Soil-Water Studies on

Oxisols and Ultisols of Puerto Rico

by

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INTRODUCTION

In vast areas of the humid tropics soils are strongly leached and very acidic. Soil acidity is commonly associated with aluminum toxicity and these factors create a hostile soil environment which chemically limits the depth of rooting of crops such as corn and sorghum. Presently, liming soil to a depth of more than the surface foot is not practical. Crops which are sensitive to soil acidity are effectively limited to the depth of the soil profile to which lime may be incorporated. This severely limits the amount of soil water and nutrients which a crop can utilize.

In the case of water, rooting limitations increase the likelihood of yield decreases when rainfall distribution is anything short of ideal. In order to assess the potential for successful cropping, information regarding climatic factors must be superimposed upon those soil physical properties which affect the water supplying characteristics of the soils. The climatic information required should include rainfall distribution and potential evapotranspiration.

The purpose of the soil-water experiments conducted in Puerto Rico during the summer of 1971 was to determine the water supplying characteristics of four soils on which fertility experimentation was in progress, or planned. An auxiliary objective was to compare several possible techniques for obtaining this information for these types of soils. A previous survey of moisture relationships of over 100 Puerto Rican soils has been made by Lugo-Lopez (1953).

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The soil-water information gained from the experiments reported here will be essential in characterizing the soils for purposes of subsequent experimentation by future workers in the area. The next logical step would be an evaluation of soil physical characteristics together with climatic data in order to predict their combined effect upon crop yield so as to assign probabilities to the likelihood of successful cropping.

MATERIALS AND METHODS

Soils

Carreras Series

Location: Corozal substation near Corozal
Classification: Typic Tropohumult, clayey, kaolinitic, isohyperthermic
Texture: Clay loam to clay
Slopes: Top of hill; 0-14 percent
Vegetation: Cultivated; corn and grass

Catalina Series

Location: Don Magero farm near Barranquitas
Classification: Typic Haplorthox, clayey, oxidic, isohyperthermic
Texture: Clay
Slopes: 3-8 percent
Vegetation: Cultivated

Torres Series

Location: Hilda Soltero farm near Cidra
Classification: Orthoxic Palehumult, clayey, kaolinitic, isohypertherm
(May be changed to Oxidic Tropohumult)
Texture: Clay
Slopes: 1-3 percent
Vegetation: Cultivated; pasture

Piña Series

Location: Fundador farm east of Manatí
Classification: Psammentic Haplorthox, sandy, isohyperthermic
Texture: Loamy sand
Slopes: 0-2 percent
Vegetation: Cultivated; pineapples

Soil Samples

To characterize the soils in the instrumented areas two pits were dug to a depth of 150 centimeters. The close location of the pits to the instrumented areas facilitated study of lateral water movement. Soil samples were taken at 15 centimeter intervals to 150 centimeters.

Undisturbed soil core samples, two per depth per pit, were taken at the 30, 60, 90, and 120 centimeter depths. These samples 7.62 centimeters in diameter by 7.62 centimeters long, were obtained by driving aluminum core rings into the ground by means of a modified Uhland Sampler. Cores were removed from the ground with pick and shovel. They were trimmed with a knife, placed in pint sized ice cream containers, and stored in a refrigerator. Loss of water while in the refrigerator resulted in some soil shrinkage from the walls of the cores on some samples high in clay. Cores were later sealed in plastic bags to reduce water loss. Upon saturation the soils expanded to fill the cores.

Undisturbed core samples were used to determine soil bulk density. Bulk densities were calculated from the dry weight of soil in the undisturbed cores after making soil-water release measurements.

Laboratory Determination of Soil-Water Release

Cores, still in the metal rings, were placed in Tempe Cells. They were initially wetted with 5×10^{-4} M $CaCl_2$ at slight tensions and finally saturated with the solution at slight positive pressure. To ensure saturation of the entire core sample, the wetting process took more than 24 hours. Pressures between 20 centimeters of water and 3/4 atmosphere were applied and the effluent volume was collected beneath each cell at each pressure step. The time required to run all pressure steps was

approximately one month.

Since there were 80 samples to be run, a second method was employed to speed the determinations. A single piece of cheese cloth was placed at the bottom of each core and attached to the metal ring using a rubber band. These cores were wetted from the bottom in low washing dishes using the same solution of calcium chloride. Six samples were then placed in a pressure plate extractor and pressure was applied at similar steps. After cores reached equilibrium with the pressure plate, they were removed and weighed. Before the cores were replaced on the pressure plate, the plate was wetted to ensure good contact between core and plate.

After the pressure step at 3/4 atmosphere, cores were weighed, then oven dried and reweighed. Soil-water contents were calculated as percent by weight and then converted to volumetric water contents and graphed versus tension.

Conversion to volumetric water content was made through the relationship:

$$P_v = \rho \cdot P_w$$

where: P_v = Volumetric water content

P_w = Water content on a dry weight basis

ρ = Soil Bulk density

Water content-tension determinations for 1/3, 2/3, 1, 5, and 15 atmospheres were made on pressure plate apparatus using disturbed soil samples and standard techniques.

Field Instrumentation

Tensiometers have been used widely as a tool in agronomic and soil-water investigations (e.g. Rhoads and Stanley, 1973; Millar and Gardner, 1972; Nielsen *et al.*, 1964; Taylor, 1952). The tensiometers used in this study

were made from 1/2 inch I.D., nominal pipe size, polyvinyl chloride (PVC) tubing, schedule 40. A porous ceramic cup was glued with epoxy to one end of the tubing and an acrylic plastic sight glass to the other. PVC solvent was used for the sight glass bond. A hole was drilled in the PVC tubing and nylon "spaghetti tubing" was attached with epoxy to the tensiometer. The "spaghetti tubing" connected the tensiometer to the manometer.

The manometers consisted of "spaghetti tubing" run through glass tubing along a meter stick and into a mercury well. The tensiometers were started by using a squeeze bottle filled with boiled water to purge air from the system. The bottle was inserted into the tensiometer sight glass. Air and then water was forced through the "spaghetti tubing" up through the mercury.

The tensiometer cups at the 7.5-centimeter depth were placed in a horizontal position ("L-shaped") while those at greater depths were vertical. Tensiometer readings were recorded as soil-water tension values at the appropriate depths. Directions and a cost estimate for construction of homemade tensiometers are attached as Appendix 1. Further information on tensiometer construction and calibration is given by Richards (1942).

Tensiometers were installed at depths of 7.5, 30, 60, 90, and 120 centimeters. At Barranquitas and Manatí one tensiometer was installed at each depth for a total of five tensiometers per plot. At Corozal and Cidra two tensiometers were installed at each depth for a total of ten per plot. Where tensiometers were duplicated, readings were averaged for that depth to obtain values of soil-water tensions. In general there was good agreement between duplicated tensiometers.

A small auger with a diameter greater than the O.D. of the PVC tubing was used to bore the holes for the tensiometers. After the instrument was inserted into the ground, soil was tightly packed around the ceramic cup and the PVC wall of the tensiometer. The importance of the backfill and tamping operation cannot be overemphasized.

After installation in the soil the tensiometers were filled with boiled tap water. Before connecting the instruments to the manometers, the tensiometers were tapped to loose bubbles from the sides of the PVC tubing. The "L-shaped" tensiometers were probed to loose bubbles entrapped horizontally.

Field Methodology

Experimental areas were square plots, 3.2 x 3.2 meters, for an area of 1/1000 hectare. Prior to irrigations, boards were installed around the plots to a depth of 15 cm. Sides were covered with plastic. Bordering the plot areas permitted uniform flooding.

Plots were irrigated by flooding with water then covered with 6 mil polyethylene plastic. The amount of water applied was determined directly at Cidra and Barranquitas in that at those sites the water was applied from a 500 gallon tank or from 55 gallon drums. At Corozal and Cidra a stop watch and a 55 gallon drum were used to determine pump discharge rates. The amount of water applied to the plot was simply discharge times time.

Field Determination and Calculation of Capillary Conductivity

Capillary conductivity is the constant relating water flux and hydraulic gradient generally under unsaturated conditions. (Hydraulic conductivity generally refers to the same constant for saturated flow.) From Darcy's law,

$$v = -K \frac{d\psi}{dx},$$

where v = flux (volume of water passing a given area in a given time) - units are cm/day

ψ = water potential in cm - This is the sum of matrix potential (soil-water tension) and gravity head

x = vertical distance in cm between sensing points (tensiometers)

Units of K, capillary conductivity, are then cm/day.

Estimates of capillary conductivity were obtained in the field using the method of Richards et al. (1956) and Ogata and Richards (1957). Plots were instrumented with tensiometers at 7.5, 30, 60, 90, and 120 centimeters. Undisturbed cores were taken and run to find the relationship between soil-water content and tension. Due to horizontation and textural differences, soil-water content versus tension was found to be depth dependent. Thus the need for a specific soil-water release curve for each depth was established.

The hydraulic gradient is the difference in tensiometer readings between any two depths divided by the distance between the tensiometers. If tensiometer readings are uncorrected, this calculation will be the total water potential, that is, the sum of matrix potential and gravity head. (Solute potential was assumed to be negligible.) If tensiometers have been corrected for depth, the depth component must be added to the matrix potential (for downward movement of water) to determine the total water potential.

In order to determine the flux of water, the plots were covered with 6 mil polyethylene plastic. Thus, water-content changes were associated only with infiltration and drainage; there was no evaporation. The assumption was made that, with time, later water movement was slight and that all water content changes occurred in a vertical downward direction. This is to say that the amount of water passing through a given point in the

profile for a certain time period was the sum of all the water content changes above that point in the same time period. Thus, for drainage, the flux at 60 cm will always be equal to or exceed that at 30 cm. This is because all water stored then lost from the upper part of the profile must drain through the depths below.

The calculation of flux was made by noting tensions T_{t_1,d_1} and T_{t_2,d_1}, (subscripts refer to time and depth respectively). With the tensions were associated water contents from the water release curves. Change in water content for a certain time and depth was assumed to be the average change in water content for a zone of soil the midpoint of which was the tensiometer. Thus, for the tensiometer at 60 cm, water content changes were assumed to have occurred uniformly between 45 and 75 cm. An exception existed for the tensiometer at 30 cm where the representative zone was considered to be from 0 to 45 cm. Multiplying the change in water content by the vertical distance gave the amount of water passing through the bottom of the first zone. For example, a loss of 2 percent in water content in a day as indicated by the tensiometer at 30 cm and the water release curve for 30 cm would give a flux of 0.9 cm/day passing through the 45 cm depth. If during the same time interval the tensiometer at 60 cm had associated with it a loss of one percent in water content then the flux at 75 cm would be 1.20 cm/day (0.90 + 0.30).

Dividing flux by hydraulic gradient gave capillary conductivity. Since capillary conductivity was associated with a hydraulic gradient between two tensiometers and water was conducted through this zone in order to pass out the point in the profile where the flux was calculated, capillary conductivity was established for the zone between tensiometers, i.e., 7.5-30, 30-60, 60-90, 90-120 cm. Capillary conductivity was linked

to water content by finding an average water content (average of 4 values) for two depths and times. Since capillary conductivity is highly water-content dependent, time intervals were kept short for calculations when water contents were rapidly changing.

RESULTS AND DISCUSSION

Water Infiltration

A graph of cumulative infiltration versus time for the four soils is shown in Figure 1. The general conclusions are:

1. The amount of water infiltrated per unit time on Carreras and Torres, the Ultisols, exceeds that for Piña or Catalina, the Oxisols. This is in part due to the greater lateral water movement in Carreras and Torres.
2. Although Catalina is a clay and Pina is a loamy sand, the amount of water infiltrated and the intake rates on the two soils were similar. It would be unusual to find soils in temperate regions of widely varied textures exhibiting like intake rates, other factors being equal.
3. Shown on the graph for comparative purposes is the infiltration versus time curve for Panoche clay loam. This is a deep, well-drained, California soil high in montmorillonitic clays (Wolf, 1967). Although the amounts of water infiltrated are much greater for the Puerto Rican soils than for the California soil, infiltration rates, at 40 minutes, are similar.

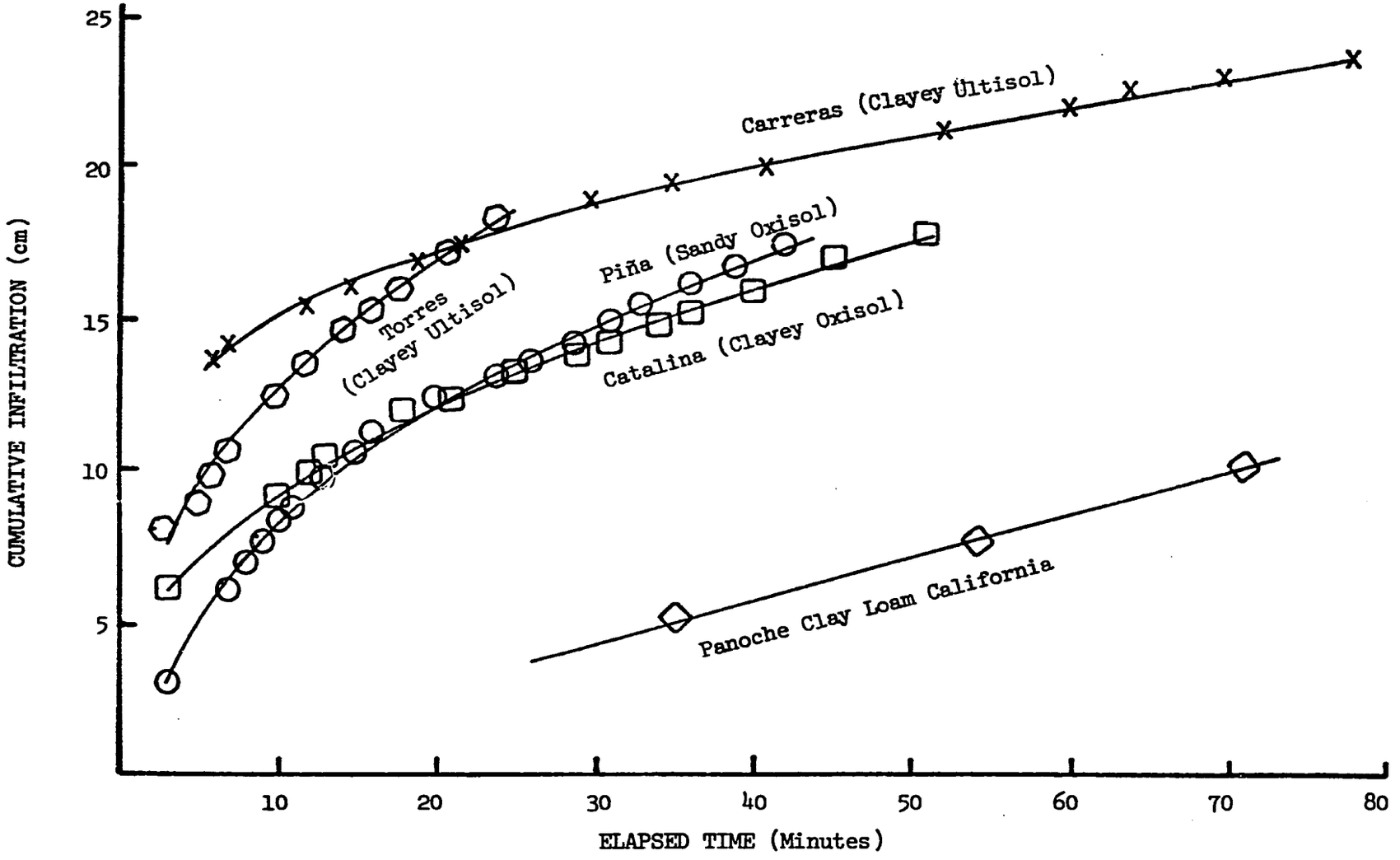


Figure 1. Cumulative infiltration versus time for four Puerto Rican soils.

Figure 2 shows cumulative infiltration versus time for two irrigations on the same plot at Corozal (Carreras clay). Before the second irrigation, polyethylene plastic was placed around the plot to a depth of 60 centimeters to restrict lateral movement. Soil-water contents (percent by dry weight) were greater prior to the second irrigation. These are presented in Table 1.

Table 1. Water content versus depth for two irrigations on Carreras clay.

Depth Centimeters	Irrigation 1	Irrigation 2
7.5	43	50
30	44	50
60	34	38
90	36	35
120	38	37

The marked reduction in rate of initial water infiltration in irrigation 2 was due to:

(1) higher initial soil-water contents;

(2) reduction in lateral water movement;

(3) compaction caused by foot traffic atop the flooded area.

At extended period of time, infiltration rates were similar. Infiltration rate at that time reflects the steady state rate of water transport through the soil when the majority of soil pores are filled and conducting water.

Lateral Movement of Water

A comparative qualitative assessment of lateral water movement was made by observing the entry of water into the pits surrounding the irrigated areas. Lateral water movement was most significant in the Carreras soil

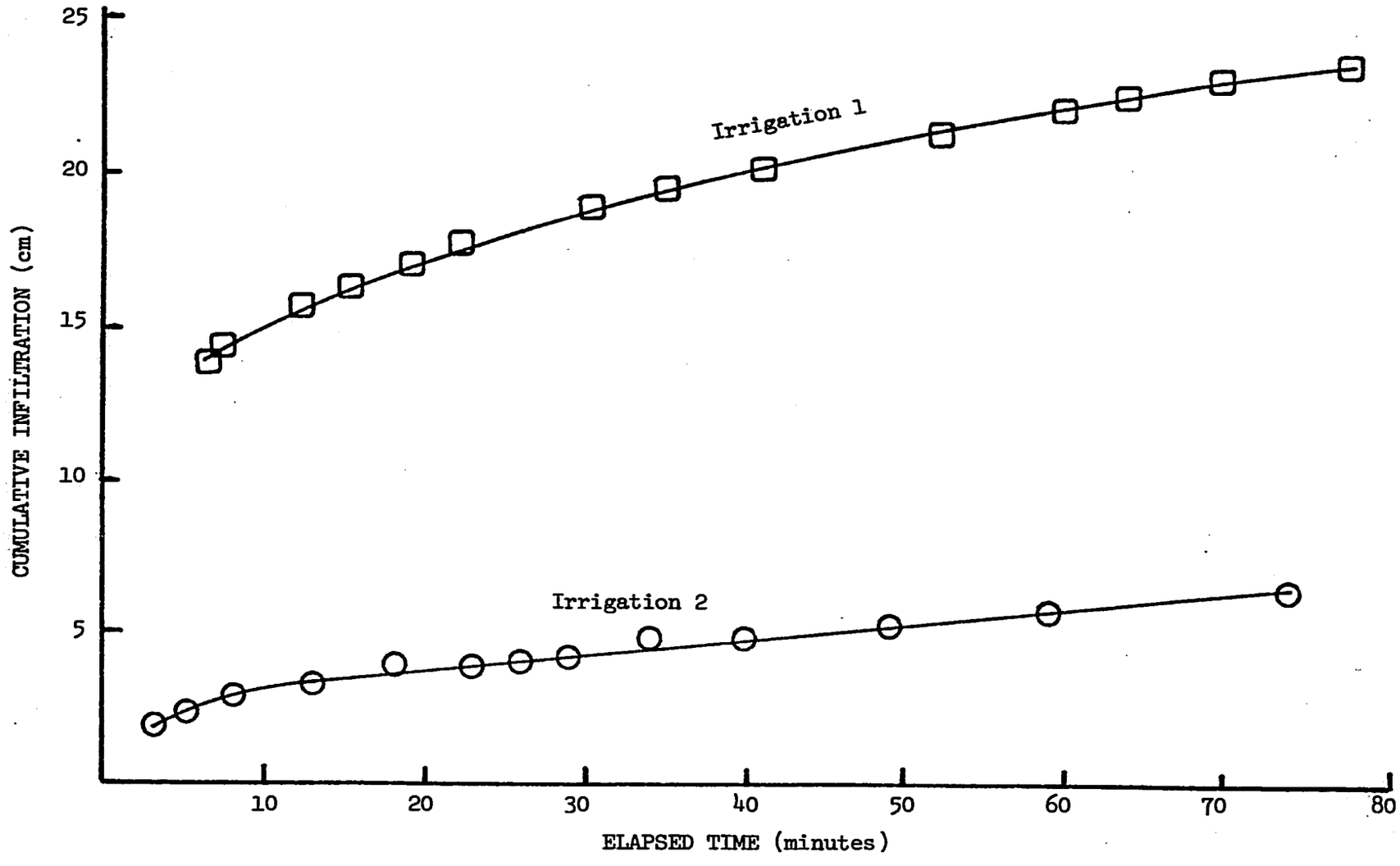


Figure 2. Cumulative infiltration versus time for Carreras clay.

(clayey Ultisol) where water movement was accelerated by dry soil conditions leading to cracking and by a relatively dense argillic horizon below 20 cm. This soil contains a mixture of 2:1 and 1:1 clays. The combination of the cracks and the relatively impervious layer resulted in a large amount of water moving downslope beneath the soil surface. The importance of soil cracks as avenues of water movement was very pronounced. It is possible in light of structural stability in this soil that the cracks may continue to play a large role as water conduits even after the soil becomes saturated.

Given rainy conditions and sufficient time, cracks will disappear reducing the extent of lateral water movement. For example, after the experimental plot and surrounding areas were wetted by rains, surface cracking was not noticeable. Twelve auger holes were dug around the plot in an attempt to follow lateral water movement. None of significance was detected. Given dry soil conditions in the Carreras soil and a sudden rainfall of 50 mm, it is unlikely that significant lateral water movement would occur.

In the Torres soil cracking was evident under dry conditions. However, this soil does not appear to have a pronounced argillic horizon. Thus the lateral water movement which occurred was observed at deeper depths.

In the Catalina soil lateral water movement was less significant than in the Carreras or Torres soils. No lateral water movement was observed in the Piña soil (sandy Oxisol).

Lateral water movement can be of importance in that the water carries with it fertilizer salts, primarily nitrates. If fertilizer trials are conducted where lateral water movement can occur in the root zone, there exists the possibility for mixing of treatments. This will depend on soil-

water status, slope, and upon rainfall intensity or extent of irrigations.

In addition, scientists concerned with pollution often look at deep leaching of salts. Perhaps under certain conditions lateral water movement (and salt movement) should also be monitored. This might aid in accounting for total salt balances within a certain system.

Soil-Water Tension Versus Time Relationships

Soil-water tensions were generally obtained from the average of two tensiometers at each depth. Tension data have been corrected for depth and for negative wetting of mercury in the spaghetti tubing.

Figure 3 shows typical tension-time relationships for an uncovered plot on the Carreras soil. Water movement was downward between all depths from 30 to 120 centimeters in response to tension differences. Upward water movement from the 30 to the 7.5-centimeter zone occurred after 11 hours. This upward tension gradient was caused by water evaporation from the soil surface.

Figure 4 shows typical tension-time relationships for extended times on the Piña soil which has been covered to prevent evaporation. With time, tensions normally increase slowly, evidence of continued slow drainage. It is evident from Figure 4 that drainage is still occurring six days after an irrigation. The magnitude of the water loss from the profile, summed over a long period, is apt to be sizeable.

In spite of wide textural differences, patterns are similar on each soil. After irrigation, soil-water tension near the soil surface drops rapidly and becomes negative reflecting super-saturated conditions or water ponded on the plot. Generally, as drainage begins at the upper depths the wetting front reaches the 90 and 120 cm depths. Two to three

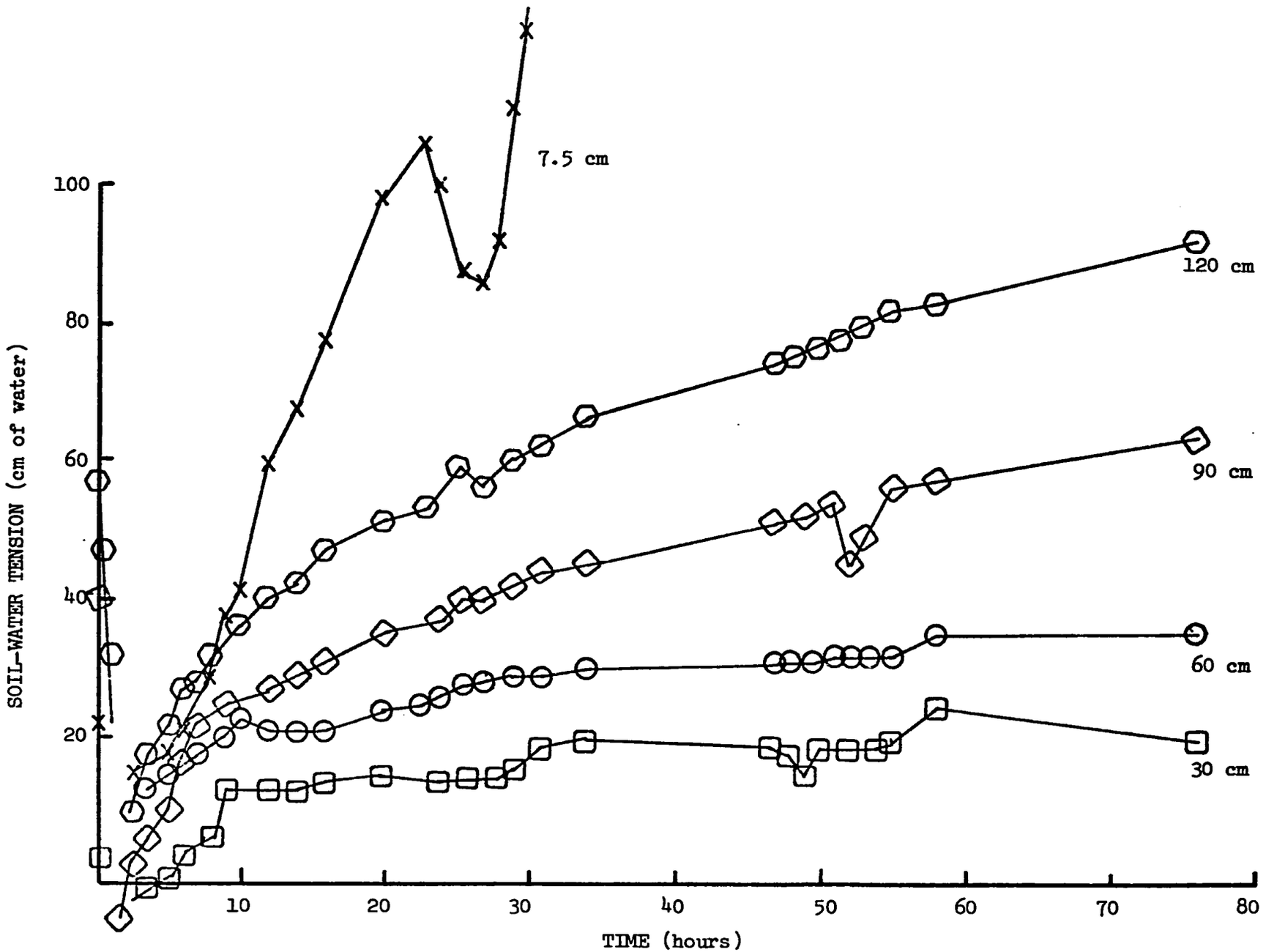


Figure 3. Soil-water tension versus time in Carreras soil at five depths.

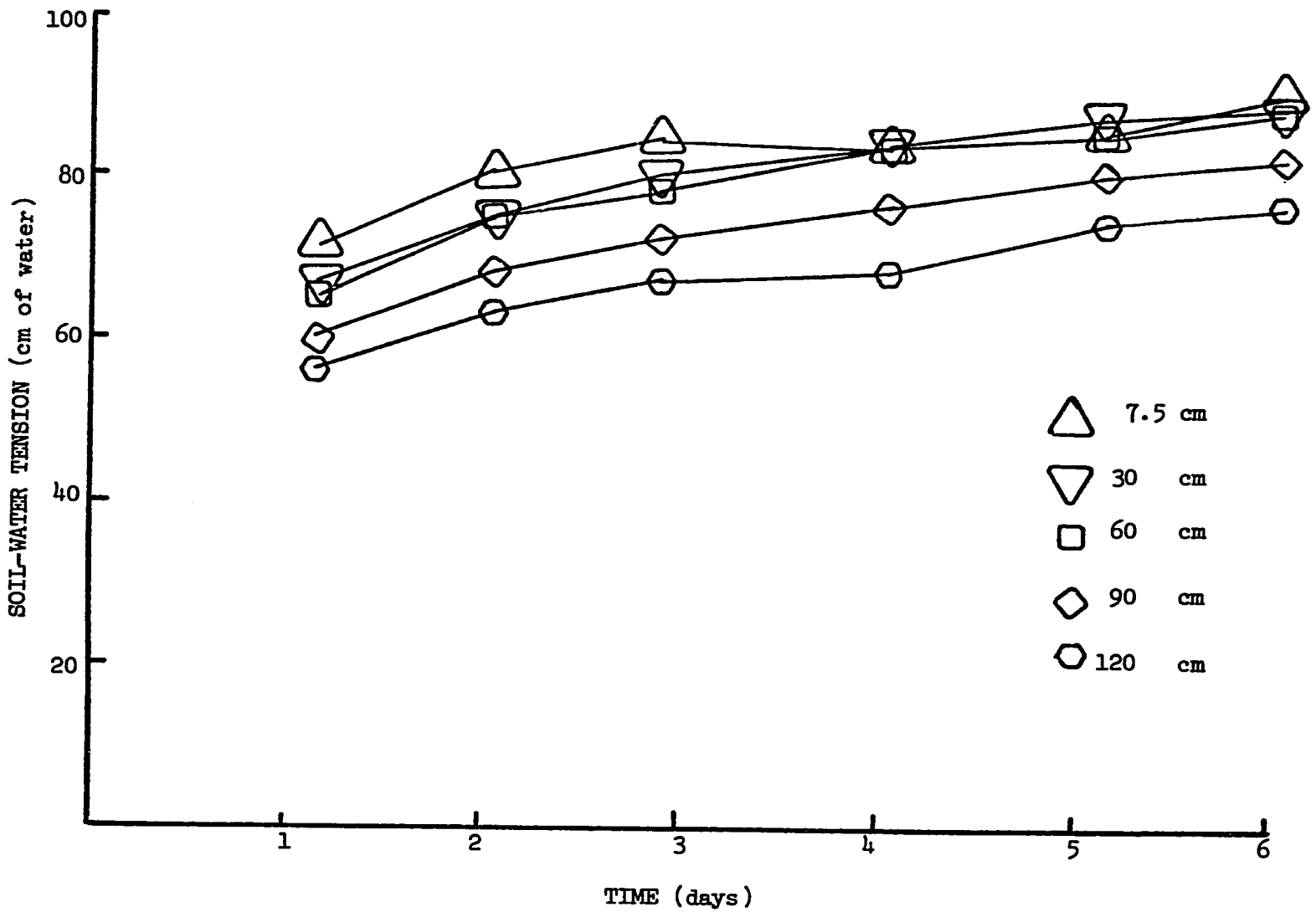


Figure 4. Curves of soil-water tension versus time in Piña soil at five depths.

hours after the irrigation, drainage has begun at all depths. With time soil-water tensions continue to increase, which is evidence of continued drainage. Data have been collected for longer periods of time, up to 35 days. Such data merely reflect slow drainage interrupted by heavy rainfalls.

Soil-Water Movement

Experiments on clayey Oxisols and Ultisols showed that water movement at saturation was extremely high as evidenced by infiltration rates (Figures 1 and 2). In other words, hydraulic conductivity at saturation was very high. After two days, drainage slowed considerably. This occurred at tensions of 1/20 bar in the clayey soils and 1/15 bar in the sandy soil. Since water movement at those tensions was so slow it appears that the capillary conductivity has decreased tremendously over a narrow range of tensions. This means that major water conducting avenues have de-watered.

The fact that water redistribution was initially very rapid and shortly thereafter very slow implies that there may be two types of water conducting avenues. A third type might be cracks in 2:1 clays as exhibited by the Carreras soil. The two types of avenues might be labeled capillary pores (micropores between soil particles) and non-capillary pores (macropores between soil aggregates). This has been postulated by Sharma and Uehara (1968). It might then be hypothesized that the major amount of soil-water movement in the wet range occurs between the surfaces of structurally stable aggregates (non-capillary pores). Thus, high structural stability would be required to explain this type of water movement. In 2:1 clays, lattice expansion would destroy the macro-structure.

After non-capillary pores have dewatered, there is little further redistribution even though within the individual aggregates the pores may be saturated. Water contents at this time may equal 50 percent by volume. The fact that individual aggregates can remain saturated while not rapidly losing moisture may be explained by the fact that the non-capillary pores have dewatered and therefore present a barrier to further redistribution of liquid water.

The analogy between water movement in this system and a sand is clear. It would appear that clayey Oxisols simulate sands in flow characteristics and in release characteristics. With regard to water movement and release in Oxisols, it may be misleading to put emphasis on texture. Perhaps structural stability, type of structure, and type of clay are more useful parameters.

Due to the effect of structure on water movement in these soils, all water release data in the wet range were obtained on undisturbed samples. At low tensions, destroying the aggregates to run a sample will have the effect of creating greater soil-water storage than would occur in the field.

Soil-Water Content Versus Soil-Water Tension

Soil-water characteristic curves (or soil-water release curves) relate volumetric soil-water content to soil-water tension. They are useful in describing the percentage of water retained for a particular soil and depth. Since the curves characterize a soil type and depth they may be used to determine soil-water content once soil-water tensions have been established using tensiometers. Use of tensiometers and these curves will permit calculation of water content changes in the soil profile.

Figures 5 to 12 are soil-water characteristic curves for the four soils. For each soil two graphs have been prepared; one for the tension range 0-0.8 bars and the second in the range 0-15 bars. On each graph four soil-water release curves have been drawn corresponding to 30-, 60-, 90-, and 120-centimeter depths. Data for the graphs were obtained in the laboratory as follows: Water content versus tension determinations in the range 0-3/4 bar were run on undisturbed core samples; disturbed samples were used in the range 1-15 bars. Each point on a curve is generally an average of four laboratory determinations. The water contents used as a basis for these curves are given in Appendix 2, Tables 1-4. As two distinct methods have been used for determining soil-water tension-water content relations, there may exist some overlap in the relationships in the vicinity of 1 bar. Therefore, water contents for certain of these tensions were obtained by interpolation and these have been so noted in Tables 1 to 4.

A comparison of the soil-water release curves in the tension range 0-800 cm of water reveals that there are differences in shapes of the curves. At low tensions (0-100 cm of water) the curves for the Piña soil, a sandy Oxisol, are very steep. In this soil, the bulk of the pores dewater at very low tensions. The curves are also fairly steep for the Catalina soil, a clayey Oxisol, but are less steep than for Torres, a clayey Ultisol intergrade to Oxisol. In contrast, the curves for the Carreras soil, a clayey Ultisol, are even less steeply sloping, indicative of gradual water release in this tension range.

It may be noted that variation between depths for any one soil is greatest for the Carreras, the soil with the most pronounced horizonation. For example, the 30- and 60- cm depths may contain as much as 5 percent

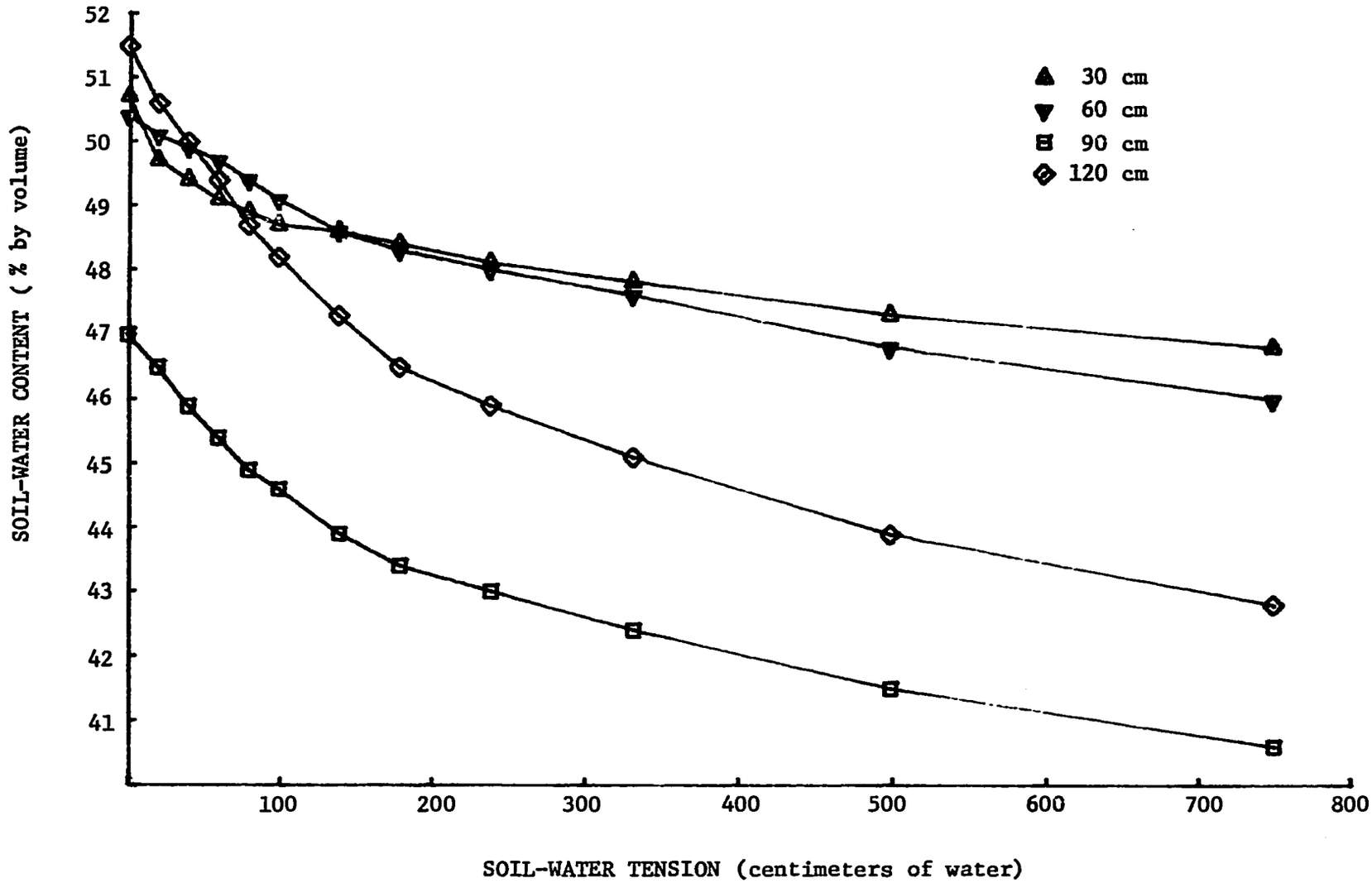


Figure 5. Curves of soil-water content vs. tension in Carreras soil at 4 depths.

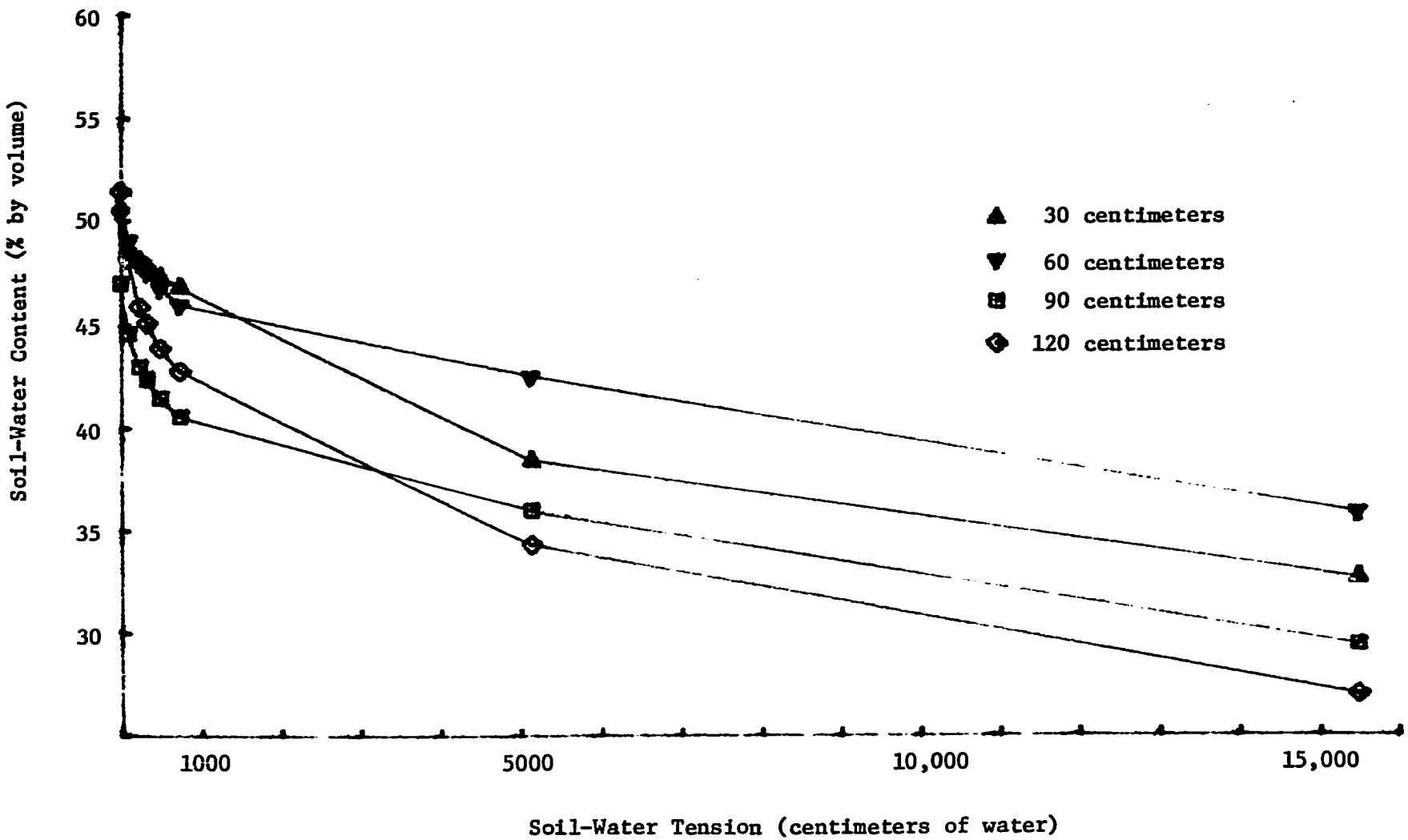


Figure 6. Curves of soil-water content vs tension in Carreras soil at 4 depths.

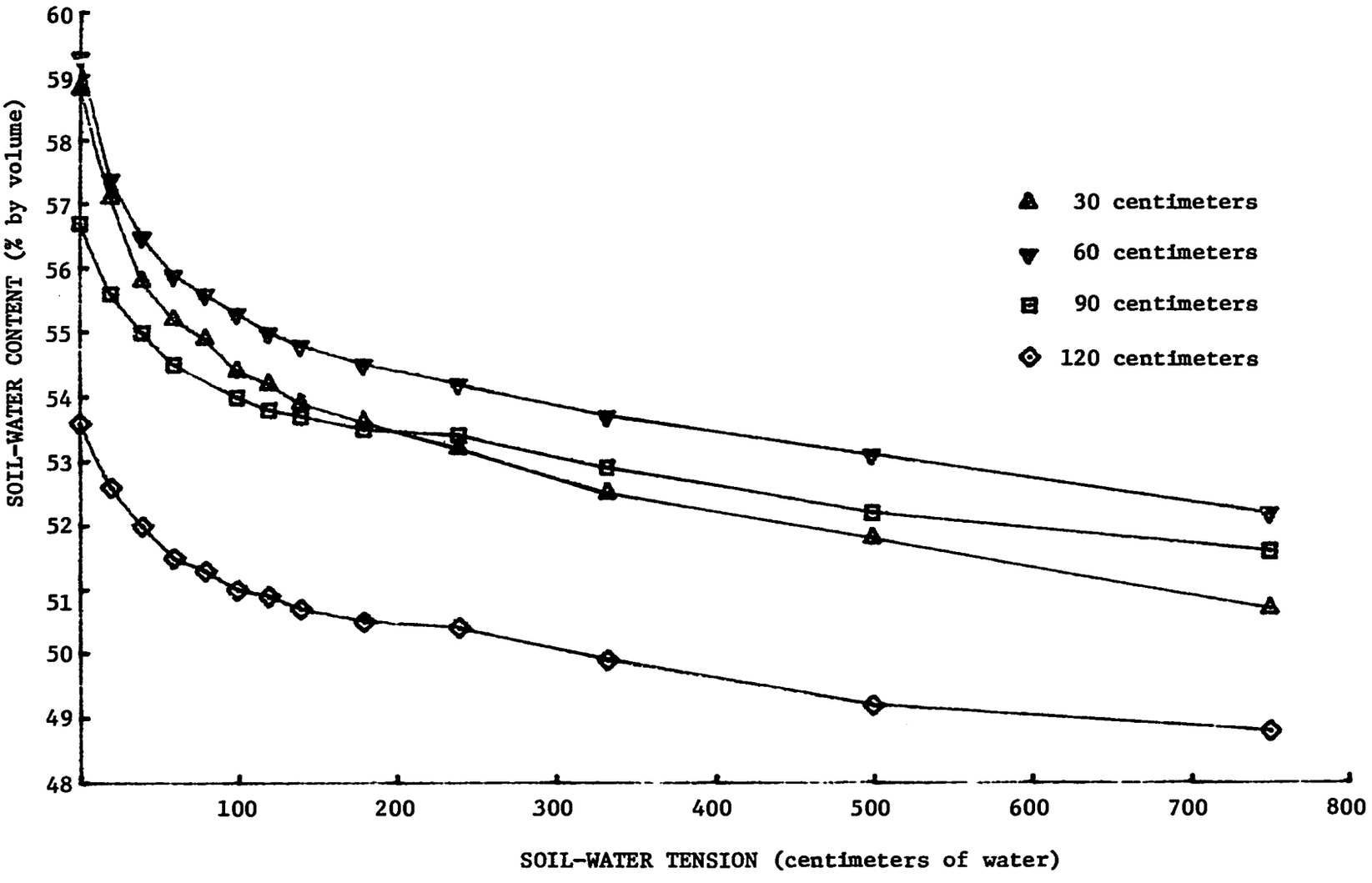


Figure 7. Curves of soil-water content vs tension in Catalina soil at 4 depths.

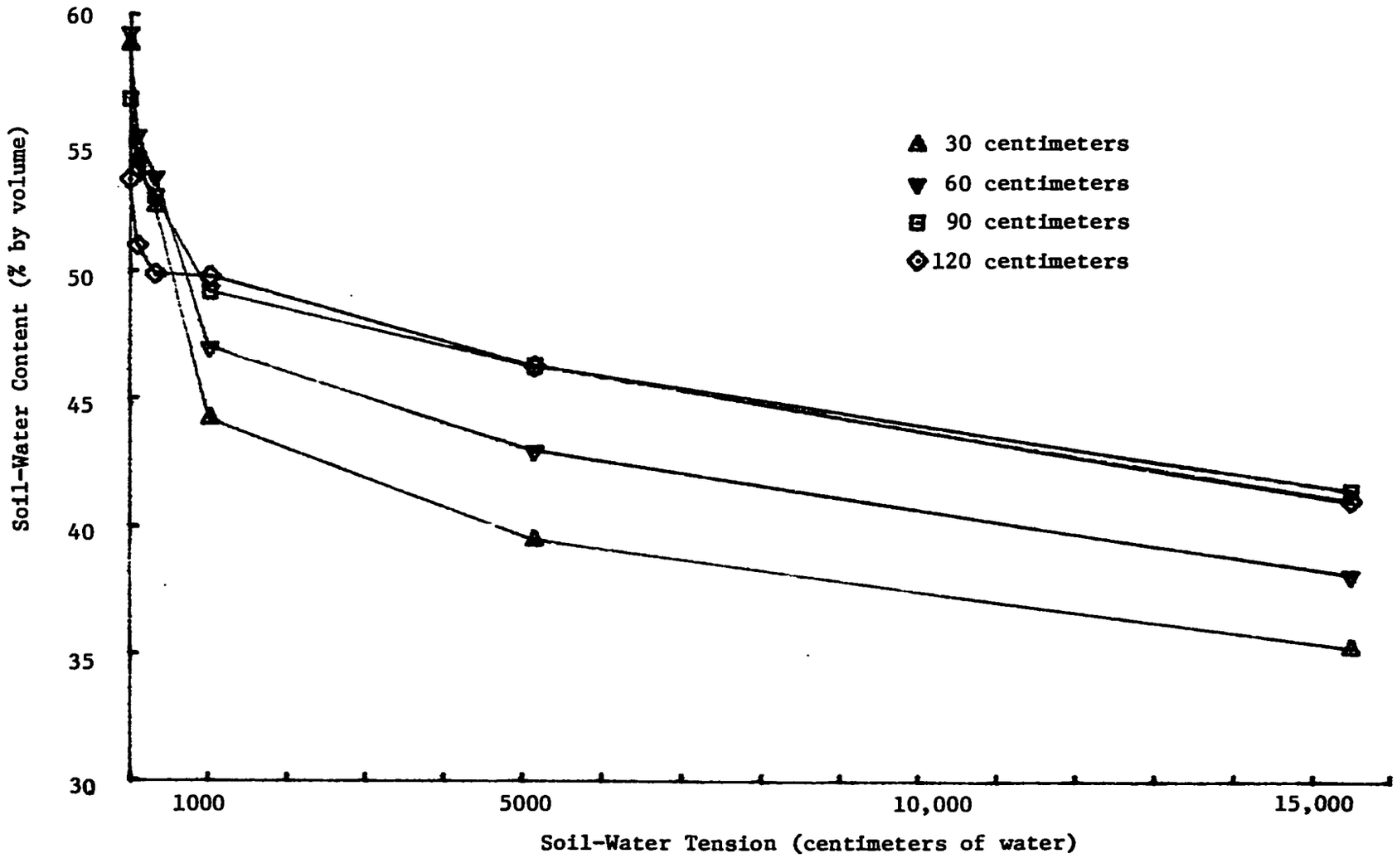


Figure 8. Curves of soil-water content vs tension in Catalina soil at 4 depths.

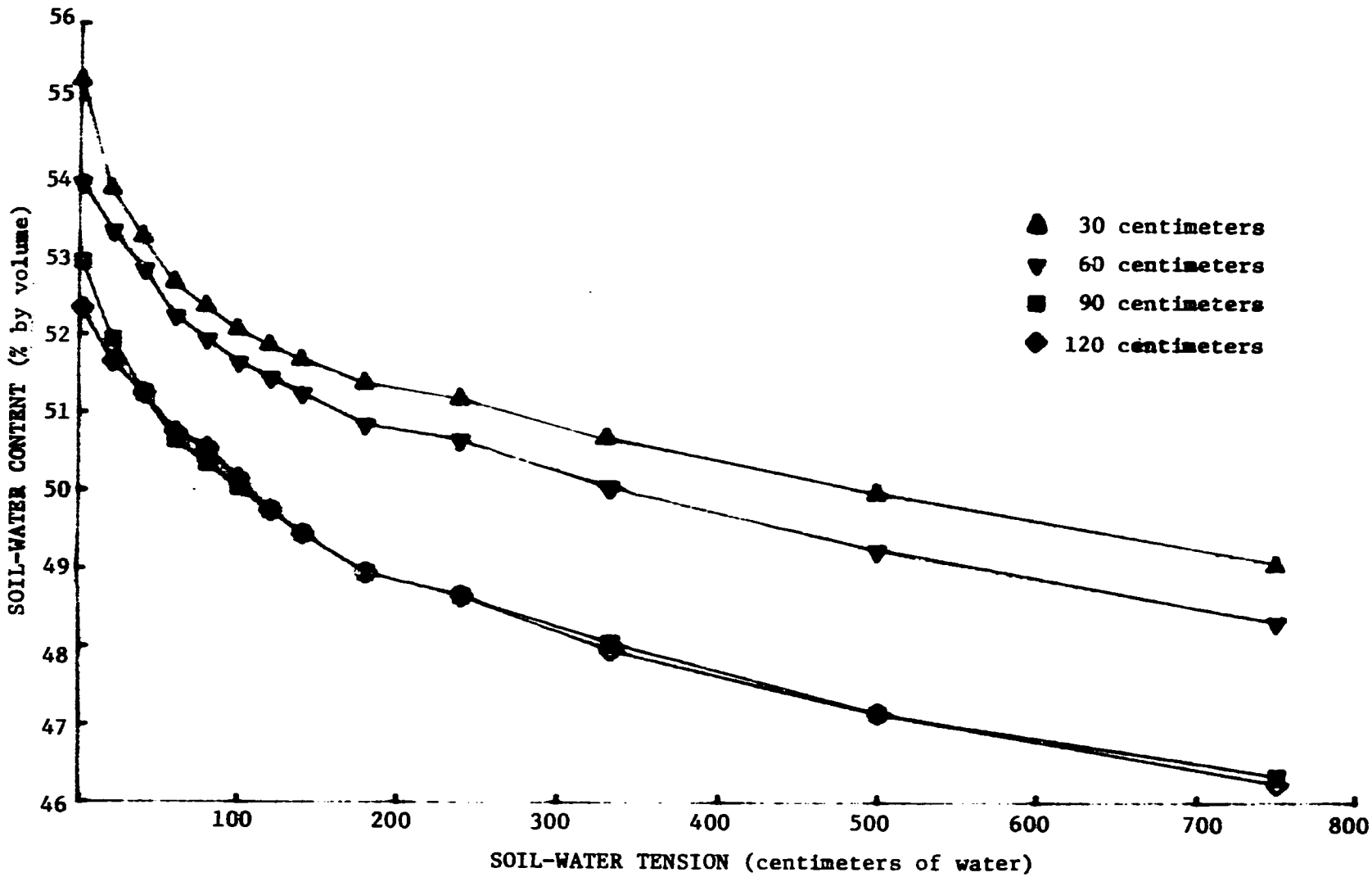


Figure 9. Curves of soil-water content vs tension in Torres soil at 4 depths.

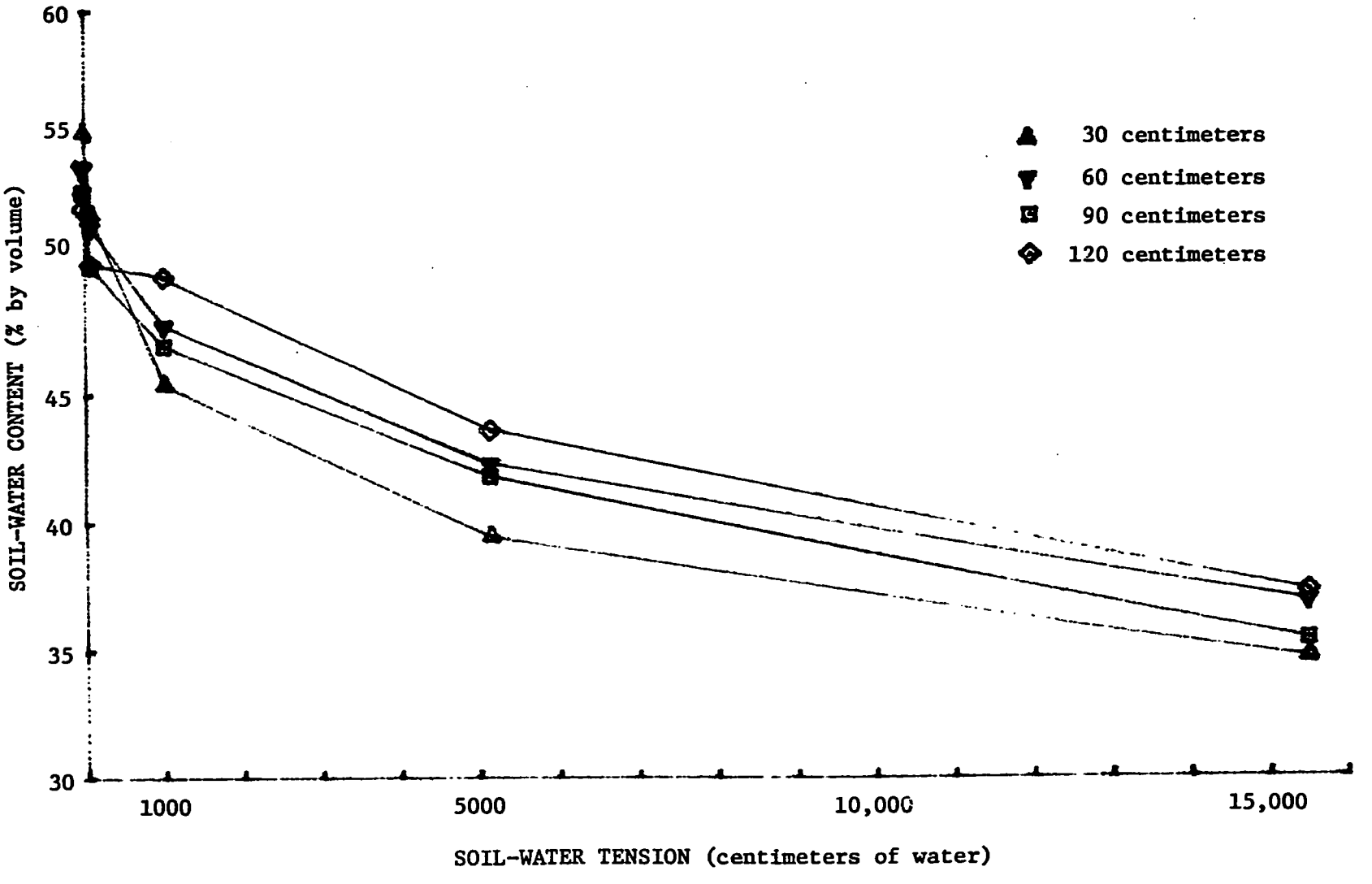


Figure 10. Curves of soil-water content vs tension in Torres soil at 4 depths.

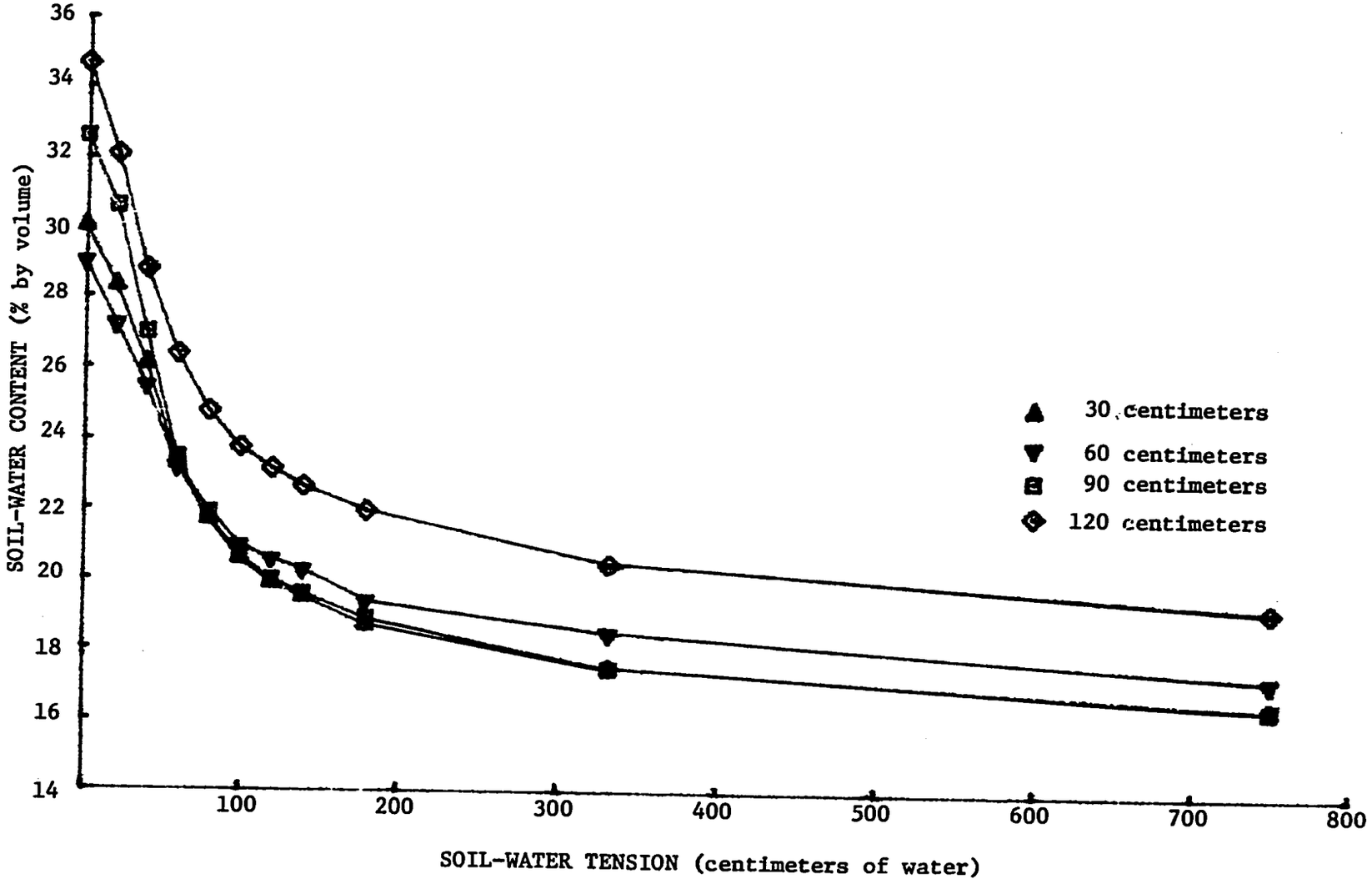


Figure 11. Curves of soil-water content vs tension in Piña soil at 4 depths.

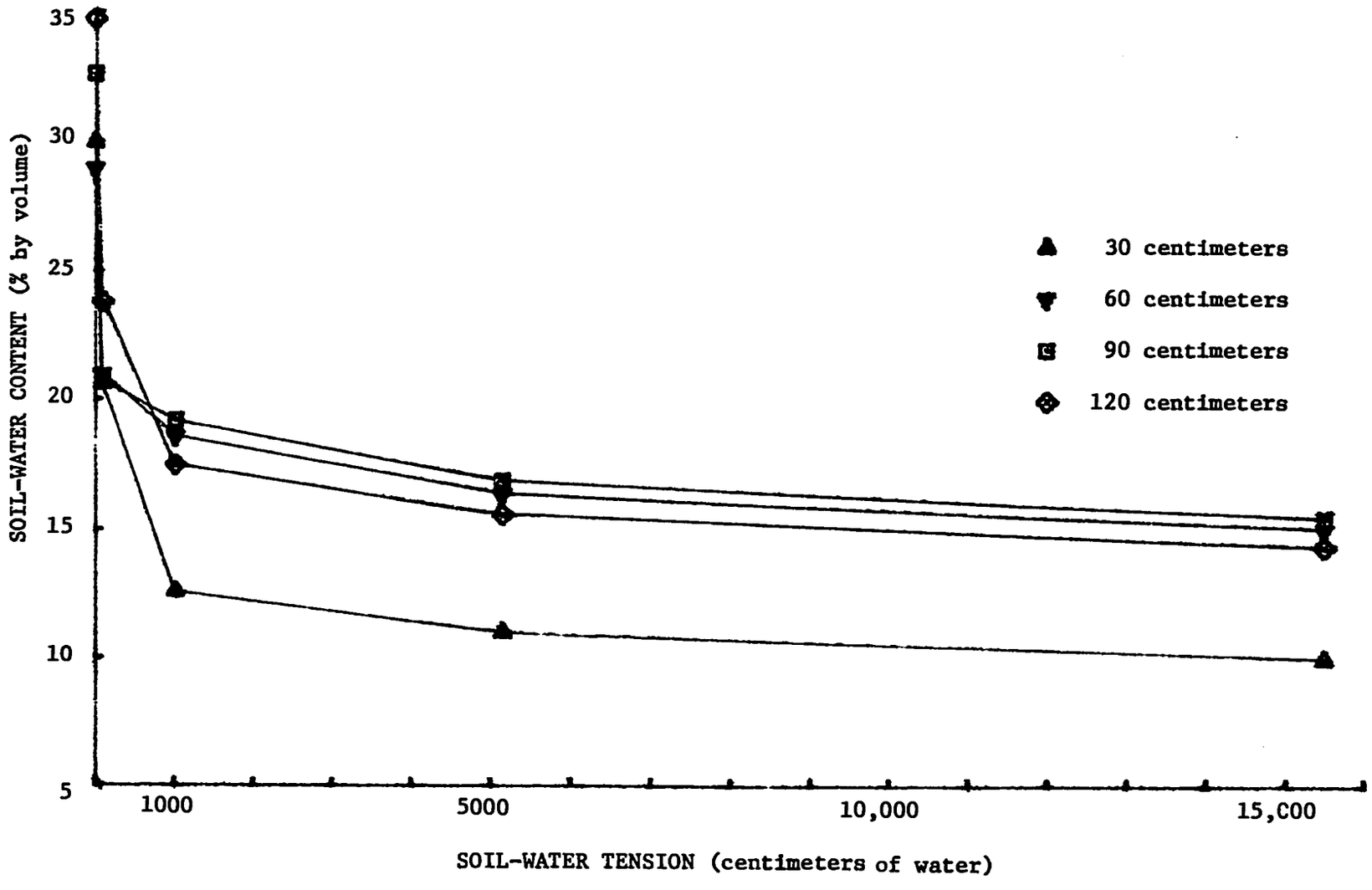


Figure 12. Curves of soil-water content vs tension in Piña soil at 4 depths.

or more water than the 90- and 120- cm depths for a given tension.

Figure 12 illustrates that the sandy Piña soil practically ceases to release water above 1 bar of tension. In contrast to the Piña, the relative steepness of the curves for the Carreras soil (Figure 6) indicates that this soil can continue to release appreciable amounts of water stored in the profile at tensions above 1 bar. In fact, approximately 3/4 of the available water in this soil is stored at tensions above 1 bar. The Catalina and Torres soils behave in an intermediate manner, with the former soil tending to release water in a manner most similar to Piña (both are Oxisols), and with the Torres soil tending somewhat toward the Carreras (both are Ultisols).

Water Holding Capacity and Available Water

The amount of available water for crop growth is considered to be the amount held in the range from field capacity to permanent wilting point (15 bar percentage). Field capacity has been defined as the water content of the soil after the soil has been wetted and allowed to drain for two or three days. In the laboratory this determination has been usually correlated with a tension of 1/3 bar. Some workers e.g. Richards and Weaver (1944) have associated 1/3 bar percentage with field capacity. Others, Griffin et al. (1966) have taken the available water range to be that held between 1/3 and 15 bars. For the Puerto Rican soils reported herein, 1/3 bar percentage gives a poor estimate of field capacity.

It is apparent from Figures 3 and 4 that the tension associated with drainage after three days is depth dependent. Also, it was observed that tensions in the field under conditions of free drainage (but no evaporation) do not reach 1/3 bar in three days but instead drain to 20-80 cm

of water (roughly 1/50 - 1/12 bar). Field capacity, therefore, was considered to be 1/15 bar for the sandy Piña and 1/20 bar for the clayey soils.

The lower end of the available water range has generally been established at the wilting point or 15 bar percentage. This implies two things: (1) That the entire amount of water is available to plants, and (2) it is uniformly available. Regarding (1), it is very unlikely that plants can use water from this entire range. Water uptake by plants is a function of root density and water conduction by the soil. At high tensions water conduction will be slow and although ample water may be present in the soil the supply system may not keep pace with plant needs if evaporative demand is high. Under those circumstances it would be correct to say that the soil water is not available, at least in the dynamic sense. Point (2) has generally been refuted for most crops. Plants will show stress and yields will be reduced at soil tension levels considerably below 15 atmospheres. In conclusions, one might say that for the soils studied the entire range of available water has been shifted to the left, 1/20 to perhaps 1 bar. Gardner (1971) expresses similar conclusions.

The question naturally arises as to the magnitude of the additional water available in the soil from 1/15 or 1/20 bar to 15 bars versus that which would be calculated conventionally by considering the available range to be 1/3 to 15 bars. The magnitude of that increase was determined to be on the order of 10-15 percent more water in the clayey soils and approximately 33 percent more water in the sandy soil. For example, data in Appendix 2, Table 1, permit calculation of the additional water in the Carreras soil. Approximately 3.5 cm of water is the additional water stored in the 120-cm profile out of a total of 20.9 cm in storage with approximately 1.10 cm of the water available in the top 60 cm. For a

crop with a root system in the top 60 cm of soil, this calculation would mean that two or more days of additional soil moisture is available for crop growth over that amount conventionally calculated.

It is apparent that correct establishment of the upper range of available water is extremely critical on a sandy soil where water contents change drastically with small soil-water tension changes. As root penetration may be restricted to the upper 30 cm because of subsoil acidity or other factors, even a 15 percent increase in water storage may be important.

Figure 13 has been drawn to compare the available water holding capacities for 30- and 60-cm rooting depths for the four soils studied. Data for Figure 13 were taken from Table 6 in Appendix 2. Table 7, Appendix 2, gives a more complete account of the water released at various soil-water tensions.

For the Piña soil (sandy Oxisol) the bulk of the water is held at tensions between 1/15 and 1 bar. From Table 7, Appendix 2, it can be noted that as much or more water is lost between saturation and 1/15 bar as between 1/15 and 1 bar. The Piña is a soil with a low amount of available water. Once 1 bar soil-water tensions are reached the crop has available at most one day of water for transpiration, assuming a 30-cm root zone. Due to capillary conductivity considerations, it is unlikely that this water would be available for crop growth.

In contrast to the Piña the bulk of the water in the Carreras soil is only available at tensions above 1 bar. This may be adequate if crop root density and soil capillary conductivity are high and evaporative demand low. However, if conditions of poor root distribution, low capillary conductivity, and high evapotranspiration exist, the water may be inadequate

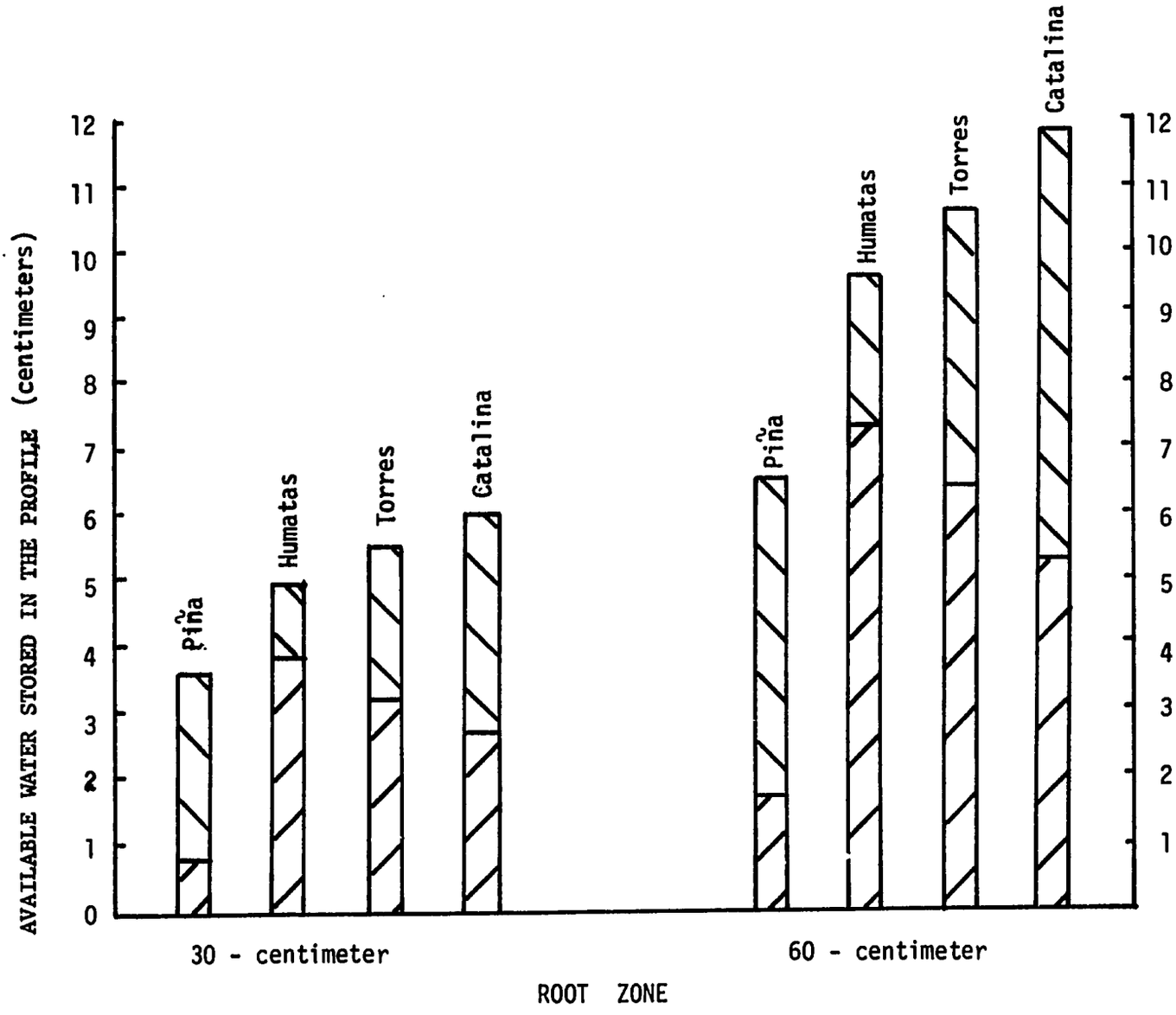
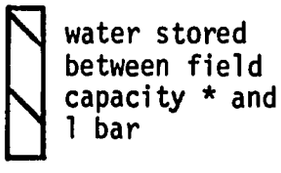
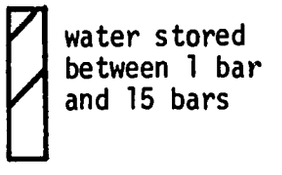


Figure 13. Water holding capacity of four Puerto Rican soils.





*field capacity established at 1/15 bar for Piña; 1/20 bar for Humatas, Torres and Catalina.

to supply plant requirements. Under the latter conditions, the soil is apt to be considered "droughty". Thus, while actual water storage is greater than in Piña, the Carreras soil may also be a poor one from a standpoint of water supplying characteristics under certain crop and climatic conditions.

Like Carreras, the Torres soil contains a high proportion of water stored above 1 bar. This is mitigated by the fact that Torres contains 50 percent more water, (two days of evapotranspiration in a 30 cm profile assuming an ET of 0.5 cm/day), than Carreras in the range 1/20 to 1 bar.

The Catalina soil has a large reservoir of available water. A large proportion of it is available at low tensions making this soil an excellent one in water supplying characteristics. The data in Table 7, Appendix 2, show that the 90- and 120-cm depths in this soil have a much narrower range of available water.

It may be noted that the two Oxisols, one sandy (Piña) and the other clayey (Catalina), contain a greater proportion of water stored between 1/15 bar and 1 bar. In contrast, the Ultisols (Carreras and Torres) have a greater proportion stored between 1 bar and 15 bars. This is probably due to soil structure characteristics in the Ultisols which release water relatively slowly. The uniformity of the Oxisol profile combined with strong aggregate stability and a large number of macropores makes for rapid water release and availability. It would be premature to apply these conclusions to all Oxisols and Ultisols.

Capillary Conductivity

Capillary conductivity is the constant relating water flux and hydraulic gradient in the Darcy equation. Capillary conductivity was calculated for

the Carreras and Piña soils. Data are not adequate to make similar calculations for Torres or Catalina where rainfalls subsequent to irrigations voided calculation of vertical water flux.

To determine capillary conductivity, hydraulic gradients and water flux were calculated. On Carreras, flux of water at the 120-cm depth on the day following the irrigation was approximately .75 cm per day. This decreased to approximately .12 cm per day seven days after the irrigation. In the second irrigation on the Carreras soil, flux of water passing through the top 120 cm of soil was .32 cm per day eight days subsequent to irrigation and three days following a heavy rainfall. Thirteen days after the irrigation (eight days after the rain), drainage occurred at the rate of .12 cm per day. Thus, in the absence of rainfall one might expect drainage from the profile to occur at the rate of 0.1 cm per day after ten days.

Values of capillary conductivity for the Carreras soil are shown in Figure 14. Data for Figure 14 are given in Table 8 of Appendix 2. Capillary conductivities decreased in relation to the soil layers as follows: 90-120, 60-90, 0-30, 30-60 cm. Thus, the top 60 cm of the profile was the least permeable and the 90 to 120-cm depth the most permeable. It can also be noted that at the 120-cm depth, a 2 percent reduction in water content resulted in a greater than 10-fold decrease in capillary conductivity. This is an example of the great dependence of capillary conductivity upon water content. Soil-water tension changes under the plastic covering were small giving a narrow range of water contents for the 0-60 cm zone. Graphed on a linear vertical axis, the apparent scatter at these depths is surpressed.

Figure 14 also shows that the best drainage occurs from the lower depths, and that the soil to the 60-cm depth restricts water movement most.

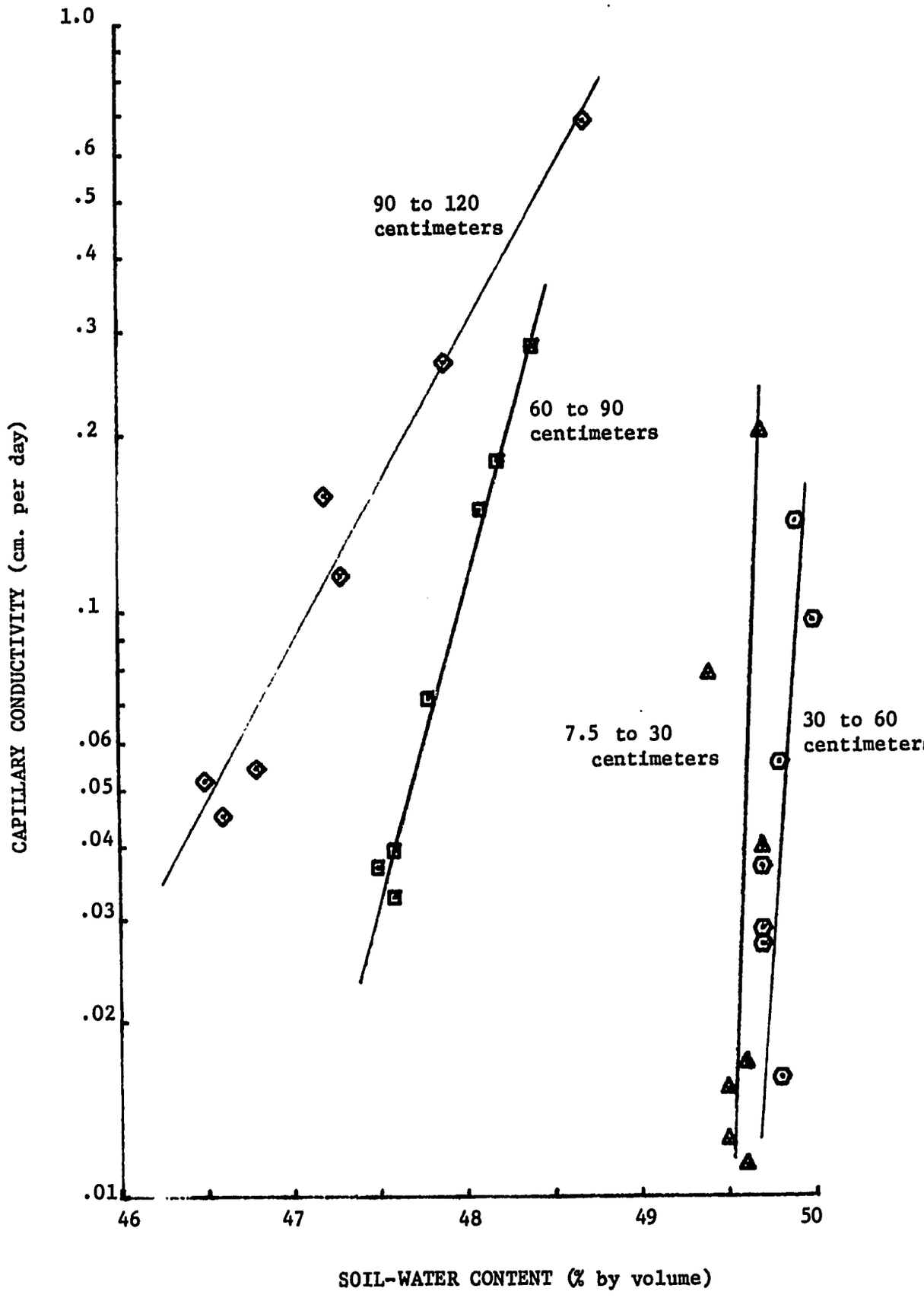


Figure 14. Capillary conductivity vs soil-water content for Carreras clay.

The 30- to 60-cm depth has been correlated with clay accumulation.

Capillary conductivity values for the Piña soil are given in Figure 15. Data for this figure are presented in Table 9 of Appendix 2. Relative to the Carreras soil, capillary conductivities are much greater. Capillary conductivity values for all depths are similar which parallels the visual uniformity of the soil.

It can be noted that capillary conductivity is highly water content dependent. In general, a 2 percent decrease in water content will result in a 10-fold decrease in capillary conductivity. This relationship is somewhat less steeply sloping for the Piña than for the Carreras soil over the range of water contents observed.

Use of capillary conductivity values in conjunction with tensiometer data can provide estimates of water flux at any depth in the profile. Such information is particularly useful when data on the magnitude of water loss beneath the root zone due to deep percolation are required in irrigation efficiency studies. A second type of application of the data is in estimating the magnitude of upward movement of water from a water table to supply a crop. For example, in the Carreras soil, 0.5 cm per day of upward water movement could be supplied across a potential gradient of 1 bar in a soil zone having a capillary conductivity of 5×10^{-4} cm per day. If the top 60 cm of the profile was taken to 3/4 of a bar by a crop which rooted only to 60 cm, we might expect soil-water tensions below 60 cm to be at about 1/10 bar. In such a situation calculations reveal that upward flux of water might be on the order of 0.06 cm per day. Thus, 10 percent of the water for evapotranspiration might be supplied from the profile beyond the root zone. The data can also be useful in providing estimates of nutrient loss to deep percolation once salt concentrations of the leachate

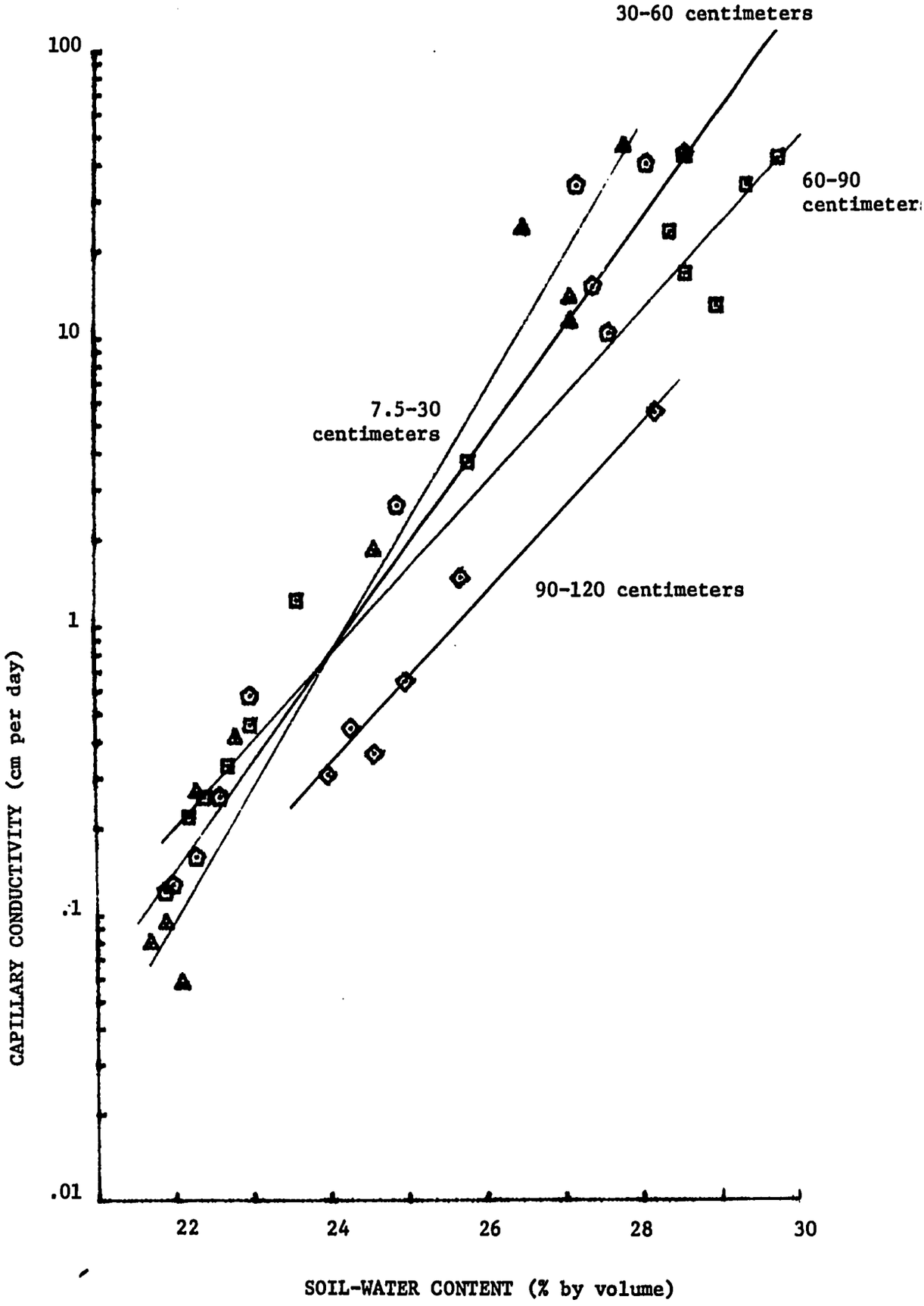


Figure 15. Capillary conductivity vs. soil-water content for Piña sand

are known. Unfortunately, the curves of Figure 14 cannot be extrapolated to provide good estimates of capillary conductivity versus water content in drier soils.

DISCUSSION OF TECHNIQUES

The comparison of techniques used to determine water retention at various tensions were the following:

Disturbed samples on pressure plate apparatus
1/3, 2/3, 1, 5, 15 bars;

Undisturbed samples (7.62 x 7.62 cm core samples)
on a) Tempe cells @ 0-750 cm tension
on b) Pressure plate apparatus @ 0-15 bars tension

Results and conclusions are as follows:

(1) In the tension range 0-750 cm, volumetric outflow from cores run on Tempe cells compared favorably with weight changes in cores placed on pressure plate apparatus and dewatered. Although no statistical analysis was made, the methods appeared to give like results over this tension range.

If both methods are available, Tempe cells may be somewhat easier to run since frequent weighings are not required. However, since the cells are very specialized equipment, it may be more convenient to run core samples on the pressure plate apparatus.

(2) In the tension range 1 to 15 bars, the undisturbed core samples run on the pressure plate apparatus did not dewater to the extent that disturbed samples dewatered. The fact that the cores did not adequately dewater, although they remained under 15 bars pressure for up to two weeks, is due to the height of the core (7.62 centimeter) and to the low capillary conductivity at high tensions. Disturbed cores have a larger percentage of their volume in contact with the plate permitting faster dewatering. As water contents determined by 15 bar disturbed samples have been well

correlated with permanent wilting in the field, that method is preferred. (3) In the tension range 0-750 cm, disturbed samples tended to overestimate the amount of water retained when compared to that retained by the undisturbed core samples. Figure 16 gives the correlation between disturbed and undisturbed samples at 333 cm of tension. Although the correlation coefficient is very high, 0.97, this is greatly influenced by the four points at low water contents obtained from the Piña sand. For example, without these four points the correlation coefficient drops to 0.68. The slope approaches 1.0. The intercept is positive which indicates the tendency of disturbed samples to overestimate water retained.

Typically, at zero tension (saturation) undisturbed samples had 90-95 percent of the voids (pores) filled with water. The remainder were filled with entrapped air. Similar calculations were made using water contents at saturation from disturbed samples and bulk density measurements from undisturbed cores. These indicated that disturbed samples had 100-125 percent of the undisturbed voids filled with water, an obvious impossibility. (4) In conclusion, disturbed samples should be used for water release characterization in the range 1-15 bars of tension. Undisturbed core samples can be used in the range 0-1 bar.

As an alternative to running soil-water release curves in the laboratory, soil tensions obtained using tensiometers could be directly related to soil-water content through a program of gravimetric soil sampling. This should be done for all depths and over a wide range of water contents. This will require a growing crop and irrigations.

The value of this approach is two-fold: (1) It circumvents the time consuming laboratory processes and delicate handling required for undisturbed soil cores; (2) It provides a <u>direct</u> correlation between tension and field soil-water content. The upper limit of tensometers is about 0.8 bar. At

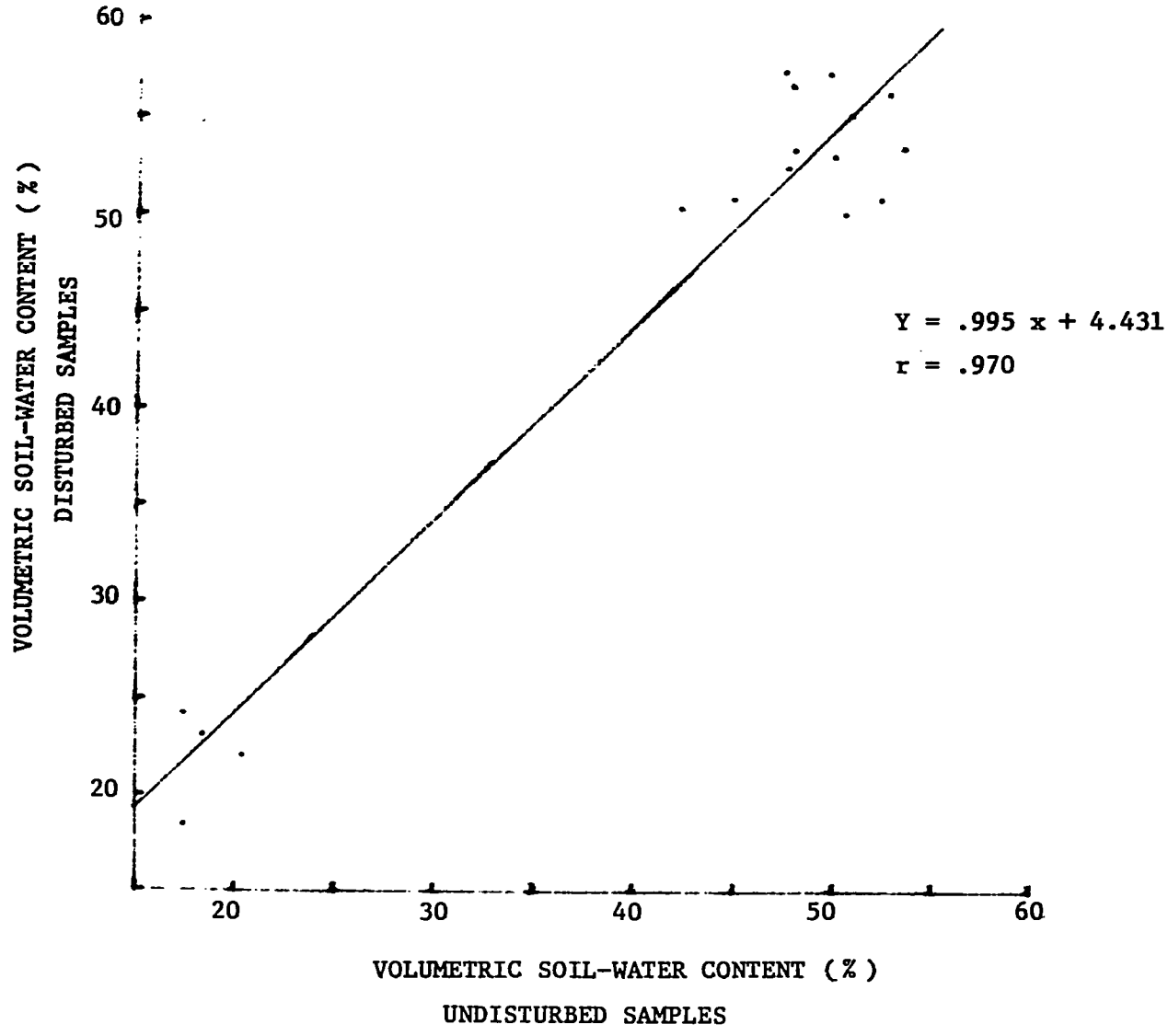


Figure 16. Correlation of disturbed & undisturbed samples for 1/3 bar tension for four Puerto Rican soils.

higher tensions readings from resistance blocks or information from neutron probe equipment can be correlated with gravimetric soil-water contents.

SUMMARY

A typical experimental design consisted of a 3 meter by 3 meter plot instrumented with tensiometers to a depth of 120 cm. The plot was flooded with water and covered with plastic to prevent evaporation. Water movement was monitored during infiltration and drainage (for up to 35 days) using the tensiometers.

In order to characterize the soil in the irrigated areas, two 150-cm pits were dug adjacent to the plots. Soil samples were taken at 15-cm intervals to a depth of 150 cm. Two undisturbed soil cores were taken each 30 cm, from 30 cm to 120 cm.

In the tension range 0-3/4 bar, correlation of soil-water content with soil-water tension was made by running undisturbed soil cores in the laboratory on Tempe Cells and on pressure plate apparatus. At higher tensions disturbed samples were run on pressure plate apparatus.

A summary of results follows:

(1) Water infiltration into all soils was very rapid. Rate of infiltration typically reached 9 cm/hour after one hour of continuous flooding. The strong structural stability of the clay soils permitted infiltration rates in excess of that for the sandy soil. Rate and amount of infiltration were inversely related to initial soil-water content.

(2) On the clay soils, lateral water movement, downslope, was a significant factor in observed high rates of water infiltration. For example, in the Torres soil, a stream of water flowing from a crack at a depth

of 105 cm was observed in a pit two meters from the irrigated area, 20 minutes after the irrigation. In the Carreras soil (Typic Tropohumult), the lateral movement was equally rapid, but occured at a depth of 20 cm. The lateral water movement in Carreras was studied further and was thought to be due to two factors: (a) Water movement in large cracks, and (b) water movement on the interface between tilled and untilled ground. This was accentuated by a clay accumulation below the plow depth. Lateral water movement may partially account for downslope movement of nitrate.

(3) Typically, values of soil-water tension after two to three days of free drainage do not exceed 20-80 cm of water (roughly 1/50 to 1/12 bar). Field Capacity was established to be 1/15 bar for the sandy soil and 1/20 bar for the clayey soils.

(4) Two avenues for soil-water movement were postulated: Capillary pores (between soil particles) and non-capillary pores (between soil aggregates). Because of water movement in non-capillary pores, flow characteristics of the clay soils resembled that of the sand. In terms of soil-water release characteristics the clays and the sand were similar.

(5) The two Oxisols, one very sandy (Piña) and the other high in clay (Catalina) tended to dewater at low tensions, whereas soil-water release in the Ultisols extended over a wider range of tensions. The sandy soil failed to release appreciable water above 1 bar of tension.

(6) The available water (in centimeters) stored in the top 30 centimeters of the soil profile was determined to be 3.6, 5.0, 5.5, and 6.0 for Piña, Carreras, Torres (Orthoxic Palehumult) and Catalina respectively. For Piña and Catalina, the two Oxisols, the bulk of the water is released between field capacity and one bar. In contrast to the

Oxisols, a high proportion of the water in the Ultisols, Carreras and Torres, is only available at tensions above 1 bar. The Catalina soil is by far the best in terms of water supplying characteristics while Carreras and Piña may be considered the worst.

(7) Values of capillary conductivity were calculated for the Carreras and Piña soils. These were found to be highly water content dependent. Using values of capillary conductivity it was estimated that only 10 percent of the water required for evapotranspiration might be supplied as upward water movement from the profile beyond the root zone

(8) Undisturbed core samples should be used to measure water retention in the wet range (0-3/4 bar) and disturbed samples should be used to measure water retention in the dry range (1/15 bars). An overestimatio of soil-water storage will be made by employing either disturbed sample techniques at low tensions or undisturbed core samples at high tension

(9) Although there was good correlation between field sampling for water contents and indirect measurements using tensiometers and laboratory determined soil-water release curves, it was suggested that values of soil-water tension be directly related to water contents through extensive gravimetric sampling.

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Lastly, the senior author acknowledges the continued support by the Agricultural Engineering Department, which enabled him to undertake this work.

Appendix I

Instructions and Cost Estimate for Tensiometers

I. Materials

The following material will be required for tensiometer construction. Sources of supply for some materials are given for convenience; this does not imply endorsement.

Tensiometers

(1) PVC plastic pipe, schedule 40, 1/2" nominal pipe size, 1/2" I.D., 7/8" O.D.

(2) Nylaflow pressure tubing, Type T, clear, 1/8" O.D. Available in 500' rolls (at about $5/roll) from:

Industrial Safety Supply Company
574 New Park Avenue
West Hartford, Connecticut 06110
(203) 233-9881

(3) Acrylic plastic pipe, 5/8" O.D. From:

Almac Plastics Inc.
47-47 36th Street
Long Island City, New York 11101

(4) Ceramic tensiometer cups, 1/2" neck, 7/8" O.D.

R & J Ceramics
1334 Silica Avenue
Sacramento, California 95815
(916) 929-8741

or

Soil Moisture Equipment Corporation
Post Office Box 30025
Santa Barbara, California 93105
Catalogue #2131
Description: 1 bar porous ceramic tensiometer cups

(5) Miscellaneous: Rubber stoppers #0; epoxy cement.

In order to read soil-water tensions, a manometer system is necessary requiring the following material:

(1) Meter stick
(2) Plastic vials for mercury well. 19 ml.
1 1/8" x 1 11/16" is suggested
(3) Mercury (120 gms/vial will serve 4 tensiometers)
(4) Mounts for meter stick and vial

II. Construction

(1) PVC should be cut to desired lengths. Cut to leave approximately 4" of PVC above the ground. Using sandpaper and cloth insure that ends of PVC are free from burrs and clean.

(2) Using a 41/64" drill bit ream out one end of the PVC to a depth of 1 1/2". This will accommodate the acrylic plastic sight glass.

(3) Cut acrylic plastic in 3" pieces and remove burrs. Insert and glue into reamed end of PVC. Use epoxy or PVC solvent. Let dry. The sight glass should protrude 1 1/2" from the PVC.

(4) Drill a hole for the nylaflow pressure tubing at the upper end of the tensiometer. This should be located about 1/2" from the top of the tensiometer and should go through one wall (only) of the PVC and the sight glass. Use a 1/8" bit.

(5) Glue nylaflow tubing to the tensiometer using epoxy. Let dry. The length of tubing will depend upon placement of the tensiometer in relation to the meter stick. Generally 10' is sufficient.

(6) Glue the tensiometer cup to the PVC using epoxy. Let dry.

III. Testing

Rather than having to remove a leaky tensiometer from the field it will pay to use care in construction, especially with regard to removing burrs and dirt, and in testing. The glued connections can give problems and should be checked to insure they are air tight. A simple test is to place the stoppered tensiometer under water and to blow air into the pressure tubing. This will reveal large leaks should they be present. Tensiometers removed from the field should be tested prior to reuse.

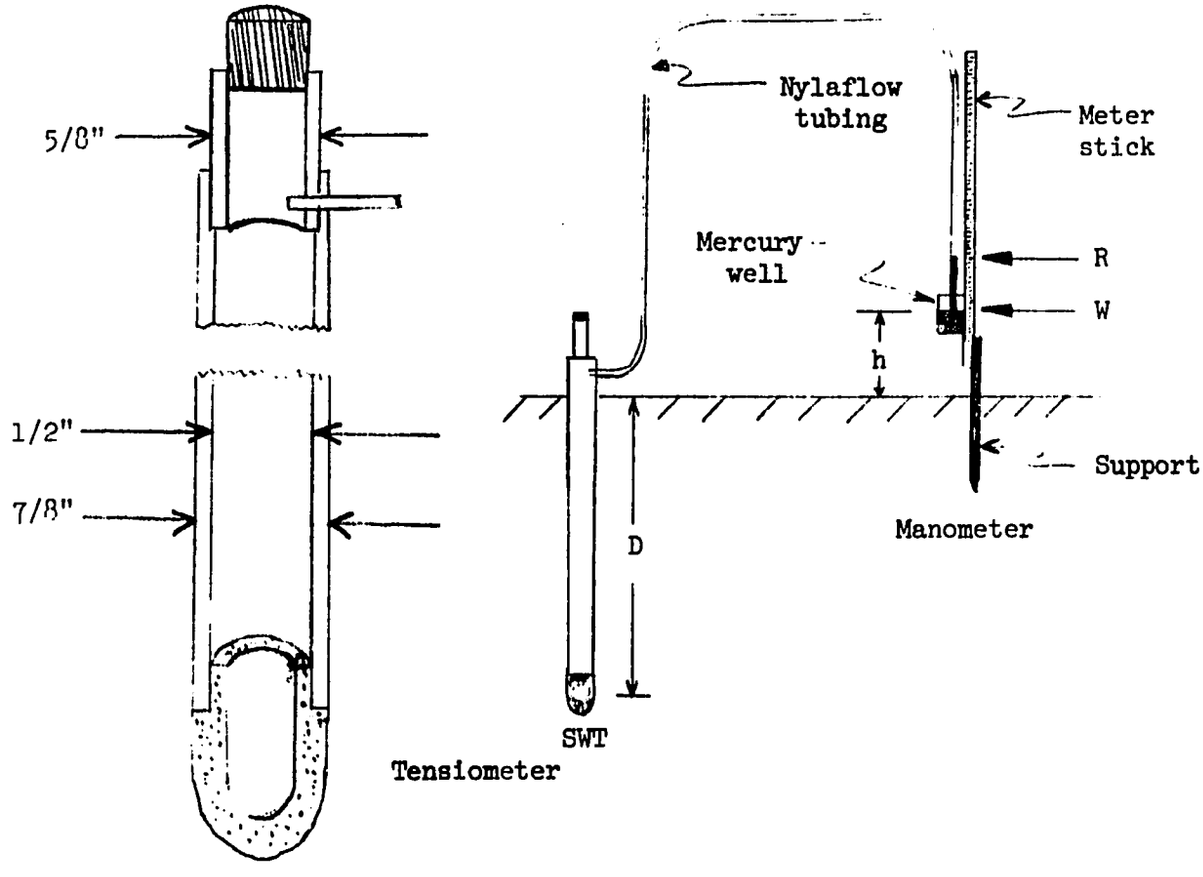
IV. Installation in Field

Auger to the desired depth using a 1" auger. Dig out the hole to approximately 3" beyond where the cup is to be placed. Pour a small amount of mud slurry into the hole and seat the tensiometer cup in the slurry. Backfill and tamp to a soil density approximating natural conditions. Run the nylaflow tubing from the tensiometer to the top of the meter stick and down into the plastic vial containing mercury. Tubing may be enclosed in glass tubing for rigidity or may be taped to the meter stick. Fill the

tensiometer with water. Using a squeeze bottle with conical cap, flush air from the system by pushing water through the sight glass and into the nylaflow tubing and mercury well. Stopper the tensiometer. Bubbles are apt to cling to the sides of a newly filled tensiometer and should be eliminated. Air bubbles may accumulate in the sight glass and should be eliminated from time to time, otherwise response will be slow and readings will be doubtful.

V. Reading Soil Water Tensions

Field data should be taken at the same time each day. Raw data must be converted to soil-water tensions using (1) given on the next page.



where: SWT = soil water tension (cm of water)

R = mercury reading on manometer (cm)

h = height of mercury well above ground (cm)

W = mercury reading in plastic vial (cm)

D = instrument depth (cm)

C = constant accounting for negative wetting of mercury in tubing. For nylaflow this = 7 cm.

$$SWT + D + h + (R - W) = (R - W)13.55 + C$$
$$SWT = 12.55(R - W) - D - h + C \qquad (1)$$

VI. Costs (August 1974)

Item	Cost
Rubber stopper #0	$ .02
Acrylic plastic tubing (sight glass)	.05
PVC schedule 40 plastic pipe - price depending on length est.	.50
Ceramic tensiometer cup - from R & J Ceramics = 47.5¢ each from Soil Moisture Equipment Corp. = 90¢ each	.48
Nylaflow pressure tubing	.10
Meter stick (1 per 4 tensiometers)	.25
Frame for meter stick	.05
Clips for nylaflow tubing and meter stick	.05
Mercury vial (well)	.20
Miscellaneous: Mercury, epoxy cement	1.50
TOTAL	$ 3.20

Commercial prices for tensiometers run from $20 to $30.

Appendix 2

Table 1. Soil-water content by volume.

(Carreras) Typic Tropohumult, clayey, kaolinitic, isohyperthermic

Tension (cm of water)	Depth (centimeters) 30 %	60 %	90 %	120 %
0	50.7	50.4	47.0	51.5
20	49.7	50.1	46.5	50.6
40	49.4	49.9	45.9	50.0
60	49.1	49.7	45.4	49.4
80	48.9	49.4	44.9	48.7
100	48.7	49.1	44.6	48.2
140	48.6	48.6	43.9	47.3
180	48.4	48.3	43.4	46.5
240	48.1	48.0	43.0	45.9
333	47.8	47.6	42.4	45.1
500	47.3	46.8	41.5	43.9
750	46.8	46.0	40.6	42.8
1033*	46.2*	45.6*	40.2*	42.5*
5165	38.4	42.5	36.0	34.3
15495	32.6	35.8	29.4	27.0

*Figures indicated with an asterisk were obtained by interpolation.

Appendix 2

Table 2. Soil-water content by volume

Catalina - Typic Haplorthox, clayey, oxidic isohyperthermic

Tension (cm. of water)	Depth (centimeters) 30 %	60 %	90 %	120 %
0	58.8	59.3	56.7	53.6
20	57.1	57.4	55.6	52.6
40	55.8	56.5	55.0	52.0
60	55.2	55.9	54.5	51.5
80	54.9	55.6	54.3	51.3
100	54.4	55.3	54.0	51.0
120	54.2	55.0	53.8	50.9
140	53.9	54.8	53.7	50.7
180	53.6	54.5	53.5	50.5
240	53.2	54.2	53.4	50.4
333	52.5	53.7	52.9	49.9
500	51.8	53.1	52.2	49.2
750	50.7	52.2	51.6	48.8
1033	44.2	47.0	49.2	48.5*
5165	39.5	43.0	46.3	46.3
15495	35.3	38.2	41.5	41.1

*Figures indicated with an asterisk were obtained by interpolation.

Appendix 2

Table 3. Soil-water content by volume

Torres - Orthoxic Palehumult, clayey, kaloinitic, isohyperthermic

Tension (cm. of water)	Depth (centimeters) 30 %	60 %	90 %	120 %
0	55.3	54.0	53.0	52.4
20	53.9	53.4	52.0	51.7
40	53.3	52.9	51.3	51.3
60	52.7	52.3	50.7	50.8
80	52.4	52.0	50.4	50.6
100	52.1	51.7	50.1	50.2
120	51.9	51.5	49.8	49.8
140	51.7	51.3	49.5	49.5
180	51.4	50.9	49.0	49.0
240	51.2	50.7	48.7	48.7
333	50.7	50.1	48.1	48.0
500	50.0	49.3	47.2	47.2
750	49.1	48.4	46.4	46.3
1033	45.4	47.8	46.0*	46.2*
5165	39.5	42.4	41.9	43.7
15495	34.7	37.0	35.5	37.4

*Figures indicated with an asterisk were obtained by interpolation.

Appendix 2

Table 4. Soil-water content by volume

Piña - Psammentic Haplorthox, sandy, isohyperthermic

Tension (cm of Water)	Depth (centimeters) 30 %	60 %	90 %	120 %
0	30.0	29.0	32.6	34.7
20	28.3	27.2	30.6	32.1
40	26.1	25.5	27.0	28.8
60	23.3	23.2	23.5	26.4
80	21.7	22.0	21.8	24.8
100	20.6	21.0	20.7	23.8
120	19.9	20.6	20.0	23.2
140	19.5	20.3	19.6	22.7
180	18.7	19.4	18.9	22.0
333	17.5	18.5	17.5	20.5
750	16.5	17.3	16.5	19.3
1033	12.6	17.2*	16.4*	17.5
5165	11.0	16.4	16.0*	15.6
15495	10.0	15.1	15.5	14.4

*Figures indicated with an asterisk were obtained by interpolation.

Appendix 2

Table 5. Bulk density of four Puerto Rican soils

Depth (centimeters)	Bulk Density (gms/cc) Carreras	Catalina	Torres	Piña
30	1.16	0.98	1.11	1.56
60	1.31	1.00	1.18	1.54
90	1.29	1.14	1.23	1.49
120	1.29	1.24	1.32	1.47

Appendix 2

Table 6. Amount of available water (in centimeters) stored in the soil profile at various tensions for four soils.

30-Centimeter Profile

	Piña	Torres	Carreras	Catalina
Field Capacity*	3.6	5.5	5.0	6.0
1 Bar	0.8	3.1	4.1	2.7
15 Bars	0	0	0	0

60-Centimeter Profile

	Piña	Torres	Carreras	Catalina
Field Capacity*	6.5	10.6	9.6	11.7
1 Bar	1.4	6.4	7.1	5.3
15 Bars	0	0	0	0

*Field capacity established to be 1/15 bar for Piña soil and 1/20 bar for Torres, Carreras, and Catalina soils.

Appendix 2

Table 7. Accumulated centimeters of water released as soil is dewatered from zero tension (saturation) to tension indicated.

Depth (centimeters)	Tension	Carreras	Catalina	Torres	Piña
30	0 cm	-	-	-	-
	50	0.45	1.05	0.69	2.40*
	100	0.60	1.32	0.96	2.82
	333	0.87	1.89	1.38	3.75
	1 bars	1.35	4.38	2.97	5.22
	5	3.69	5.79	4.74	5.70
	15	5.43	7.05	6.18	6.00
60	0 cm	-	-	-	-
	50	0.18	0.93	0.42	1.92*
	100	0.39	1.20	0.69	2.40
	333	0.84	1.68	1.17	3.15
	1 bars	1.44	3.69	1.86	3.54
	5	2.37	4.89	3.48	3.78
	15	4.38	6.33	5.10	4.17
90	0 cm	-	-	-	-
	50	0.42	0.60	0.60	3.00*
	100	0.72	0.81	0.87	3.57
	333	1.38	1.14	1.47	4.53
	1 bars	2.04	2.25	1.80	4.86
	5	3.30	3.12	3.33	4.98
	15	5.28	4.56	5.25	5.13
120	0 cm	-	-	-	-
	50	0.54	0.57	0.39	2.73*
	100	0.99	0.78	0.66	3.27
	333	1.92	1.11	1.32	4.26
	1 bars	2.70	1.53	1.86	5.16
	5	5.16	2.19	2.61	5.73
	15	7.35	3.75	4.50	6.09

* 70 cm of tension

Appendix 2

Table 8. Capillary conductivity and water content as functions of soil-water tension in Carreras soil.

Depth cm	Tension cm	Capillary Conductivity cm/day	Water Content % by volume
7.5-30	21	.0395	49.7
	26	.0169	49.6
	29	.0113	49.6
	34	.0125	49.5
	38	.0153	49.4
	26	.2000	49.7
	41	.0778	49.4
30-60	22	.1414	49.9
	29	.0552	49.8
	34	.0160	49.8
	38	.0271	49.7
	42	.0368	49.7
	19	.0960	50.0
	33	.0288	49.7
60-90	18	.2819	48.4
	30	.1800	48.2
	42	.0713	47.8
	51	.0328	47.6
	57	.0369	47.5
	27	.1487	48.1
	50	.0394	47.6
90-120	17	.6827	48.7
	42	.2650	47.9
	64	.1575	47.2
	80	.0544	46.8
	90	.0519	46.5
	60	.1152	47.3
	91	.0452	46.6

Appendix 2

Table 9. Capillary conductivity and water content as functions of soil-water tension in Piña sand.

Depth cm	Tension cm	Capillary Conductivity cm/day	Water Content % by volume
7.5-30	16	41.794	28.6
	25	45.649	27.8
	31	11.272	27.1
	36	23.810	26.5
	30	13.618	27.1
	51	1.829	24.6
	66	.413	22.8
	73	.268	22.3
	76	.058	22.1
	78	.094	21.9
	81	.080	21.7
30-60	10	43.021	28.6
	16	39.879	28.1
	21	10.288	27.6
	25	33.588	27.2
	23	15.021	27.4
	46	2.629	24.9
	63	.577	23.0
	70	.258	22.6
	74	.160	22.3
	78	.128	22.0
	80	.121	21.9
60-90	11	41.832	29.8
	15	33.644	29.4
	19	12.852	29.0
	23	23.228	28.4
	22	16.599	28.6
	43	3.726	25.8
	60	1.236	23.6
	66	.458	23.0
	70	.332	22.7
	74	.258	22.4
	77	.221	22.2

Table 9 cont'd

Depth cm	Tension cm	Capillary Conductivity cm/day	Water Content % by volume
90-120	39	5.512	28.2
	55	1.474	25.7
	61	.646	25.0
	64	.364	24.6
	67	.447	24.3
	71	.309	24.0