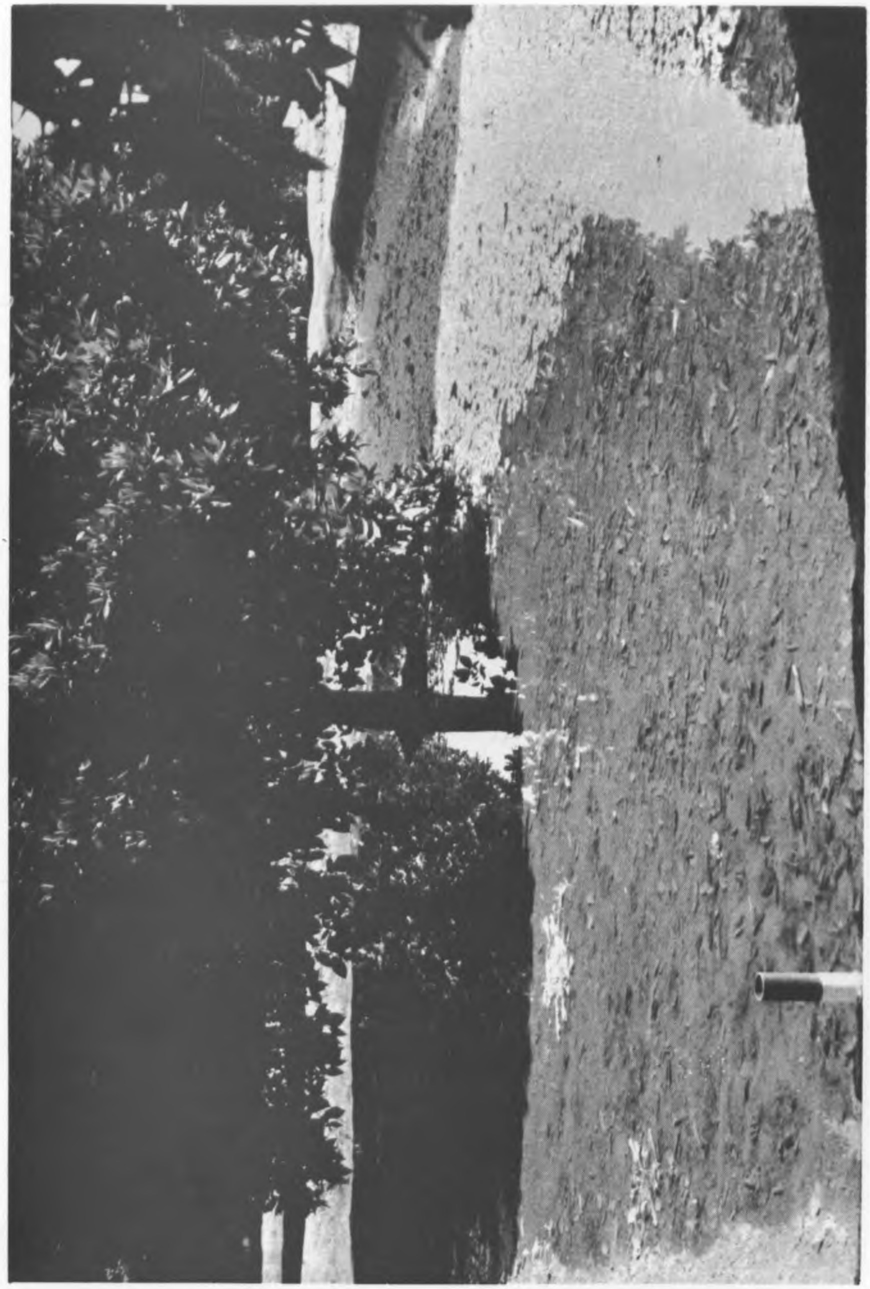


Fig.49 Treatment 4. Details of areas covered by water 24 hours after irrigation.

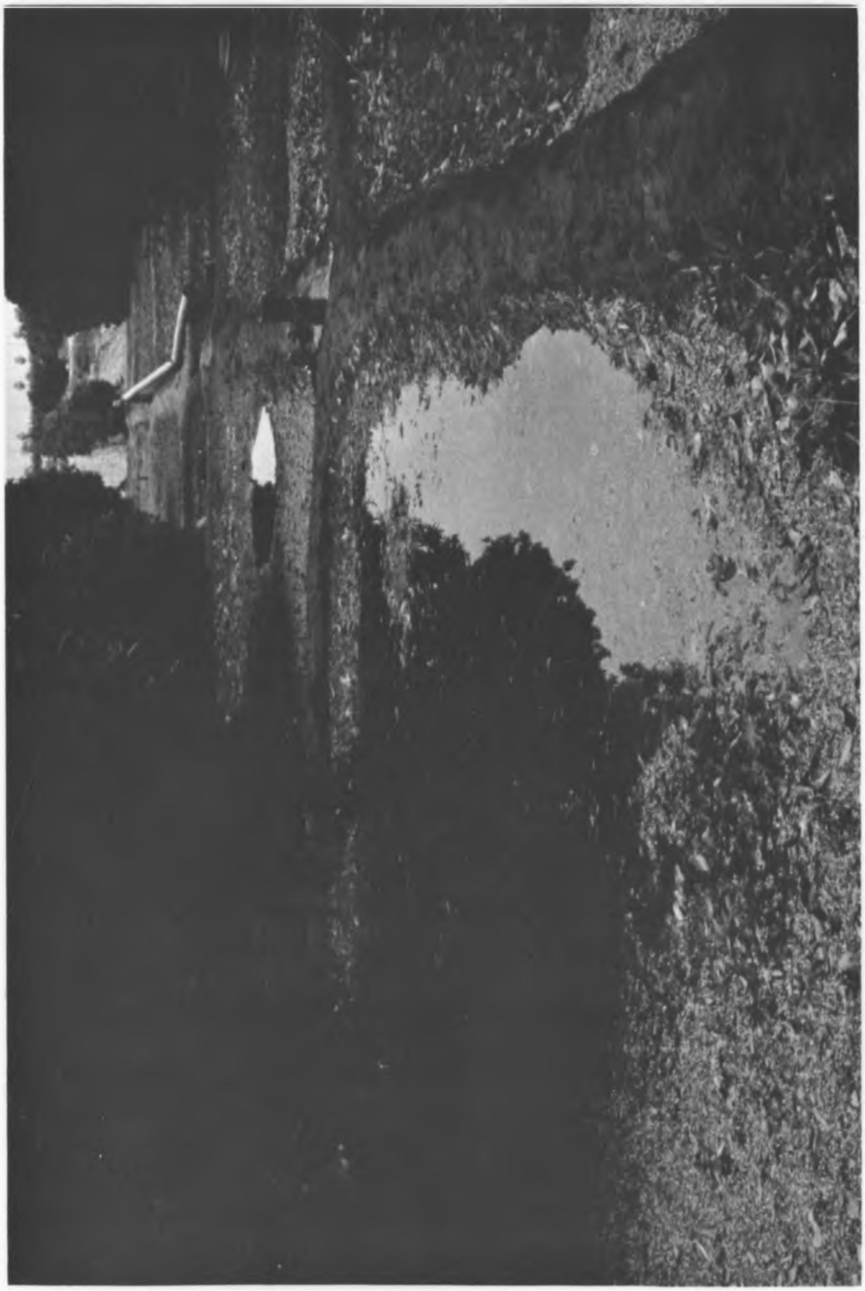


Fig. 50 Treatment 3. Details of areas covered by water 48 hours after irrigation.

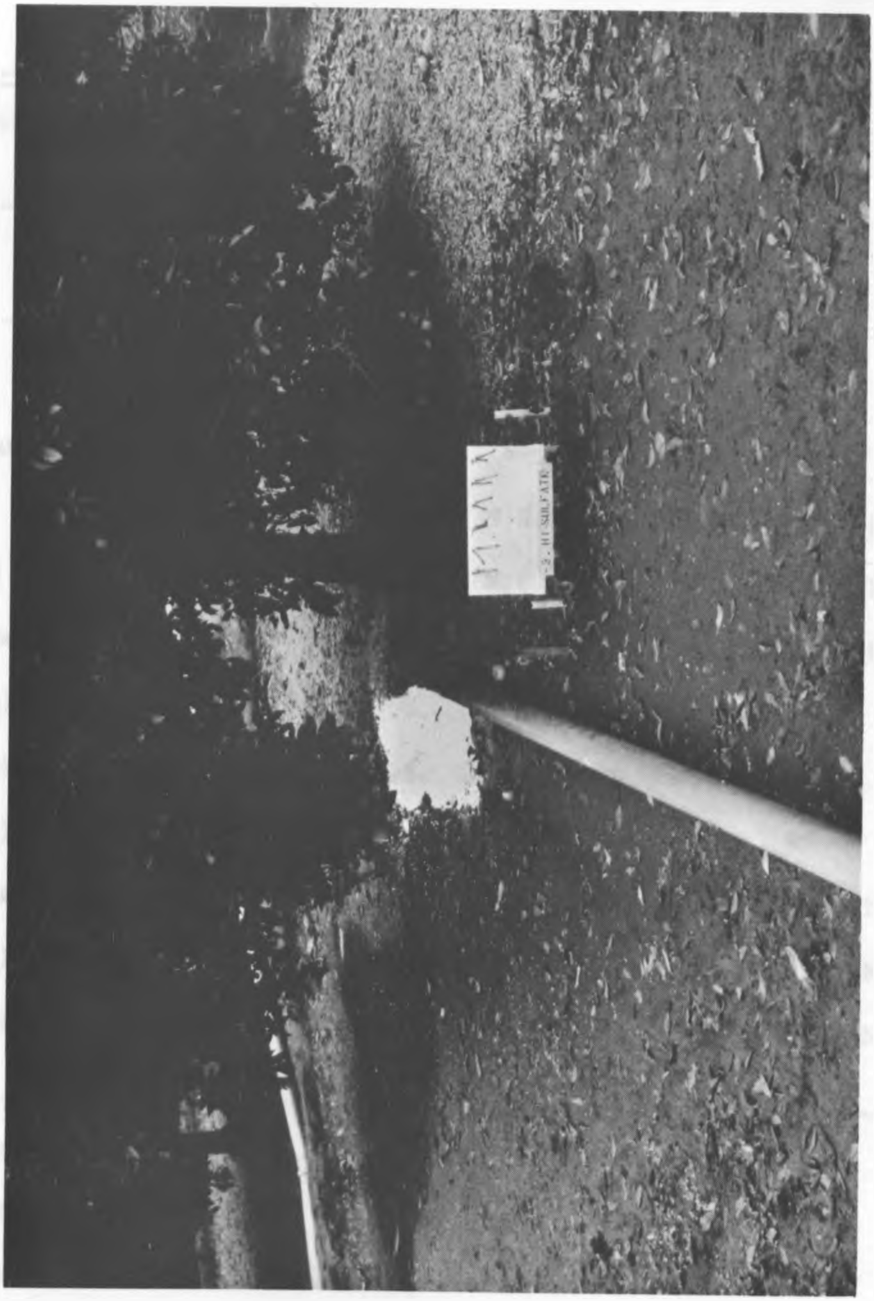


TABLE 30

SUMMARY OF ANALYSIS VARIANCE, SATURATED EXTRACT ANALYSIS

1967-1970 FALL ONLY (SEPT.-OCT.), 30 CM (1 FT.) DEPTH

Factors	EC mmho/cm	$Ca^{++}+Mg^{++}$	Na^{+}	HCO_3^-	Cl^-	$SO_4^=$	NO_3^-	SAR
		---------------meq/100g soil--------						
R	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
T	**	**	**	**	**	**	N.S.	**
Y	**	N.S.	N.S.	**	**	*	**	**
Linear	**	N.S.	**	**	**	N.S.	**	**
TxY	N.S.	N.S.	N.S.	**	*	N.S.	N.S.	N.S.
$Y(T_1)$	N.S.	N.S.	N.S.	**	N.S.	N.S.	N.S.	N.S.
Y Linear (T_1)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Y (T_2)	**	N.S.	N.S.	**	*	N.S.	*	N.S.
Y Linear (T_2)	*	N.S.	N.S.	**	N.S.	N.S.	*	N.S.
Y (T_3)	**	N.S.	*	**	N.S.	**	*	N.S.
Y Linear (T_3)	**	N.S.	*	**	N.S.	N.S.	N.S.	N.S.
Y (T_4)	*	N.S.	**	N.S.	**	N.S.	N.S.	**
Y Linear (T_4)	*	N.S.	**	N.S.	**	N.S.	N.S.	**

R = Replicates

T = Treatments

Y = Years

N.S. = Not Significant

** - Significant at 1% Level

* = Significant at 5% Level

TABLE 31

ANALYSIS OF VARIANCE, SATURATED EXTRACT ANALYSIS

1967-1970 FALL ONLY (SEPT.-OCT.), 30 CM (1 FT.) DEPTH

Treat.	EC mmho/cm	$Ca^{++}+Mg^{++}$	Na^{+}	HCO_3^-	Cl^-	$SO_4^=$	NO_3	SAR
		------------meq/100g soil					----------------	
T_1	1.05	6.19	2.83	3.13	1.55	3.00	1.49	1.63
T_2	2.26	11.66	7.34	2.43	5.21	9.69	1.91	2.99
T_3	2.98	14.83	12.62	3.26	1.77	19.20	2.39	4.60
T_4	2.10	10.41	8.05	2.82	9.15	4.82	1.92	3.74
Rep.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Treat.	**	**	**	**	**	**	N.S.	**

Treat. = Treatments

Rep. = Replicates

** = Significant at 1% Level

* = Significant at 5% Level

TABLE 32

ANALYSIS OF VARIANCE, SATURATED EXTRACT ANALYSIS

1967-1970 FALL ONLY (SEPT.-OCT.), 30 CM (1 FT.) DEPTH

Year	EC mmho/cm	$Ca^{++}+Mg^{++}$	Na^{+}	HCO_3^-	Cl^-	$SO_4^=$	NO_3^-	SAR
		----------------	meq/100g soil	----------				
1967	1.78	11.33	6.86	2.46	3.90	7.54	5.03	2.86
1968	1.54	9.83	7.20	2.60	3.46	10.34	0.76	3.11
1969	2.83	9.19	6.22	3.67	3.57	7.71	0.38	2.85
1970	2.24	12.74	10.56	2.90	6.74	11.12	1.55	3.88
Y	**	N.S.	**	**	**	*	**	**
Y Linear	**	N.S.	**	**	**	N.S.	**	**

Y = Year

** = Significant at 1% Level

* = Significant at 5% Level

N.S. = Not Significant

APPENDIX 3. SOIL PARTICLE SIZE ANALYSIS

TABLE 33

CITRUS IRRIGATION EXPERIMENT, FIELD 10-B

(INITIAL CONDITION)

1957

SAND CONTENTS IN PERCENTAGE

Depth in cm	Treatments T_1	T_2	T_3	T_4	Mean/Depth	Significant Level[1] 5%	1%
30	61.20	61.40	61.60	61.40	61.40	c	z
60	61.60	60.80	61.40	61.80	61.40	c	z
90	66.00	65.80	66.60	63.80	65.55	b	y
120	74.20	74.80	77.20	75.40	75.40	a	x
R = Replication							N.S.
T = Treatment							N.S.
D = Depth							**(1%)
DxT = Depth x Treatment							N.S.

[1]Sand contents in percentage with no letter in common are statistically different. Sand contents with one or more letters in common are not different.

TABLE 34

CITRUS IRRIGATION EXPERIMENT, FIELD 10-B

(INITIAL CONDITION)

1957

SILT CONTENTS IN PERCENTAGE

Depth in cm	T_1	T_2	T_3	T_4	Mean/Depth	Significance Level[1] 5%	1%
30	25.40	25.00	24.80	25.60	25.20	a	x
60	24.80	25.40	24.80	25.20	25.05	a	x
90	21.60	21.60	21.20	23.80	22.05	b	y
120	17.40	17.00	15.20	16.20	16.45	c	z
R = Replication							N.S.
T = Treatment							N.S.
D = Depth							**(1%)
D x T = Depth x Treatment							N.S.

[1] Silt contents in percentage with no letter in common are statistically different. Silt contents with one or more letters in common are <u>not</u> different.

TABLE 35

DUNCAN'S MULTIPLE RANGE TEST OF MEAN DIFFERENCES, 1972 TREATMENTS

(T_1, T_2, T_3, T_4) VS. 1972 NON-IRRIGATED TREATMENT (T_5)

SAND CONTENT IN PERCENTAGE

Depth	Treatment					Significance Level[1] 5%				
	T_1	T_2	T_3	T_4	T_5	T_1	T_2	T_3	T_4	T_5
0-30	53.60	53.63	54.10	53.53	57.37	a	a	a	a	a
30-60	49.60	48.53	47.70	47.20	52.87	a	a	a	a	a
60-90	53.70	53.33	53.13	53.97	55.00	a	a	a	a	a
90-120	61.17	64.63	61.63	60.57	60.07	a	a	a	a	a

T_5 = Non-irrigated treatment

[1] Sand content with no letters in common are statistically different. Sand content with one or more letters in common are not different.

TABLE 36

DUNCAN'S MULTIPLE RANGE TEST OF MEAN DIFFERENCES, 1972 TREATMENTS (T_1, T_2, T_3, T_4) VS. 1972 NON-IRRIGATED TREATMENTS (T_5)

SILT CONTENT IN PERCENTAGE

Depth	Treatment					Significance Level[1]									
						5%					1%				
	T_1	T_2	T_3	T_4	T_5	T_1	T_2	T_3	T_4	T_5	T_1	T_2	T_3	T_4	T_5
0-30	32.17	30.10	31.30	31.33	31.07	a	a	a	a	a	z	z	z	z	z
30-60	34.03	34.10	34.27	34.43	33.57	a	a	a	a	a	z	z	z	z	z
60-90	30.30	30.50	30.03	28.80	31.33	a	a	a	a	a	z	z	z	z	z
90-120	25.00	21.53	24.37	25.30	27.33	a,b	b	a,b	a,b	a	z	z	z	z	z

T_5 = Non-irrigated treatment

[1] Silt content with no letters in common are statistically different. Silt content with one or more letters in common are not different.

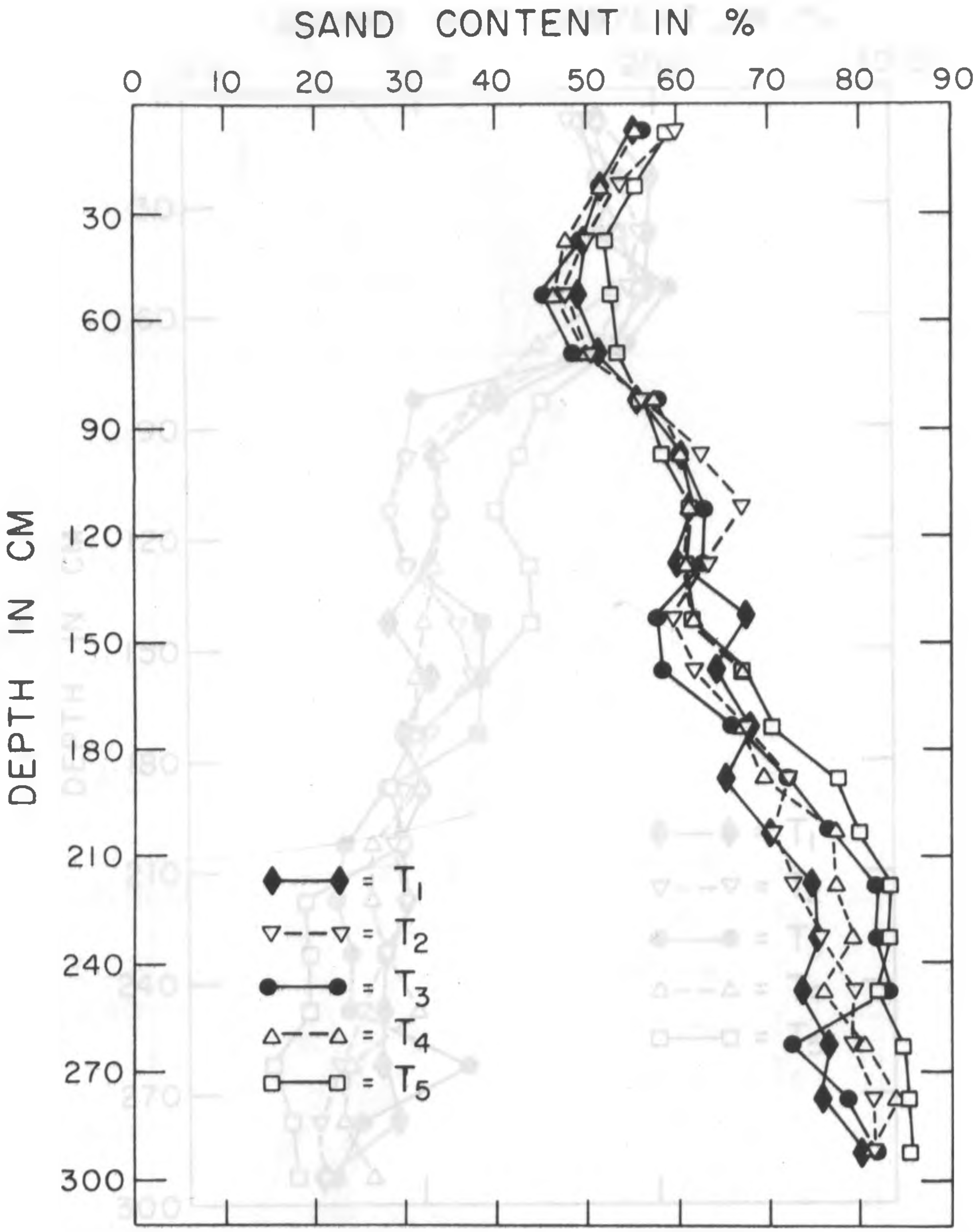


Fig. 51 Average distribution of sand content in percentage. Treatments T_1, T_2, T_3, T_4 and non-irrigated treatment (T_5). Depth 0-300 cm (0-10 ft); Spring 1972.

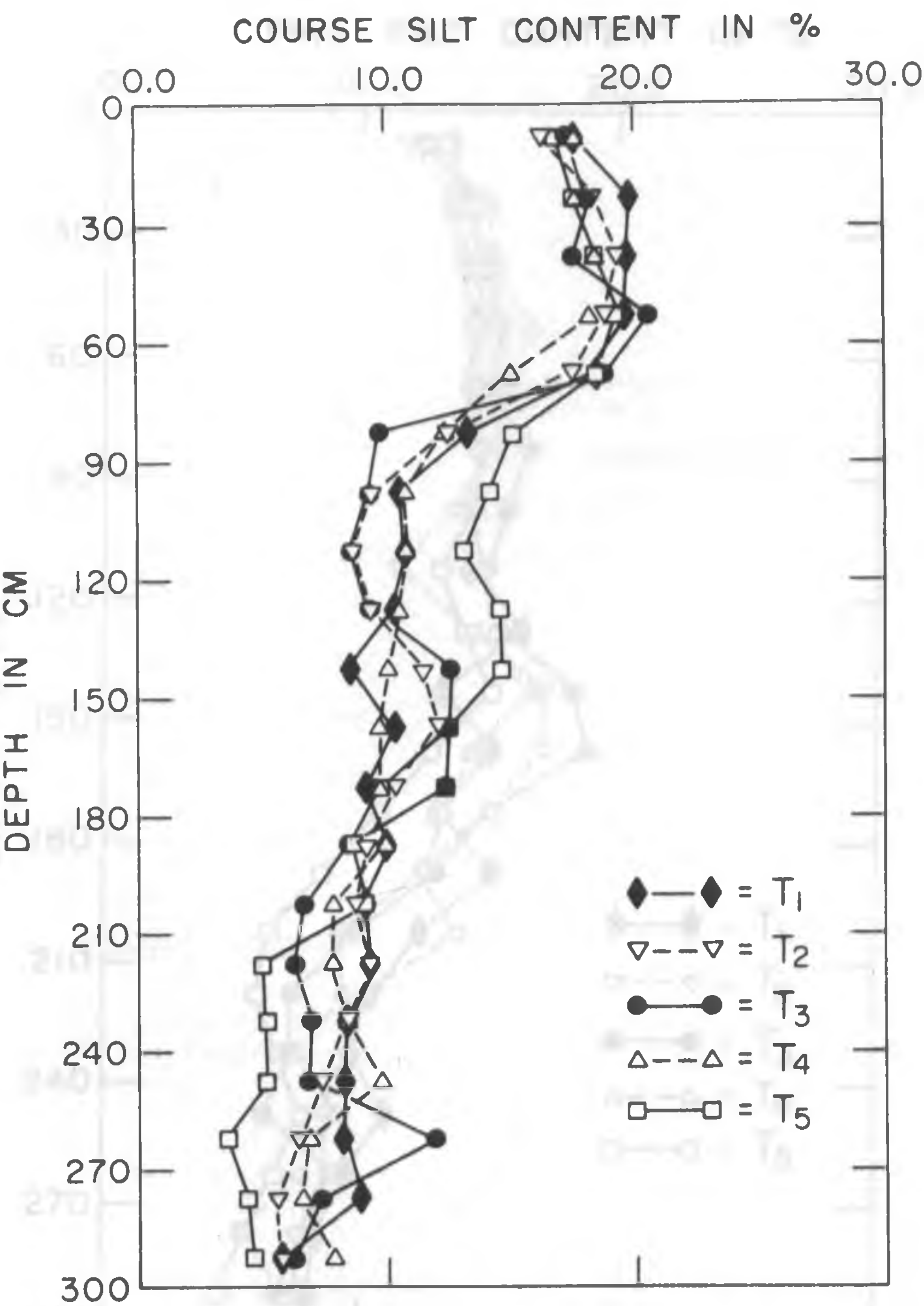


Fig. 52 Average distribution of coarse silt content in percentage. Treatments: T_1, T_2, T_3, T_4 and non-irrigated treatment (T_5). Depth 0-300 cm (0-10 ft); Spring 1972.

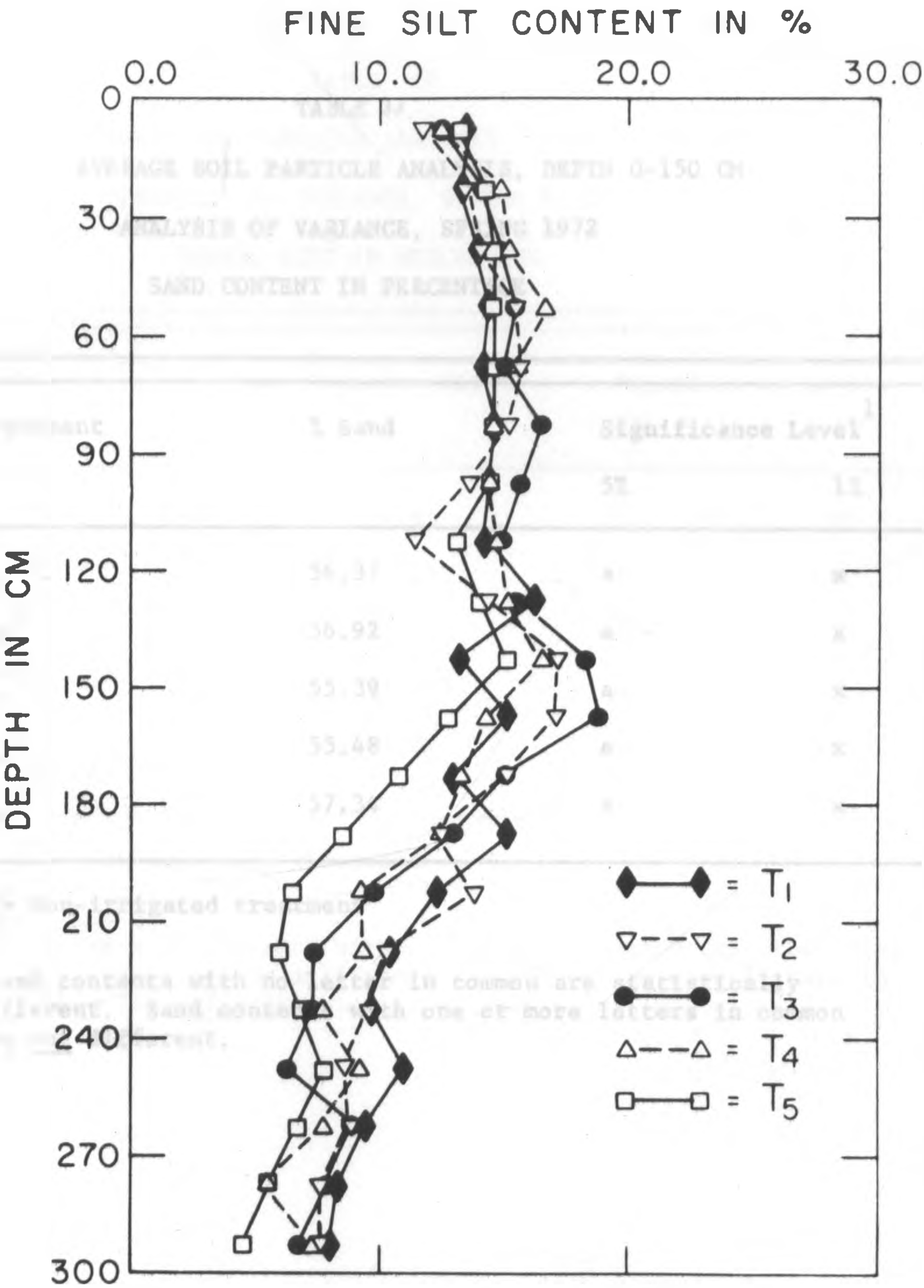


Fig. 53 Average distribution of fine silt content in percentage. Treatments: T_1, T_2, T_3, T_4 and non-irrigated treatment (T_5). Depth 0-300 cm (0-10 ft); Spring 1972.

TABLE 37

AVERAGE SOIL PARTICLE ANALYSIS, DEPTH 0-150 CM

ANALYSIS OF VARIANCE, SPRING 1972

SAND CONTENT IN PERCENTAGE

Treatment	% Sand	Significance Level[1]	
		5%	1%
T_1	56.37	a	x
T_2	56.92	a	x
T_3	55.39	a	x
T_4	55.48	a	x
T_5	57.34	a	x

T_5 = Non-irrigated treatment

[1] Sand contents with no letter in common are statistically different. Sand contents with one or more letters in common are not different.

TABLE 38

AVERAGE SOIL PARTICLE ANALYSIS, DEPTH 0-150 CM

ANALYSIS OF VARIANCE, SPRING 1972

COARSE SILT IN PERCENTAGE

Treatment	% Coarse Silt	Significance Level[1] 5%	1%
T_1	14.91	a	x
T_2	14.22	a	x
T_3	14.25	a	x
T_4	14.16	a	x
T_5	16.32	a	x

T_5 = Non-irrigated treatment

[1]Coarse silt contents with no letter in common are statistically different. Coarse silt contents with one or more letters in common are not statistically different.

TABLE 39

AVERAGE SOIL PARTICLE ANALYSIS, DEPTH 0-150 CM

ANALYSIS OV VARIANCE, SPRING 1972

FINE SILT CONTENT IN PERCENTAGE

Treatment	% Fine Silt	Significance Level[1]	
		5%	1%
T_1	14.22	a	x
T_2	14.24	a	x
T_3	15.32	a	x
T_4	15.04	a	x
T_5	14.19	a	x

T_5 = Non-irrigated treatment

[1]Fine silt contents with no letter in common are statistically different. Fine silt contents with one or more letters in common are not different.

TABLE 40

AVERAGE SOIL PARTICLE ANALYSIS, DEPTH 0-150 CM

ANALYSIS OF VARIANCE, SPRING 1972

CLAY CONTENT IN PERCENTAGE

Treatment	% Clay	Significance Level[1]	
		5%	1%
T_1	14.51	a,b	x
T_2	14.63	a,b	x
T_3	15.04	a	x
T_4	15.33	a	x
T_5	12.16	b	x

T_5 = Non-irrigated treatment

[1] Clay contents with no letter in common are statistically different. Clay contents with one or more letters in common are not different.

TABLE 41

AVERAGE SOIL PARTICLE ANALYSIS, DEPTH (159-300 CM)

ANALYSIS OF VARIANCE, SPRING 1972

SAND CONTENT IN PERCENTAGE

Treatment	% Sand	Significance Level[1]	
		5%	1%
T_1	72.24	a	x
T_2	74.34	a	x
T_3	75.49	a	x
T_4	76.33	a	x
T_5	80.15	a	x

T_5 = Non-irrigated treatment

[1]Sand contents with no letter in common are statistically different. Sand contents with one or more letters in common are not different.

TABLE 42

AVERAGE SOIL PARTICLE ANALYSIS, DEPTH 150-300 CM

ANALYSIS OF VARIANCE, SPRING 1972

COARSE SILT CONTENTS IN PERCENTAGE

Treatment	% Coarse Silt	Significance Level[1]	
		5%	1%
T_1	8.73	a	x
T_2	8.33	a	x
T_3	8.85	a	x
T_4	8.45	a	x
T_5	6.95	a	x

T_5 = Non-irrigated treatment.

[1] Coarse silt contents with no letter in common are statistically different. Coarse silt contents with one or more letters are <u>not</u> different.

TABLE 43

AVERAGE SOIL PARTICLE ANALYSIS, DEPTH 150-300 CM

ANALYSIS OF VARIANCE, SPRING 1972

FINE SILT CONTENTS IN PERCENTAGE

Treatment	% Fine Silt	Significance Level[1]	
		5%	1%
T_1	11.32	a	x
T_2	11.04	a	x
T_3	10.11	a,b	x
T_4	9.56	a,b	x
T_5	7.55	b	x

T_5 = Non-irrigated treatment

[1] Fine silt contents with no letter in common are statistically different. Fine silt contents with one or more letters in common are not different.

TABLE 44

AVERAGE SOIL PARTICLE ANALYSIS, DEPTH 150-300 CM

ANALYSIS OF VARIANCE, SPRING 1972

CLAY CONTENTS IN PERCENTAGE

Treatment	% Clay	Significance Level[1] 5%	1%
T_1	7.71	a	x
T_2	6.29	a	x
T_3	5.55	a	x
T_4	5.67	a	x
T_5	5.35	a	x

T_5 = Non-irrigated treatment

[1]Clay contents with no letter in common are statistically different. Clay contents with one or more letters in common are different.

APPENDIX 4. SOIL WATER RETENTION AND WATER RELEASE

Fig. 54 The relationship between average volumetric water content and soil suction in bars for treatments T_1, T_2, T_3 and T_4, at depth 0-30 cm, August 1971.

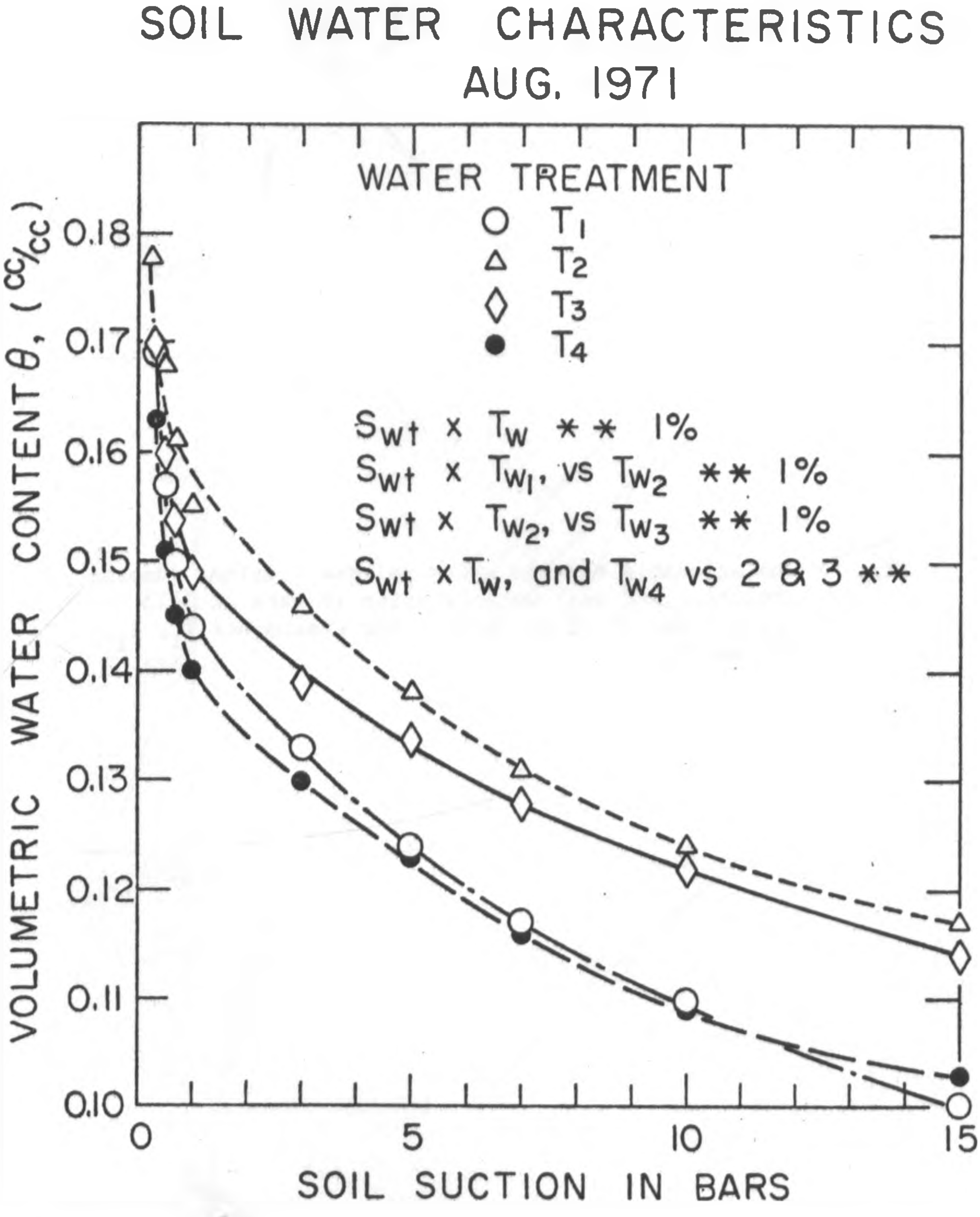
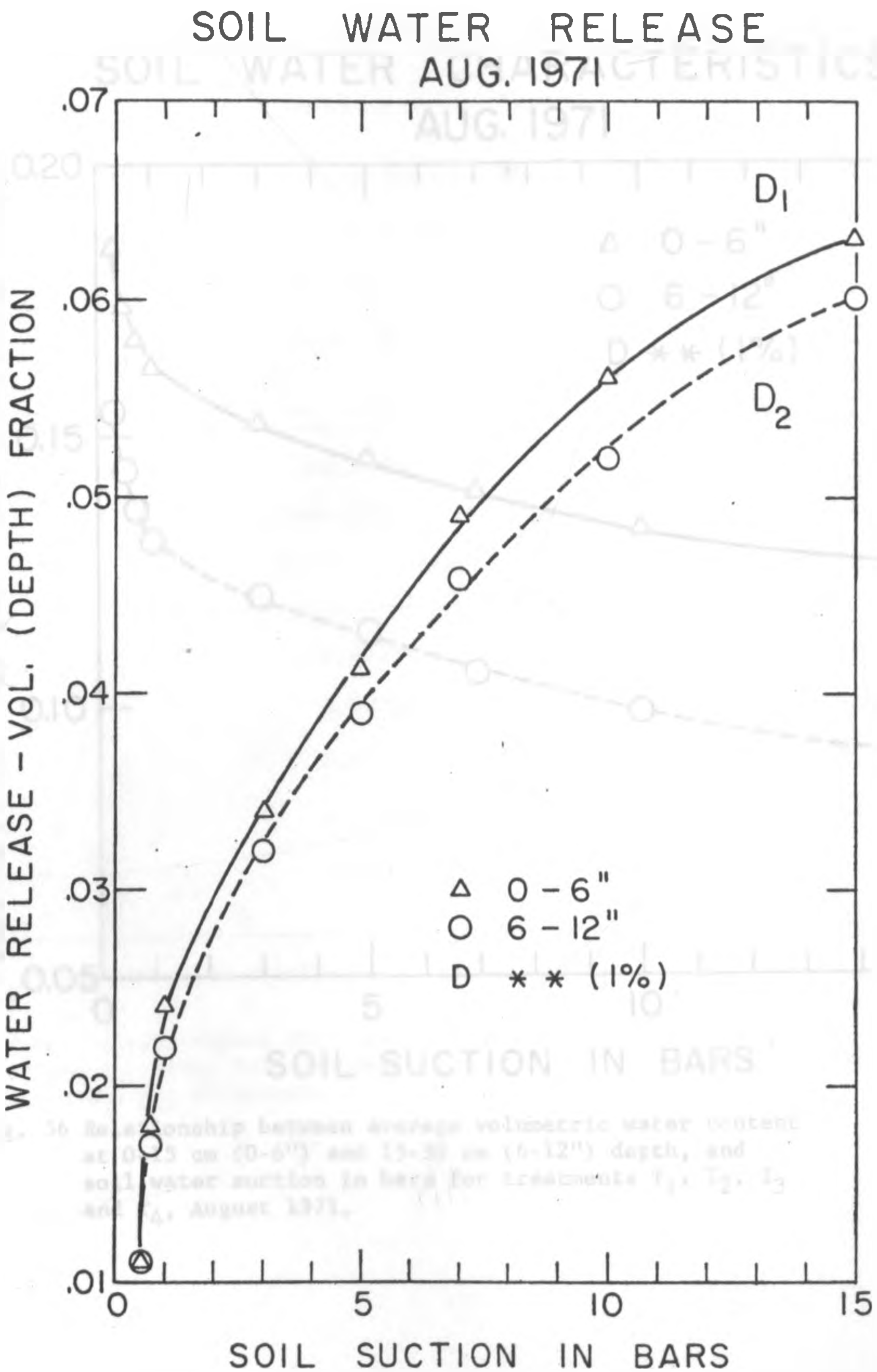

SOIL WATER CHARACTERISTICS
AUG. 1971
WATER TREATMENT
T1
T2
T3
T4
Swt x Tw ** 1%
Swt x Tw1, vs Tw2 ** 1%
Swt x Tw2, vs Tw3 ** 1%
Swt x Tw, and Tw4 vs 2 & 3 **
VOLUMETRIC WATER CONTENT θ, (cc/cc)
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0
5
10
15
SOIL SUCTION IN BARS

Fig. 55 Relationship between water release - volume (depth) fraction and soil water suction in bars at 0-15 cm (0-6") and 15-30 cm (6-12") for treatments T_1, T_2, T_3 and T_4.


SOIL WATER RELEASE
AUG. 1971
WATER RELEASE - VOL. (DEPTH) FRACTION
.07
.06
.05
.04
.03
.02
.01
0
5
10
15
SOIL SUCTION IN BARS
D1
D2
△ 0 - 6"
○ 6 - 12"
D ** (1%)

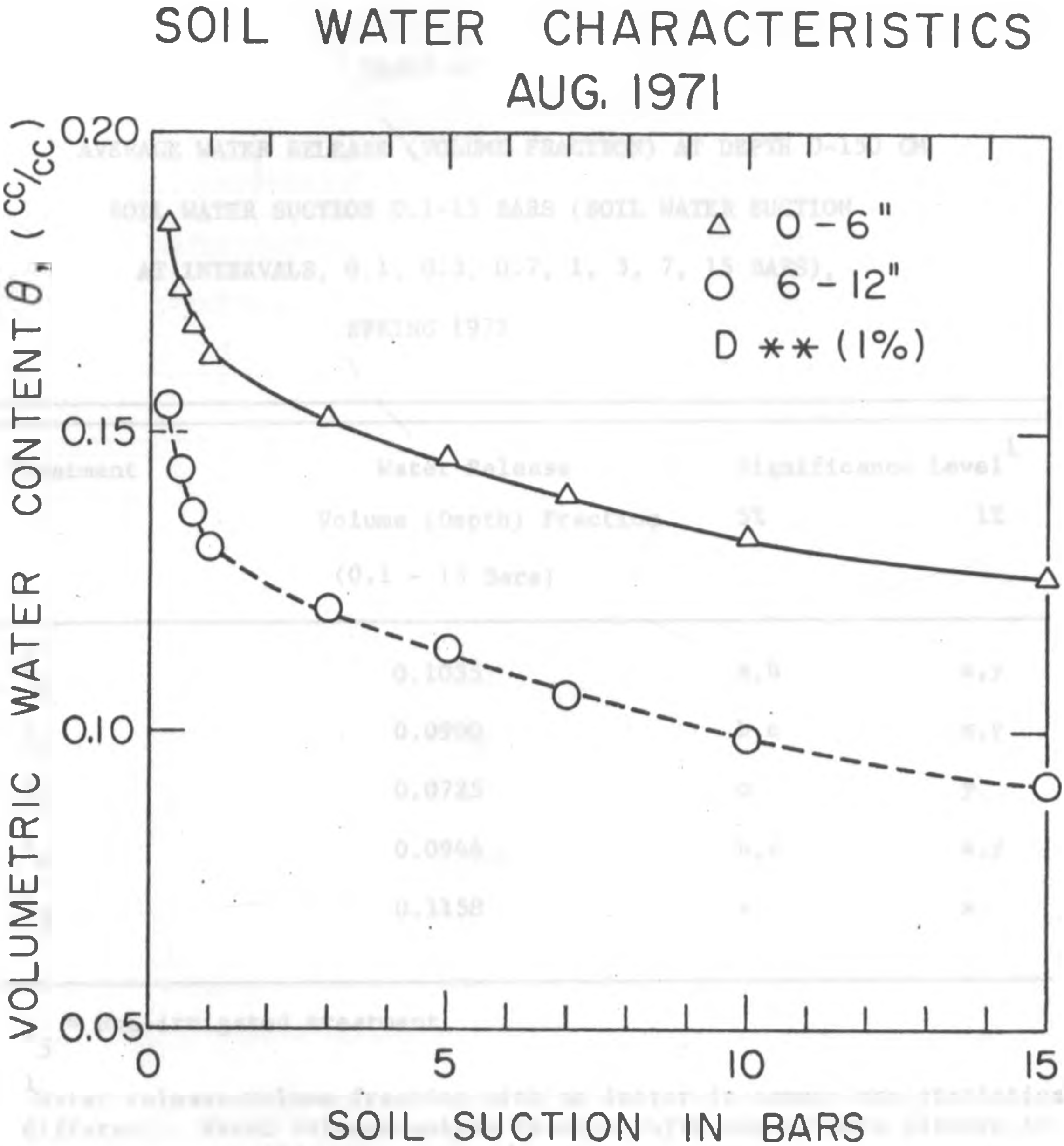


Fig. 56 Relationship between average volumetric water content at 0-15 cm (0-6") and 15-30 cm (6-12") depth, and soil water suction in bars for treatments T_1, T_2, T_3 and T_4, August 1971.

TABLE 45

AVERAGE WATER RELEASE (VOLUME FRACTION) AT DEPTH 0-150 CM SOIL WATER SUCTION 0.1-15 BARS (SOIL WATER SUCTION AT INTERVALS, 0.1, 0.3, 0.7, 1, 3, 7, 15 BARS), SPRING 1972

Treatment	Water Release Volume (Depth) Fraction (0.1 - 15 Bars)	Significance Level[1] 5%	1%
T_1	0.1035	a,b	x,y
T_2	0.0900	b,c	x,y
T_3	0.0725	c	y
T_4	0.0946	b,c	x,y
T_5	0.1158	a	x

T_5 = Non-irrigated treatment

[1]Water release-volume fraction with no letter in common are statistically different. Water release-volume fraction with one or more letters in common are not different.

TABLE 46

AVERAGE WATER RELEASE (VOLUME FRACTION) AT DEPTH 150-300 CM SOIL WATER SUCTION 0.1 - 15 BARS (SOIL WATER SUCTION AT INTERVALS, 0.1, 0.3, 0.7, 1, 3, 7, 15 BARS), SPRING 1972

Treatment	Water Relase Volume (Depth) Fraction (0.1 - 15 Bars)	Significance Level[1] 5%	1%
T_1	0.1182	a	x
T_2	0.1306	a	x
T_3	0.0764	b	x
T_4	0.0878	b	x
T_5	0.0701	b	x

T_5 = Non-irrigated treatment

[1]Water release-volume fraction with no letter in common are statistically different. Water release-volume fraction with one or more letter in common are not different.

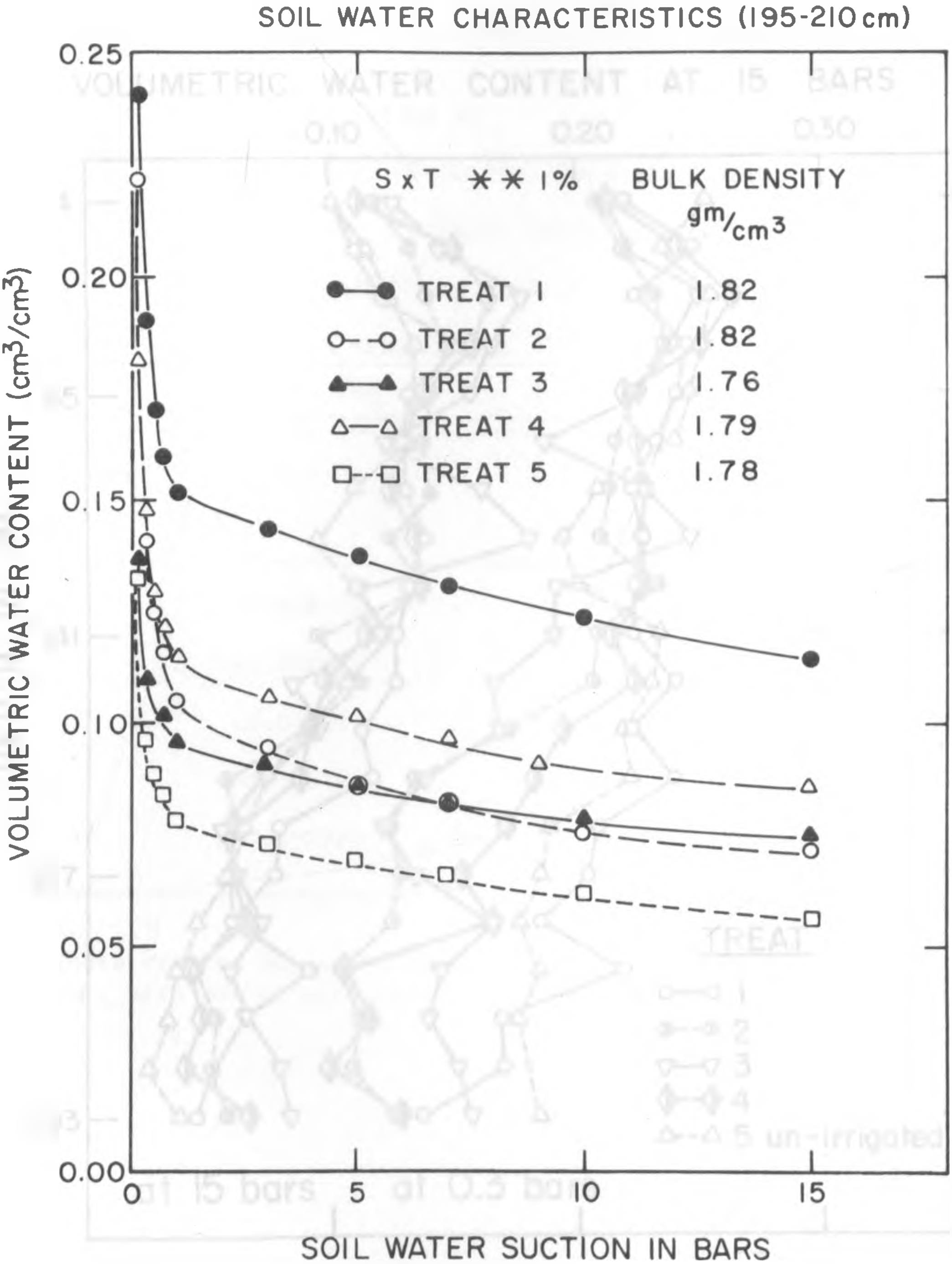


Fig. 57 Relationship between volumetric water content (cm^3/cm^3) and soil water suction in bars. Treatments: T_1, T_2, T , T and non-irrigated: depth 195-210 cm (6 1/2 - 7 ft). Analysis of variance; soil water suction(s) X Treatments(T) **(1%). Spring 1972.

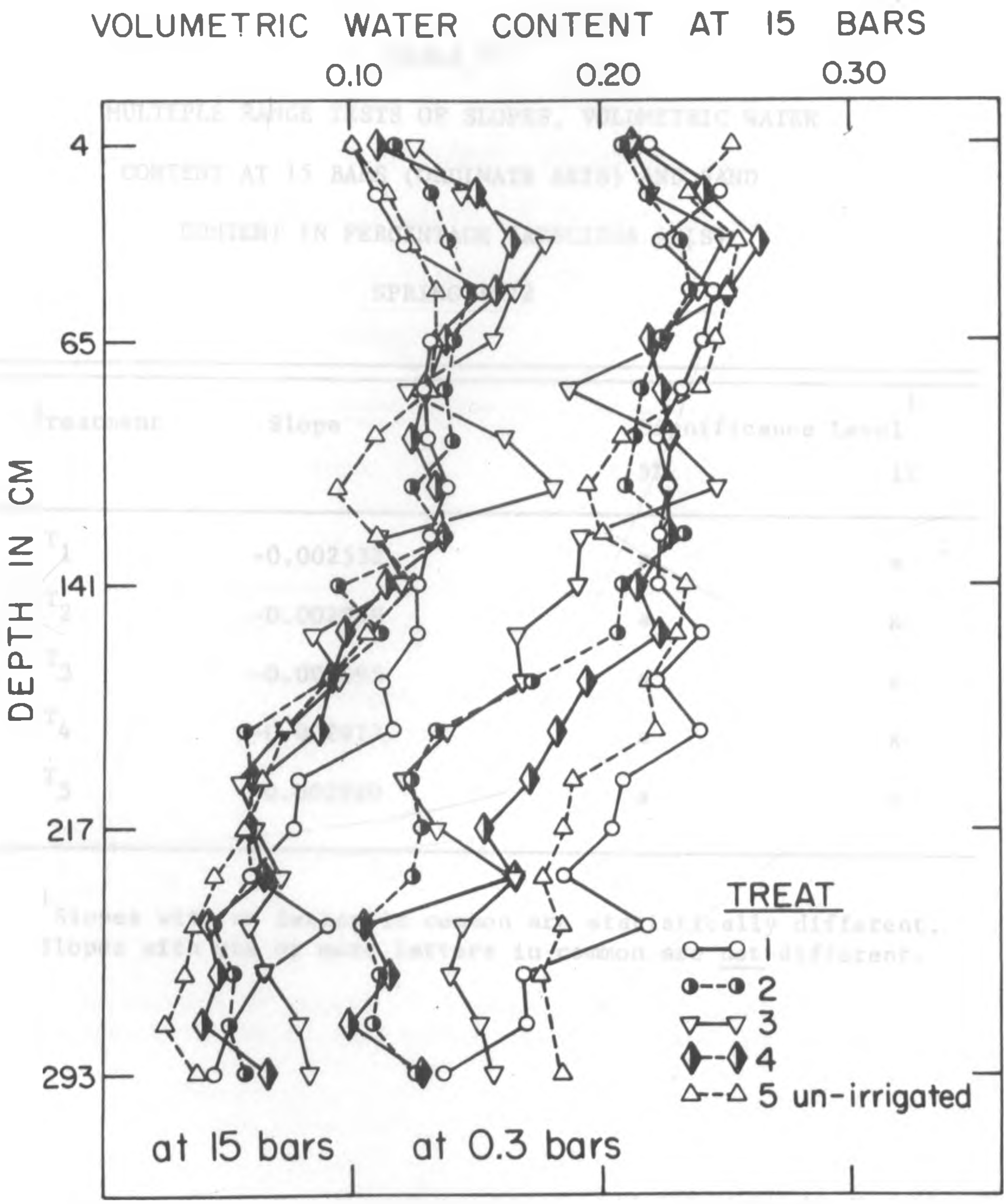


Fig. 58 Relation between depth in cm and actual data of volumetric water content (cm^3/cm^3) at 0.3 and 15 bars. Treatments T_1, T_2, T_3, T_4 and non-irrigated treatment (T_5). Depth 0-300 cm (0-10 ft); Spring 1972.

TABLE 47

MULTIPLE RANGE TESTS OF SLOPES, VOLUMETRIC WATER CONTENT AT 15 BARS (ORDINATE AXIS) AND SAND CONTENT IN PERCENTAGE (ABSCISSA AXIS)

SPRING 1972

Treatment	Slope	Significance Level[1] 5%	1%
T_1	-0.002532	a	x
T_2	-0.002898	a	x
T_3	-0.002595	a	x
T_4	-0.002977	a	x
T_5	-0.002920	a	x

[1] Slopes with no letter in common are statistically different. Slopes with one or more letters in common are not different.

TABLE 48

MULTIPLE RANGE TESTS OF SLOPES, VOLUMETRIC WATER CONTENT AT 15 BARS (ORDINATE AXIS) AND COARSE SILT CONTENT IN PERCENTAGE (ABSCISSA AXIS)

SPRING 1972

Treatment	Slope	Significance Level[1]	
		5%	1%
T_1	0.002915	c	y
T_2	0.005094	b,c	x,y
T_3	0.003785	b,c	y
T_4	0.007285	a	x
T_5	0.005830	a,b	x,y

[1]Slopes with no letter in common are statistically different. Slopes with one or more letters in common are not different.

TABLE 49

MULTIPLE RANGE TESTS OF SLOPES, VOLUMETRIC WATER CONTENT AT 15 BARS (ORDINATE AXIS) AND FINE SILT CONTENT IN PERCENTAGE (ABSCISSA AXIS)

SPRING 1972

Treatment	Slope	Significance Level[1] 5%	Significance Level[1] 1%
T_1	0.008335	a,b	x
T_2	0.008178	a,b	x
T_3	0.005940	b	x
T_4	0.008222	a,b	x
T_5	0.009148	a	x

[1] Slopes with no letter in common are statistically different. Slopes with one or more letters in common are not different.

TABLE 50

MULTIPLE RANGE TESTS OF SLOPES, VOLUMETRIC WATER CONTENT AT 15 BARS (ORDINATE AXIS) AND CLAY CONTENT IN PERCENTAGE (ABSCISSA AXIS)

SPRING 1972

Treatment	Slope	Significance Level[1] 5%	Significance Level[1] 1%
T_1	0.005801	b	y
T_2	0.005782	b	y
T_3	0.006576	b	x,y
T_4	0.006347	b	x,y
T_5	0.008941	a	x

[1] Slopes with no letter in common are statistically different. Slopes with one or more letters in common are not different.

APPENDIX 5.

COMPUTER OUTPUT USED IN TABLES 16-19 AND 23-27

Numbers in D Format are easy to read once the system is understood. At the far right end of D is found followed by a number such as 02. This means that the decimal place should be moved two places to the right to get the number's correct value. If the number following the D is a negative number, the decimal place is moved that many places to the left. If it is a zero. the decimal point remains as printed. Thus a number ·12345678 02 would be read 12·345678; ·12345678 00 would be read ·0012345678. Some times a number will be found followed by D-06, D-07, or D-08, therefore, the number would be multiplied by 10^{-6}, 10^{-7} and 10^{-8} respectively to give the right value. Sometimes a number such as 0.5799999 02 will be found. This number would read 58.0. The numbers appearing in the computer are generally correct at least 6 decimal places.

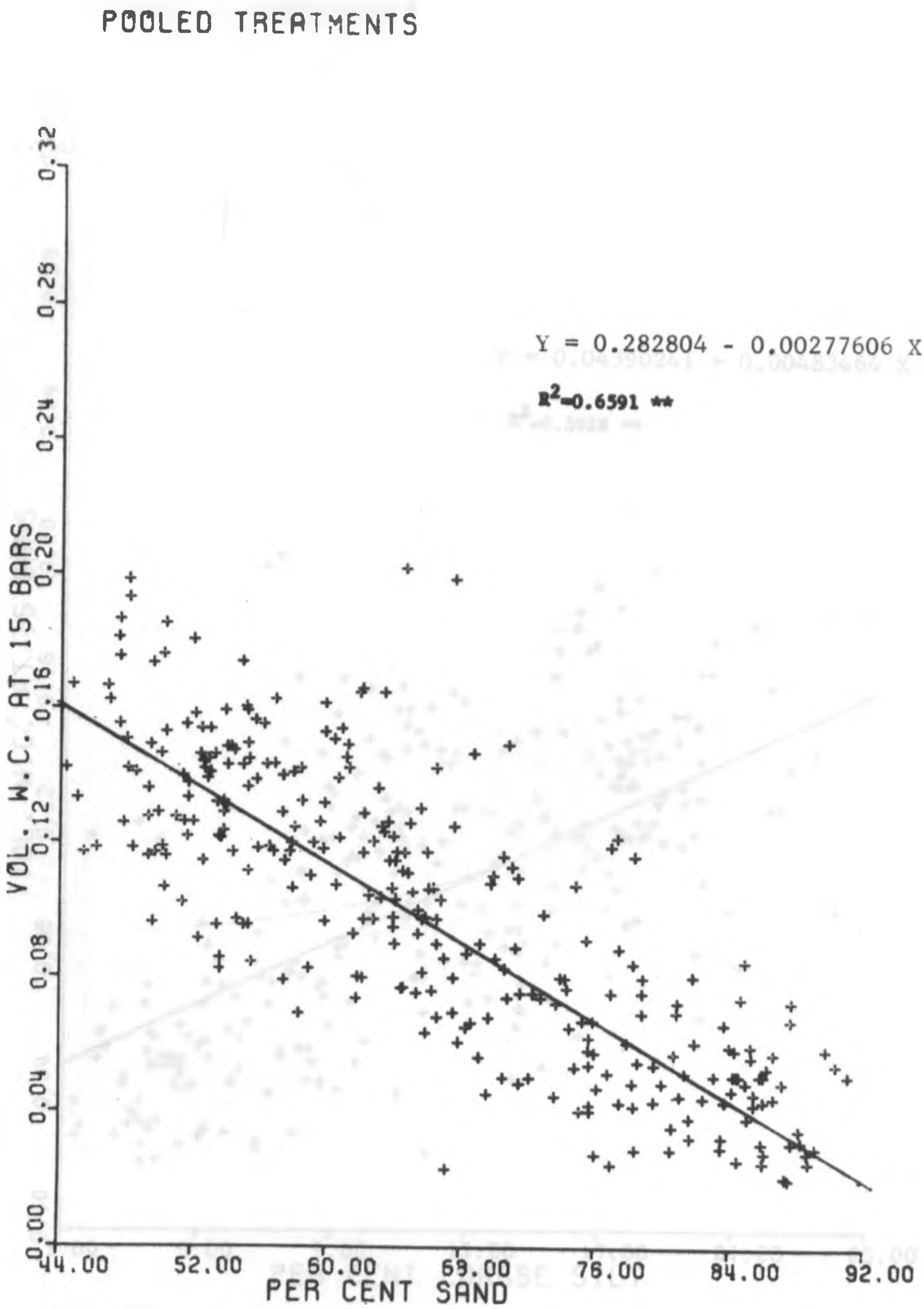


Fig. 59 Pooled Treatments. Relationship between volumetric water content at 15 bars and percentage sand content.

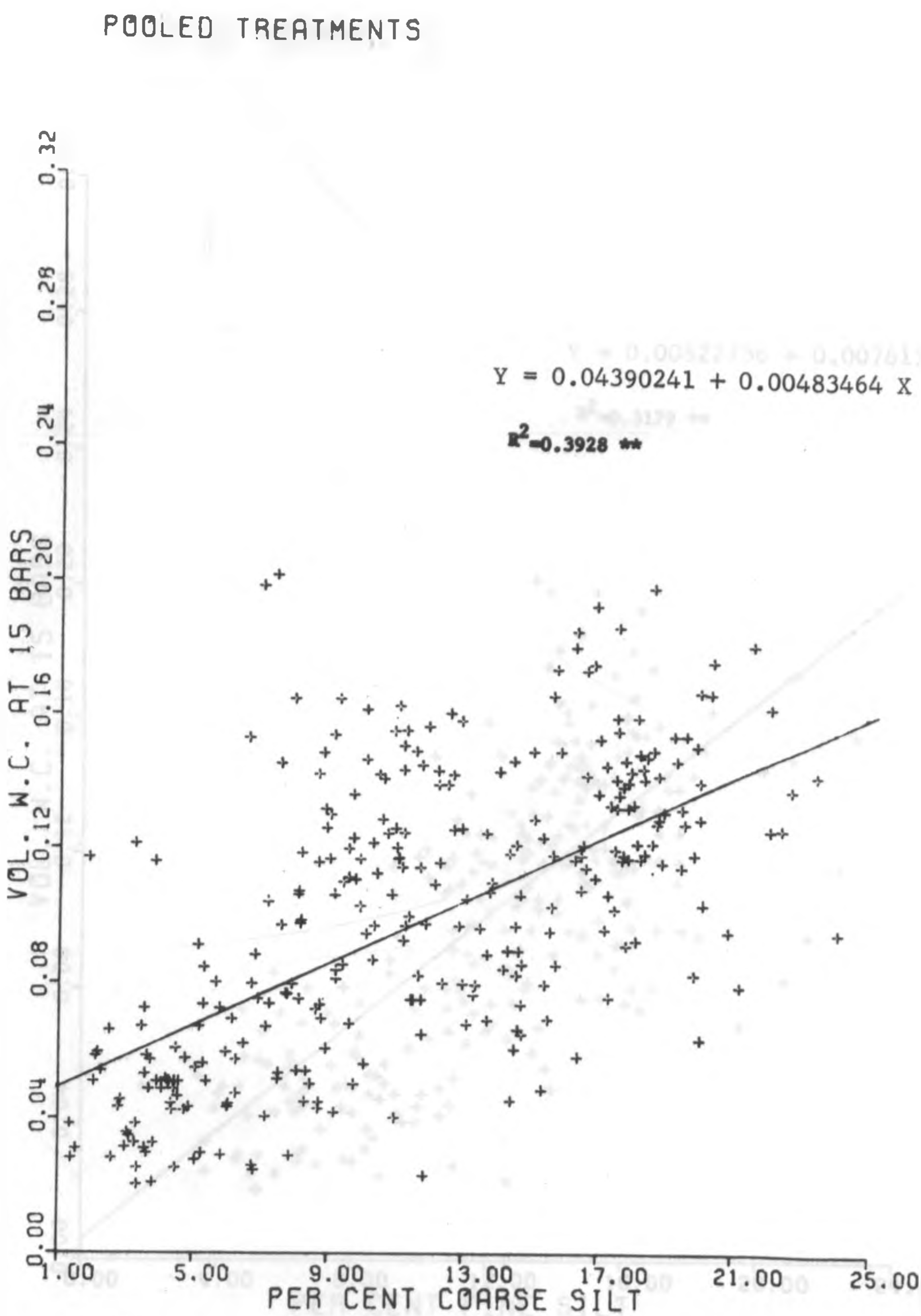


Fig. 60 Pooled Treatments. Relationship between volumetric water content at 15 bars and percentage coarse silt content.

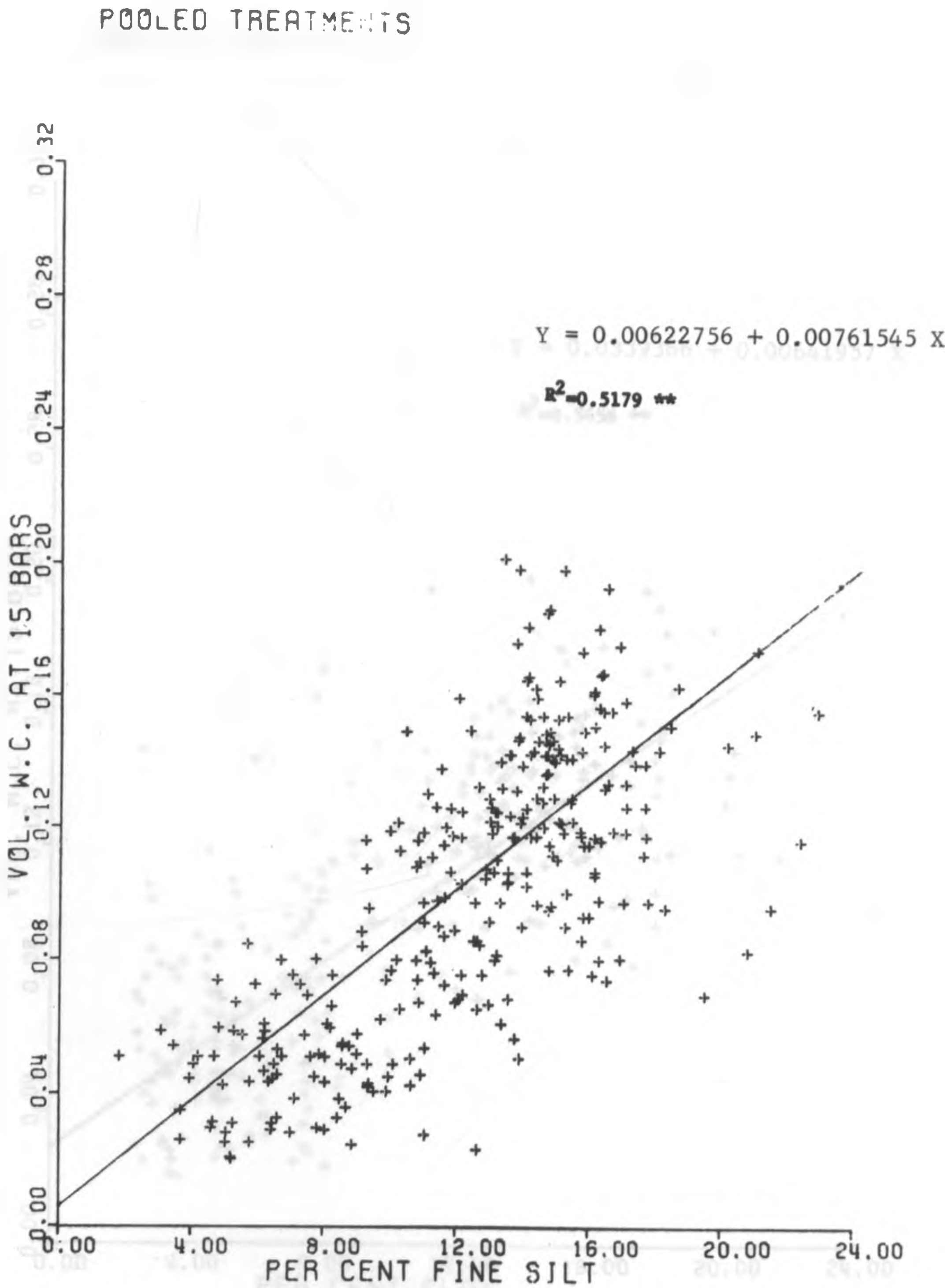


Fig. 61 Pooled Treatments. Relationship between volumetric water content at 15 bars and percentage fine silt content.

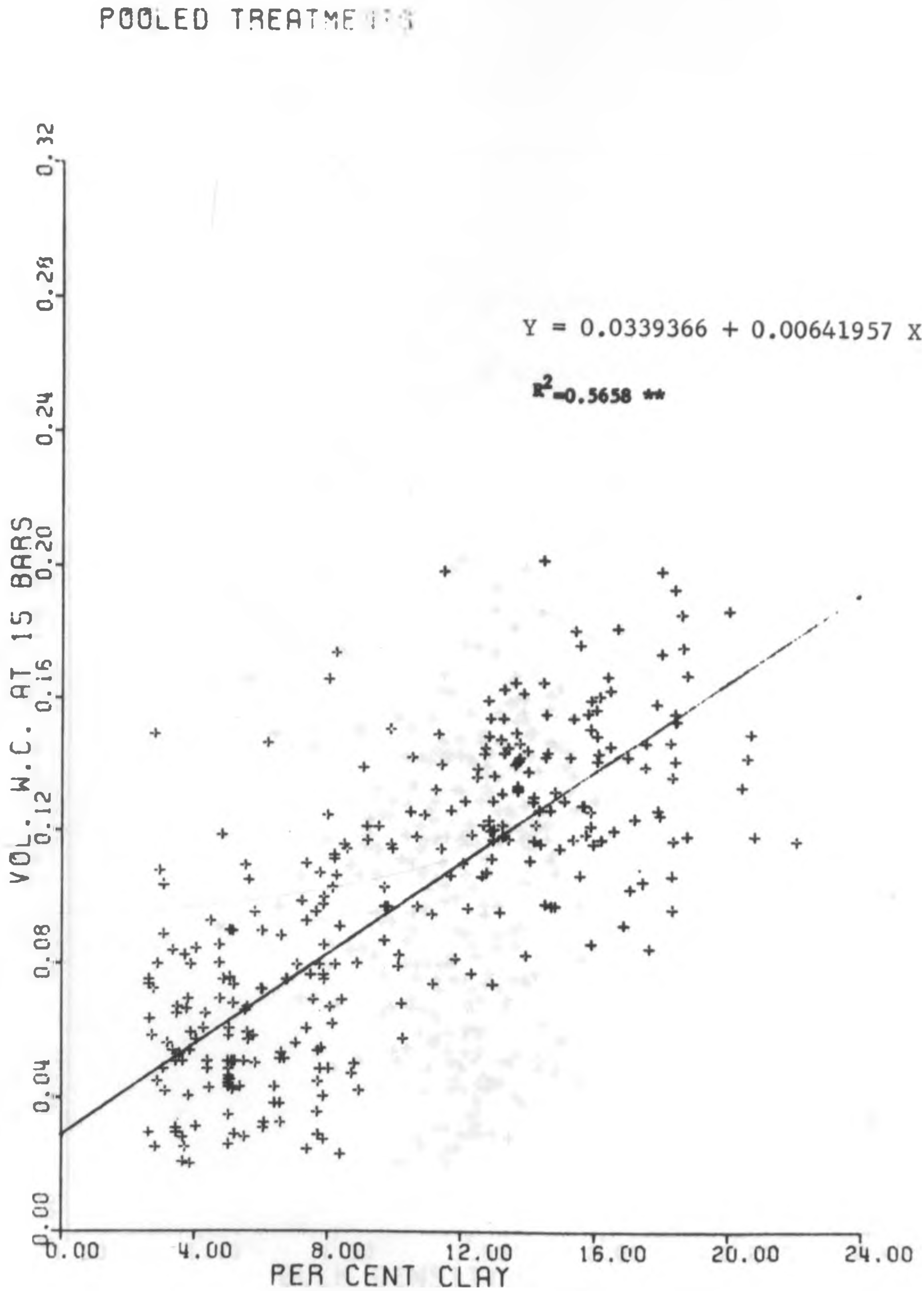


Fig. 62 Pooled Treatments. Relationship between volumetric water content at 15 bars and percentage clay content.

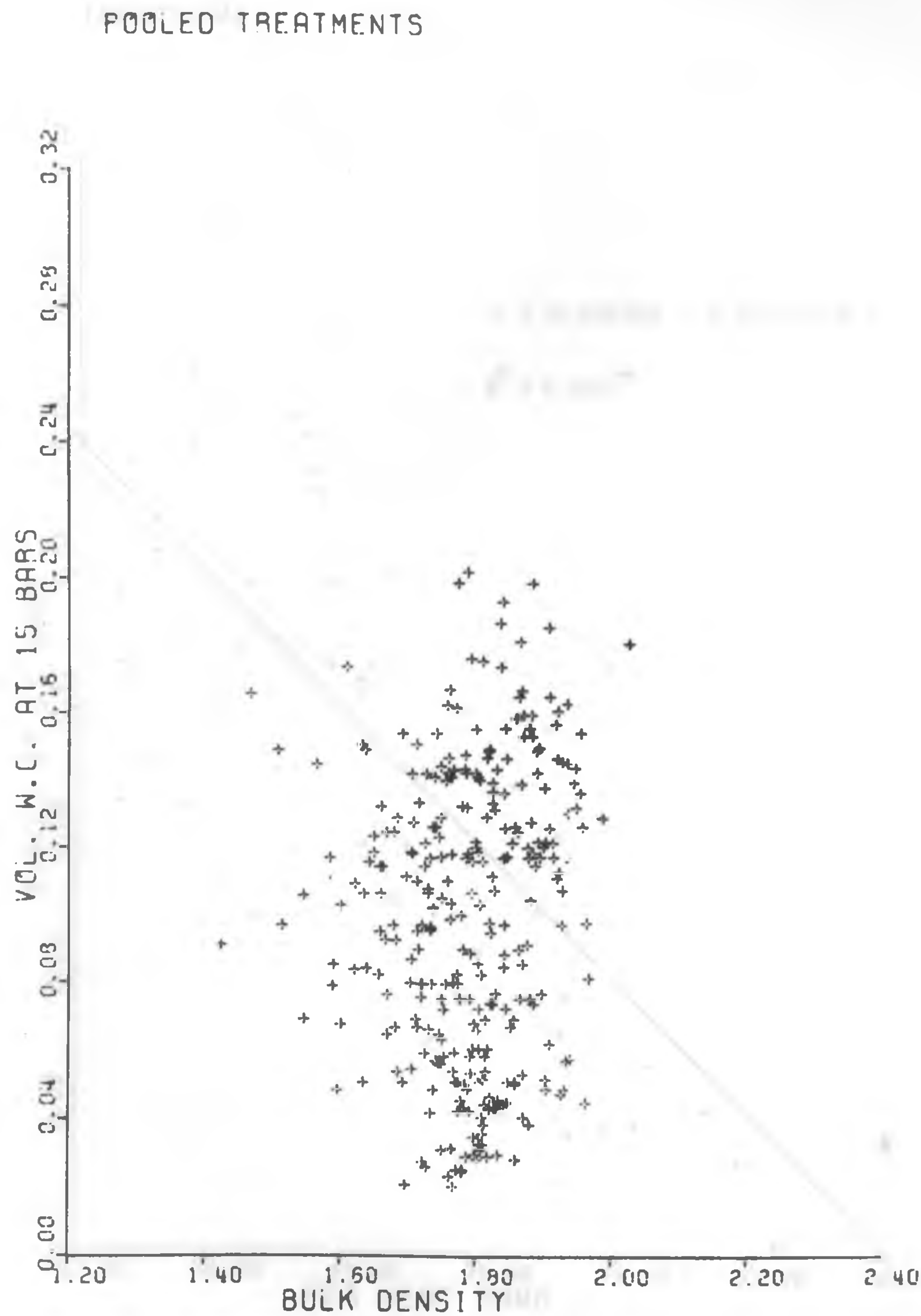


Fig. 63 Pooled Treatments. Relationship between volumetric water content at 15 bars and bulk density.

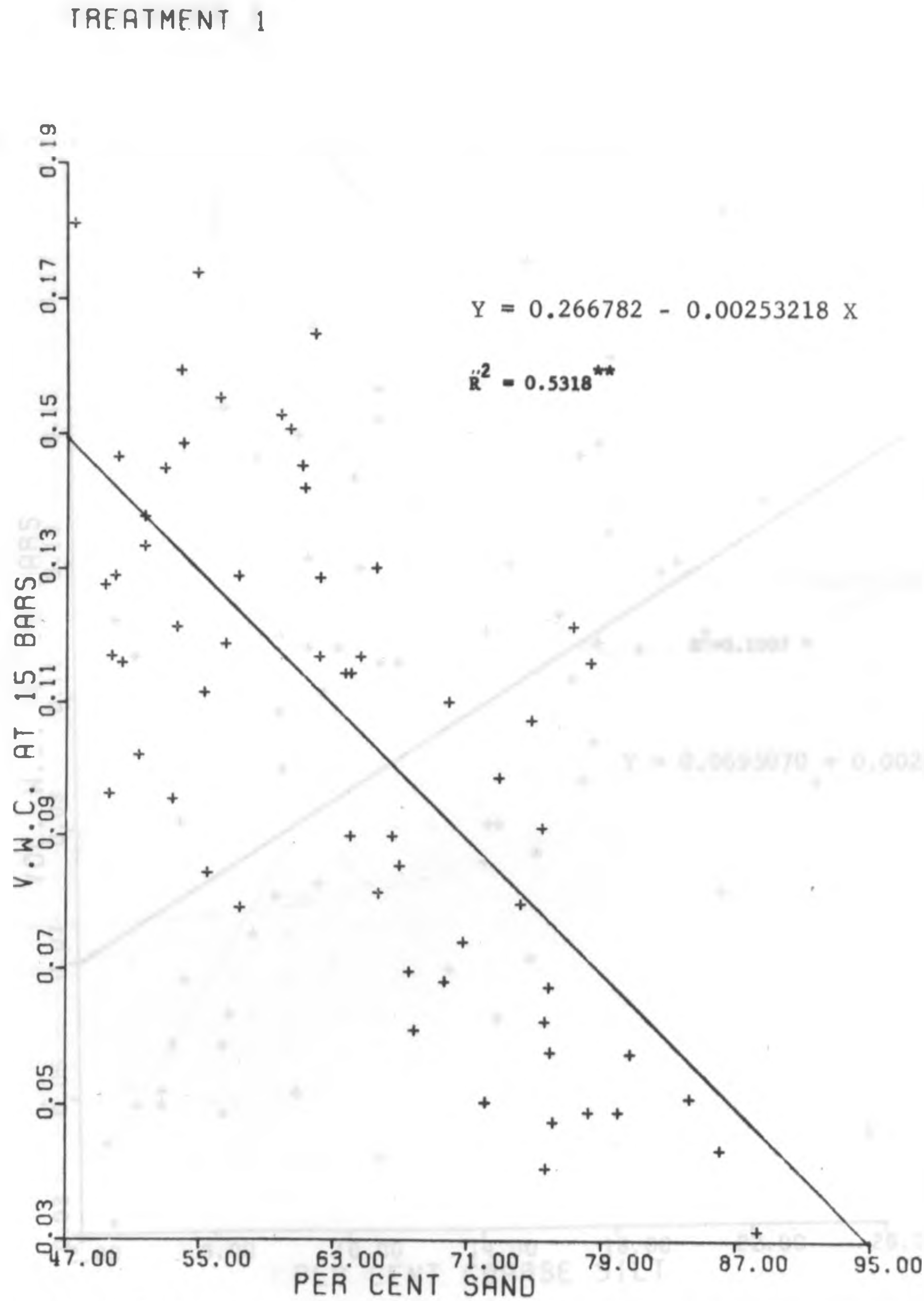


Fig. 64 Treatment 1. Relationship between volumetric water content at 15 bars and percentage sand content.

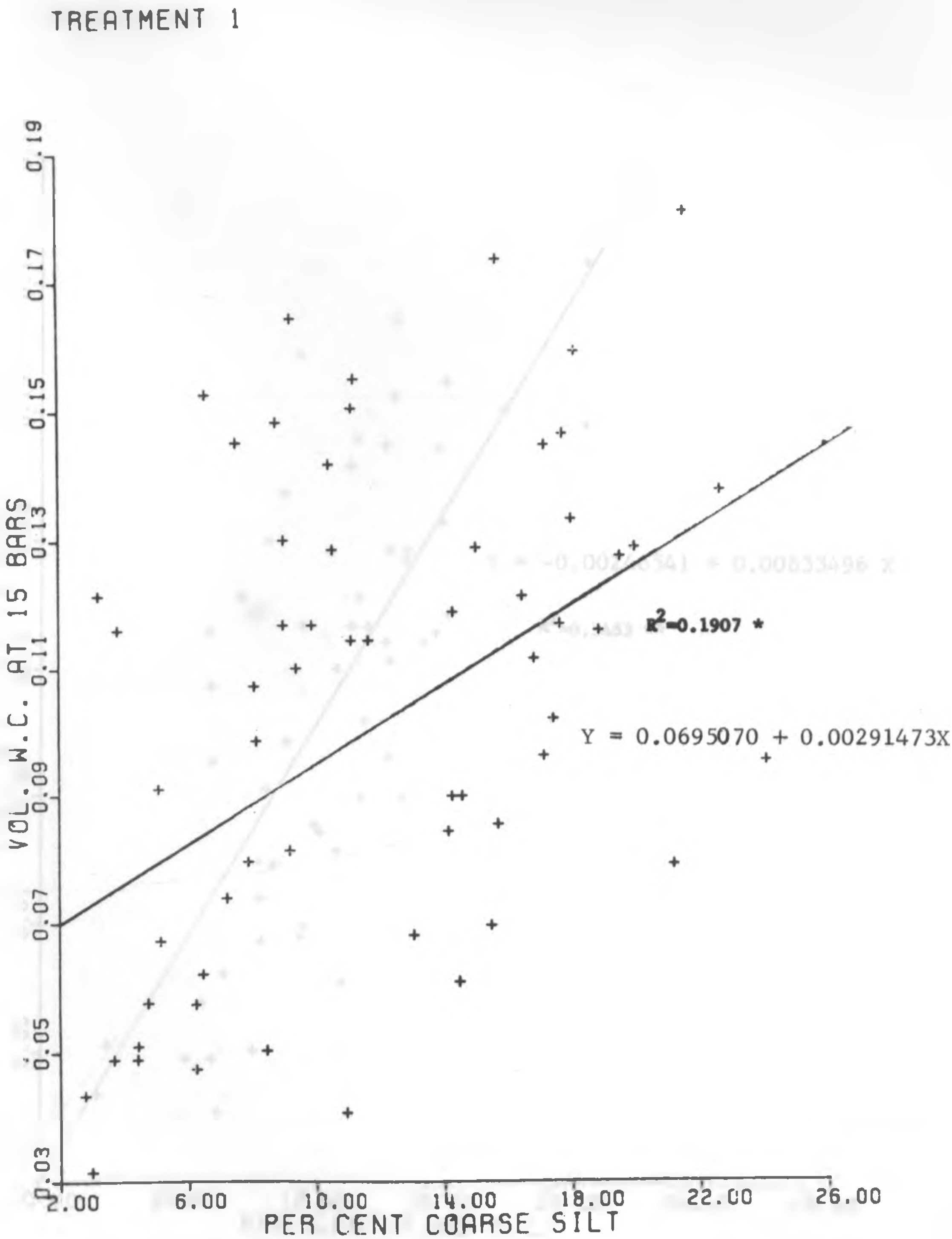


Fig. 65 Treatment 1. Relationship between volumetric water content at 15 bars and percentage coarse silt content.

TREATMENT 1

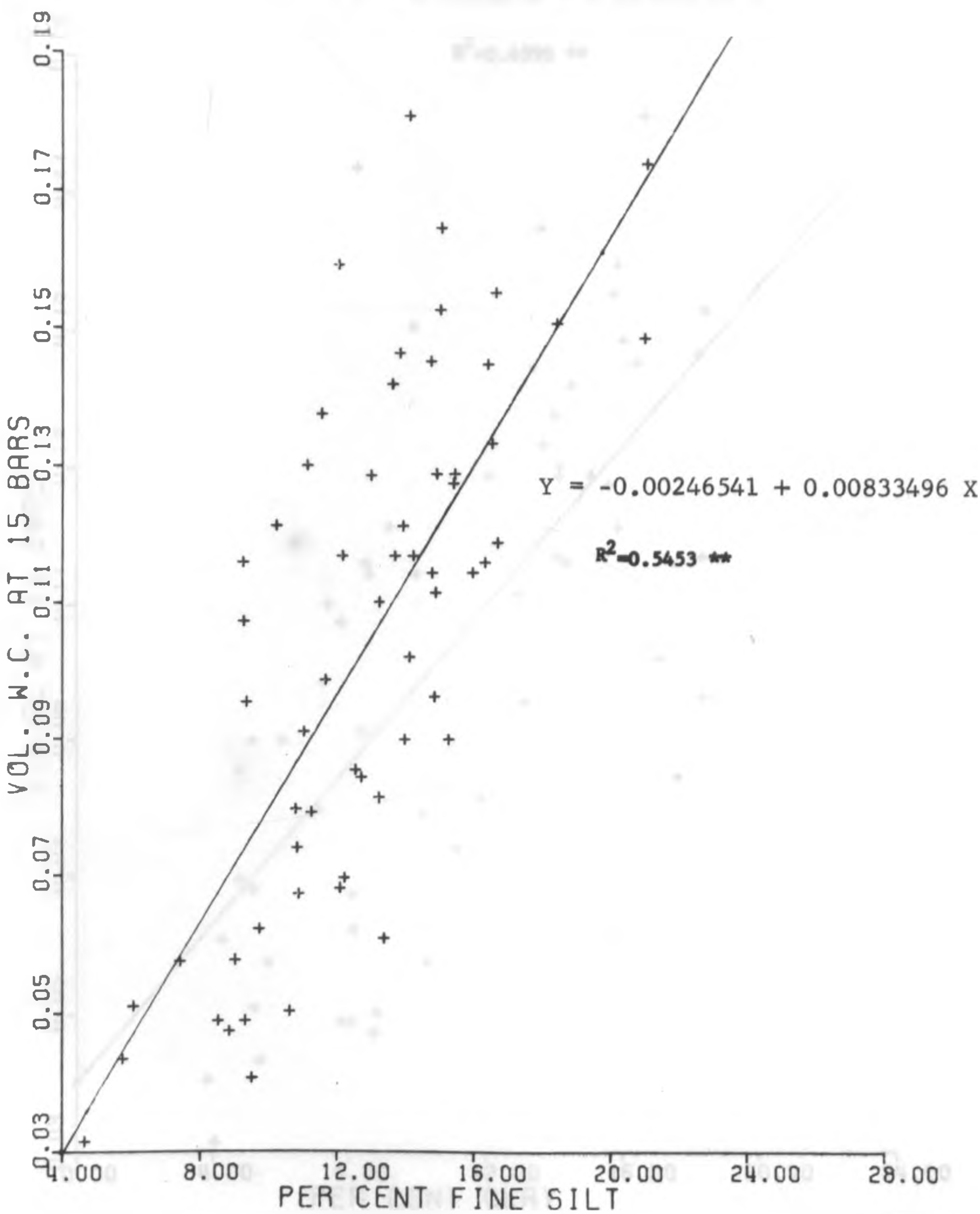


Fig. 66 Treatment 1. Relationship between volumetric water content at 15 bars and percentage fine silt content.

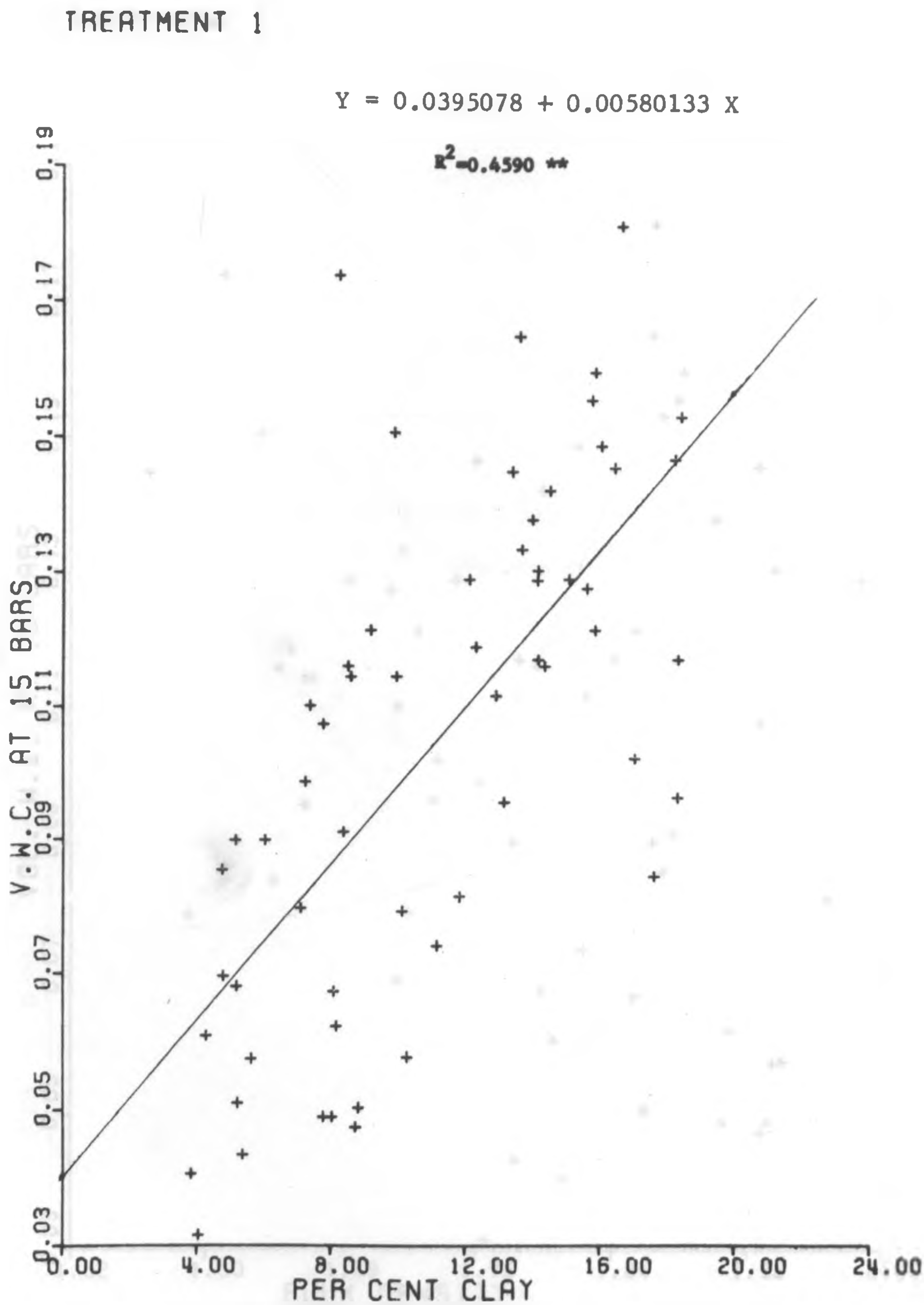


Fig. 67 Treatment 1. Relationship between volumetric water content at 15 bars and percentage clay content.

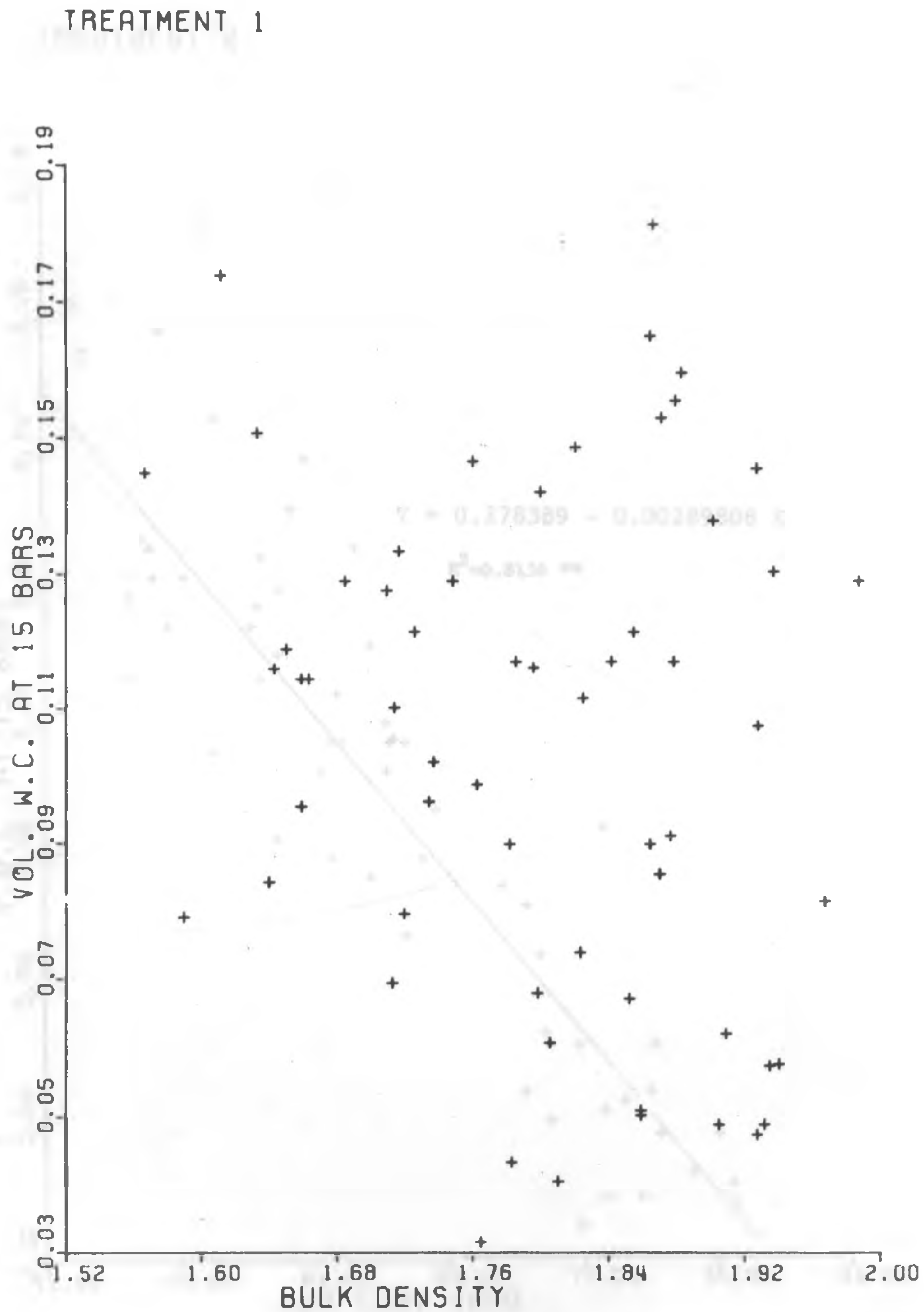


Fig. 68 Treatment 1. Relationship between volumetric water content at 15 bars and bulk density.

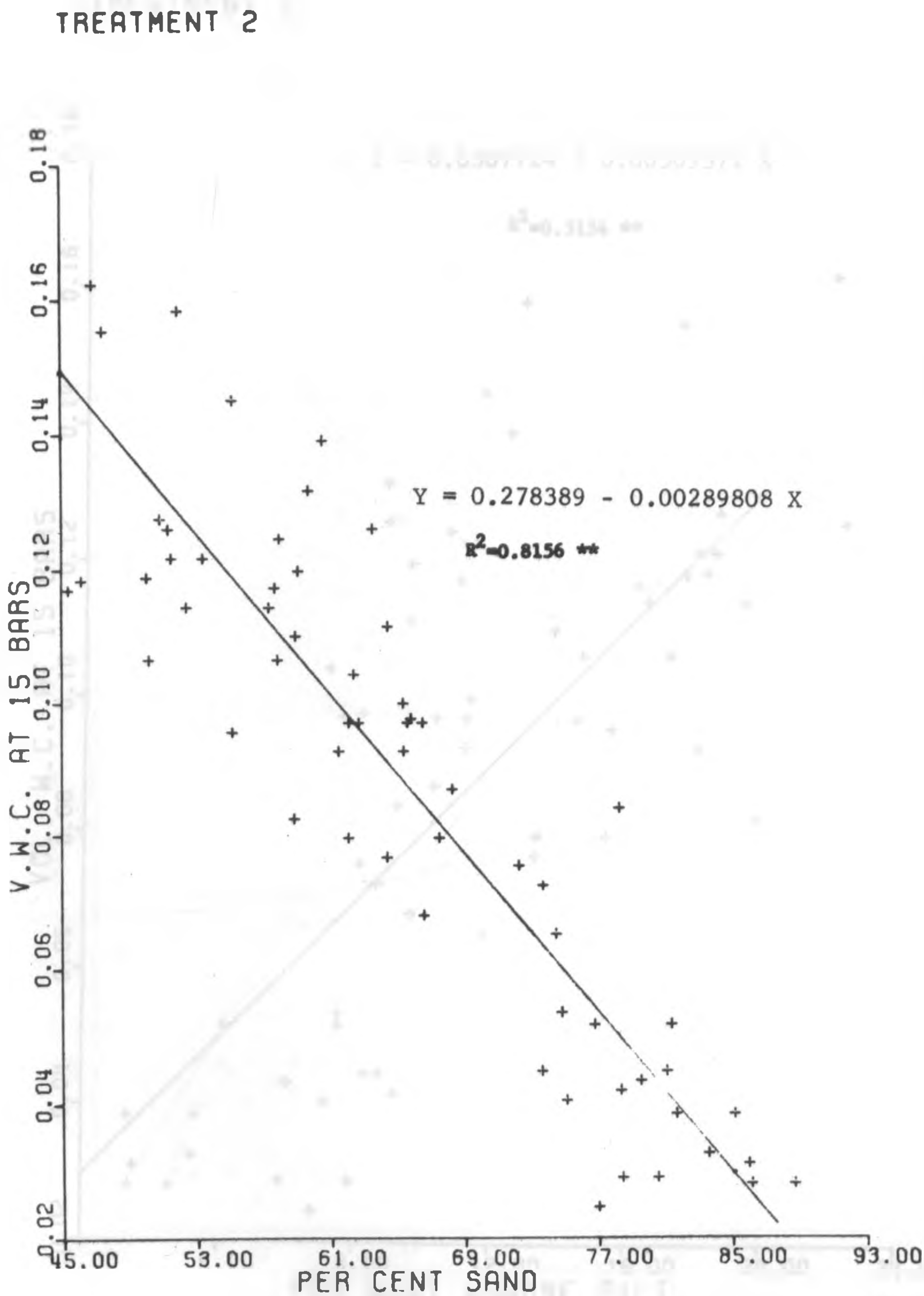


Fig.69 Treatment 2. Relationship between volumetric water content at 15 bars and percentage sand content.

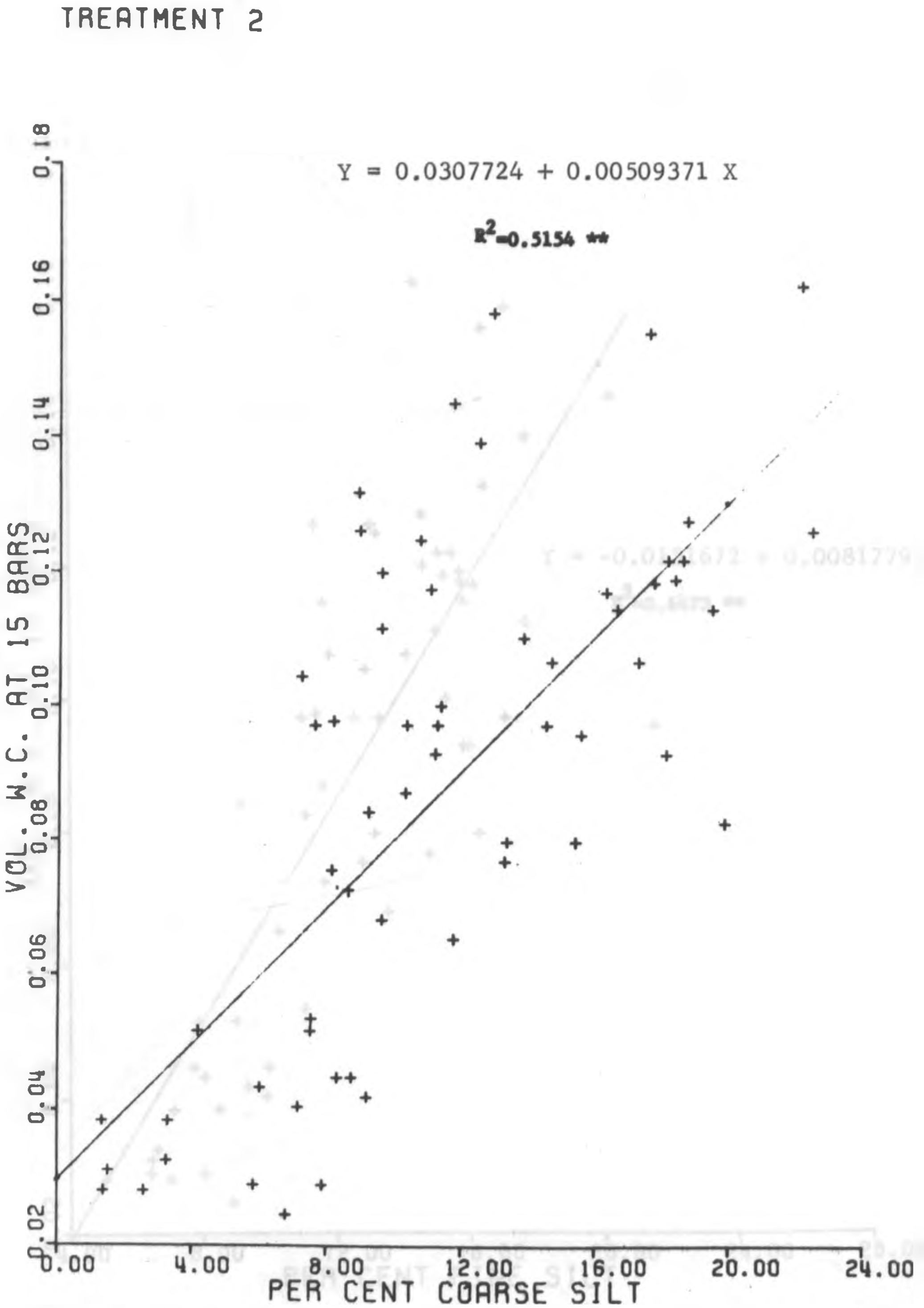


Fig. 70 Treatment 2. Relationship between volumetric water content at 15 bars and percentage coarse silt content.

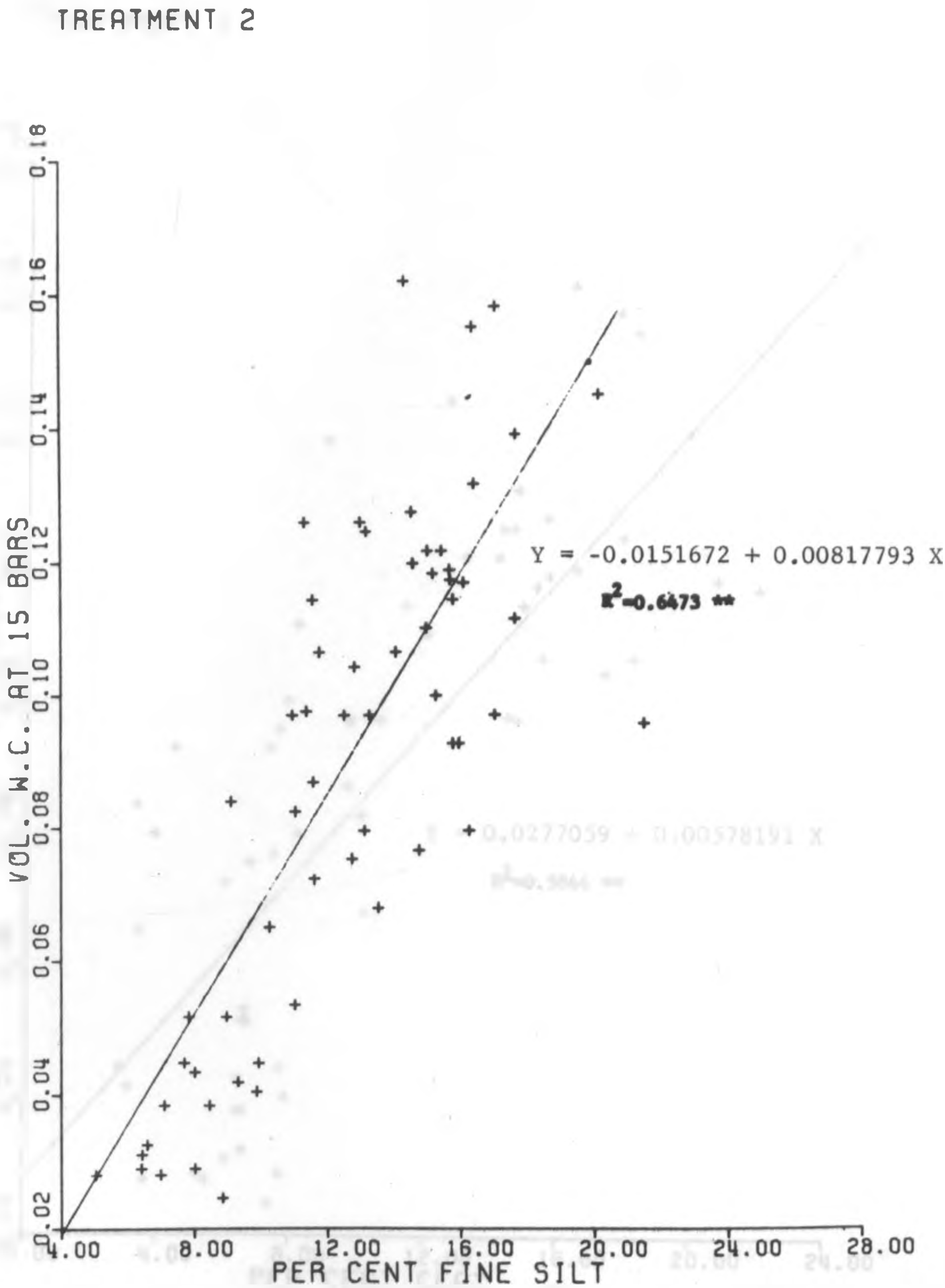


Fig. 71 Treatment 2. Relationship between volumetric water content at 15 bars and percentage fine silt content.

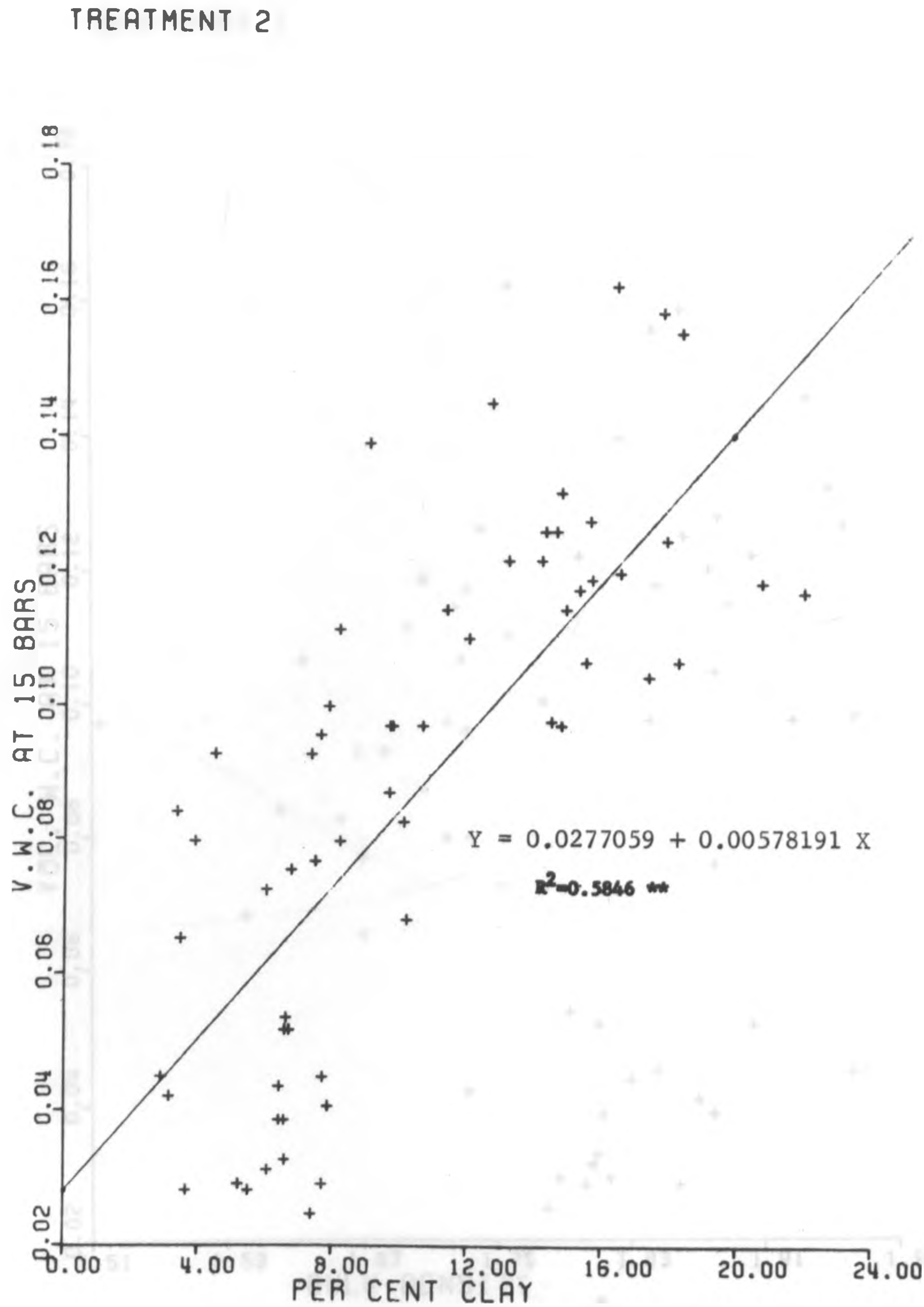


Fig. 72 Treatment 2. Relationship between volumetric water content at 15 bars and percentage clay content.

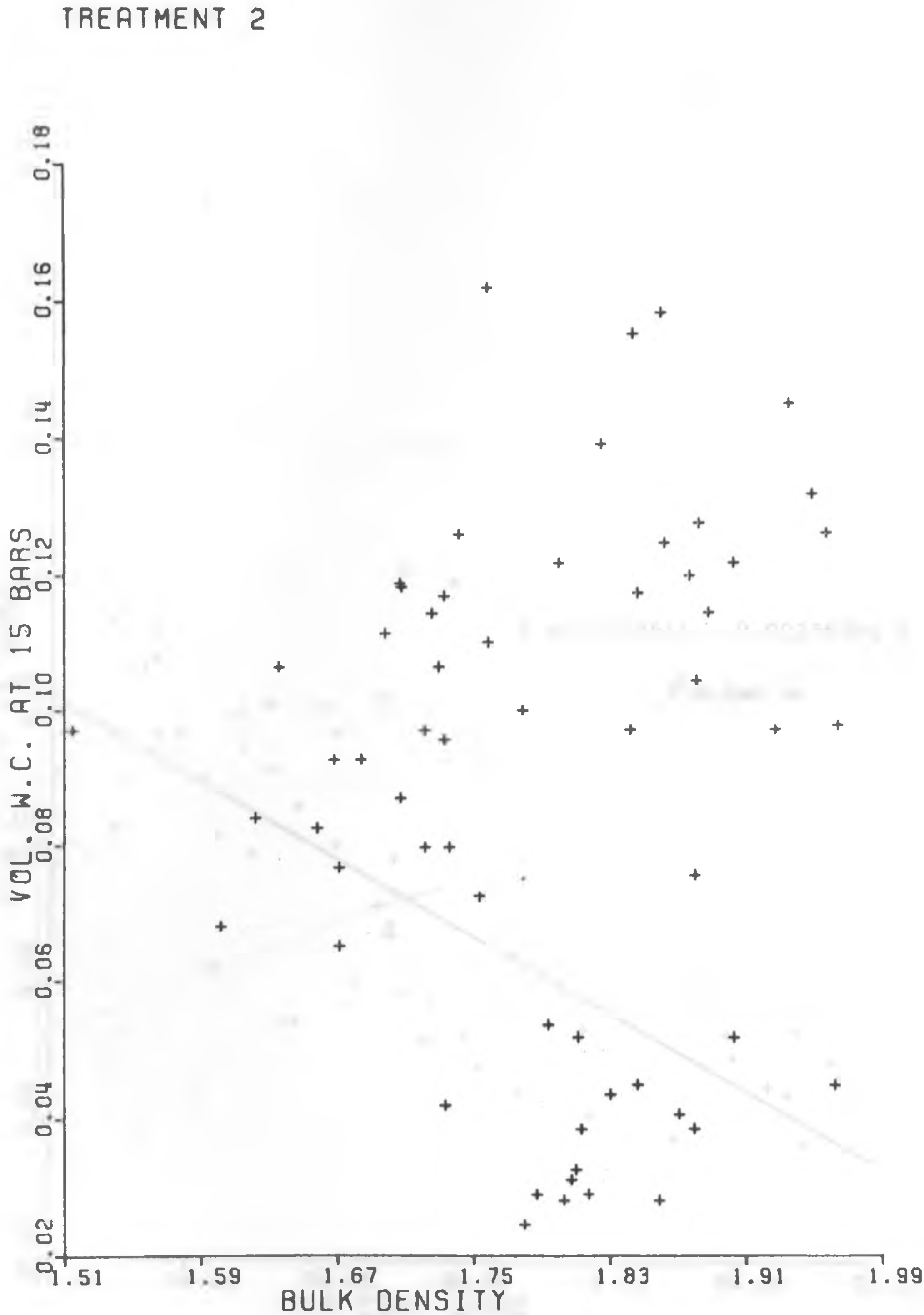


Fig. 73 Treatment 2. Relationship between volumetric water content at 15 bars and bulk density.

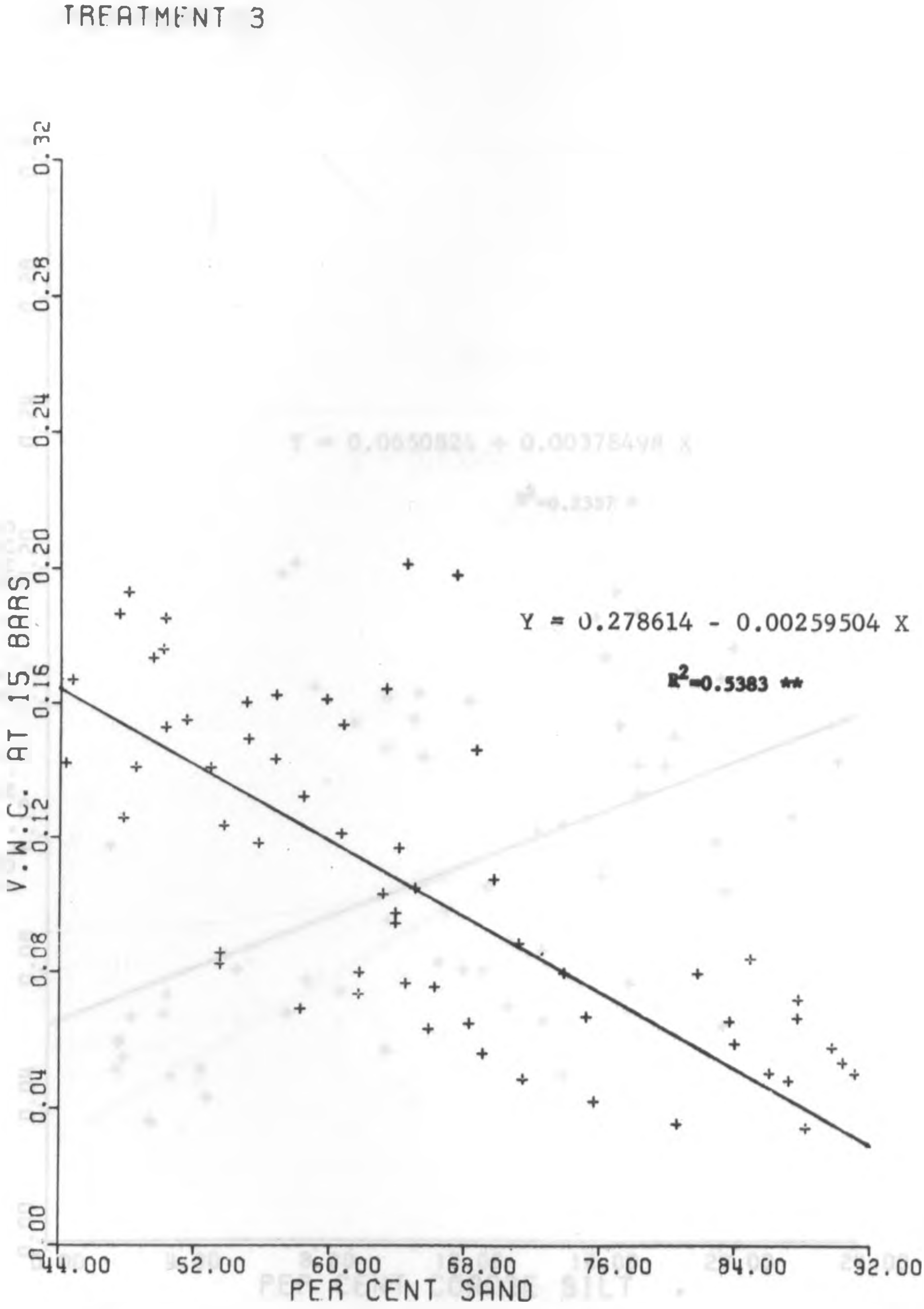


Fig. 74 Treatment 3. Relationship between volumetric water content at 15 bars and percentage sand content.

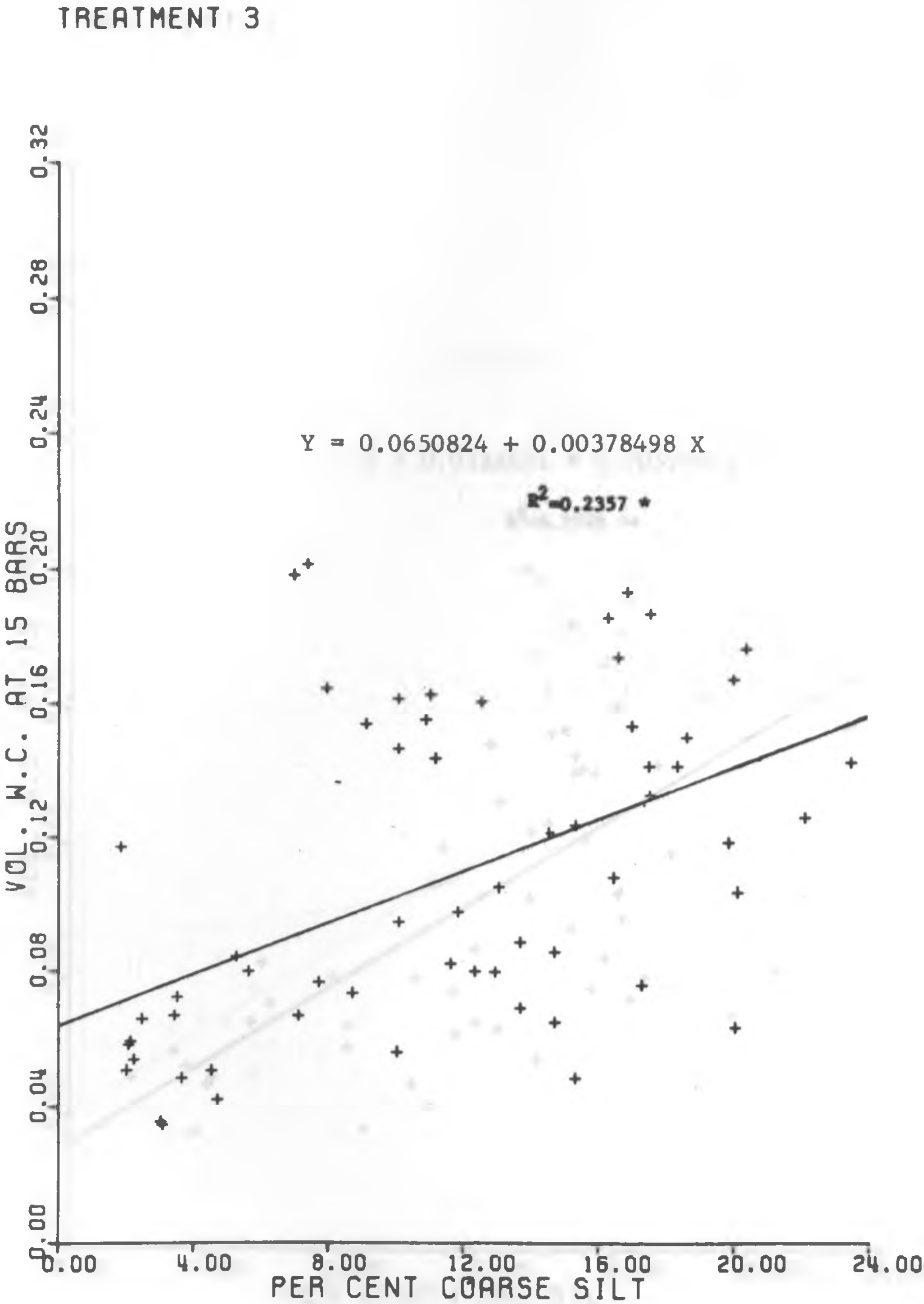


Fig. 75 Treatment 3. Relationship between volumetric water content at 15 bars and percentage coarse silt content.

TREATMENT 3

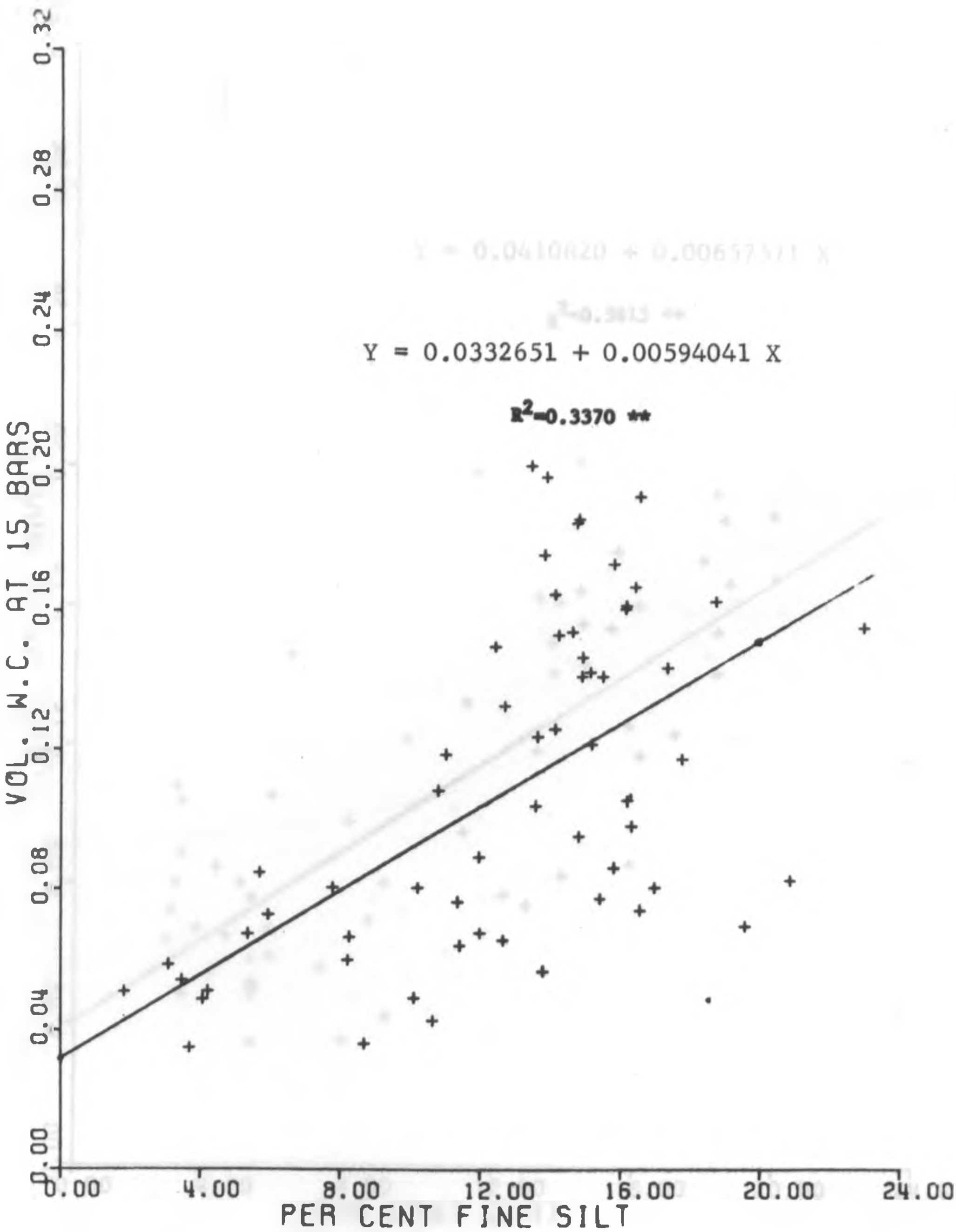


Fig.76 Treatment 3. Relationship between volumetric water content at 15 bars and percentage fine silt content.

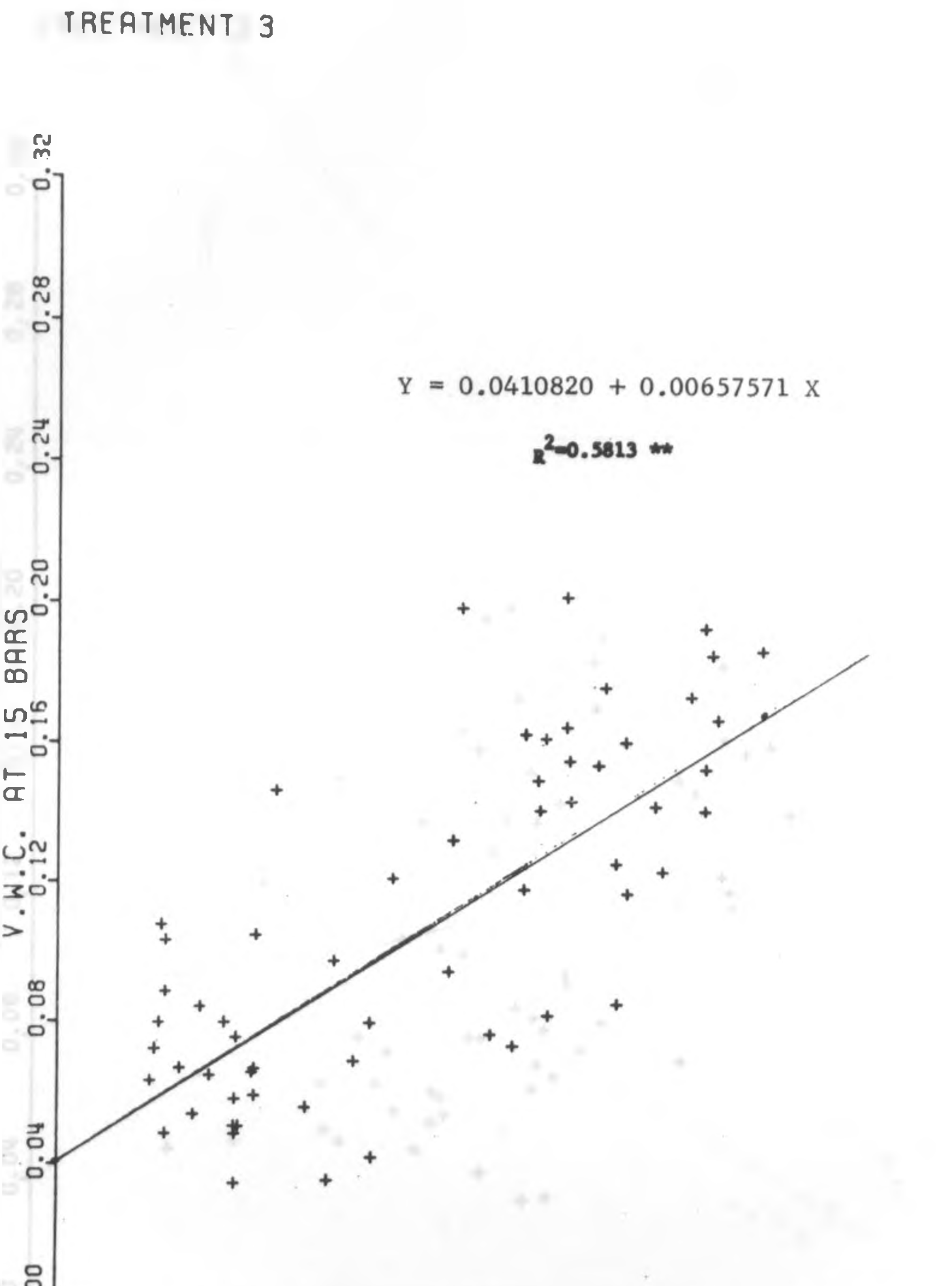


Fig.77Treatment 3. Relationship between volumetric water content at 15 bars and percentage clay content.

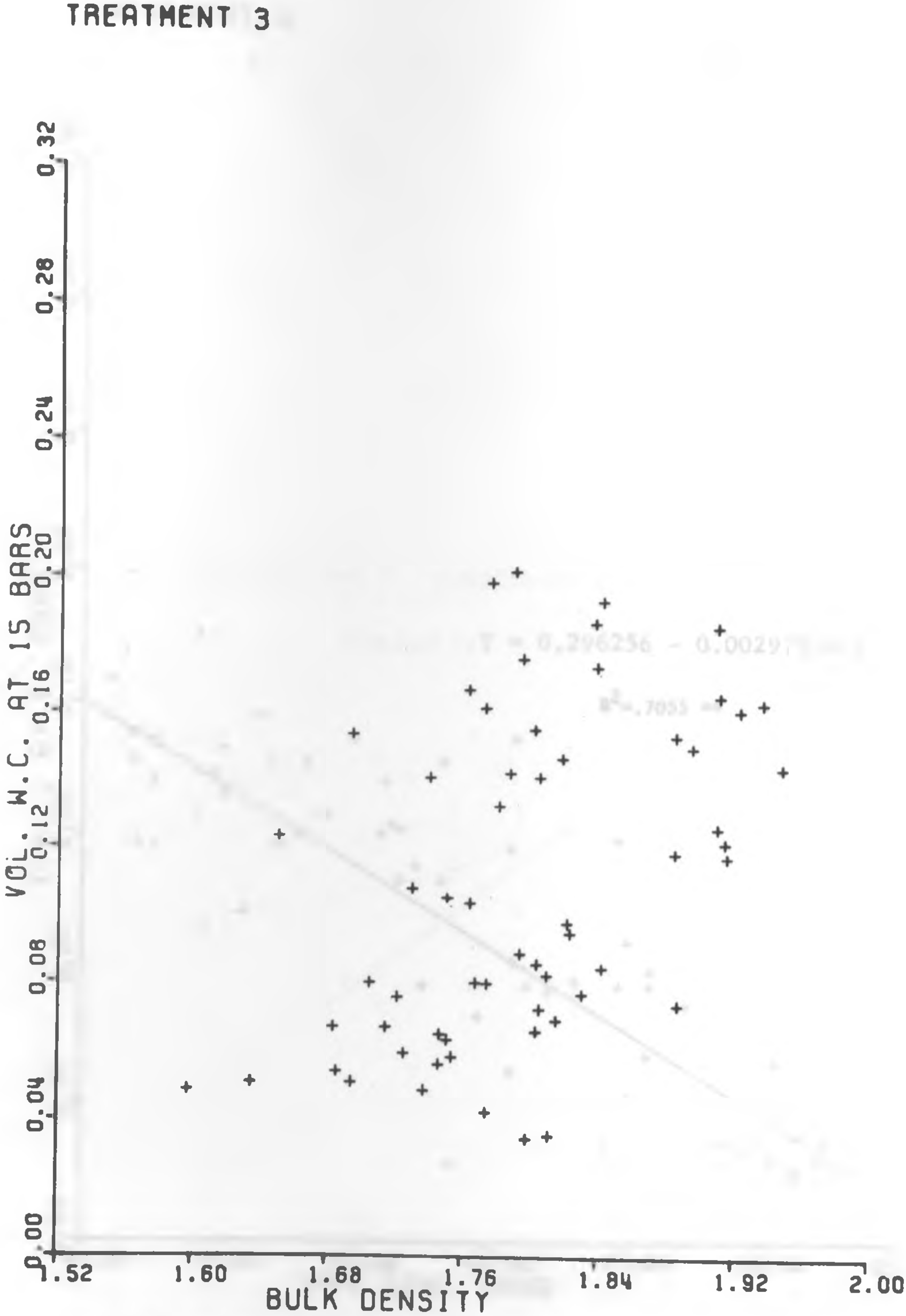


Fig. 78 Treatment 3. Relationship between volumetric water content at 15 bars and bulk density.

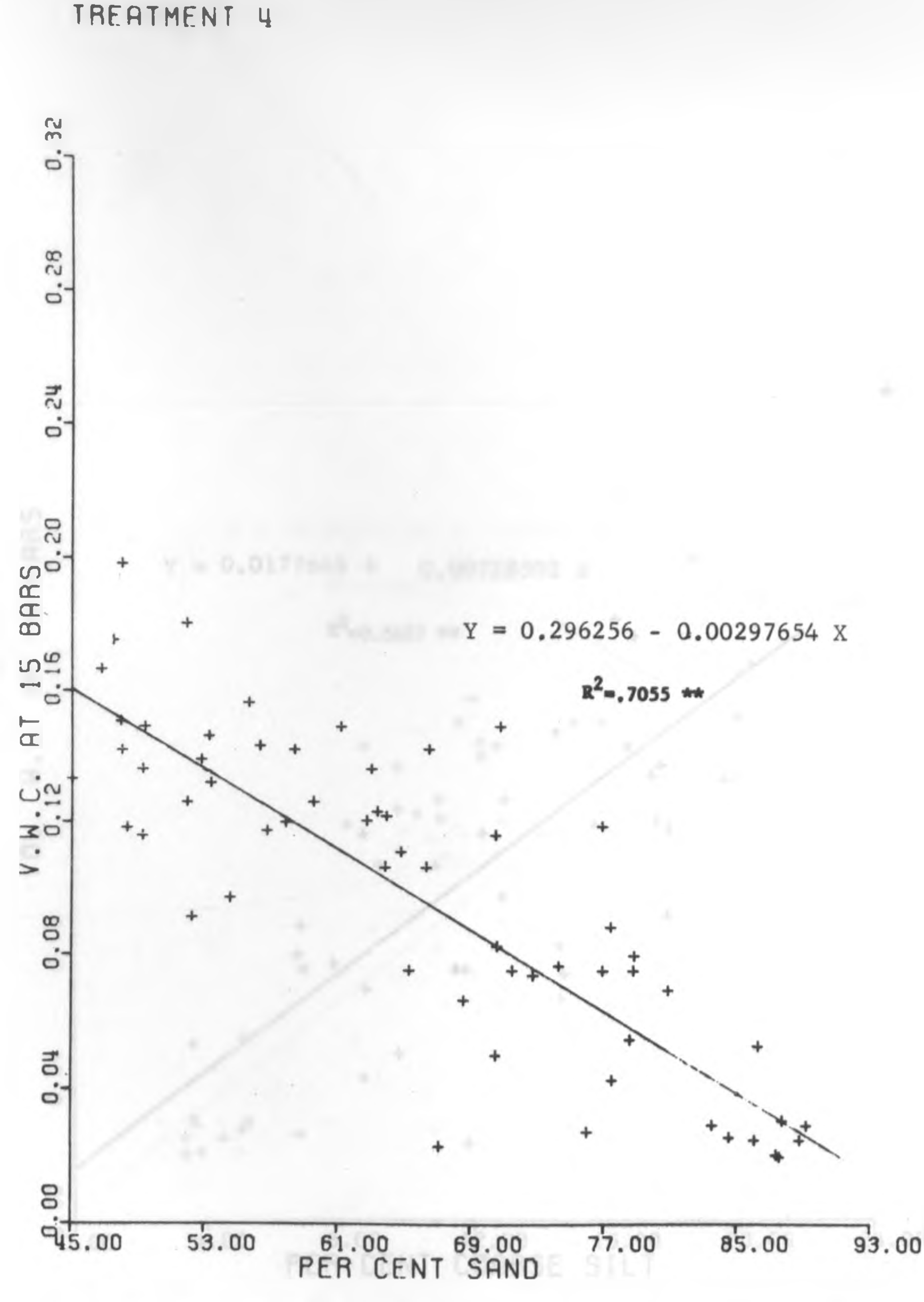


Fig. 79 Treatment 4. Relationship between volumetric water content at 15 bars and percentage sand content.

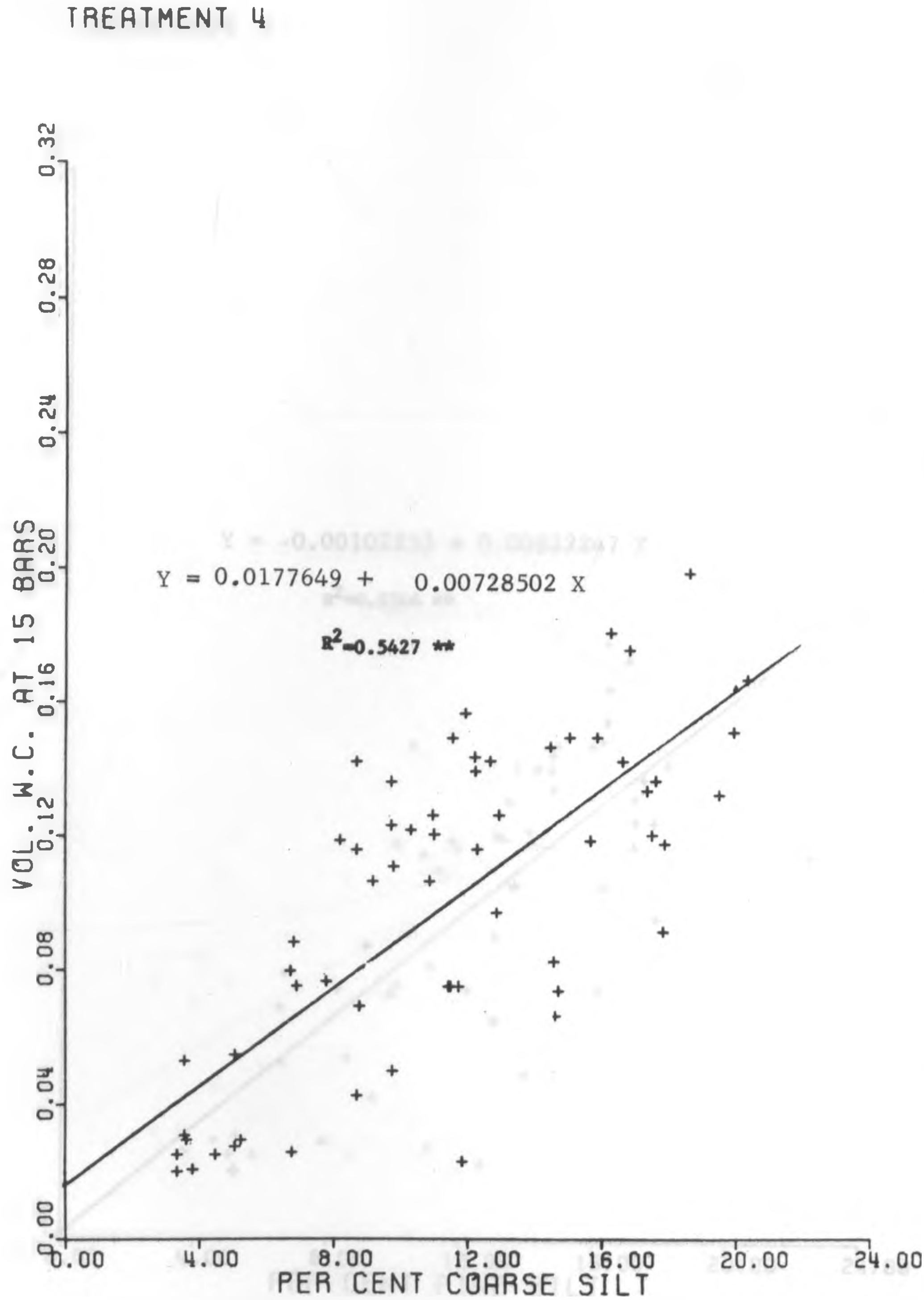


Fig. 80 Treatment 4. Relationship between volumetric water content at 15 bars and percentage coarse silt content.

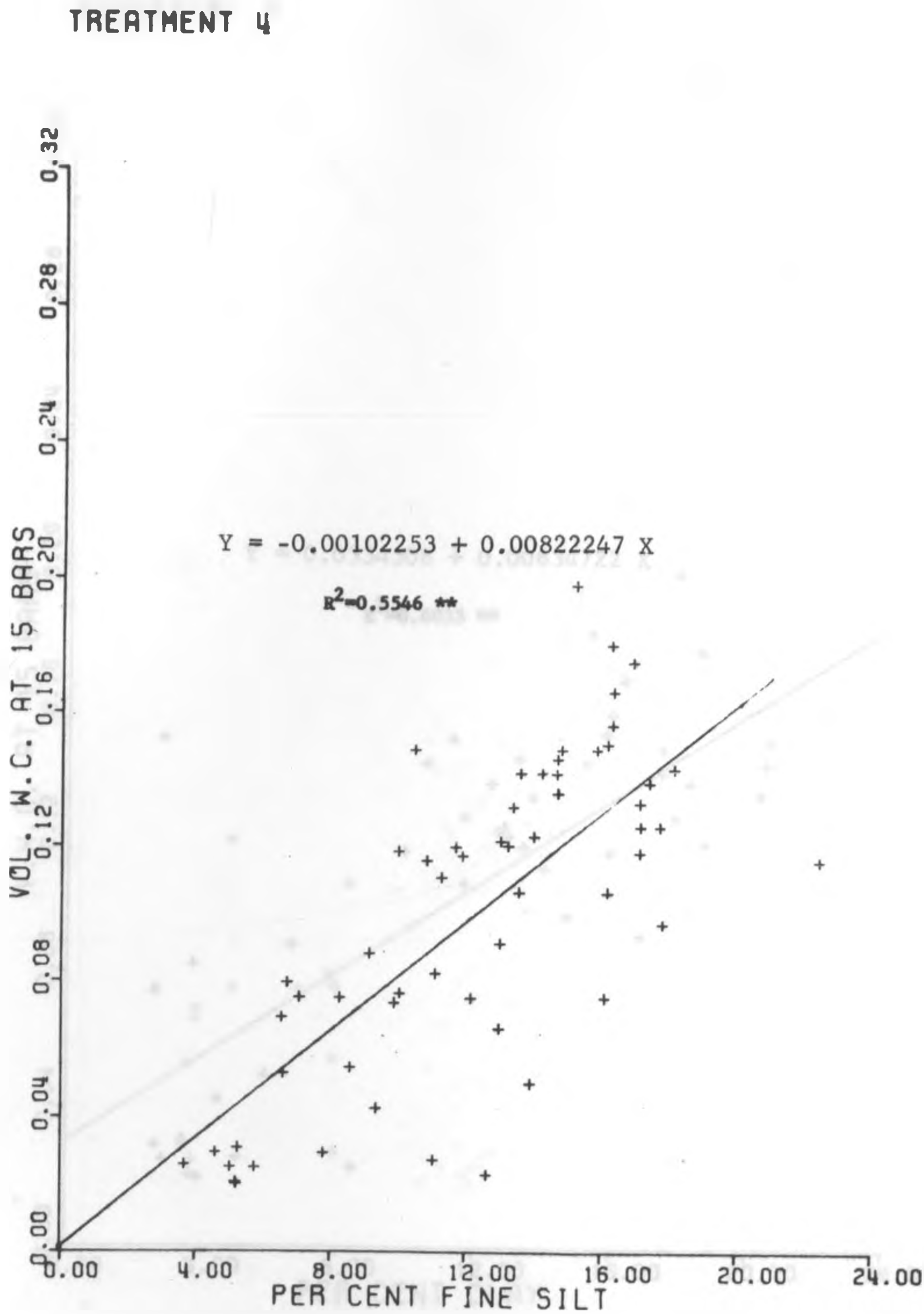


Fig. 81 Treatment 4. Relationship between volumetric water content at 15 bars and percentage fine silt content.

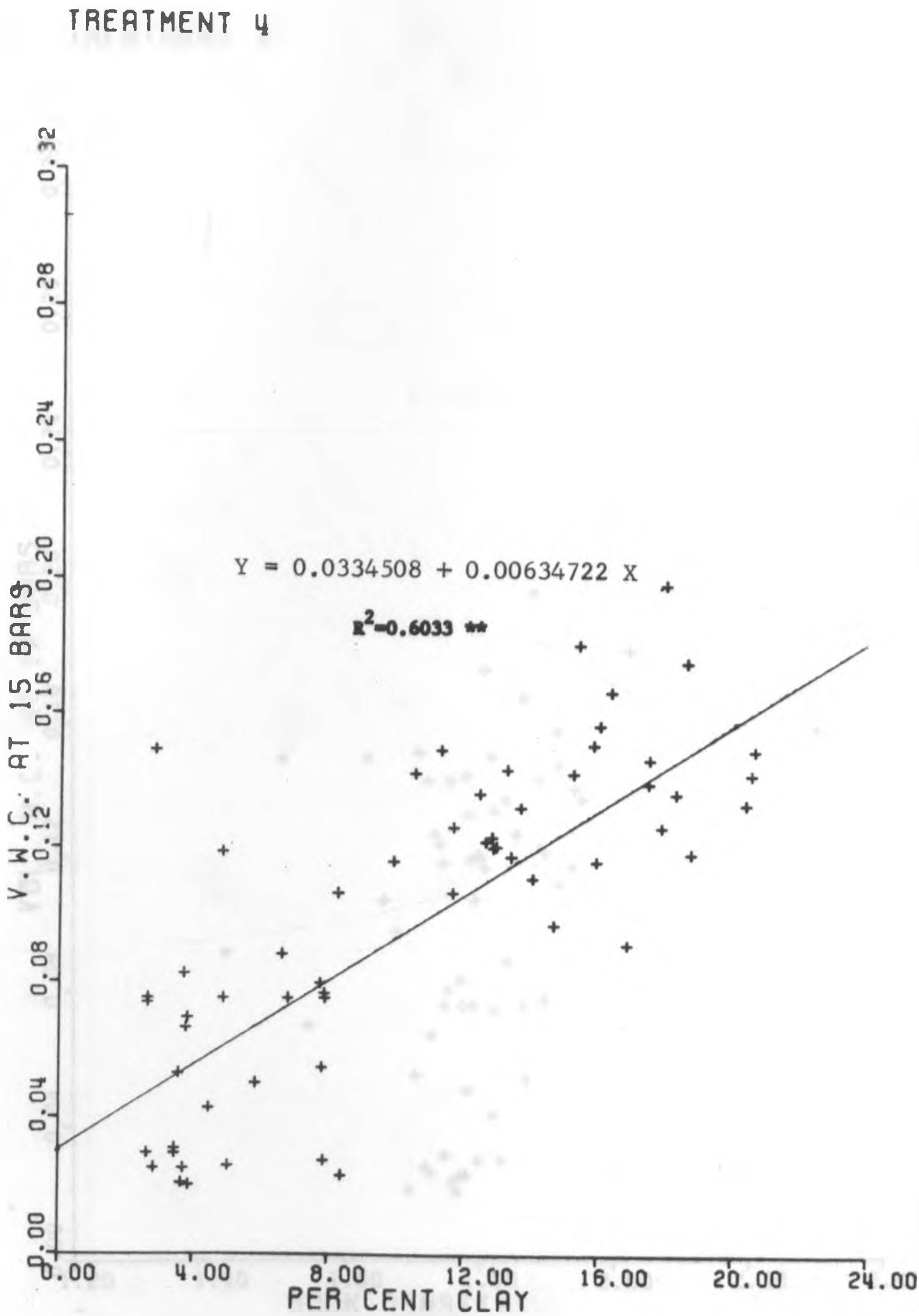


Fig. 82 Treatment 4. Relationship between volumetric water content at 15 bars and percentage clay content.

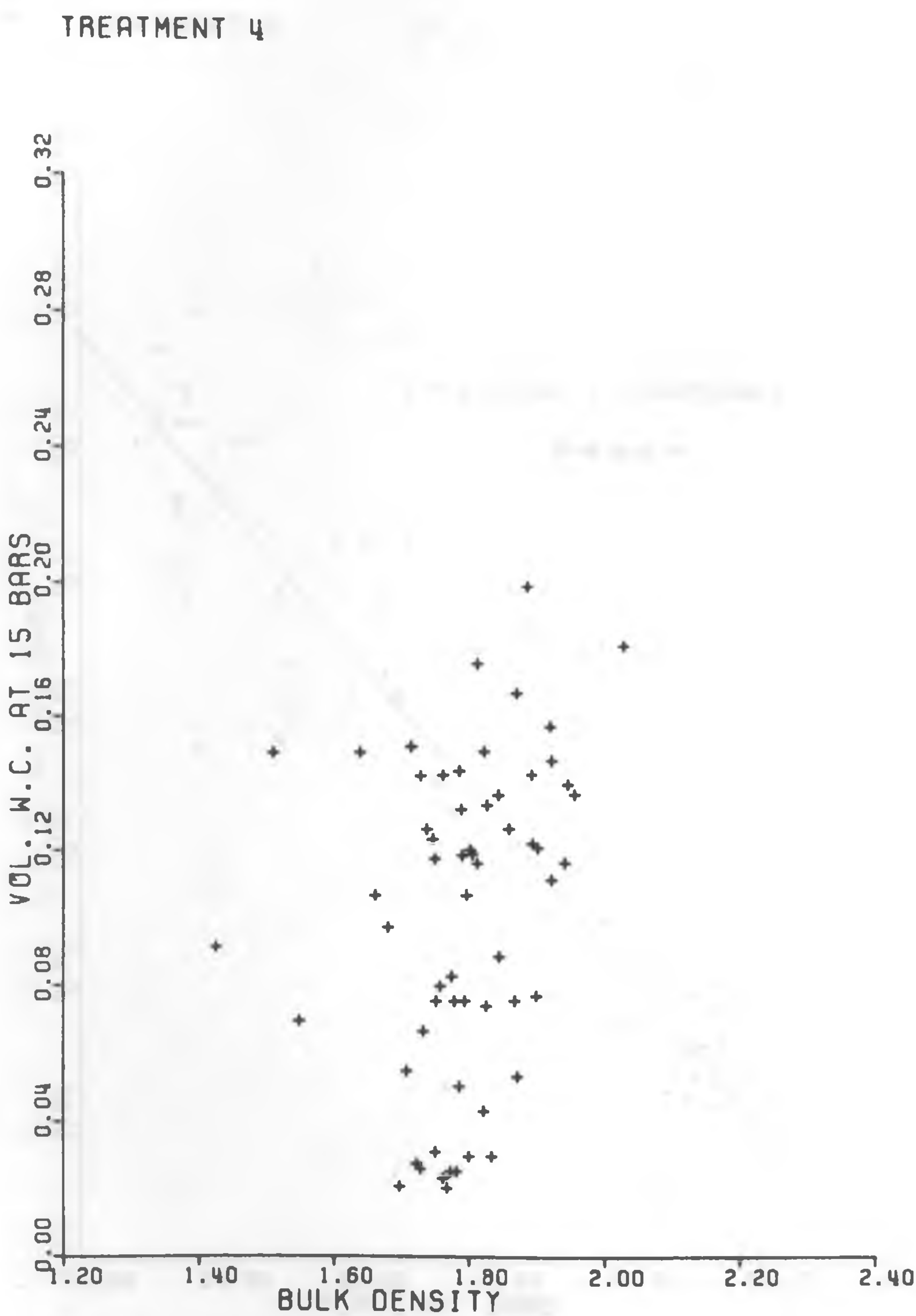


Fig. 83 Treatment 4. Relationship between volumetric water content at 15 bars and bulk density.

TREATMENT 5

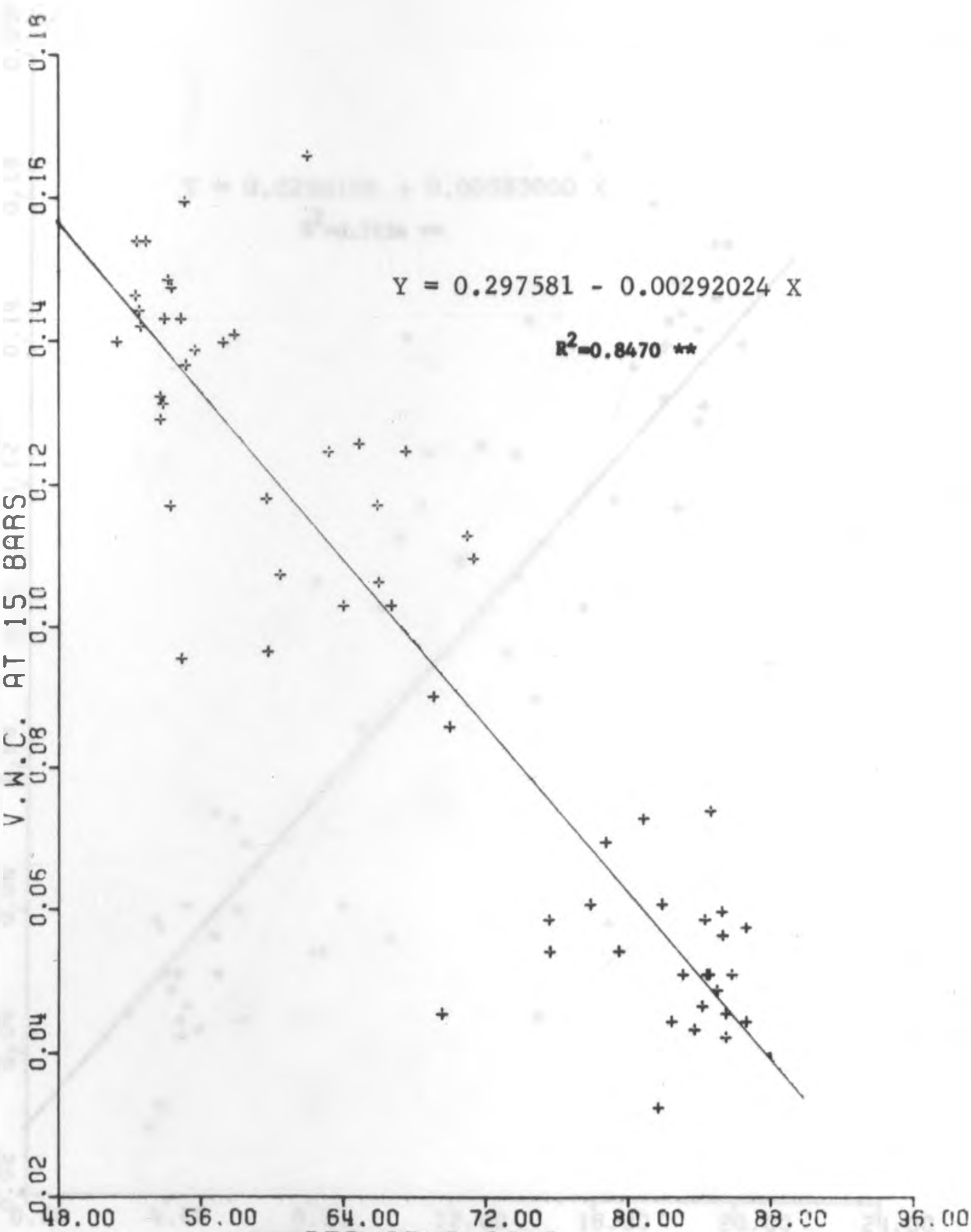


Fig. 84 Non-Irrigated Treatment. Relationship between volumetric water content at 15 bars and percentage sand content.

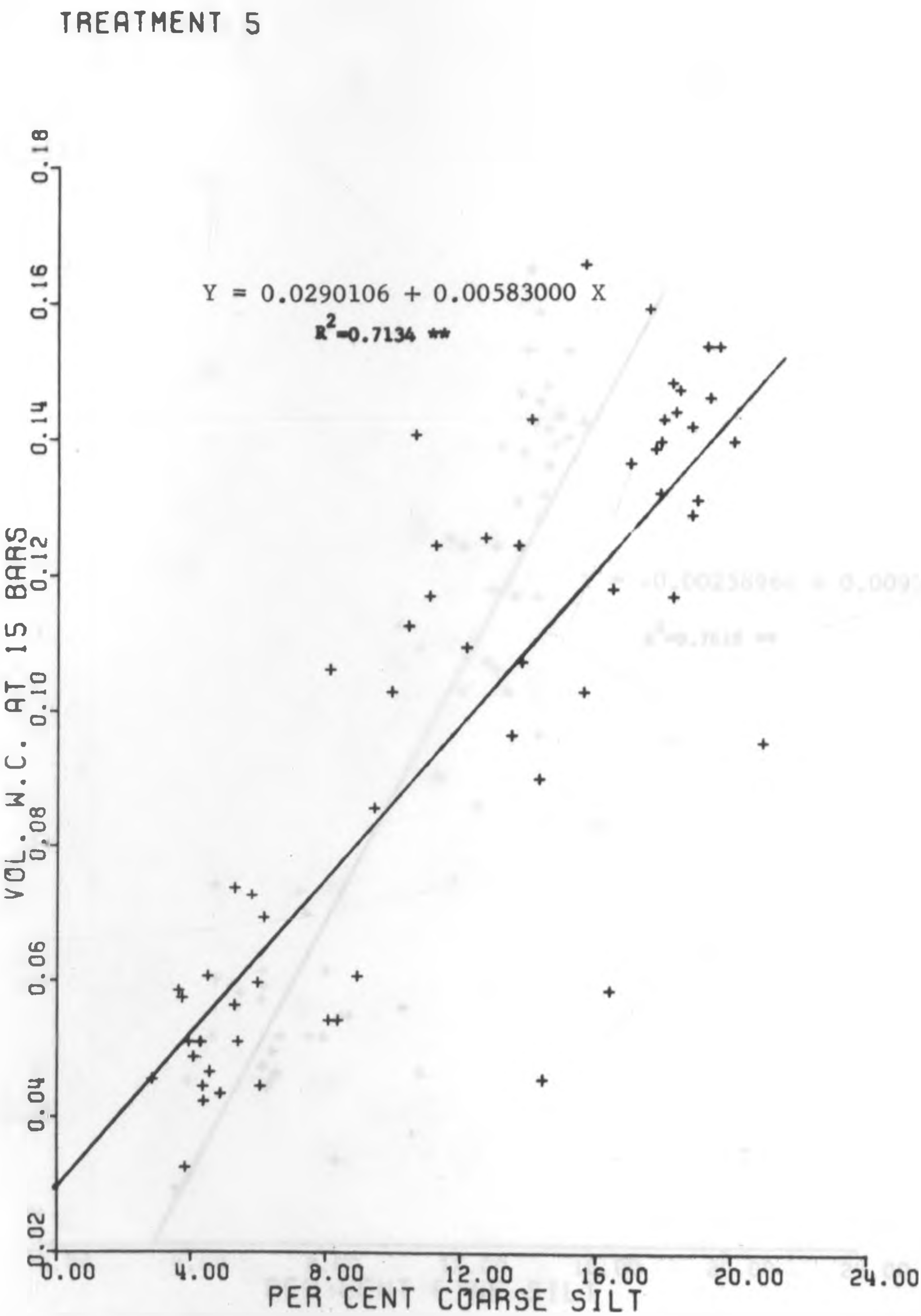


Fig. 85 Non-Irrigated Treatment. Relationship between volumetric water content at 15 bars and percentage coarse silt content.

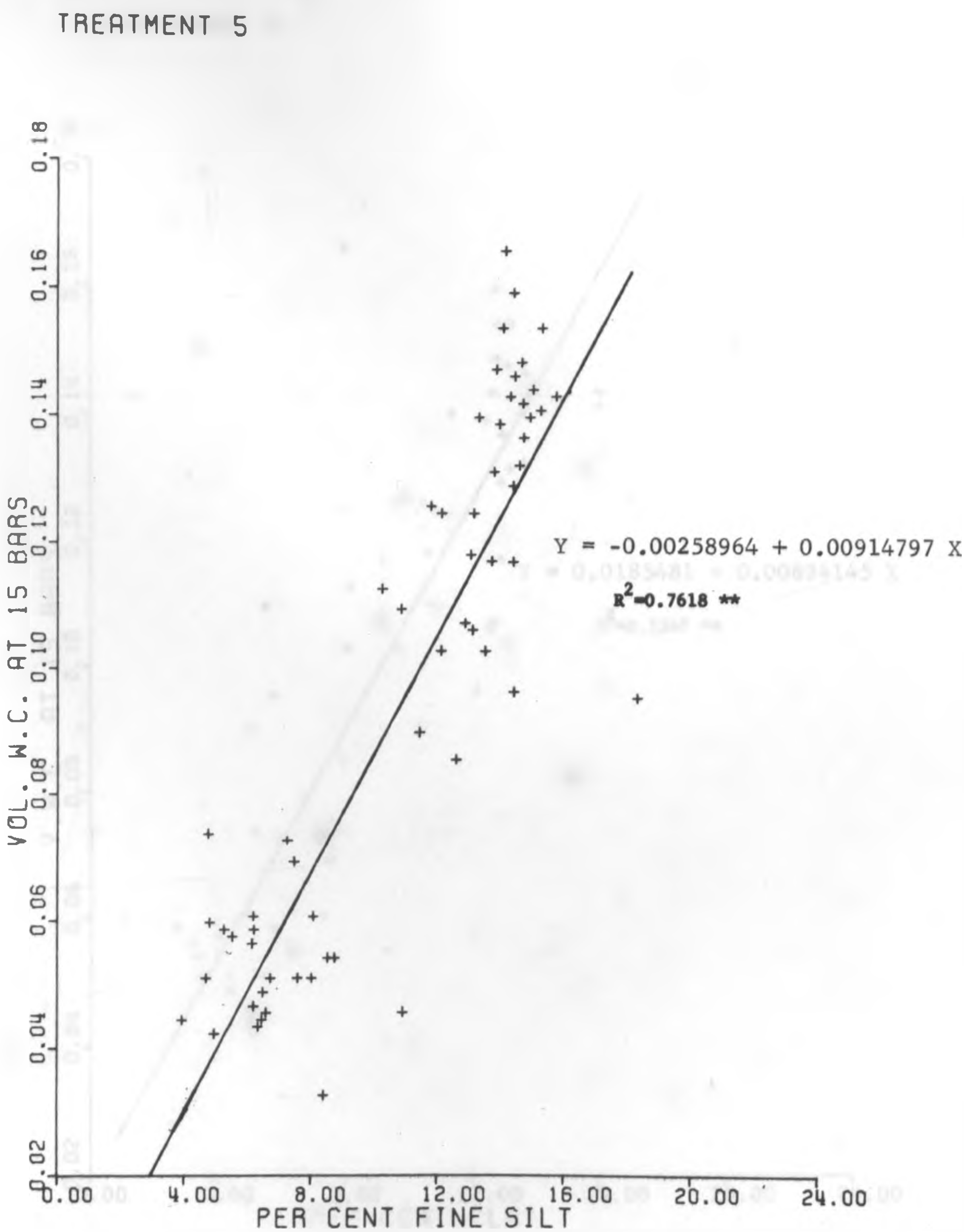


Fig.86 Non-Irrigated Treatment. Relationship between volumetric water content at 15 bars and percentage fine silt content.

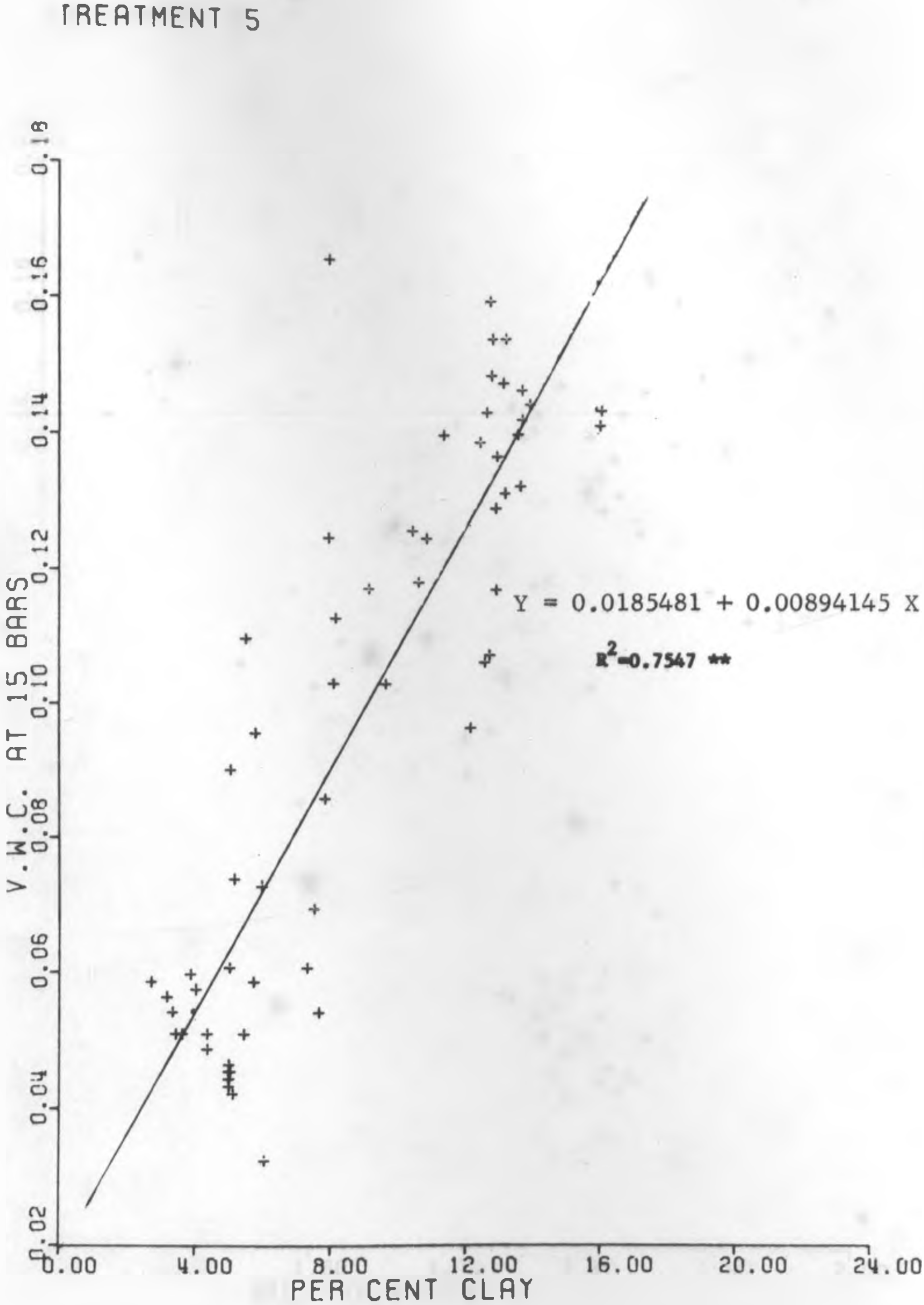


Fig.87 Non-Irrigated Treatment. Relationship between volumetric water content at 15 bars and percentage clay content.

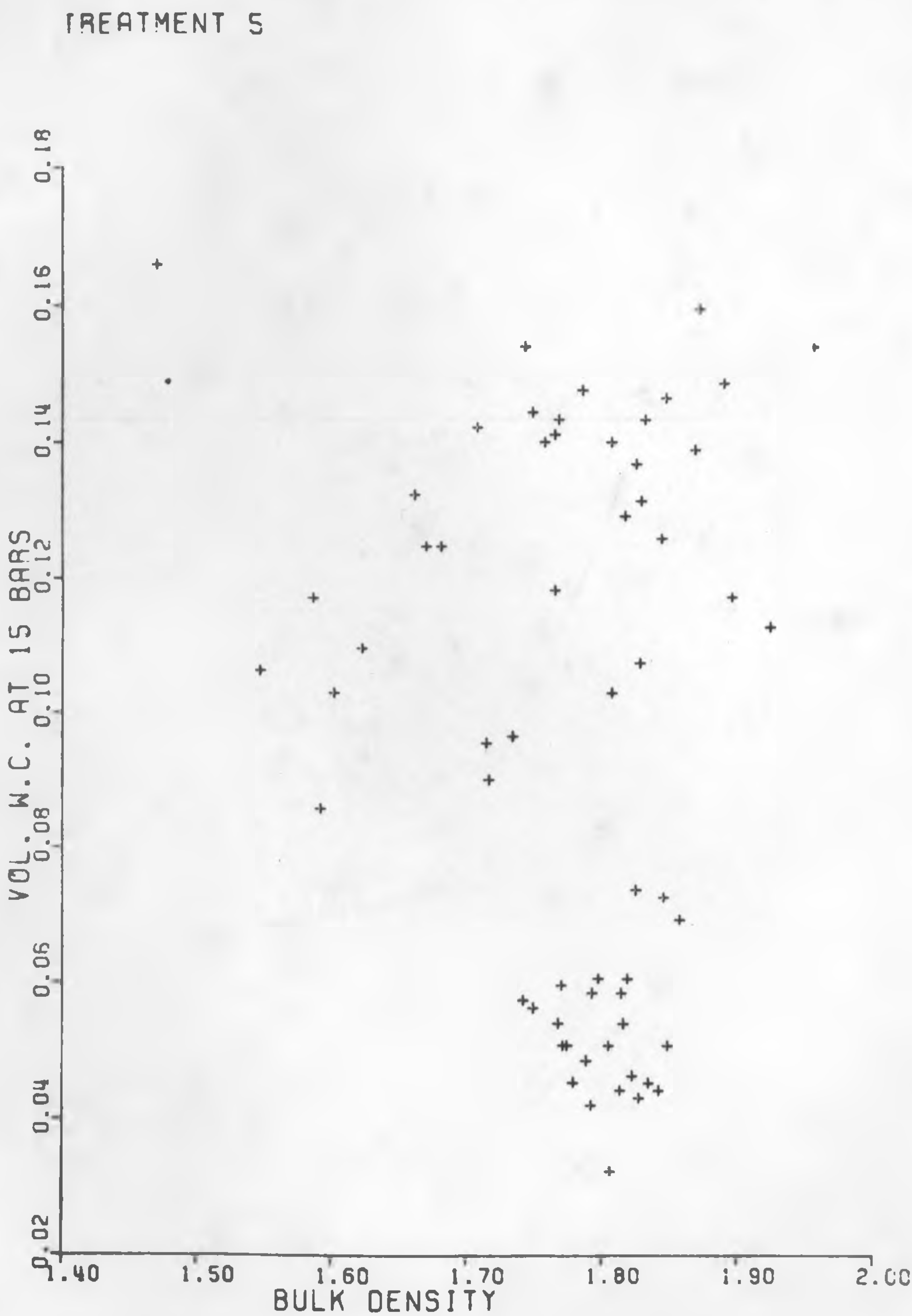


Fig.88 Non-Irrigated Treatment. Relationship between volumetri
water content at 15 bars and bulk density.