DETERMINED BY AN ENERGY EQUATION

BY SOIL MOISTURE MEASUREMENT

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EVAPOTRANSPIRATION OF FRUIT TREES AS DETERMINED BY AN ENERGY EQUATION AND BY SOIL MOISTURE MEASUREMENT

by

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INTRODUCTION

During recent years, the practice of using irrigation to supplement natural rain fall, has become more common among tree fruit growers.

Since the investment in irrigation equipment is rather large, the grower would like to have the assurance that there will be a higher value fruit crop as a result of irrigation, to eventually pay for the investment.

The value of the irrigated crop is increased not only by greater tonage, but by quality also, as large fruit is worth more than small fruit. This fact alone is not sufficient assurance that irrigation is desirable. The duration and frequency of the drought must also be great enough that the irrigated orchard will produce crops of sufficiently higher value than unirrigated orchards in order to justify the effort and expense of irrigating.

Basic information on the rate of water use by the fruit trees must be known in order that the length of time required for exhaustion of the soil water supply may be predicted. When a drought exceeds the time that it takes the tree to use the available moisture, the crop will suffer. In peaches and cherries this is particularly true during the weeks just prior to harvest as this is when these fruits make their largest gain in size, but is true in apples to a lesser extent, all through the growing season.

When the length of time that is required for removal of the soil moisture is known, the frequency of droughts of this length or greater length may be determined from existing Michigan weather studies. With this information, the number of times a grower might expect to have need of irrigation equipment could be predicted, and consequently the return on his investment could be estimated.

The problem resolves itself to one of knowing the amount and rate of water use by the fruit trees. Considerable work has been done in the area of water requirement on other plants, but very little has been done in the humid areas with regard to fruit trees. Most of the values of water consumption for fruit trees at present, are based on estimates.

The Penman energy budget method of predicting evapotranspiration has been used on some orchards in the Eastern United States. Because the Penman method is very general and is not exactly designed for orchards, the results are questionable.

The intent of this study was to measure the water consumption and rate of use for apples, peaches and cherries in a Michigan orchard and compare this to rates of water use as computed by an energy equation. This comparison will give an indication of the reliability of the results given by the energy method.

II. REVIEW OF LITERATURE

Moisture Use by Trees

The problem of measuring the water used by trees and plants is complex and one on which considerable work has been done. There are numerous factors which influence the amount of water used by trees and plants. The soil conditions that affect the water use and the rooting depth of plants are nutrition, texture, and compaction. Climatic conditions such as the amount of energy received, length of day, temperature of the air, wind, evaporation and relative humidity influence water use of the plant as does competition for the water by other plants.

Relating to soil moisture, Viehmeyer and Hendrickson (13, 19, 52,53) and Veihmeyer (48) in their work in California have found that in the range of readily available moisture (between field capacity and permanent wilting point) the transpiration rate is independent of the soil moisture. They report (15, 50 , 51) that there is no benifit in irrigating before permanent wilting point is reached, only additional cost, and that it is not detrimental to allow the trees to reach permanent wilting point if this condition does not exist for more than a few days. When water is applied, recovery is swift. The effects are pronounced if the trees remain dry for several weeks. They also cite (54) water use rates of from .1 inches/day for coastal region, to .4 inches/day for the warm inland areas of California.

Magness, Degman and Furr (29) report that the growth of apples was not slowed down until the moisture content of the soil was near the permanent wilting point in the driest part of the root zone. They found that the growth rate was restored when the soil moisture was restored provided the foliage was not damaged, but that the ultimate size of the fruit was reduced in proportion to the length of the drought.

Magness (31) reports that in Eastern United States, mature orchards use about 4 inches of water per month during full leaf of the trees, May 1 to September 30 or 20 inches for the season, and that the moisture extraction is proportional to feeder root density.

Taylor and Furr(41) found that the tree did not suddenly run out of water and wilt, but rather as permanent wilting point was reached, moisture was pulled from the fruit for transpiration. This was not detrimental to the tree or crop if not allowed to exist for a prolonged time. There was no advantage in not having the soil reach the permanent wilting point before water was applied.

Kenworthy (24) found that when 80 percent of available moisture was used, tree growth was decreased. His experiments were on a finer textured soil than Hendrickson and Viehmeyer's and were concerned more with growth than yield.

In a survey of soil water requirements and availability, Kelley(23) cites moisture extraction patterns for various crops, all of which take 80 - 90 percent of their water from the top 3 feet. He reports a transpiration ratio of

500 - 1000 parts water required for every part of dry matter produced in alfalfa. This ratio depends on factors such as moisture content, soil type, soil compaction, soil fertility, and climatic factors. Kelley's summary of work done on the availability of soil moisture indicates that water above wilting percentage is not equally available in terms of plant growth.

Another factor that may have a bearing on the soil water-plant growth, relationship, is the fertility of the soil. It is a well established fact as pointed out by Hanks (11) that as the fertility increased the water required for plant growth decreased. Stoltenberg (39) found that when a nutrient deficiency is limiting plant growth, differences in transpiration rate due to soil moisture level may not be evident.

The extent of competition by sod and other plants for the moisture in an orchard has an influence on the amount of moisture available for tree growth and fruit production. Clean cultivation in peach and sour cherry orchards has become a rather well established practice to conserve moisture. Kenworthy (25) found that under clean cultivation practice, the infiltration capacity of the soil decreased with age, probably due to a reduction in organic matter. On the other hand with orchards in sod, the water absorbing and retaining properties improved with age.

Alderfer and Shaulis (1) reported that in peach orchards the infiltration capacity was decreased when heavy sods were used, until the sods had time to become well established. They concluded that trashy cultivation on a deep soil appeared to be the best method of improving infiltration.

Higdon (21) found that clovers, alfalfas and quack grass depleted moisture faster than other grasses. He found that mowing the sod decreased moisture depletion at low soil moisture but increased it at high soil moisture due to rapid regrowth. He concluded that a crown mulch seemed to be the best method of retaining sod without serious competition between sod and tree for moisture.

Willits and Erickson(57) report from their work on alfalfa, clover, fescue and blue grass that above permanent wilting point, moisture use ranged from a maximum of .13 inches per day down to .02 inches per day during the dormant time of mid summer. They also found that the stage of crop development had more affect on water use than did climatic conditions.

Shaw (38) reported that in a Massachusetts apple orchard a heavy mulch proved very satisfactory and more fruit was produced than similarly fertilized and cultivated orchards.

Toenjes, Higdon and Kenworthy (45) report that conserving moisture is best done in Michigan with a shallow rooted sod cover. Toenjes (44) found that in pear orchards in Michigan after 12 years, the orchard in sod had larger trees, produced more and the soil was less dense than in orchards under clean cultivation.

Tree root distribution and depth also have a bearing on the amount of water the tree can reach. Havis (12) found that in Ohio on Wooster Silt Loam, peach tree root distribution was related to soil profile. About 60 percent of the roots were in the top foot, 85 percent in the top two feet with very few roots penetrating the "C" horizon.

W. S. Rogers (3) reports in England that apple tree roots extended beyond the branches of the tree and that most of the roots were in the top soil layer. Sandy soil produced a shallow root scaffolding and the smallest trees. Loamed soil had the deepest roots and largest trees.

Viehmeyer and Hendrickson (49) report that at a given depth on uniform soils, uniform root structure will cause the soil midway between the rows to reach permanent wilting point as soon as it will the soil close to the tree. They state (54) that it is not true that with-holding water will make roots go deep seeking water, nor is it true that light irrigation encourages shallow rooting. They attempt to show that capillary moisture does not move by capillary action but remains as it is until removed by the plant.

The work of Wiersma, and Veihmeyer (56) does not lend support to the theory that plants can pick up moisture by leaves in a high humidity atmosphere and exude the moisture from their roots in dry soil areas, pick up nutrients and take up this water again for plant growth.

Proebsting (34) reports in California that temperature as well as water affect tree growth. He found 75°F. to be the best temperature for growth. Where temperatures were 85 - 95°F. he found very few roots in the top foot. Most roots were in the 2 -5 foot layer with few below the 5 foot depth.

Hinrichs (22) found that the compaction of the soil had a definite effect on the rooting of peach trees. Loosening the soil by digging to a 4 foot depth was very beneficial in stimulating root growth and top development.

Measured Transpiration of Fruit Trees

The use of moisture blocks and a Bouyoucos Bridge has been the most common method of measuring soil moisture and estimating evapotranspiration of plants. Anderson, and Edlefsen (2) report that block measurements are very much reproducible in behavior and blocks possess a like resistance at similar moisture content. They found that the blocks could be calibrated at all moisture contents if they were in soils with actively transpiring trees, but that there was a tremendous lag in response by the block if plants were not growing on the area.

Edlefsen, Anderson and Marcum (7) report that moisture blocks in all the soils they tested had approximately the same resistance for permanent wilting point. They had resistance readings of 400-600 ohms at field capacity or above and 500,000 ohms when all available moisture was gone.

Bouyoucos and Mick (4) have made exhaustive studies on determining moisture consumption by use of moisture blocks. They report excellent dependability and reproducibility.

Magness (30) conducted a a study intended to show the relationship of apple growth to soil moisture. He found that fruit growth is fairly uniform when the tree has available water and retarded when the wilting point of the soil is reached. He reports a very close correlation between growth and the hours that stoma were opened.

Hendrickson and Veihmeyer (14) have shown that the growth of peaches is characterized by three distinct periods. The first being rapid and ending about the first week; the second, slow lasting from early June until late July; the third, final period of rapid growth. They found that the final size was reduced if the available water was exhausted during the growing season.

Lilleland (28) reports that the cyclic growth of the peach is characteristic of many stone fruits. First, fast for a short time period; second, slow for a long time period; third, fast until harvest. The last stage was the most critical as far as final size was concerned.

Hendrickson and Veihmeyer (16) report that the volumetic growth rate of pears increases during the season as contrasted to uniform apple growth and cyclic growth of peaches.

Pieniazek (33) found that the transpiration rate of apple fruit was very high early in the season when the apple skin was permeable, then decreased to a minimum at harvest, and increasing again if the fruit became over ripe.

Verner (55) made daily measurements of apple development and reports a variable rate of growth. He found that when the evaporation power of the air is low, the apple swells rapidly due to moisture available to the fruit. This lasted for a day or two and then leveled off to normal even though humidity remained relatively high. Days of high evaporation were accompanied by slow rates of growth. The rate of growth seemed to depend more on evaporating power of the air than on air temperature.

Tetley (42) found the growth rate of apples decreased during periods of rainy sunless weather, but the average rate of increase over the season was nearly constant.

Energy Methods of Computing Evapotranspiration

Gentilli (8) has pointed out that semi- emperical equations for evapotranspiration do not give the same results, so obviously not more than one equation can be generally correct. Halstead and Covey (9) state as reasons why Gentilli's conclusion is true:

1. Areas and differences between surrounding country;

2. Correlation between temperature and evapotranspiration is complicated by the fact that actual evapotranspiration tends to lower both the maximum and mean temperature;

3. Any system which employs only one wind speed (as Penman) must rely on extremely crude measurements of turbulance;

4. Any method which is based upon mean monthly and even daily figures must depend upon a correlation between instantanious and mean values which varies with season, location and climate.

Lemon, Glaser and Satterwhite (27) show that evapotranspiration is a function of three things; soil moisture, plant, and meteorological factors, and any attempt to predict evapotranspiration without considering all pertinent factors will meet with only qualified success. They point out that evapotranspiration is controlled by soil moisture tension, physiological factors, relation of soil of irrigated areas to that of its surroundings, as well as purely meteorological factors of radiation, wind air temperature and humidity.

Criddle (6) presented a comparison of various energy equations pointing out advantages and limitation of each. The procedure outlined by Penman(32) has been found fairly acceptable and was the method used by T. V. Wilson (58) in his work on peaches in South Carolina.

Anderson (3) from his work at Lake Hefner, Oklahoma has presented a very exhaustive study of evaporation as computed by energy-budget methods versus actual measured evaporation from a lake. The energy equation he used was the Penman formula. He reports that the classical equation must be modified. Best results were obtained by measuring the solar energy in place of a calculation, as the reflection depends on sun altitude and surface and not on wind. Anderson reports the energy budget gives ± 5 percent accuracy for periods of 7 days of longer.

III. PROCEDURE

The study was conducted on the Michigan State University Horticulture farm in East Lansing. (See figure 1.) Three trees each of apples, peaches and cherries were selected for the measurements. Care was used to choose trees well within the orchard proper in order to eliminate border effects and also to choose healthy, typical, mature trees. It is of interest to note that the apple orchard had a sod cover while the peach and cherry orchards were clean cultivated.

Moisture Blocks Installation

Bouyoucos moisture blocks were used to measure soil moisture and were placed in four locations around the three apple trees. (See figure 2.) Location "A" being beneath the drip point of the branches and location "C" being midway between "A" and the trunk. Location "B" was also at the drip point, and "D" midway between "B" and the trunk, but "B" and "D" were on a line perpendicular to a line through "A" and "C". This was done in an attempt to minimize any affect the tree might have on intercepted solar radiation and consequently result in a difference in soil moisture. Moisture blocks were placed at depths of 1 foot, 2 feet, and 3 feet in each location around the apples. A bucket auger was used to bore the hole to place the blocks, as it was thought that the bucket auger would disturb root structure as little as possible.

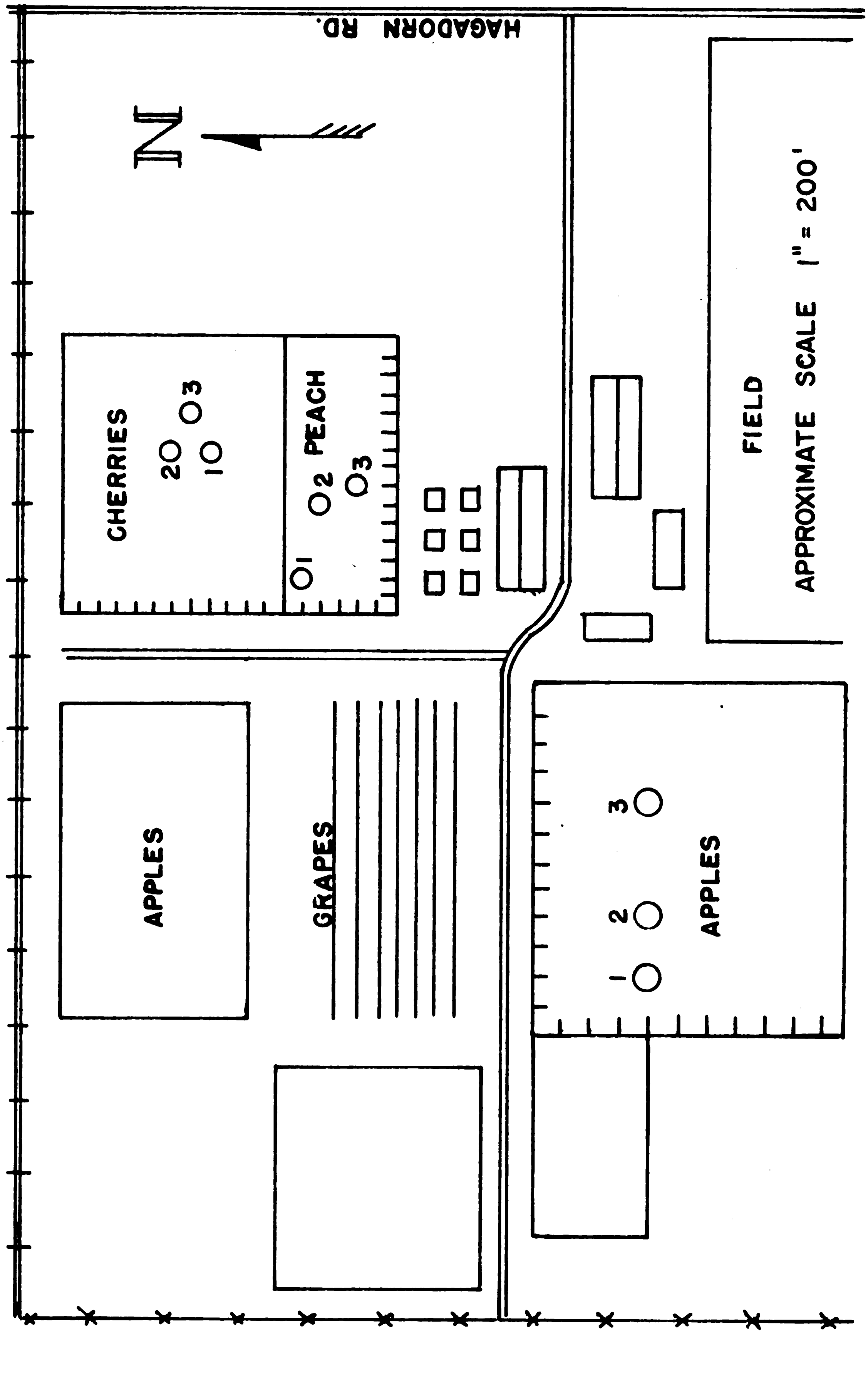

FIGURE 1 SKETCH OF HORTICULTURE FARM

Blocks were also placed in similar locations around peach trees and cherry trees, but only at depths of 1 and 2 feet as these trees are fairly shallow rooted, with the bulk of the roots in this depth. Before the blocks were buried, they were fitted with thermocouples so temperature correction readings could be made. The blocks were soaked to bring them up to saturation point.

Readings were taken on these 84 blocks twice a week, beginning in July and continuing until harvest of the apples, a period of 12 weeks. Resistance readings were made by use of the Bouyoucos bridge and temperature readings by a direct reading potentiometer. Rainfall records were obtained from a standard rain guage kept at the orchard.

Moisture Block Calibration

An attempt to field calibrate the blocks was made during the summer. This procedure was abandoned due to the difficulty of obtaining soil samples close enough to the blocks to give an accurate moisture content to correspond to the resistance reading. Due to the difficulty of field calibrating the blocks, a laboratory calibration was used. The soil was found to fall into 13 different groups. This was based on resistance readings at field capacity moisture content. Samples of these 13 soils were taken for calibration at the time of block removal, and the blocks that were used in these soils were used to calibrate them. The method of calibration used was that described by Bouyoucos. This method employs a series of small metal trays made of screening, which contain the moisture blocks, surrounded by the soil to be checked. The series of trays were wetted with distilled water and allowed to dry out. When a block dried to a desired resistance point a spatula was used to remove all soil but that 1/8 inch adjacent to the block. This layer of soil surrounding the block was removed for the moisture determination. The small trays that held the soil sample and block were made of a 1/4 inch mesh screen, in an attempt to equalize the evaporation opportunity around the block. A paper liner was put inside the tray and the soil, block and water added. Seven resistance points were checked for each soil, at approximate saturation, 2000, 5000, 10,000, 20,000, 50,000, and 70,000 ohms. These values were plotted giving resistance vs. soil moisture curves for the 13 soil groups. The calibration process was conducted at 70° F. room temperature to give a zero temperature correction.

Processing of Data

The soil moisture resistance reading taken for the trees were corrected for temperature using the resistance temperature slide rule, that is based on the Bouyoucos temperature correction chart. Those corrected readings were then transposed to percent soil moisture, values using the resistance vs. soil moisture curves. (See appendix II.)

The percent moisture of the four blocks at each depth level were averaged to give a single percent moisture for that particular depth at each tree.

In order to convert percent soil moisture to inches of water, it is necessary to know the bulk density of the soil. Five bulk density samples, (three inch diameter cores) were pulled for each soil type. The five samples were oven dried, bulk density determined and averaged. The bulk density was then used to determine the amount of water in inches that was held in each foot of soil depth for all trees. The amounts of water held in each foot of soil under each tree were added, giving a total quantity of water in inches under the tree. This quantity of water remaining was found for each tree for each day of data collection. These bi-weekly values of water quantity were plotted vs. time, to indicate the water use of the trees.

The 13 soil groups were classified by the soil classification and mapping section of the Soil Science Department and ranged from fine sand, loamy sand, sandy loam to one sample of loam. It was necessary to know the permanent wilting point and field capacity for the 13 soil groups. To find field capacity, five field samples for each soil type were removed. This was done by using a soil auger, early in the spring several days after a rain. These samples were weighted and oven dried to determine the moisture content. A pressure membrane laboratory procedure (35), using 6 atmospheres of pressure was used to find the permanent wilting point of these soils. (See appendix II.)

It was believed from observation and literature cited, that the bulk of the roots will be in the upper 2-3 feet of soil and that the major part of water used will come from this area. However, to investigate this theory a little more completely, soil borings were taken for every foot of depth to a depth of 6 feet and a radius from the trunk out to mid row at intervals of 2-3 feet. (See figures 3, 4, and 5.) Soil moisture percentages were determined from these samples in an attempt to locate the extent of dry soil or the maximum depth from which the tree was removing water.

Plotting of Data

The plot of the values of soil moisture content versus time involved some difficulties due to the spasmotic rains that occured throughout the first part of the summer. A precipitation rate greater than the rate of water used by the tree during the same period would result in an increase in soil moisture content. Under these conditions it became very difficult to estimate the water used by the tree. The percolation rates of the water through the soils were not known, hence it was difficult to know the length of time required for the blocks to reach equilibrium after a rain. Plotting this data results in graphs similar to the one shown in figure 9. Because of these difficulties with rainfall, a different procedure for handling the data was used. It was decided that in order for any reliability to be attached to the data, usable readings must be in a sequence of two or more, and must follow a rain by two or more days. To plot the data for the difficult 3-4 week period in July and August, the total precipitation in inches for the period was totaled, starting from a known soil moisture content on July 25 and drawing a constant slope to a known soil moisture content on August 13, thus an average moisture use rate for the period was established.

The above procedure was used for the August 18 to August 30 period also, after which time the absence of rain permitted a very reliable sequence of readings to be taken until harvest.

Plotting the data in dry weather provided the most reliable picture of water use, the slope of the curve gives the rate of water consumption a basis for comparison of the evapotranspiration of the trees.

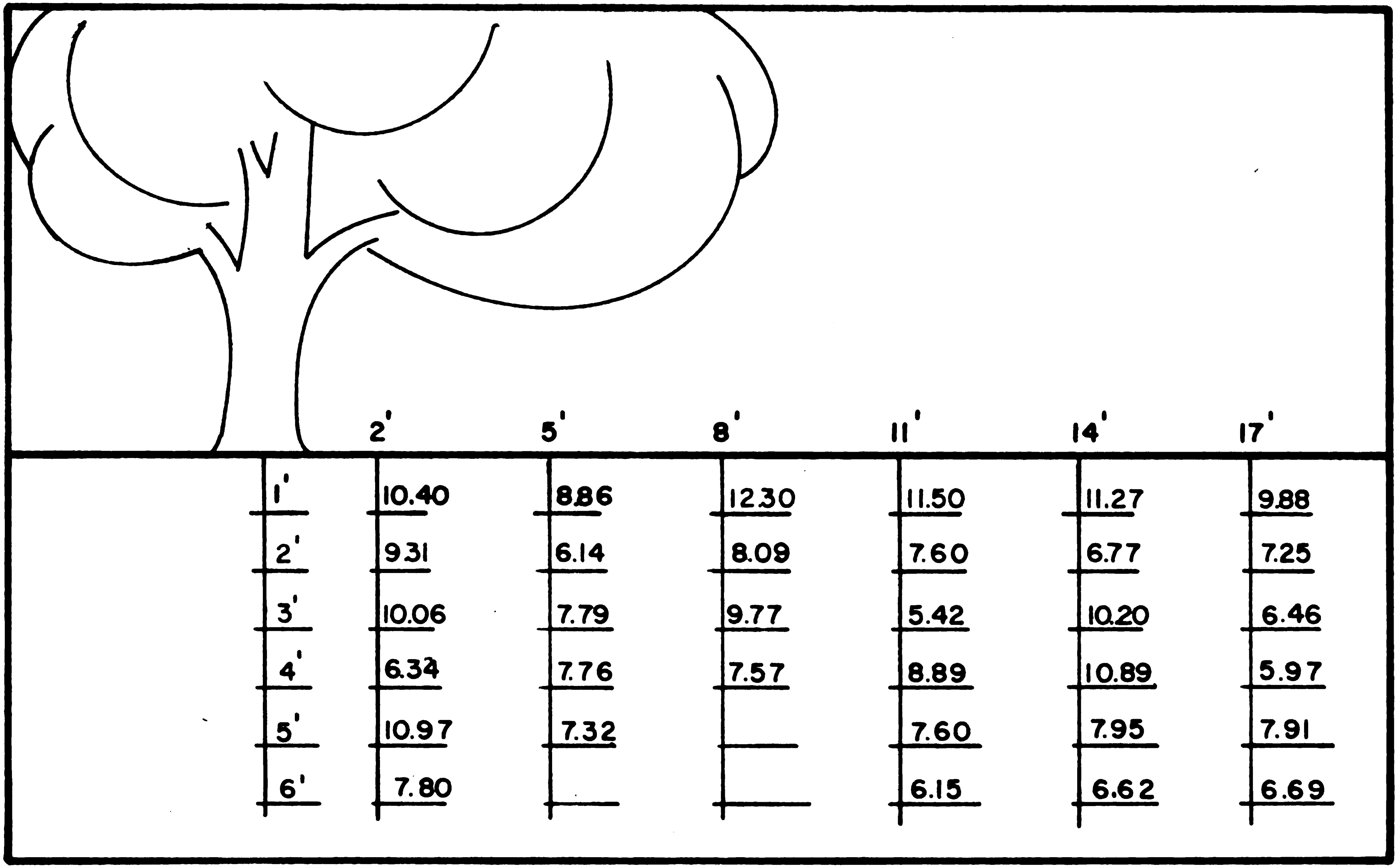

FIGURE 3 PERCENT SOIL MOISTURE IN APPLE ORCHARD SEPT. 1

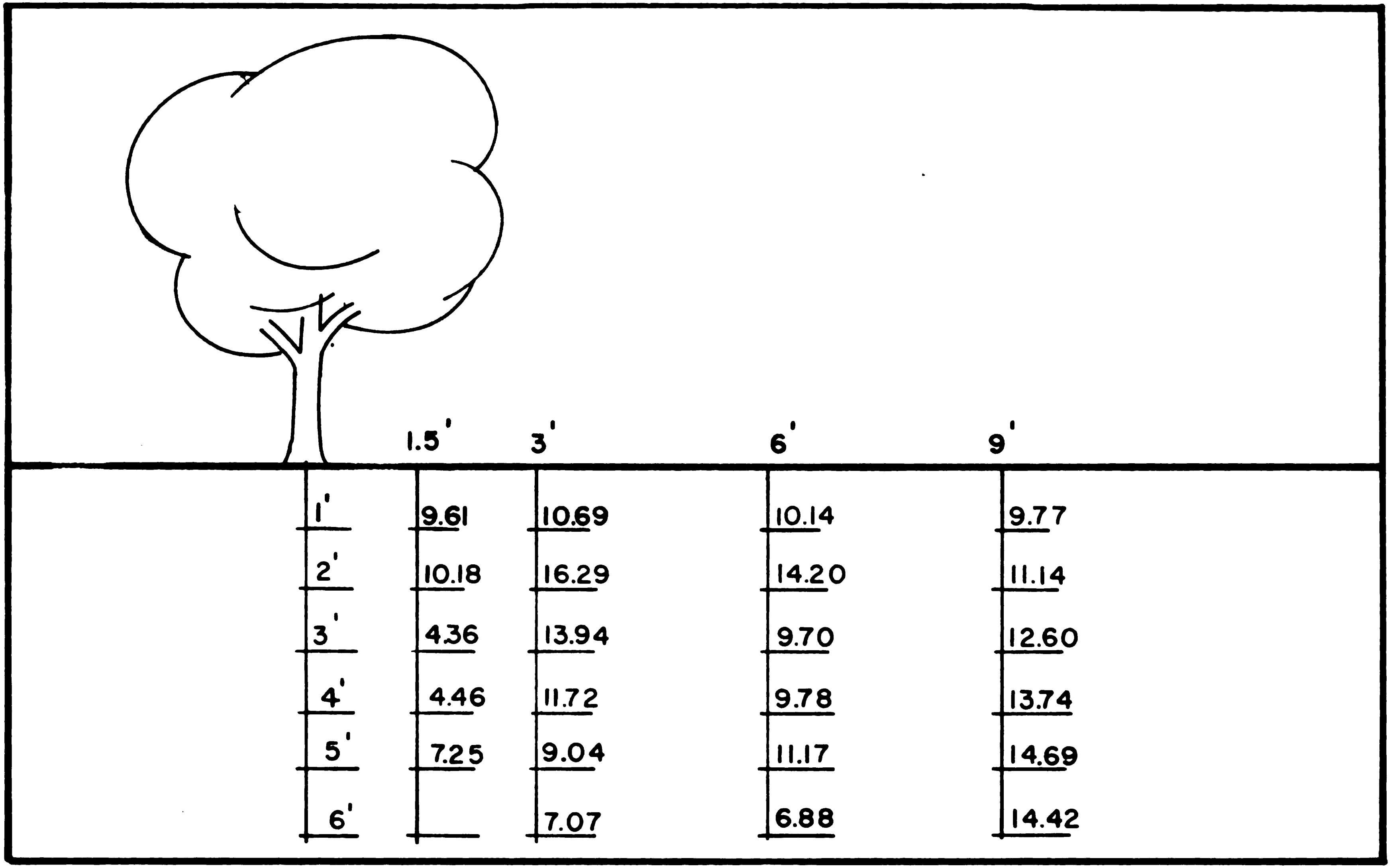

FIGURE 4 PERCENT SOIL MOISTURE IN PEACH ORCHARD SEPT. 1

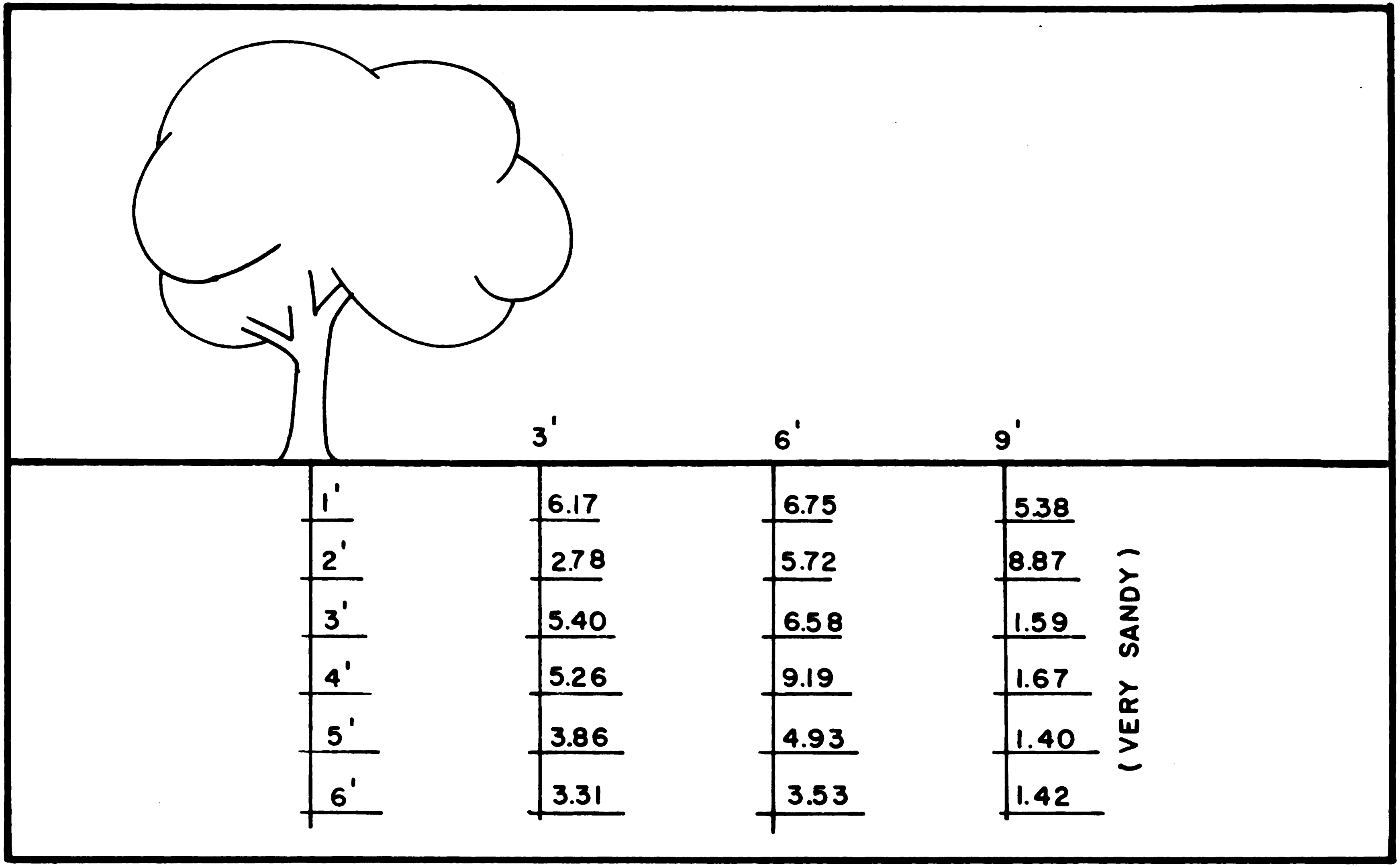

FIGURE 5 PERCENT SOIL MOISTURE IN CHERRY ORCHARD SEPT. 1

Energy Equation

The energy equation for evapotranspiration the author chose to use was developed by Penman. This procedure has proven quite reliable within its limitations. The limitation being that the time period considered must be 7 days or more. The accuracy of estimate decreases as the period considered decreases, due to differences in energy storage. This energy storage averages out over a period of time, so as the period of time increases, the accuracy of estimate also increases. The length of periods under consideration for this study are 7 day increments. Values of wind speed, temperature, length of day, hours of sunshine, and humidity were recorded and averaged to give an average value of each for the weekly period. A slight deviation from the calculated formula for radiation was used. This was in the form of actual recorded values of total radiation from the pyroheliometer that is located at the University Experiment Farm. This substitution was used as it was thought it would provide a measurement that would give greater accuracy than a value calculated from an equation.

The average weekly climatic values were then substituted in the Penman formula which was solved to give a solution in terms of inches of water per day, that would be evapotranspired from a vegetative surface. Daily values were found for the 12 week period, and plotted against time to provide a graph of rate of water use by the trees. A comparison could then be made between measured water use and calculated water use.

Calculation of evapotranspiration by the Penman formula involves the following equation:

$$E_t = \frac{\Delta H + .27\ Ea}{\Delta + .27/SD}$$

where:

E_t = potential evapotranspiration in mm/day.
Δ = slope of saturated vapor pressure curve. (see appendix X, A.)
H_t = net radiation.
E_a = Auxiliary quantity.
S = factor denoting influence of diffusion resistance
D = factor denoting influence of length of day.

Net radiation values were obtained by altering the emperical equation of:

$$H_t = Ra\ (1-r)\ (.18 + .55\ \tfrac{n}{N}) - \sigma Ta^4 (.56 - .092\sqrt{ed})(.1 + .9\tfrac{n}{N})$$

to include the Epply Pyroheliometer values of radiation. This took the form of:

$$H_t = (1-r)\ (\text{Pyroheliometer})\ \sigma Ta^4 (.56 - .092\sqrt{ed})(.1 + .9\tfrac{n}{N})$$

Pyroheliometer values were obtained from the ARS-SWCRB-USDA Cooperative Project

r = 0.20 radiation reflection coefficient for vegetation.
$\frac{n}{N}$ = ratio actual to possible hours of sunshine.
σ = Stefan Boltzman constant 2.01×10^{-9} mm/day.
Ta = absolute temperature of air R.
e_d = saturation vapor pressure at mean dew point.
n = hours of sunshine.

Values of E_a were calculated from:

E_a = $.35\ (ea-ed)(1+.0098u_2)$ mm/day.
e_a = saturation vapor pressure at mean air temperature.
u_2 = wind speed at two meters. $u_2 = u_h \times \frac{(\log 6.6)}{\log h}$
Ra = mean monthly extra terrestial radiation in mm of H_2O/day.

Values of S were calculated from:

$S = La/(La + 0.16)$
where La = effective diffusion length of air which is equal to $.65\ (1+ 0.0098\ u_2)$

Values of D were calculated from:

$D = N/24 + 1/\pi \quad \sin N\pi/24$
N = hours from sunrise to sunset.

Pyroheliometer values of gm-cal/cm^2 were converted to mm of water.

$$\text{Example} - 418 \text{ cal/cm} \times \frac{1 \text{ c.c.}}{\text{gm of } H_2O} \times \frac{1}{590 \text{ cal/gm}(H_2O \text{ Vapor})}$$

$$\times \frac{10\text{mm}}{\text{cm}} = 7.09 \text{ mm of } H_2O \text{ Evaporated.}$$

The question arose, of the actual percentage of solar energy that the trees were intercepting. If the energy that falls on the ground is not used to evaporate water from this surface, due to dry soil conditions, it is conceivable that it may be available as heat energy to remove water from the tree. Therefore it is necessary to know the percentage that the intercepted energy is of the total energy. This was investigated by measuring the tree crown diameter and row spacing, giving an indication of the ground covered by the trees. (See figures 6, 7 and 8.)

The values of evapotranspiration as given by the Penman equation using calculated values of radiation were found for comparison purposes. Values of Ra were used as described by Criddle (6) and the equation handled in the general way. This comparison of evapotranspiration, calculated from computed radiation values is shown in table 1

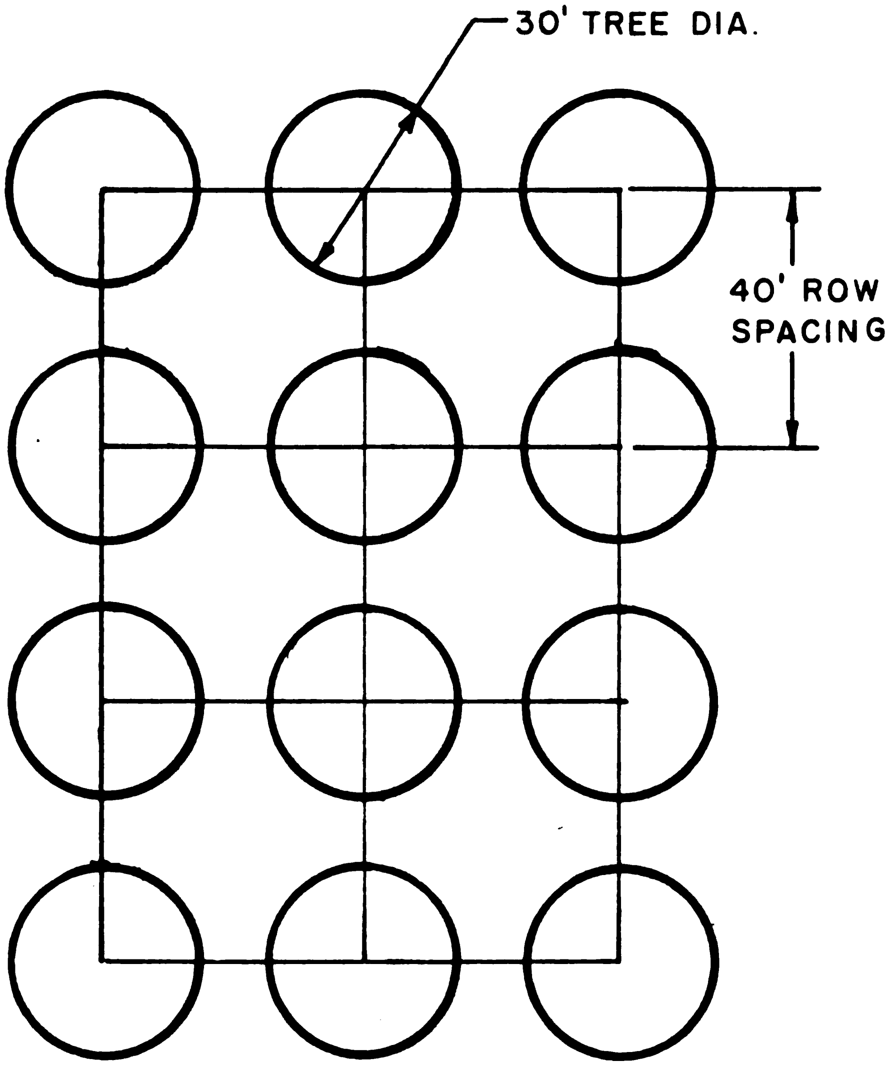

FIGURE 6

APPLE ORCHARD TREE SPACING

TREE COVER — 44 %

OPEN — 56 %

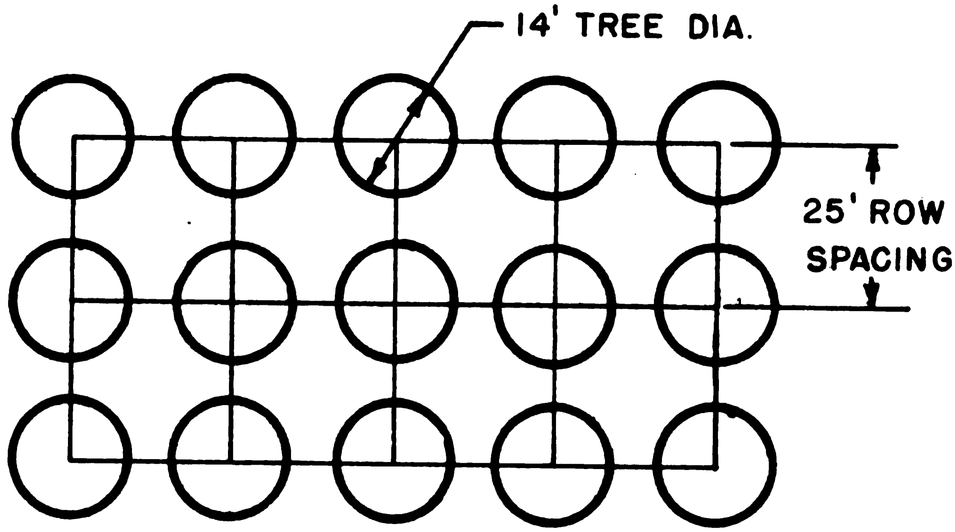

FIGURE 7

PEACH ORCHARD TREE SPACING

TREE COVER - 25 % OPEN - 75 %

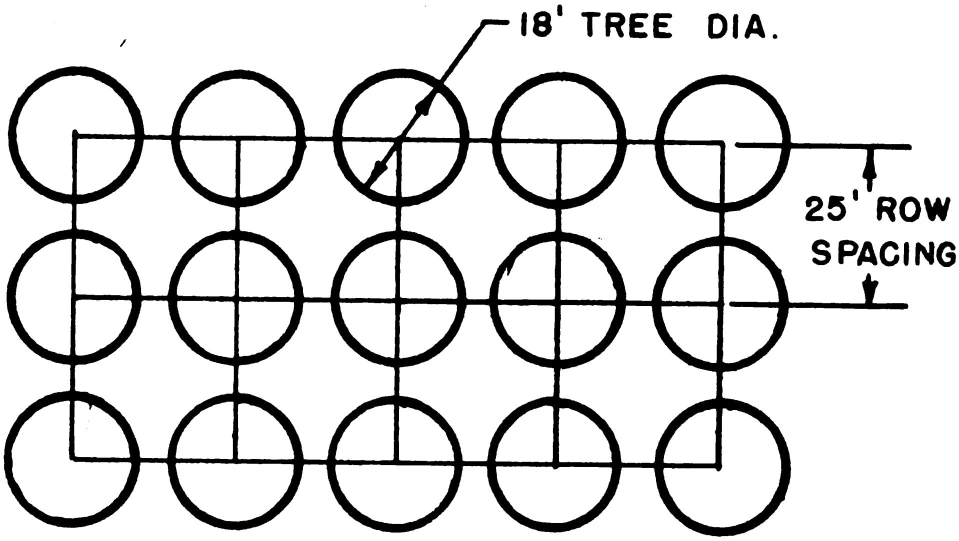

FIGURE 8

CHERRY ORCHARD TREE SPACING

TREE COVER - 41 % OPEN - 59 %

IV. DISCUSSION OF RESULTS

Calculated Water Consumption

As all the trees under study were within 1000 feet of each other, they were all subjected to the same climatic environment, so theoretically, using the Penman energy equation, they would all have the same opportunity for potential evapotranspiration. Plotting the values calculated from the Penman Equation for weekly increments provided the rate of water use curve shown in figure 19. This curve was also overlaid on figures 20-28 to make an easier comparison.

The rate of water use data given by the energy equation, was affected by temperature and this accounts partly for the trend of the curve. The curve shows a rate of approximately .12 inches per day in early July decreasing fairly consistently to a rate of approximately .07 inches per day late in September.

Measured Water Consumption

The graphs figure 10-18 show the amount of water in inches that was present in the soil. The rains in mid summer raised the soil water content to near field capacity, from which point water consumption continued without interuption until the soil moisture content was near permanent wilting point. This provided a fairly reliable picture of water use for this period. The average slope of this water use curve was calculated for weekly increments to give the rate of water use per week. This calculation was broken down to daily rate figures. The daily rate of water consumption is shown plotted for each tree in figures 20-28.

Apple Tree Evapotranspiration Curves (Figures 20,21 and 22)

A comparison between the rate use curves (moisture blocks) of the apple trees, shows there is not exact agreement on the rates of water use. The variation in root structure, tree size and soil texture can largly be held responsible for this difference. Superficially, soil texture may appear to have more effect on the rate of water use than it actually does. The fact that a plant growing in a coarse texture soil would remove the available water faster than it would if grown on a fine textured soil, would make it appear that it was using the water at a higher rate.

Although there is not exact agreement between trees, the general trend of all three is similar. The water use rate is fairly low for all early in July, about .05 inches per day. This rate increased to a maximum of .16 inches per day toward the end of August and then gradually decreased again to about .05 inches per day.

Peach Tree Evapotranspiration Curves (Figures 23, 24 and 25)

The behavior pattern for the tree peach trees is similar to that of the apples in that there is not exact agreement between individual trees, but the general trend of all is in agreement. The rate of water use was fairly low .04 - .05 inches per day when the data recording was begun in July. It remained low increasing slowly during the rainy part of the summer, until about the middle of August. At this point there was a sharp increase in rate, all three trees reaching a maximum rate of approximately .24 inches per day, at harvest time, the first week in September. Following harvest, the rate of water use declined sharply to .06 inches per day throughout the remaining part of September.

This trend of water use, low during the mid part of the growing season, and increasing during the final few weeks of growth until harvest, lends support to the findings of Viehmeyer and Hendrickson (15) and Lilleland (28) regarding the growth rate of peaches.

<u>Cherry Tree Evapotranspiration Curves</u> (Figures 26,27 and 28)

The graph of water use rate for cherries shows the greatest difference between trees; but, some general trends may be seen.

The cherries were just entering their ripening stage as data recording was begun on July 12. This is indicated by the high rate of water use of approximately .20 inches per day during the first two weeks, decreasing to a minimum of .03 inches per day in the fourth week. This minimum rate continued during the wet part of the summer until the sixth week. At this time the weather became fairly warm and dry, and as the cherries were not harvested, the rate of water use took a sharp increase reaching a maximum of .32 inches per day during the 8th and 9th week. Pieniazek (33) reports similar increase in water use by apples when they were not harvested. From the 9th week on to the end of September, the cherries began to dry up and drop off, which was accompanied by a decreasing rate of moisture use to the minimum of .03 inches per day.

Similarities and Differences Between Measured Water and Calculated Water Consumption
(Figures 20-28)

From a study of the graphs, it is obvious that there is considerable variation between the Penman curve for evapotranspiration and the curve developed from moisture block data for any fruit tree considered in this experiment. The differences between the calculated evapotranspiration and measured evapotranspiration vary with the type of fruit tree being considered.

The author feels that there is valid justification for these differences. Although the Penman equation produces fair results for a period of time of a few weeks or longer, Halstead and Covey (9) have pointed out that some rather crude estimation of climatic conditions, greatly affect the accuracy over a short time interval. It is interesting to note that while weekly rates of evapotranspiration varied considerable, the total evapotranspiration for the complete experiment (12 weeks) for all trees studied was within 7.7 percent of the total calculated from the Penman equation. This lends support to the fact that as the time interval considered increases, the agreement between calculated and actual evapotranspiration improves.

Another reason why there is considerable variation between Penman rates and measured rates, is due to the physiological characteristics of the fruit tree. The Penman equation was first developed for a body of water, and modified to include a factor to simulate the evaporation from a vegetative surface. The factor is very nondescriminating with regard to the type of vegetation surface, assigning the same value to all, with no regard as to varying water requirements of plants with maturing fruit crops.

Penmans original work was done using 12 cylinders, 6 feet deep and 2 1/2 feet in diameter. They were treated as uniform surfaces of open water, bare soil and turfed soil. He found that when the water table was deeper than 24 inches, the soil and turf surfaces were not kept supplied with moisture for the maximum evaporation rate, and actual values did not correspond to the calculated values.

In explaining values of evapotranspiration that did not agree with calculated values, Penman states on page 144 (32): "From the conclusions, one would expect the corresponding values of the annual evaporation from cropped land to be 3/4 of Ea (water surface evaporation) if the crop transpired at maximum rates all the year; in practice the rates will be less than this because of the ripening process in annual vegetation and /or the lack of summer rainfall."

In an attempt to explain the larger amount of water indicated as used, above the amount shown possible to transpire by the energy available, the possibility of water storage in the fruit was investigated. The average yield of an apple tree is about 15 bushel. The apple weight is 45 pounds per bushel and water content is 84.1 percent. This gives a total water storage of 567.5 pounds of water or 8.78 cubic feet. This quantity of water spread out over the area from which the tree removes its water, amounts to about .034 inches of water for the season, a very negligable amount. It is obvious then, that if only a small portion of the water is actually stored in the fruit crop, the balance of the water extracted from the soil must be transpired. The question then logically arises, that the Penman equation is based on heat or the energy that is available to evaporate water, and if this heat is not available, how can water be transpired. This can be explained by noting the amount of solar radiation that is intercepted by the trees. In the case of the Penman formula, the rate of evapotranspiration is calculated and it is assumed that the figure found, for example .12 inches per day, represents the quantity of water that it is possible to evaporate from 100 percent of the area considered. The situation of the orchard differs from the assumed set up for Penman procedure, in that the trees in the orchard only intercept about 44 percent or less of the solar energy. The remaining 56 percent of solar energy falls on the ground between rows and when the ground is wet, this energy is used to evaporate moisture from this surface. This leaves the water transpired by the trees proportional to the 44 percent of the energy they receive. As the ground drys out and grass goes dormant, the energy that falls on the ground is changed to heat and is available to pick up water from the tree. This energy combined with that intercepted by the tree can conceivably double the energy available for transpiration from the tree. This is supported by the results of the graphs which show the rate of water used by the tree about double the Penman values, during the warm dry part of the season.

The comparison of calculated values of evapotranspiration based on phyroheliometer radiation data and values based on computed radiation are shown in table 1. This comparison shows that weekly evapotranspiration rates based on computed radiation range from a minimum of 1% error on the 4th week to a maximum of 41 % on the 11th week. The values are random with some being high, others low. The average error for the 12 week period was 3% of the value given by the pyroheliometer. This emphasizes again that the accuracy of values of evapotranspiration calculated by the Penman equation increase as the length of time considered increases.

TABLE I

COMPARISON OF CALCULATED EVAPOTRANSPIRATION USING PYROHELIOMETER RADIATION VALUES AND COMPUTED RADIATION VALUES

Week	E_t in/day (Pyroheliometer Radiation Values)	E_t in/day Calculated Radiation Values	Percent Error
1	.116	.128	+10
2	.098	.103	+ 5
3	.119	.099	-17
4	.083	.096	+16
5	.101	.117	+16
6	.103	.104	+ 1
7	.081	.088	+ 9
8	.082	.085	+ 4
9	.078	.064	-18
10	.0592	.045	-24
11	.044	.048	+ 8
12	.055	.032	-41

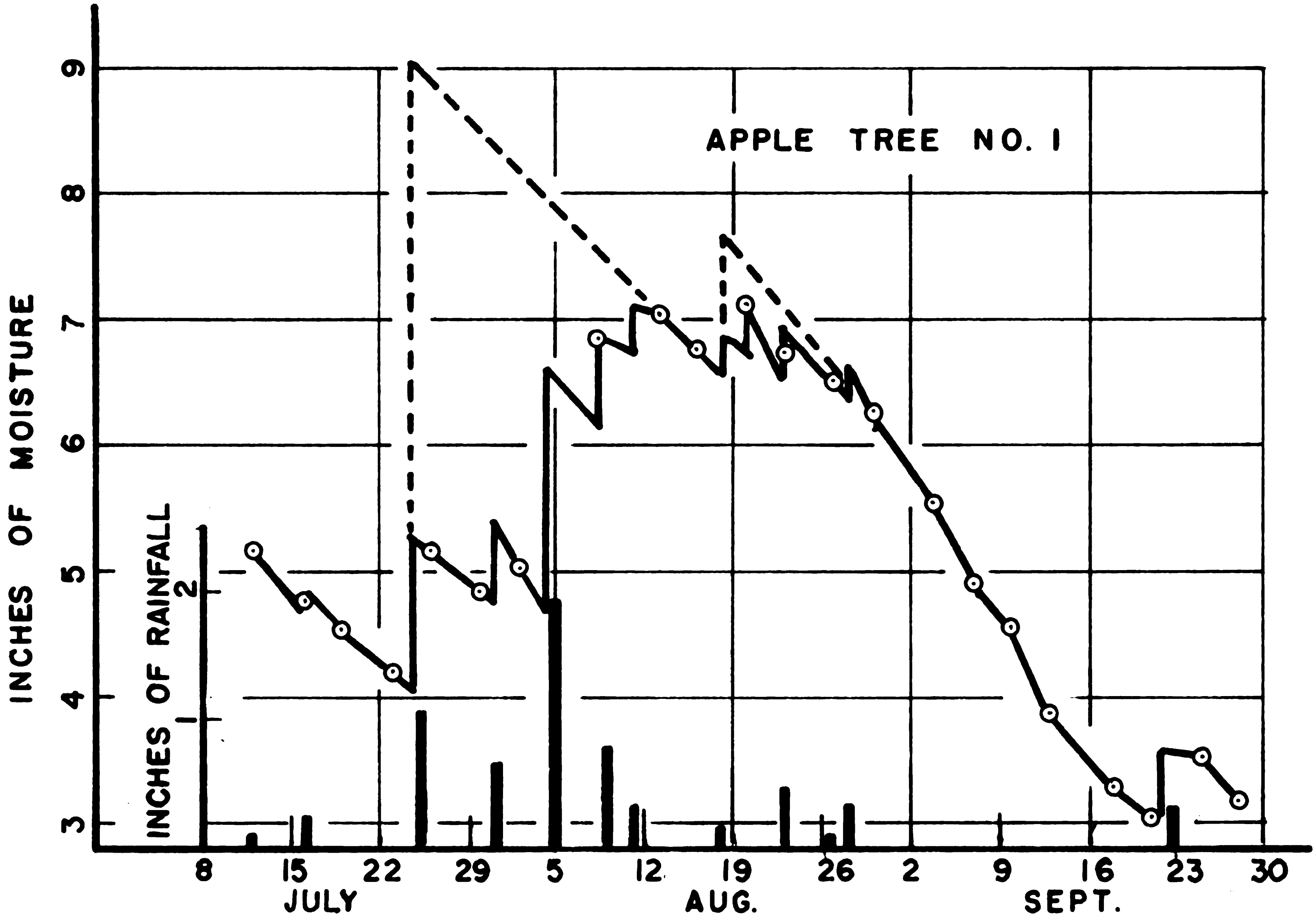

FIGURE 9 SOIL MOISTURE DEPLETION & RAINFALL 1956

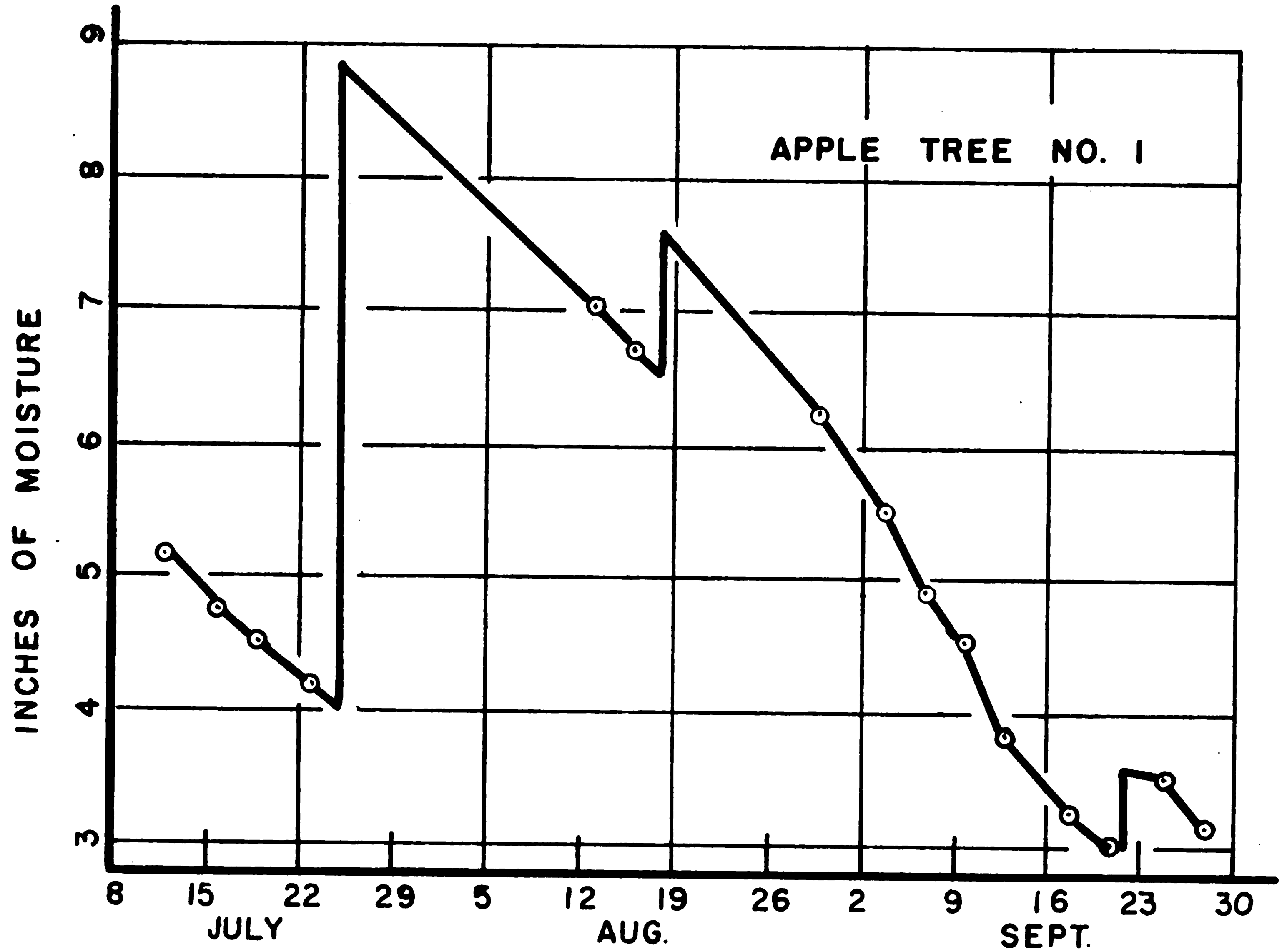

FIGURE 10 SOIL MOISTURE DEPLETION FOR APPLE TREE NO. 1 1956

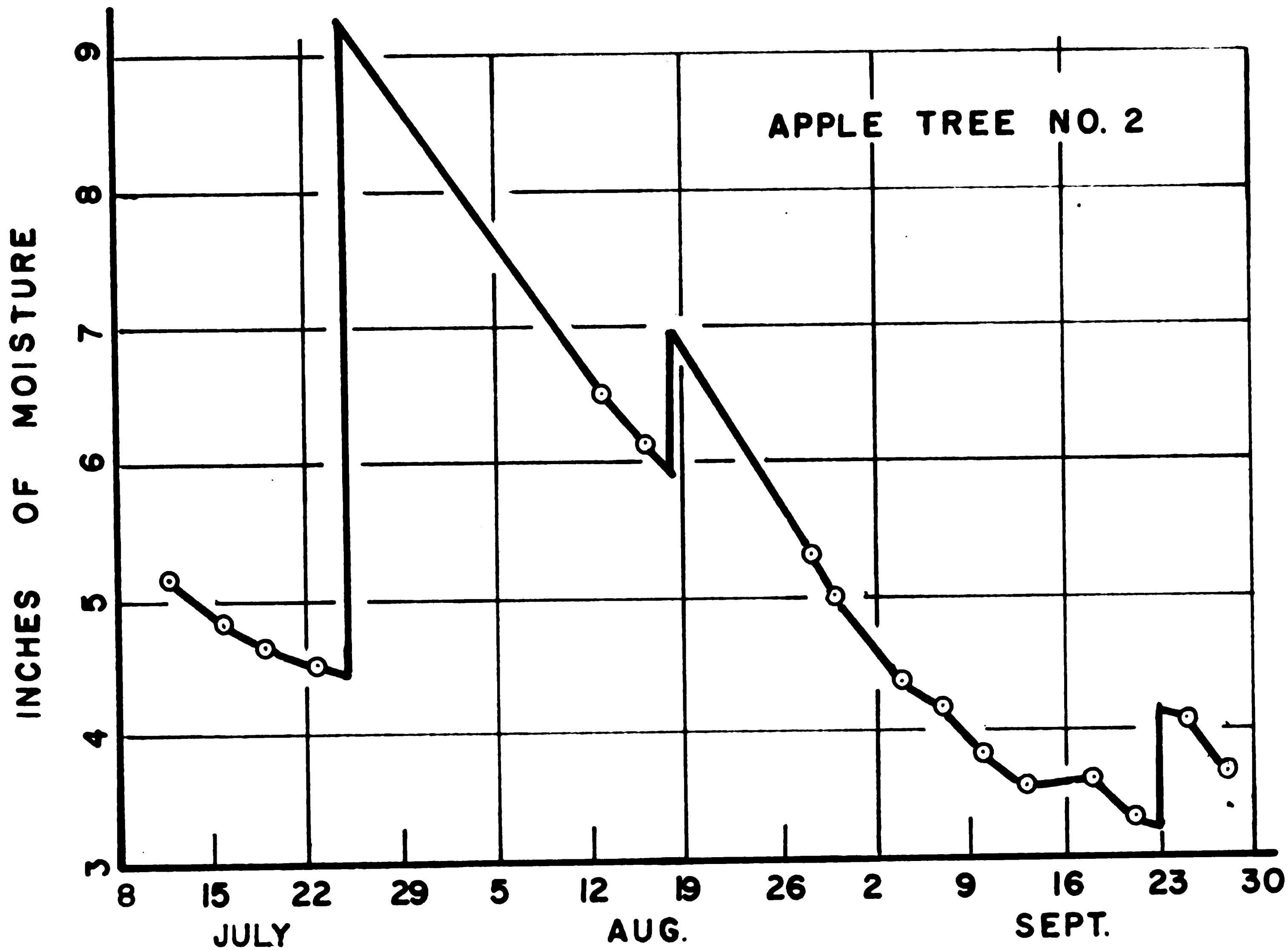

FIGURE 11 SOIL MOISTURE DEPLETION FOR APPLE TREE NO. 2 1956

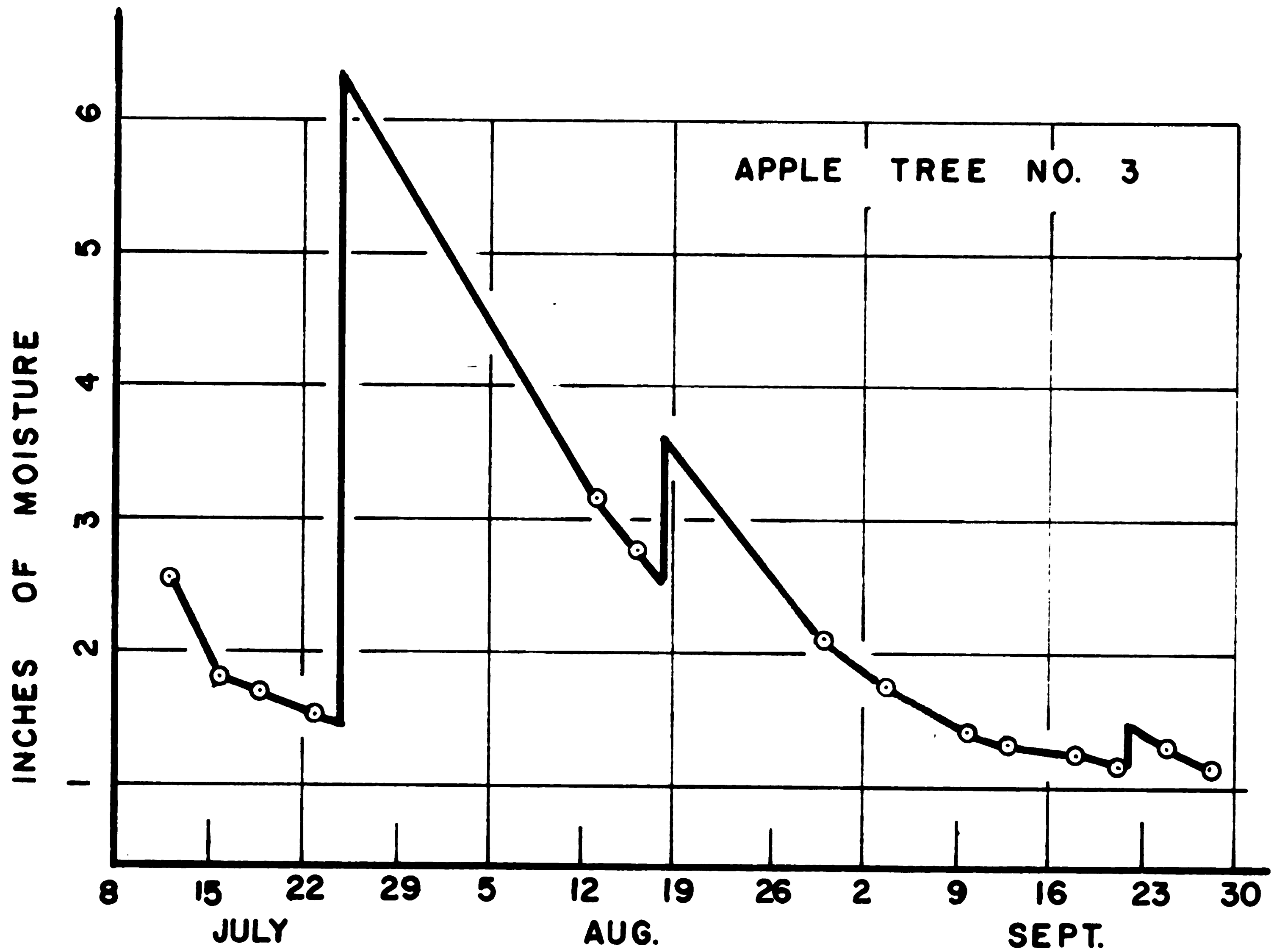

FIGURE 12 SOIL MOISTURE DEPLETION FOR APPLE TREE NO. 3 1956

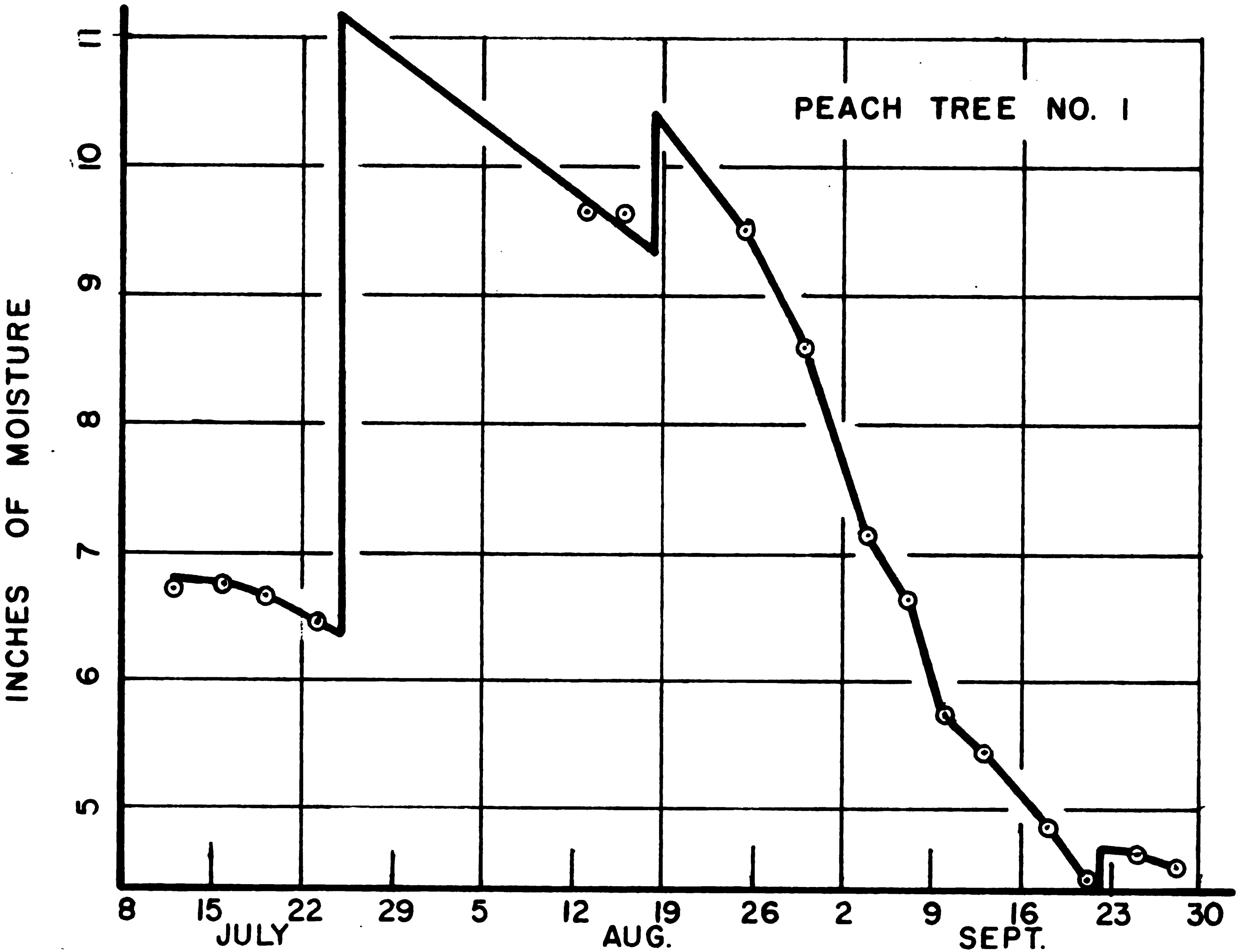

FIGURE 13 SOIL MOISTURE DEPLETION FOR PEACH TREE NO. 1 1956

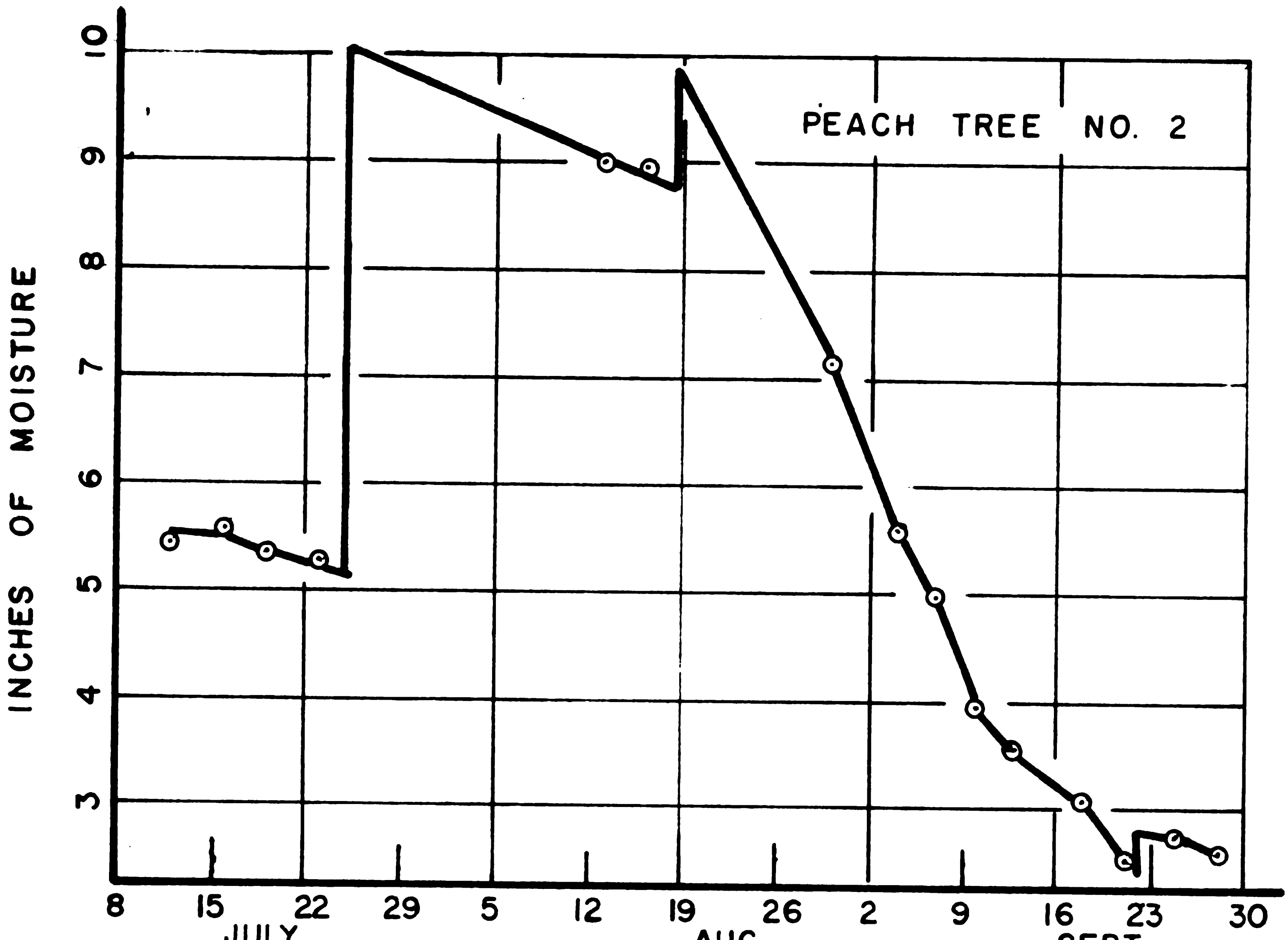

FIGURE 14 SOIL MOISTURE DEPLETION FOR PEACH TREE NO. 2 1956

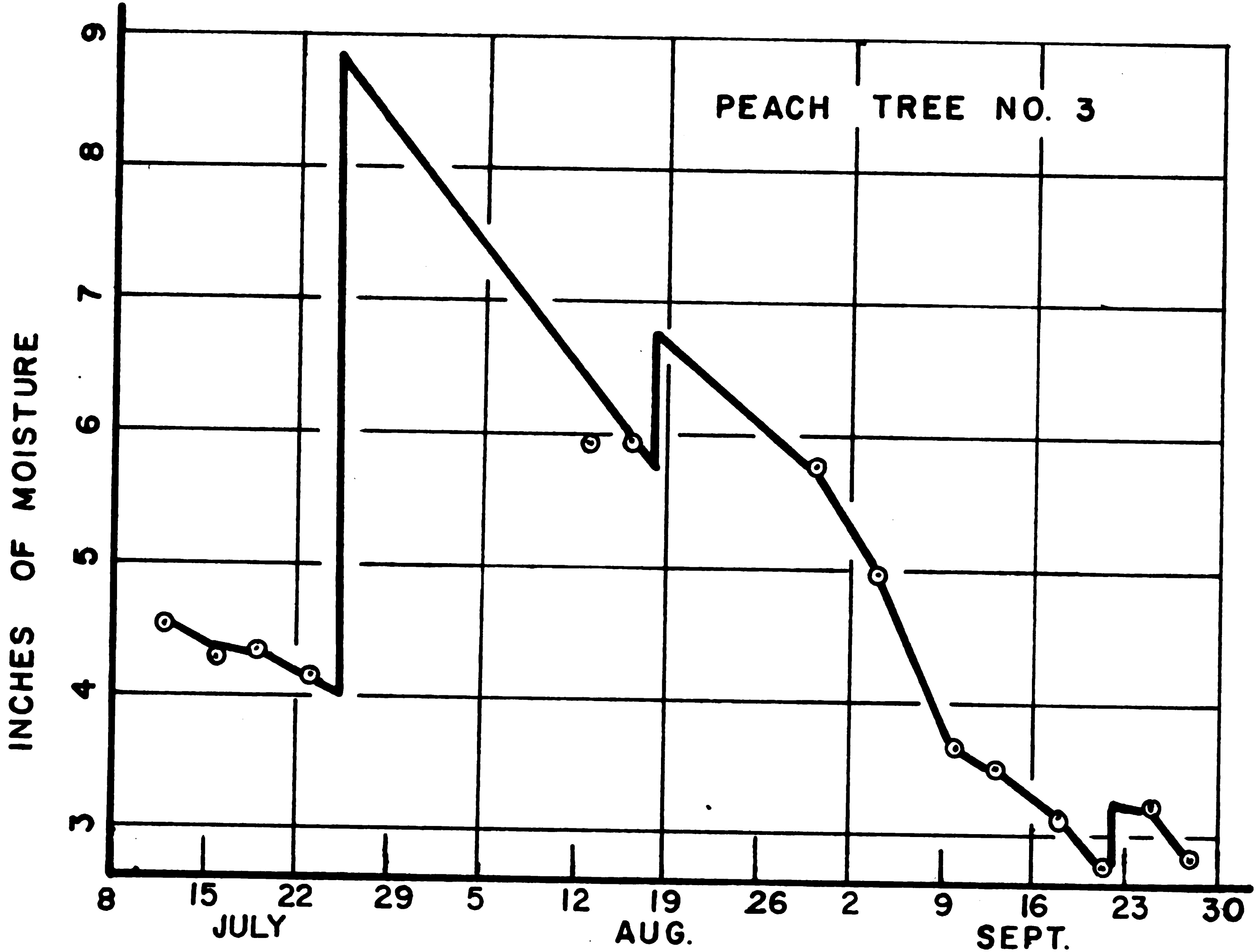

FIGURE 15 SOIL MOISTURE DEPLETION FOR PEACH TREE NO. 3 1956

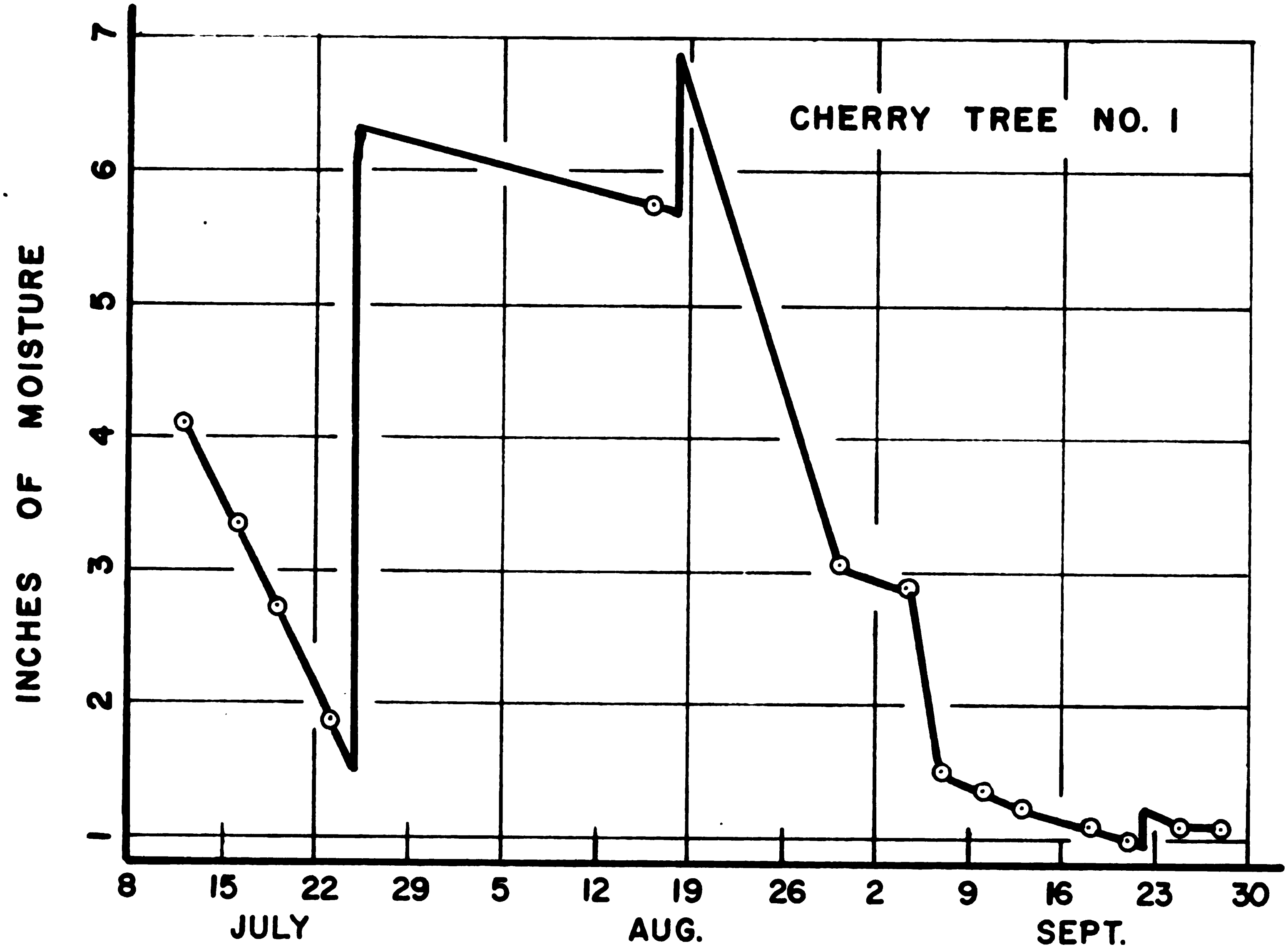

FIGURE 16 SOIL MOISTURE DEPLETION FOR CHERRY TREE NO. 1 1956

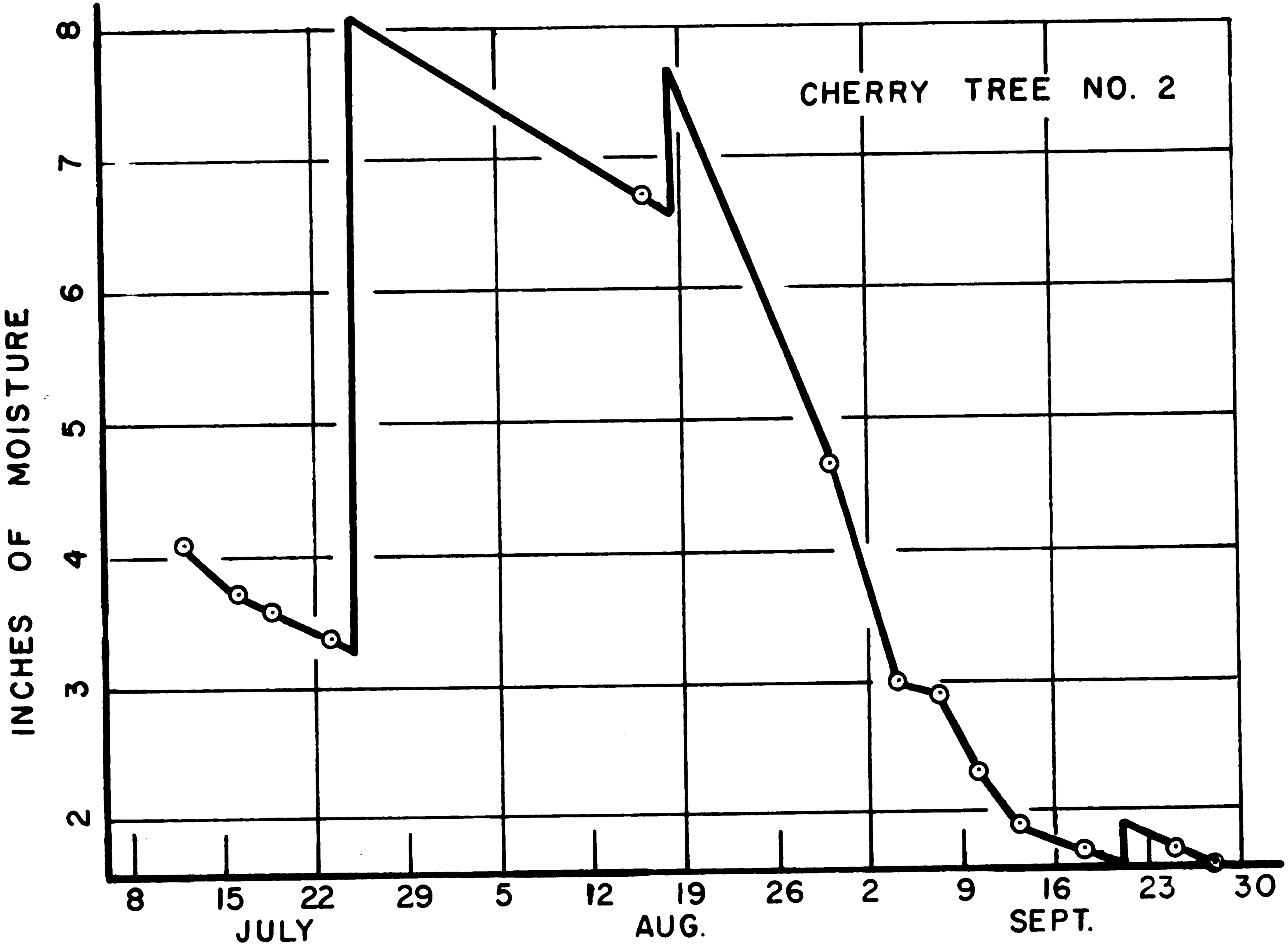

FIGURE 17 SOIL MOISTURE DEPLETION FOR CHERRY TREE NO. 2 1956

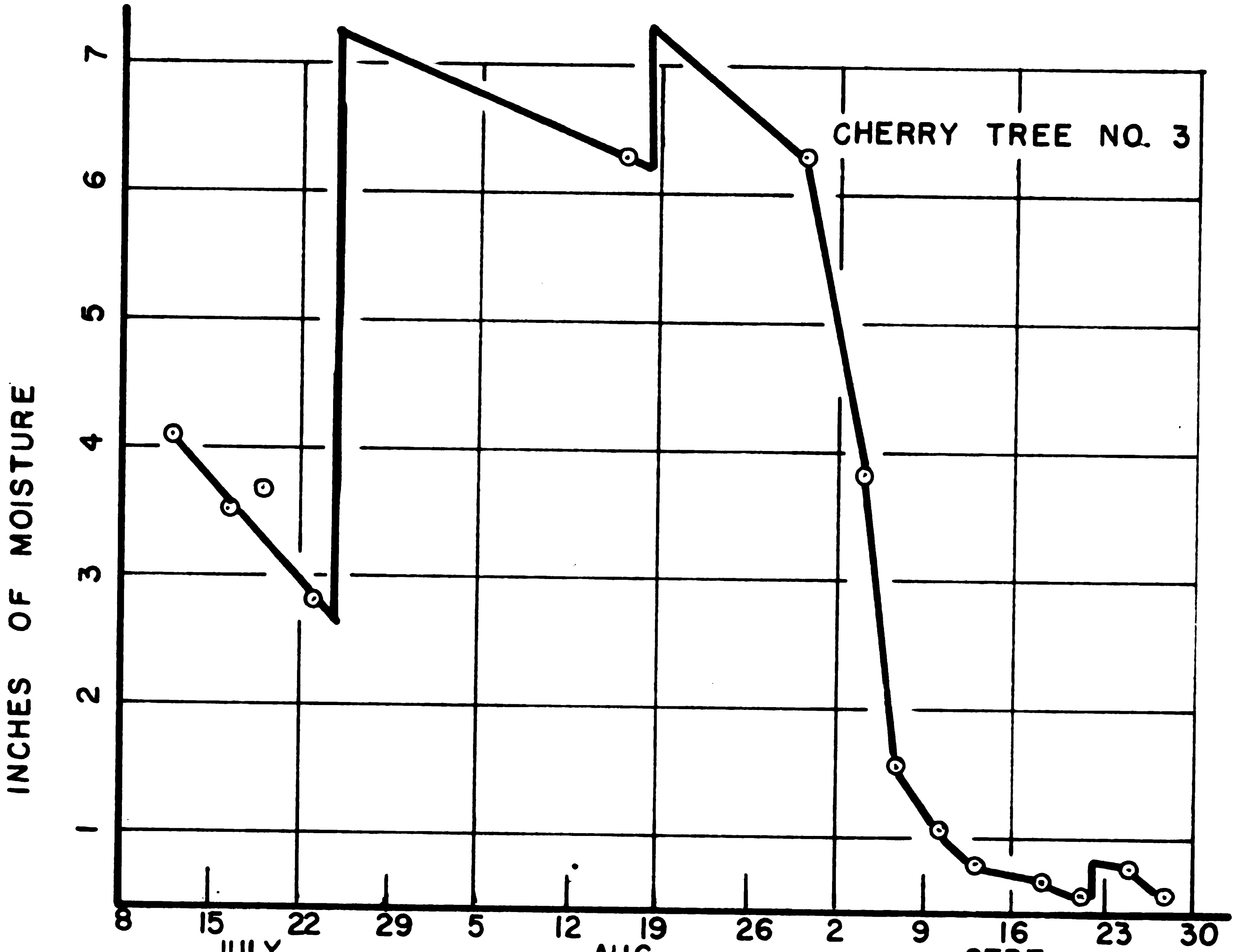

FIGURE 18 SOIL MOISTURE DEPLETION FOR CHERRY TREE NO. 3 1956

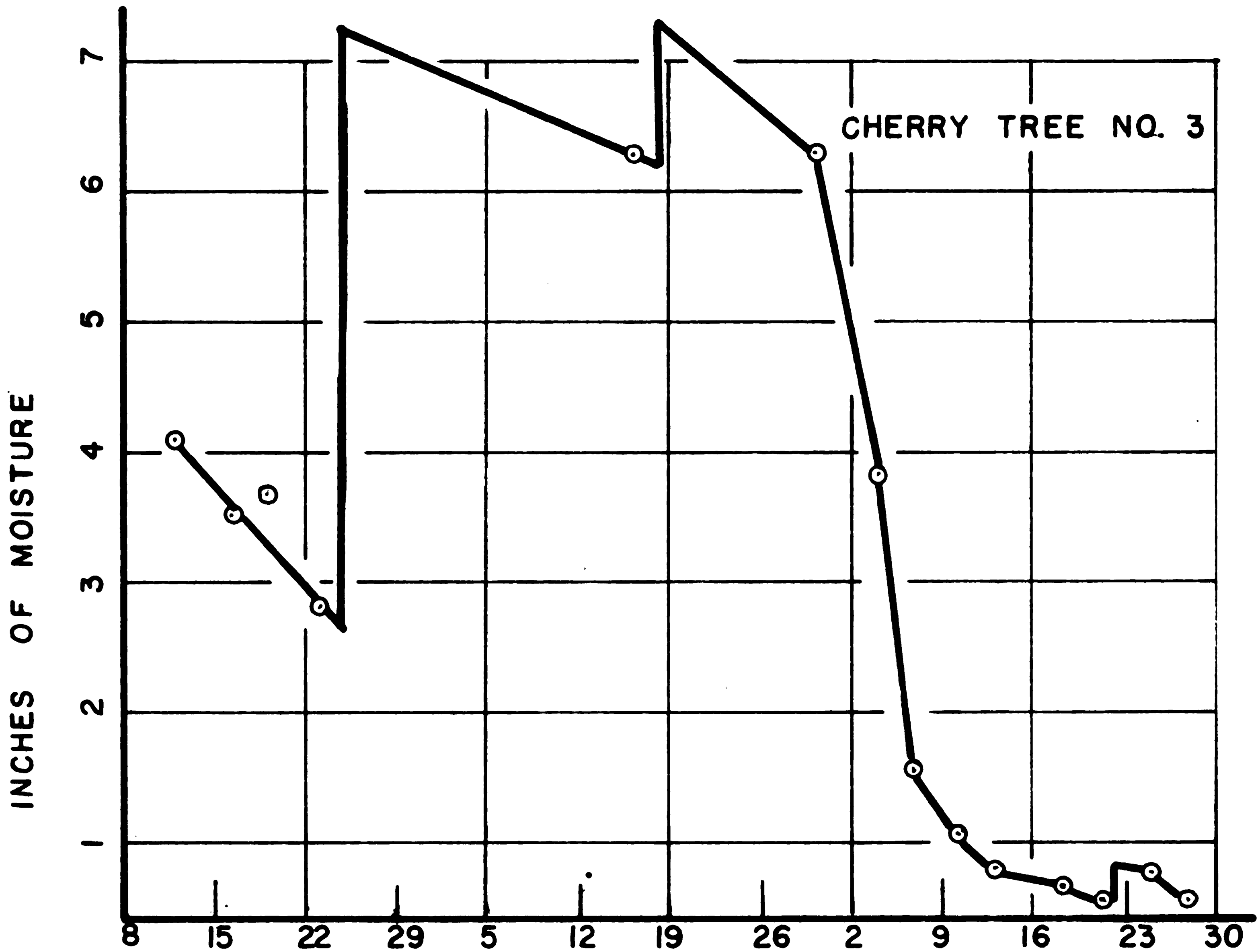

FIGURE 18 SOIL MOISTURE DEPLETION FOR CHERRY TREE NO. 3 1956

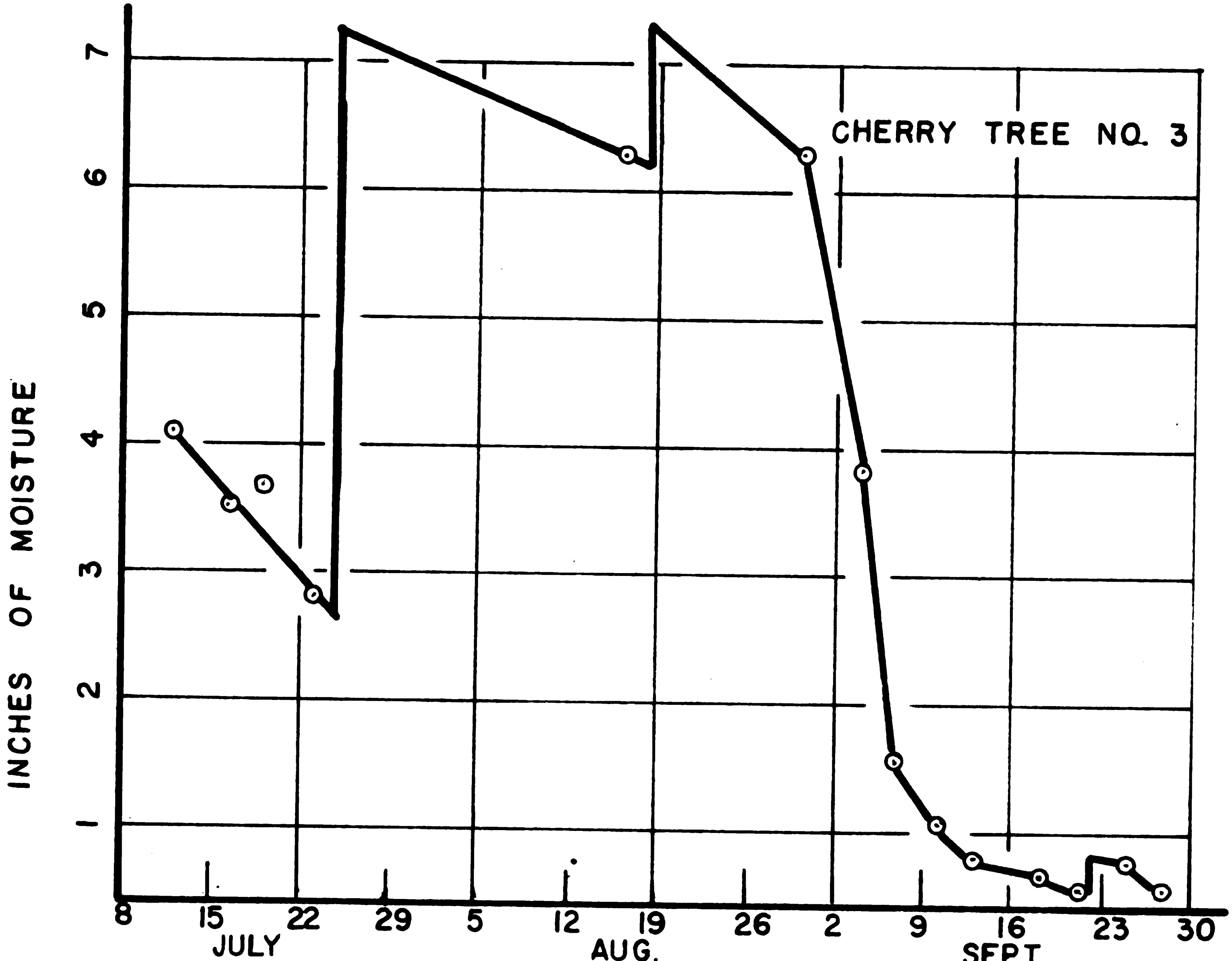

FIGURE 18 SOIL MOISTURE DEPLETION FOR CHERRY TREE NO. 3 1956

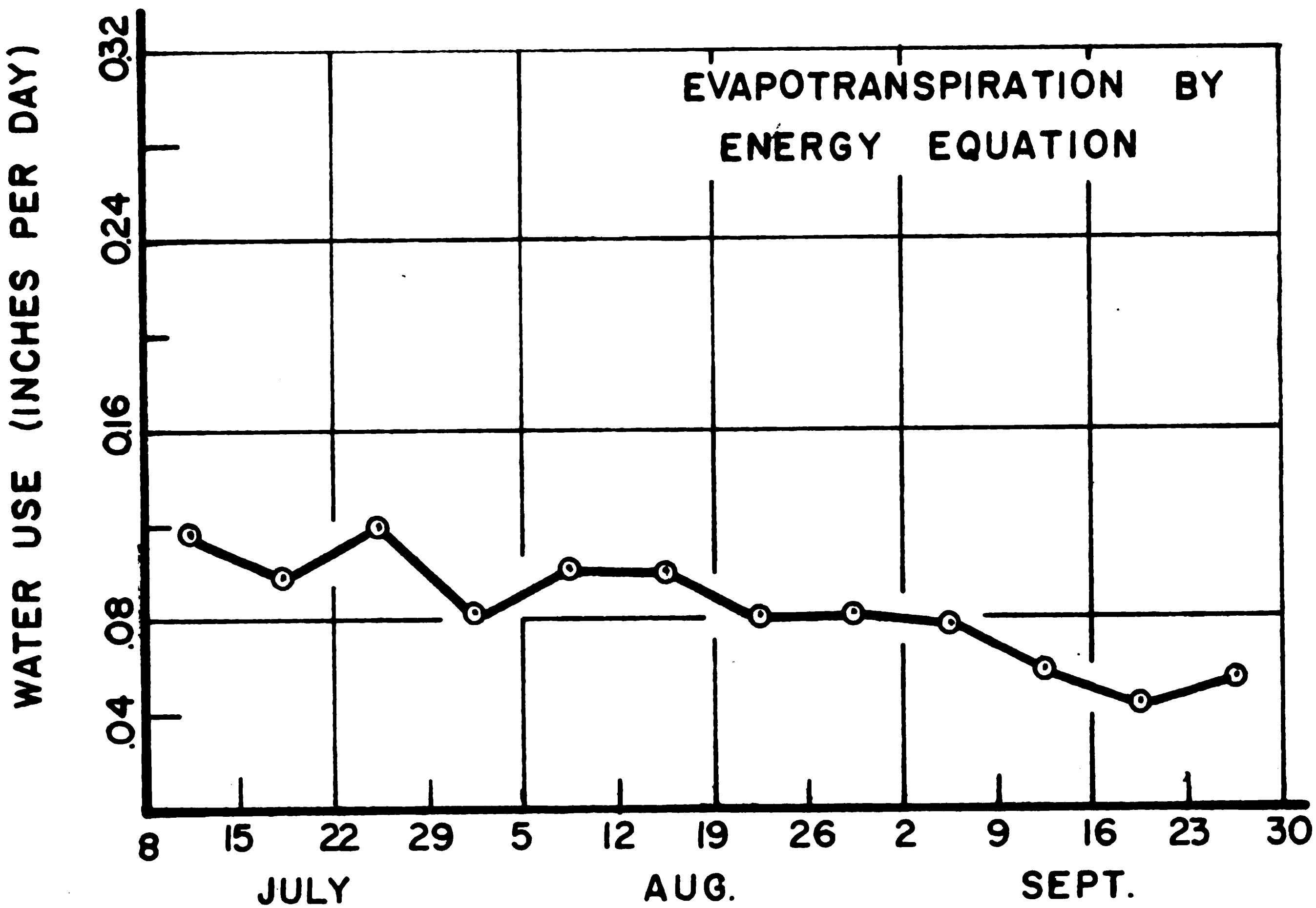

FIGURE 19 CALCULATED AVERAGE WEEKLY WATER CONSUMPTION 1956

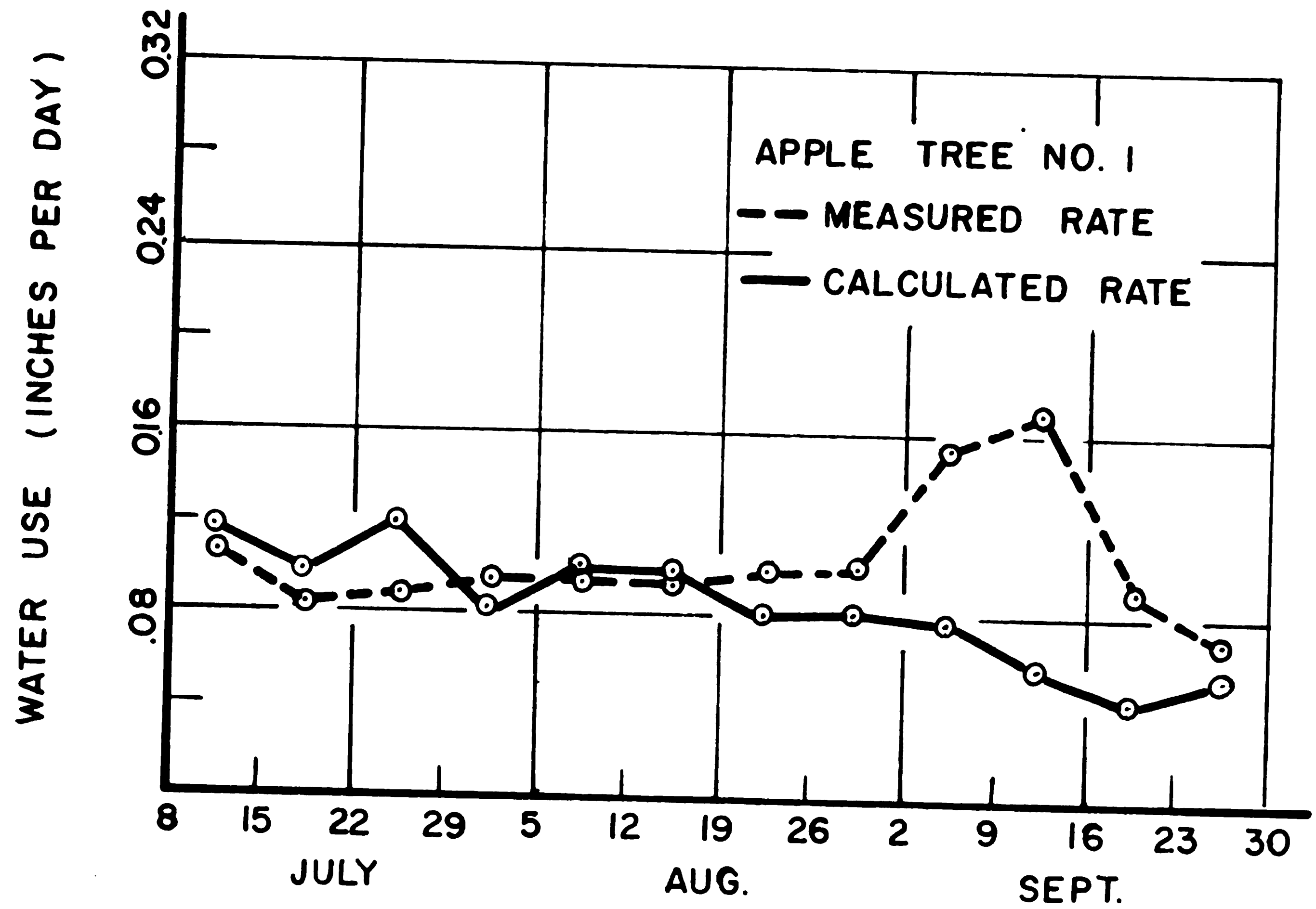

FIGURE 20 AVERAGE WEEKLY WATER CONSUMPTION FOR APPLE TREE NO. 1 1956

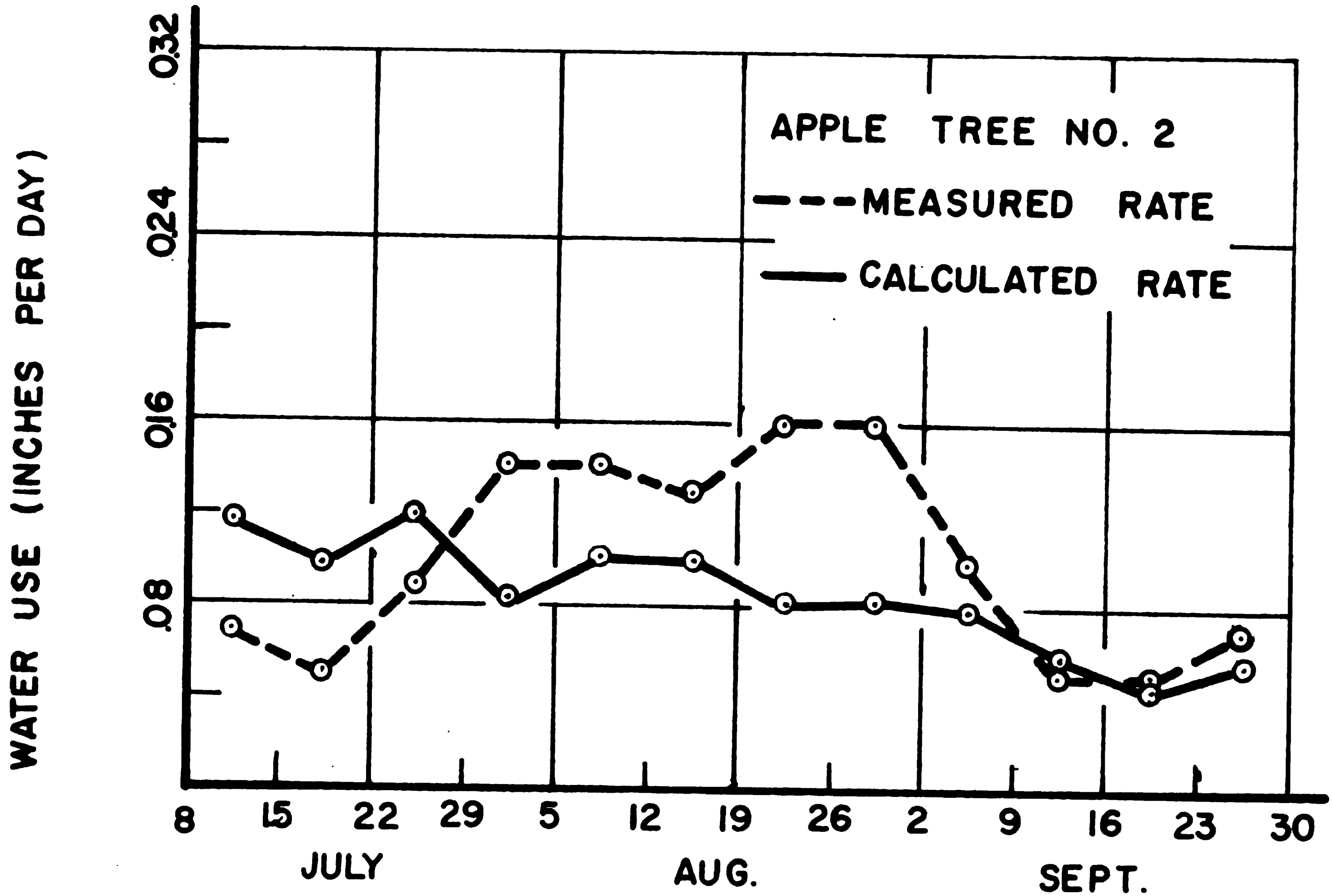

FIGURE 21 AVERAGE WEEKLY WATER CONSUMPTION FOR APPLE TREE NO. 2 1956

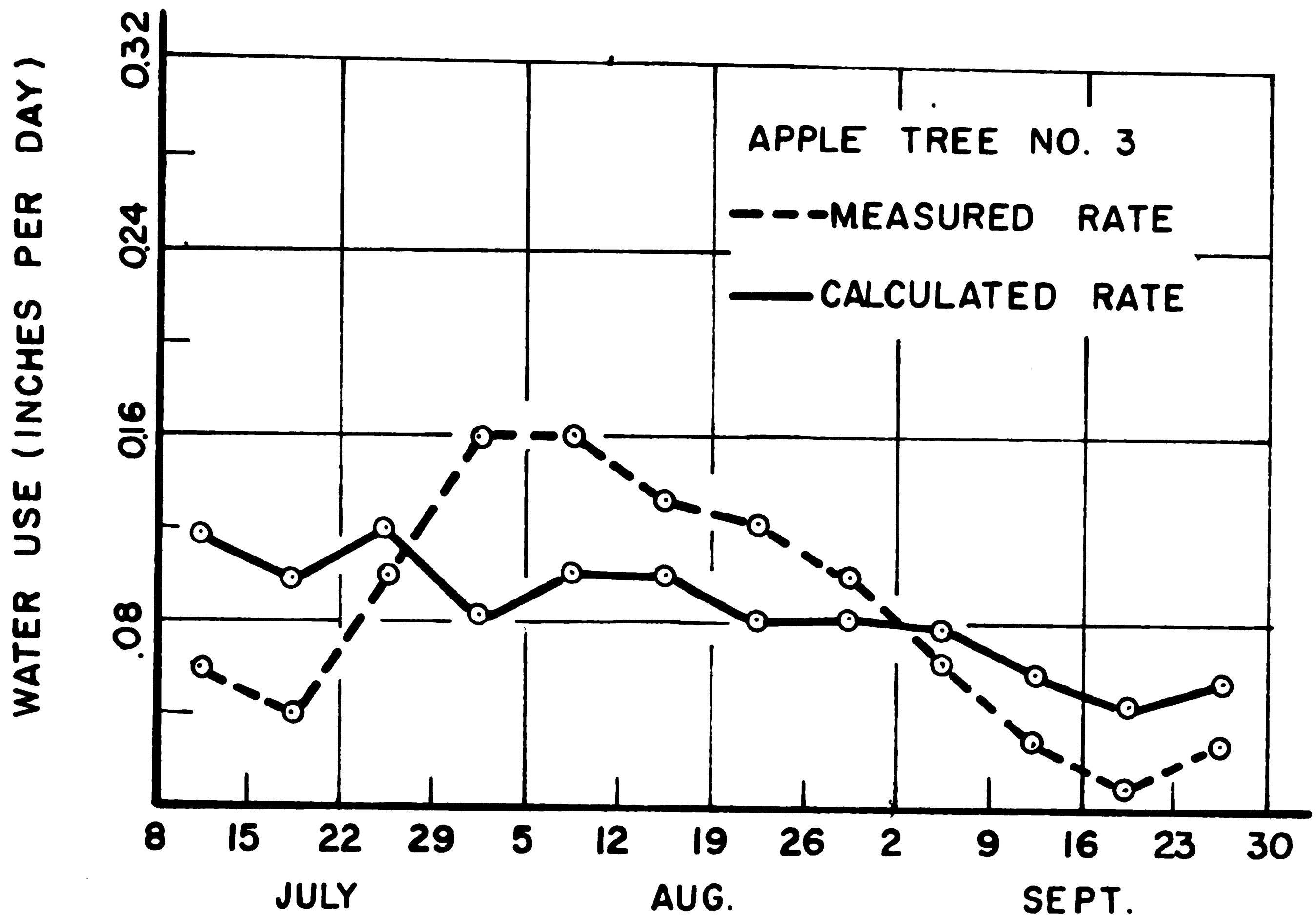

FIGURE 22 AVERAGE WEEKLY WATER CONSUMPTION FOR APPLE TREE NO. 3 1956

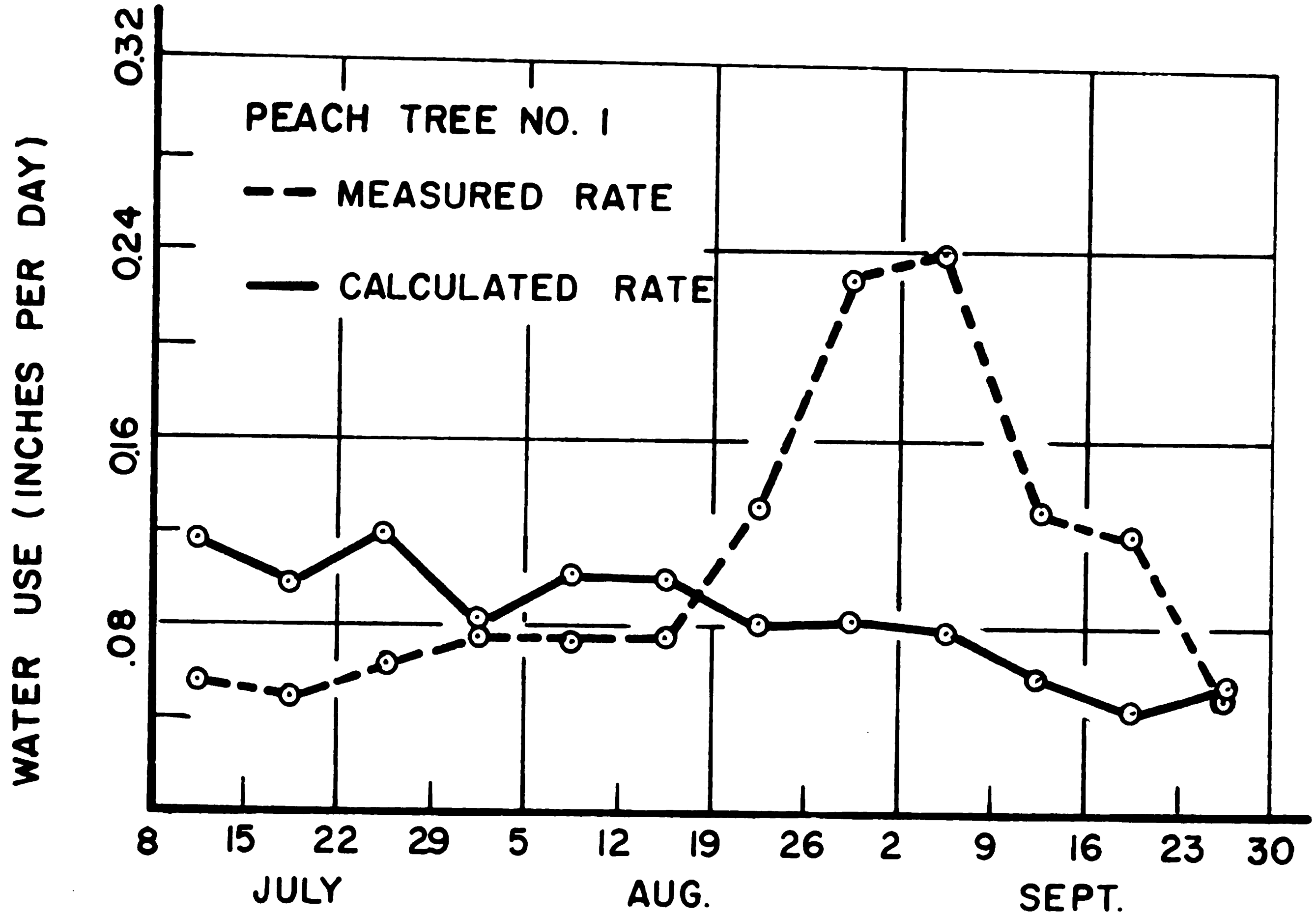

FIGURE 23 AVERAGE WEEKLY WATER CONSUMPTION FOR PEACH TREE NO. 1 1956

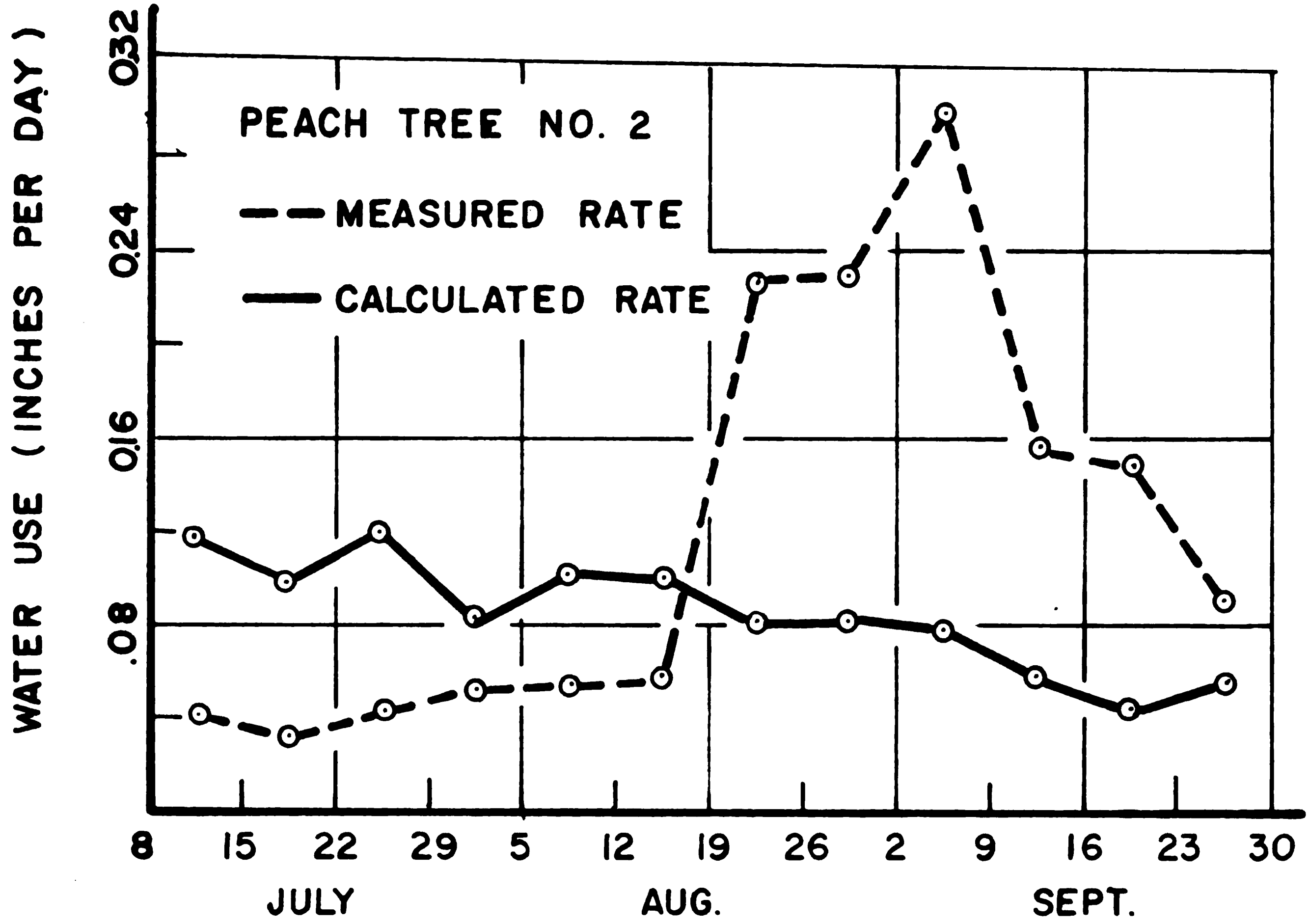

FIGURE 24 AVERAGE WEEKLY WATER CONSUMPTION FOR PEACH TREE NO. 2 1956

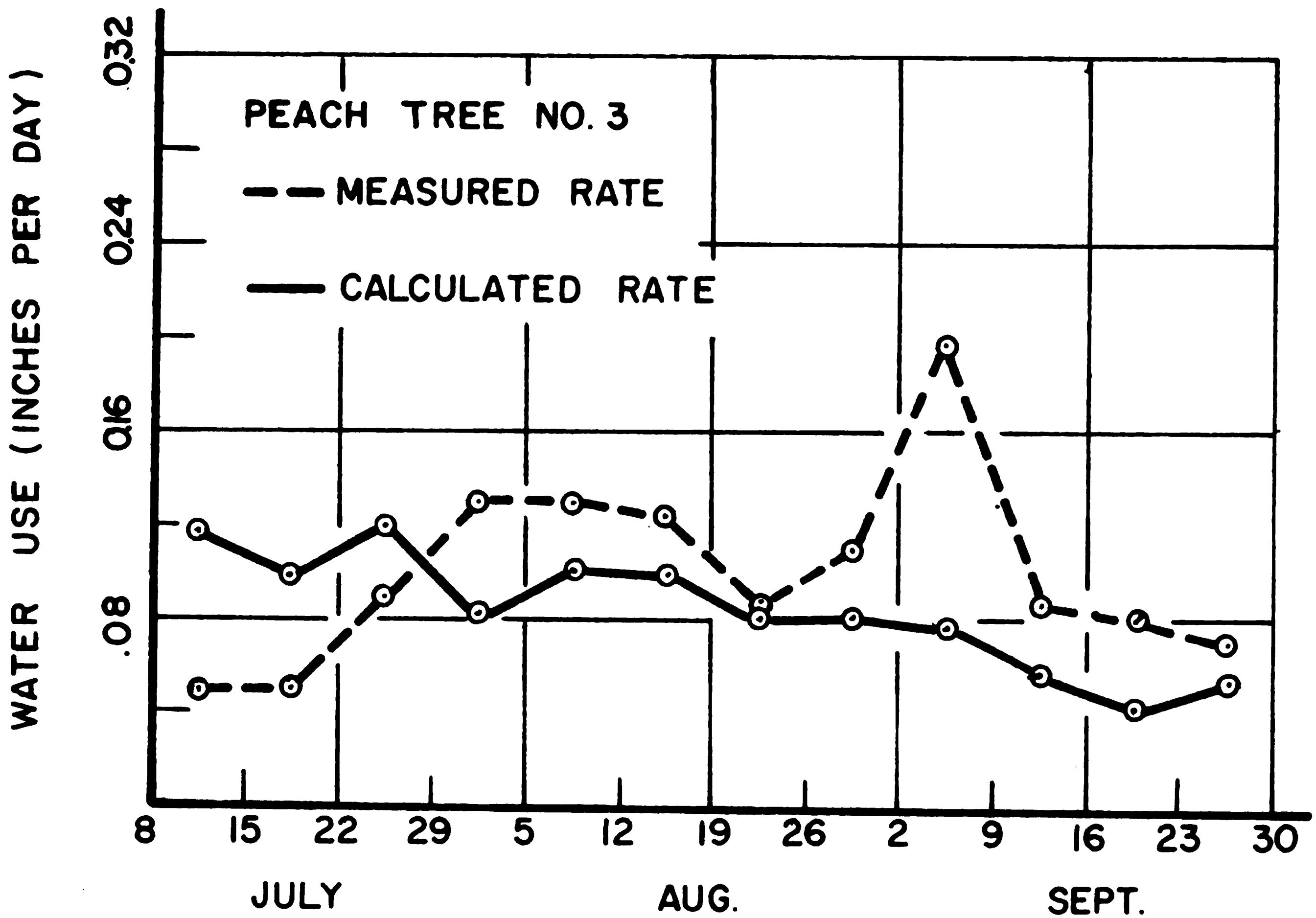

FIGURE 25 AVERAGE WEEKLY WATER CONSUMPTION FOR PEACH TREE NO. 3 1956

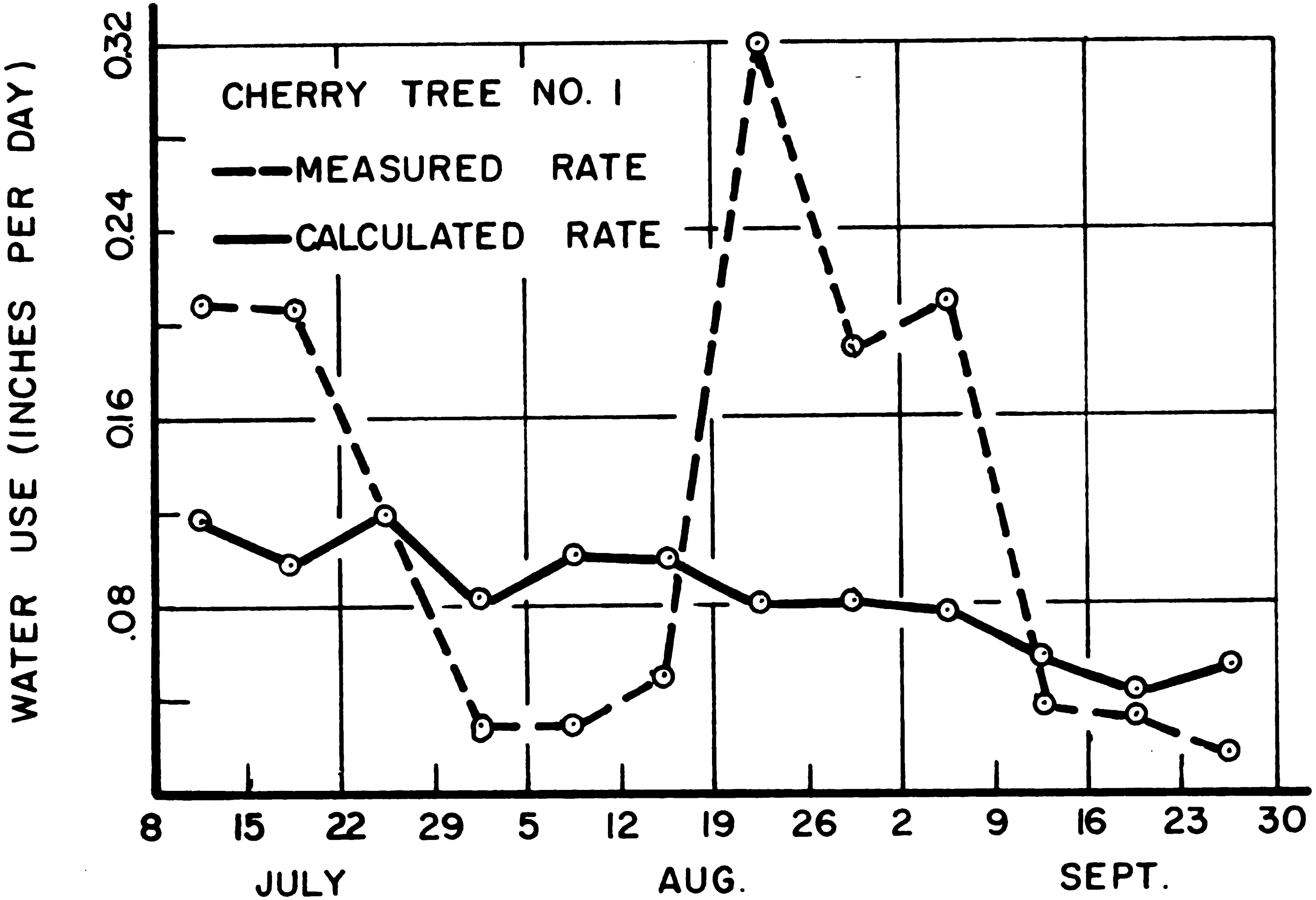

FIGURE 26 AVERAGE WEEKLY WATER CONSUMPTION FOR CHERRY TREE NO. 1 1956

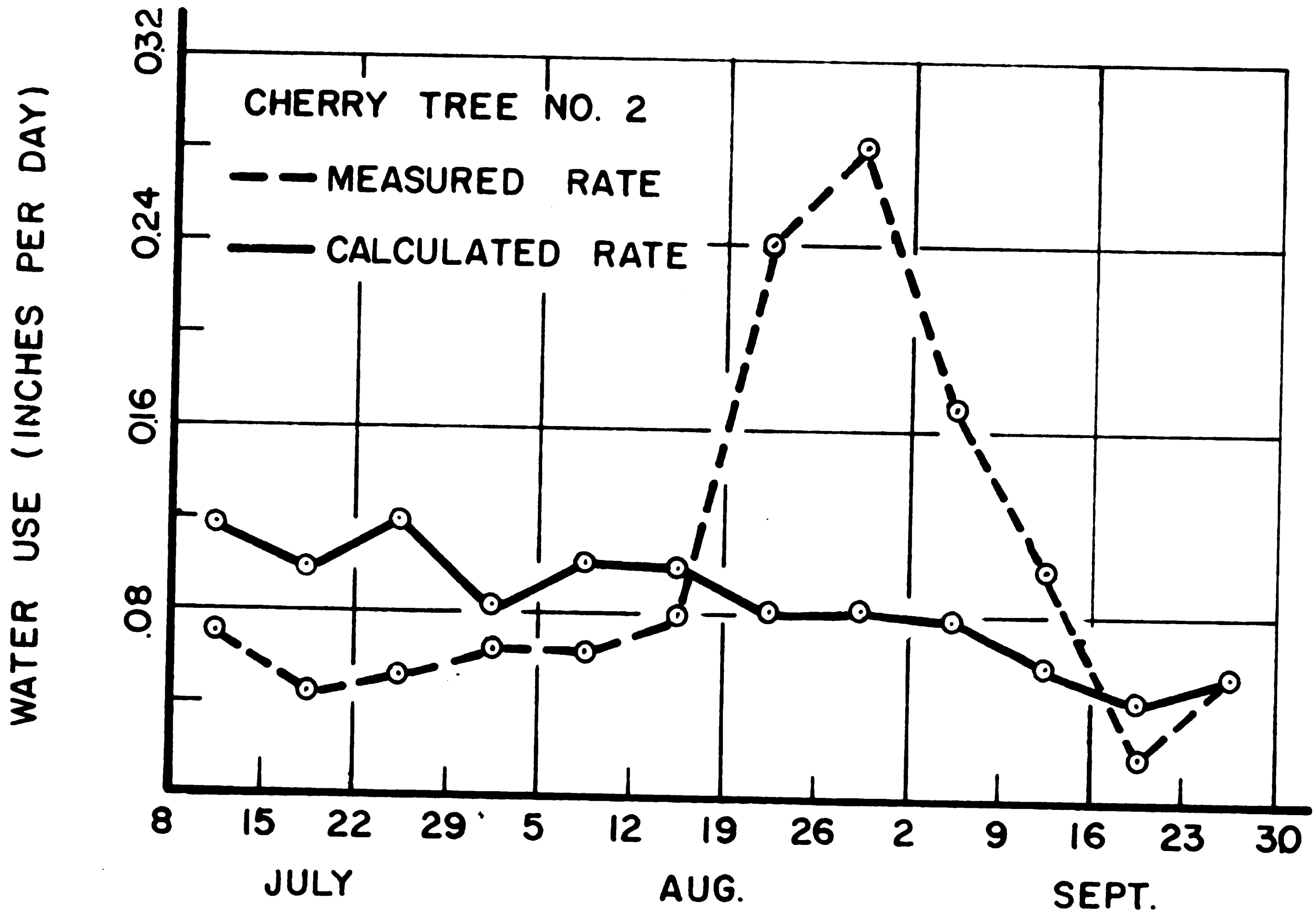

FIGURE 27 AVERAGE WEEKLY WATER CONSUMPTION FOR CHERRY TREE NO. 2 1956

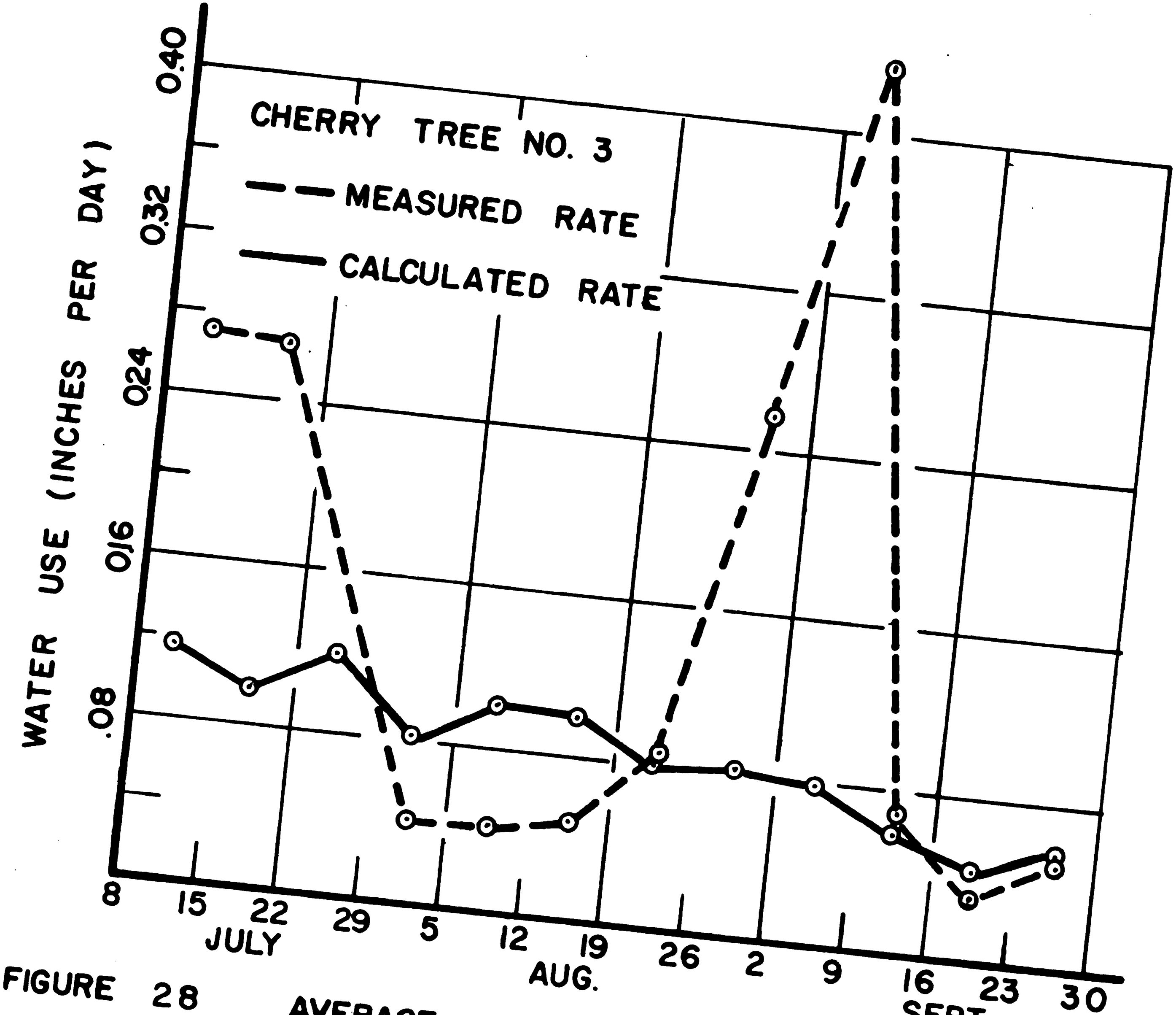

FIGURE 28 AVERAGE WEEKLY WATER CONSUMPTION FOR CHERRY TREE NO. 3 1956

V. CONCLUSIONS

From a study and comparison of the graphs of water use rate given by Bouyoucos moisture blocks, and the potential evapotranspiration rate calculated by the Penman procedure, the following observations are noted:

1. The potential evapotranspiration as calculated for weekly intervals by the energy equation, is not a reliable indication of the actual evapotranspiration of fruit trees. This is due to the partial ground cover by trees, variations in root structure, soil conditions and physiological plant functions.

2. The solar energy falling between rows, is available to the tree when the ground is dry or the cover vegetation is dormant, and accounts for a much higher rate of water use by the tree than would normally be expected.

3. The use of moisture blocks makes possible a more reliable procedure for determining the correct time of irrigation than does the energy equation.

4. The rate of water use indicated by the energy equation, should be multiplied by a factor of 3 or 4 when using this method to determine the time of irrigation, prior to harvest, for a young orchard.

5. Irrigation water should be placed as near the tree as possible rather than in mid row in order to be available to the roots.

6. The physiology of a maturing fruit crop causes a variation in moisture use. This is particularly true in peaches and cherries, which have a low moisture use rate in mid season, increasing prior to harvest and decreasing again at harvest.

VI. SUGGESTIONS FOR FUTURE STUDY

To further check the reliability of the Potential Evapotranspiration as given for orchards, by the Penman method, and to possibly alter the modifying coefficients so that they would be more correct, various other studies could be made. These might be:

1. Make a more exhaustive study of the same type as done here, using many more moisture blocks on a uniform soil type. This would eliminate variables and give more weight to the data.

2. Use another method of checking water consumption, such as neutron scattering method.

3. Employ a weighing lysimeter to obtain the quantity of water used by a fruit tree during a growing season. Use this information to alter the energy equation to include the area and plant affect, thus giving more reliable results.

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APPENDIX I

GROUPING OF MOISTURE BLOCKS INTO THE THIRTEEN SOIL GROUPS

Soil Group	1	2	3	4	5	6
Tree	Apple 1	Apple 1	Apple 2	Apple 2	Apple 3	Apple 3
Block Location	A-1,2,3		A-1,2	A-3	A-1,2	A-3
and Depth in	B-1,2	B-3	B-1,2,3		B-1,2,3	
Soil	C-1,2	C-3	C-1,2	C-3	C-1,2	C-3
	D-1,2	D-3	D-1,2	D-3	D-1,2	D-3

Soil Group	7	8	9	10	11	12	13
Tree	Peach 1	Peach 2	Peach 3	Cherry 1	Cherry 2	Cherry 1	Cherry 3
Block Location	A-1,2	A-1,2	A-1,2	A-1	A-1,2	A-2	A-1,2
and Depth	B-1,2	B-1,2	B-1,2	B-1	B-1,2	B-2	B-1,2
in Soil	C-1,2	C-1,2	C-1,2	C-1	C-1,2	C-2	C-1,2
	D-1,2	D-1,2	D-1,2	D-1	D-1,2	D-2	D-1,2

APPENDIX II

FIELD CAPACITY - WILTING POINT, BULK DENSITY AND CALIBRATION CURVES OF SOILS

Soil No.	Soil Texture	Permanent Wilting Point % Moisture	Field Capacity % Moisture	Bulk Density Gm/3 inch core
1	Sandy Loam	2.64	12.56	554.2
2	Sandy Loam	4.68	15.33	599.9
3	Sandy Clay Loam	6.63	17.71	571.0
4	Loamy Sand	2.51	9.30	578.9
5	Fine Sand	1.41	8.45	578.8
6	Fine Sand	1.52	10.57	555.7
7	Loam	7.71	16.85	611.5
8	Loamy Sand	2.83	12.24	571.8
9	Loamy Fine Sand	2.87	12.90	589.6
10	Sandy Loam	3.57	10.24	507.7
11	Sandy Loam	3.72	13.15	600.1
12	Loamy Sand	2.73	11.58	541.3
13	Loamy Fine Sand	2.04	8.84	529.0

APPENDIX II CONTINUED

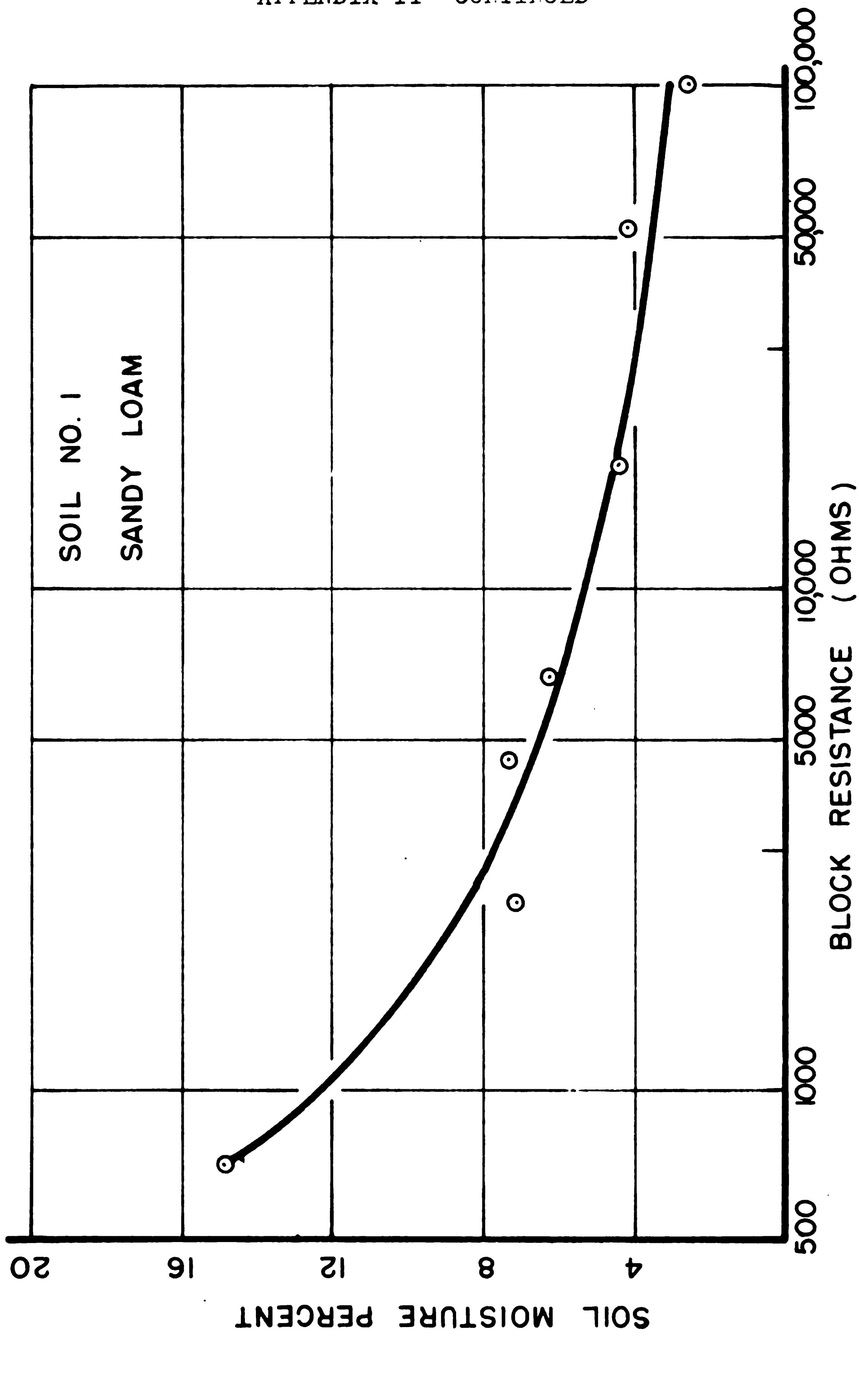


FIGURE 29 CALIBRATION CURVE FOR SOIL NO. 1

APPENDIX II CONTINUED

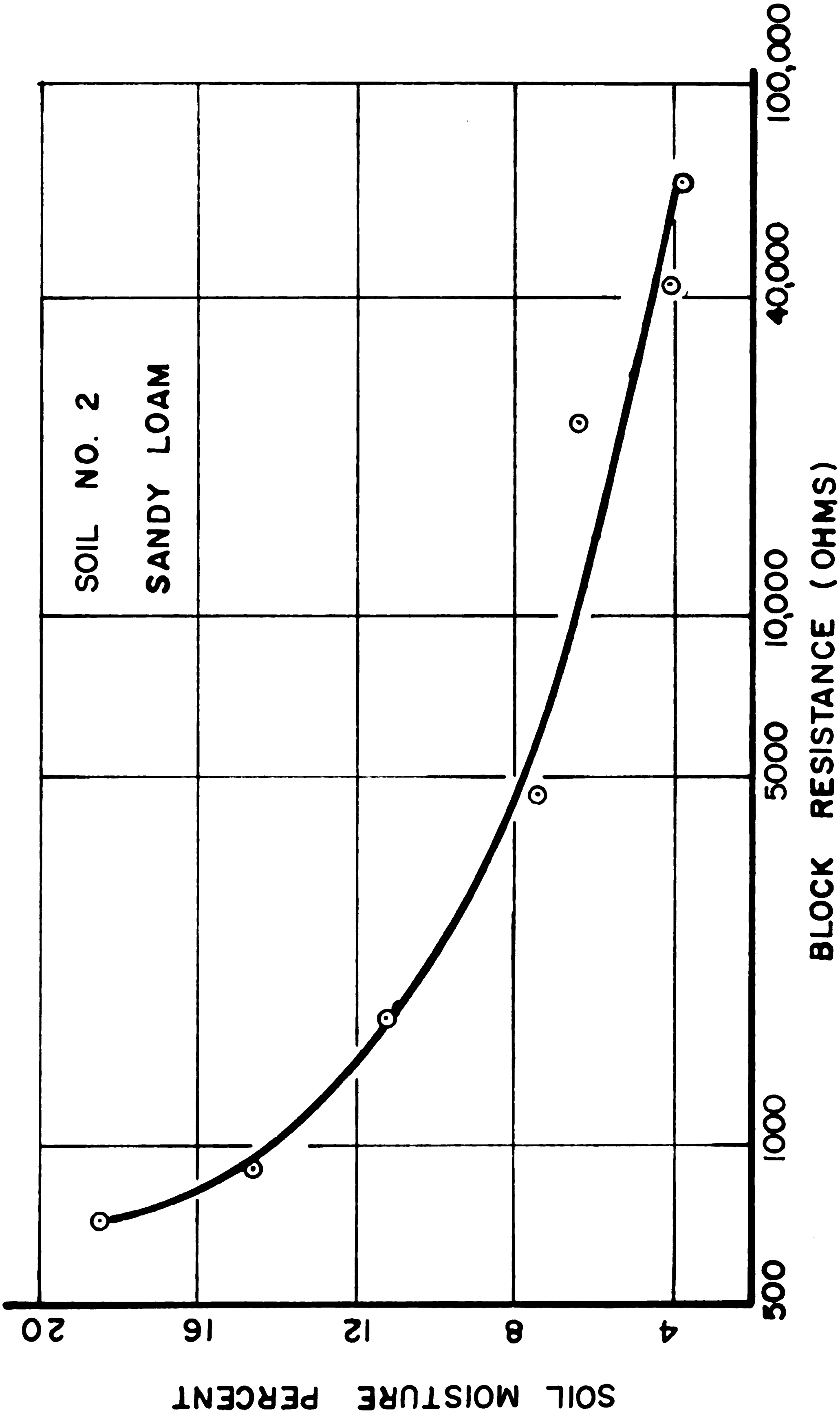


FIGURE 30 CALIBRATION CURVE FOR SOIL NO. 2

APPENDIX II CONTINUED

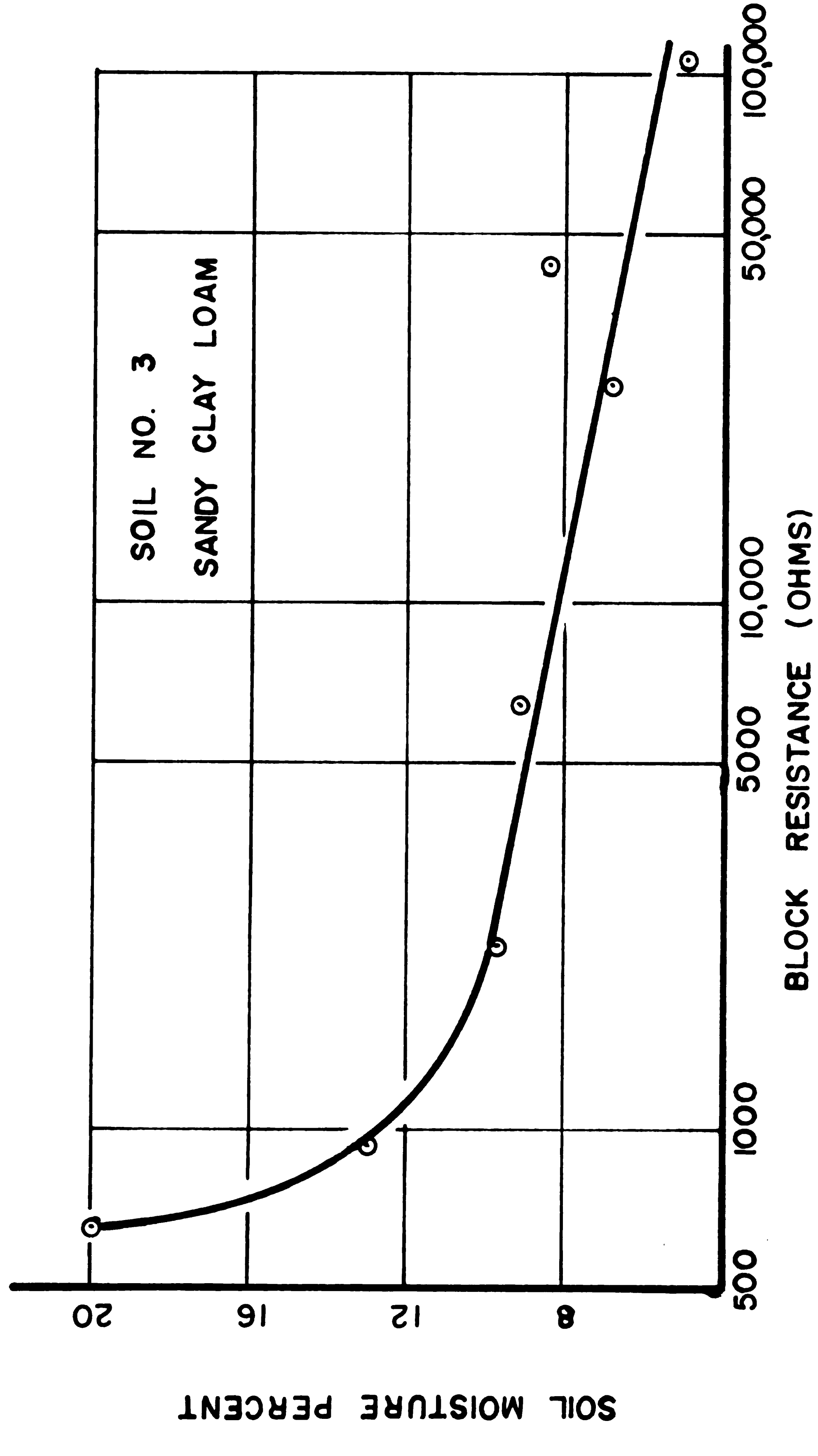


FIGURE 31 CALIBRATION CURVE FOR SOIL NO. 3

APPENDIX II CONTINUED

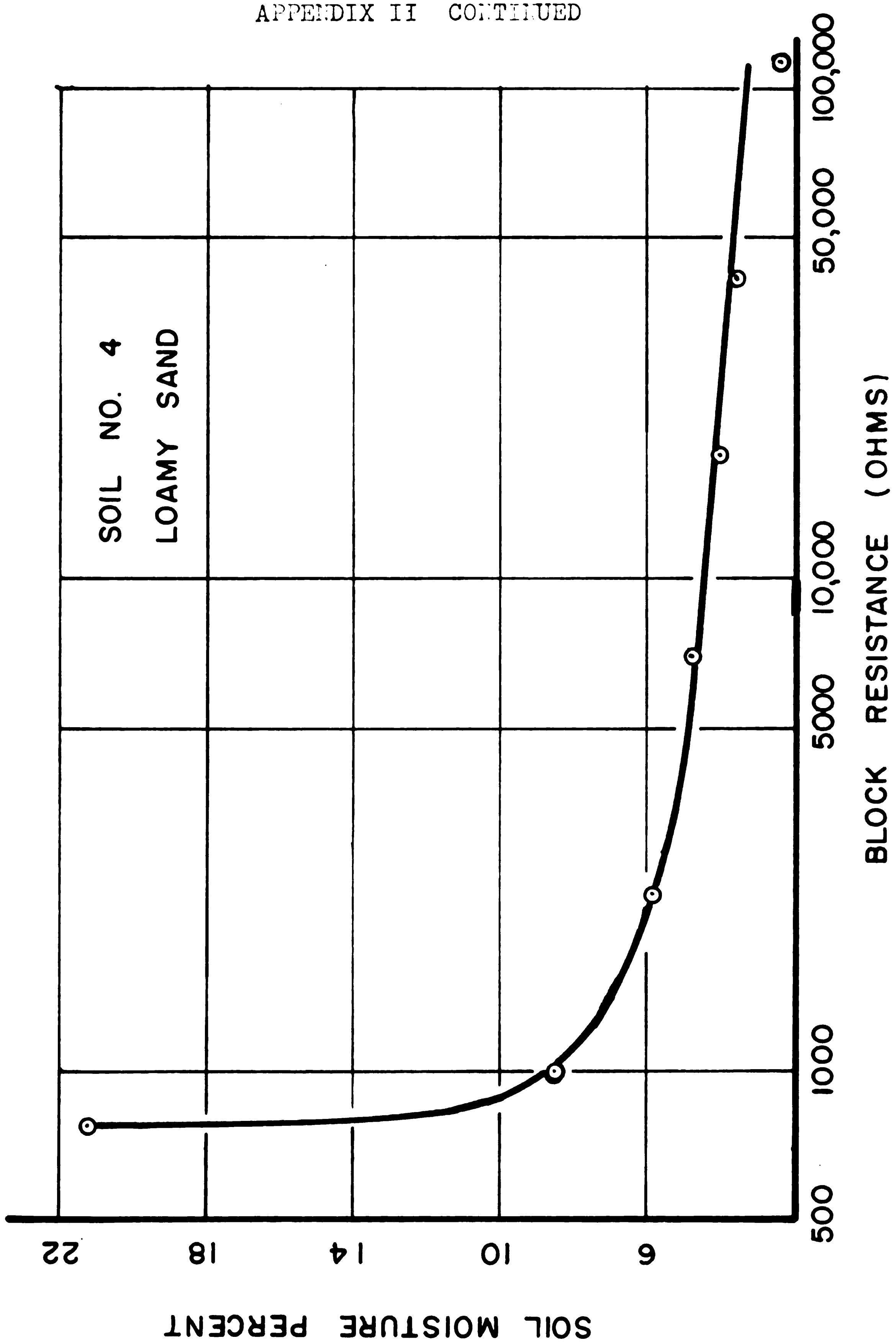


FIGURE 32 CALIBRATION CURVE FOR SOIL NO. 4

APPENDIX II CONTINUED

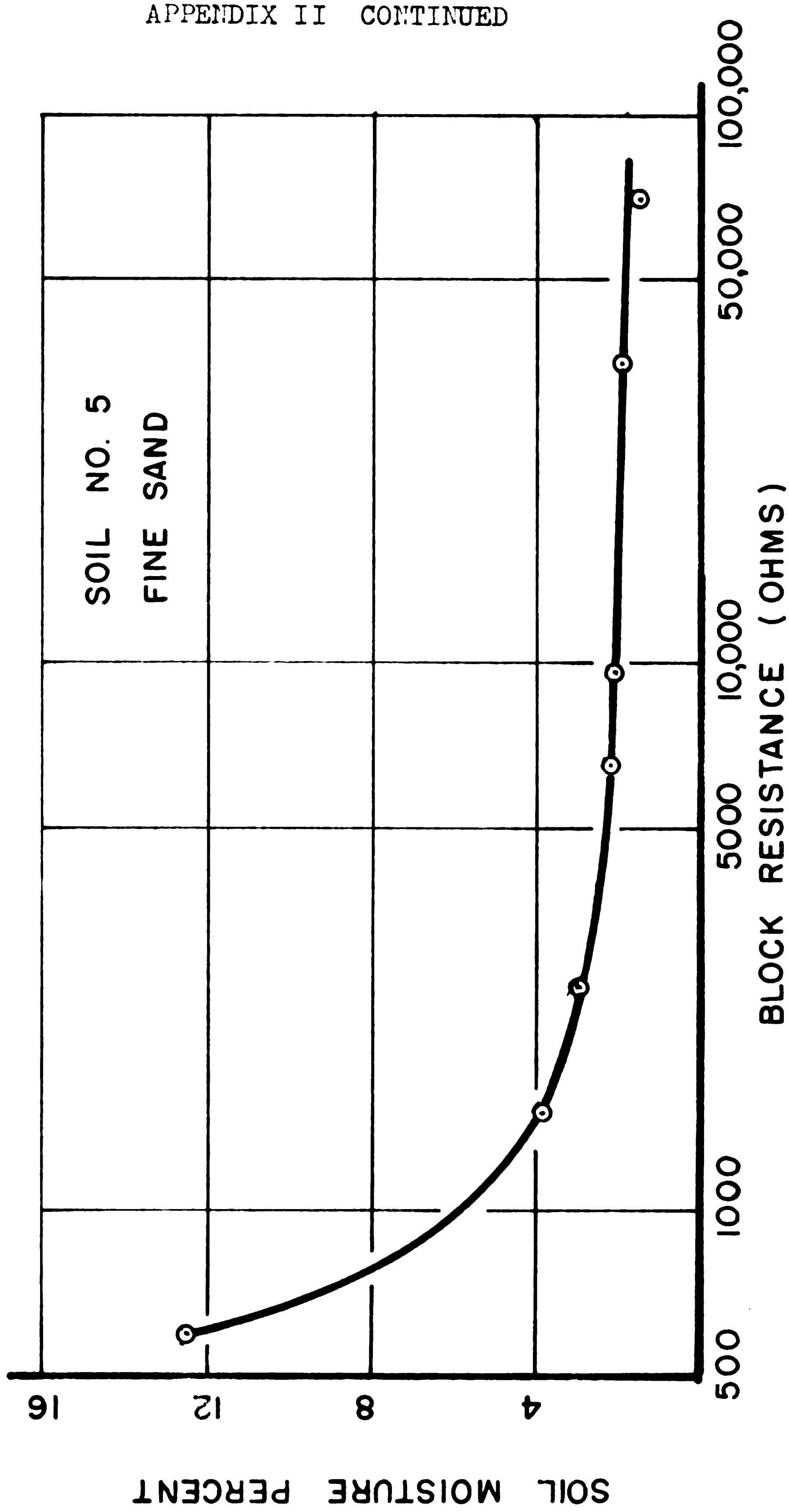


FIGURE 33 CALIBRATION CURVE FOR SOIL NO. 5

APPENDIX II CONTINUED

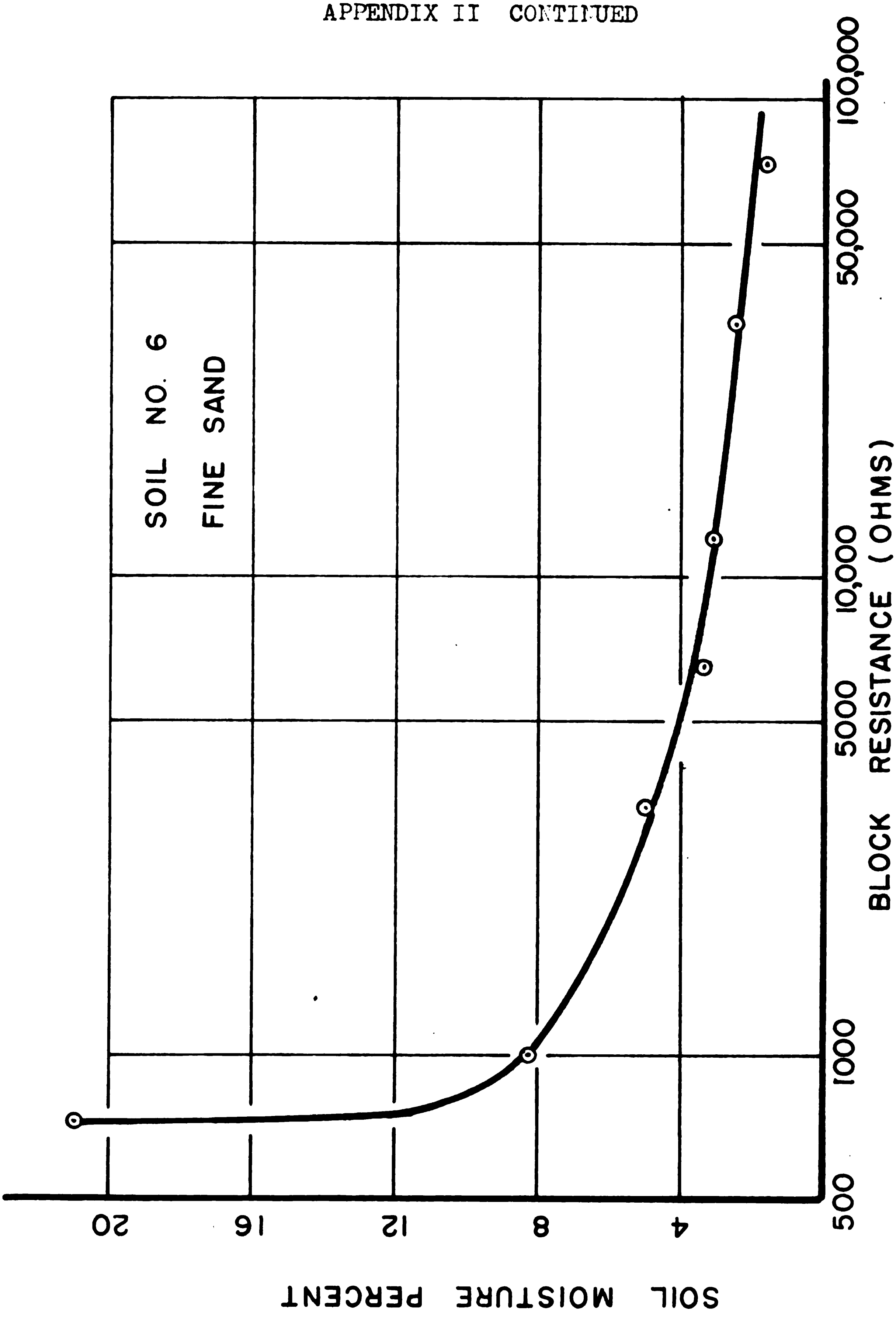


FIGURE 34 CALIBRATION CURVE FOR SOIL NO. 6

APPENDIX II CONTINUED

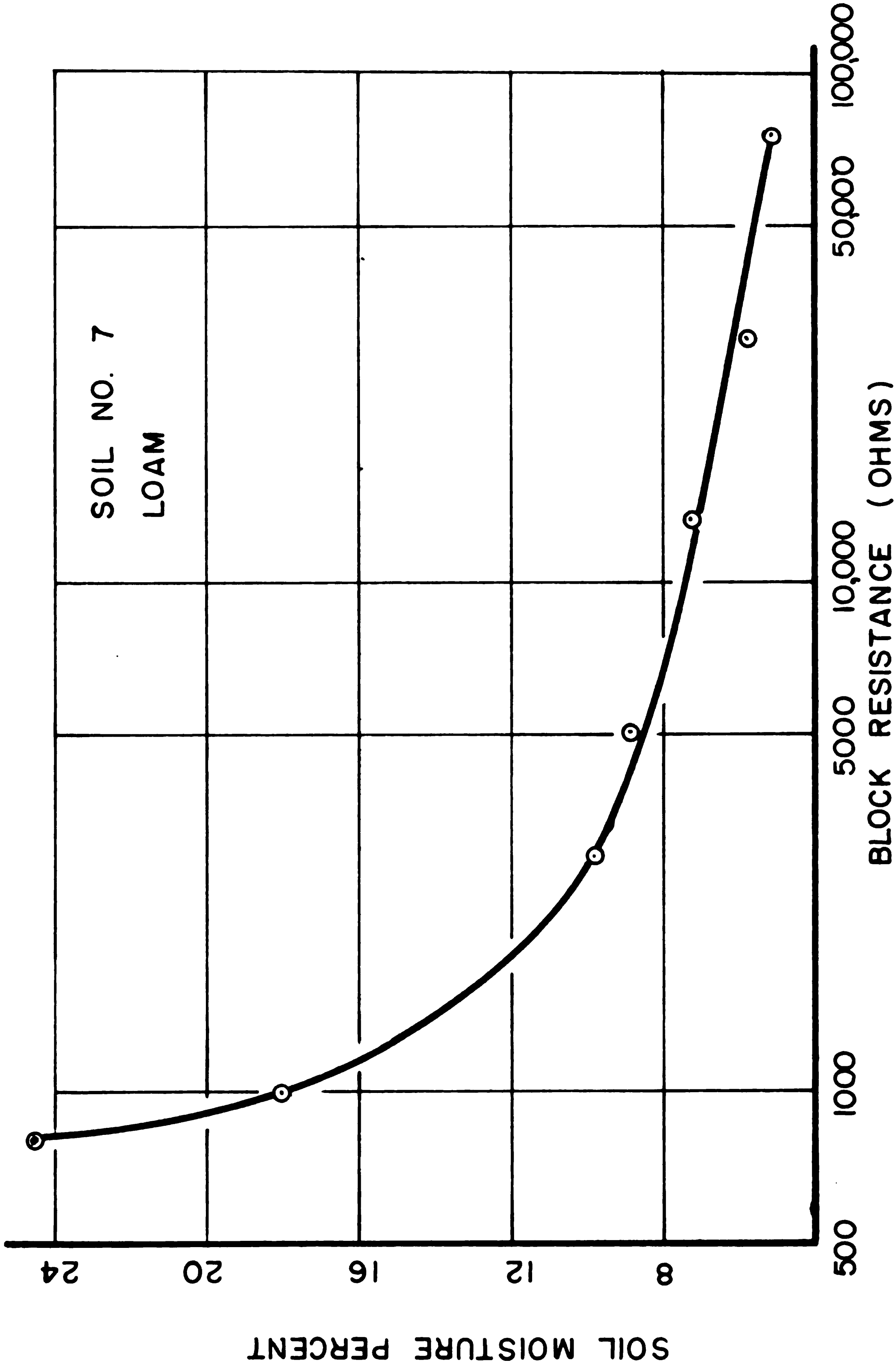


FIGURE 35 CALIBRATION CURVE FOR SOIL NO. 7

APPENDIX II CONTINUED

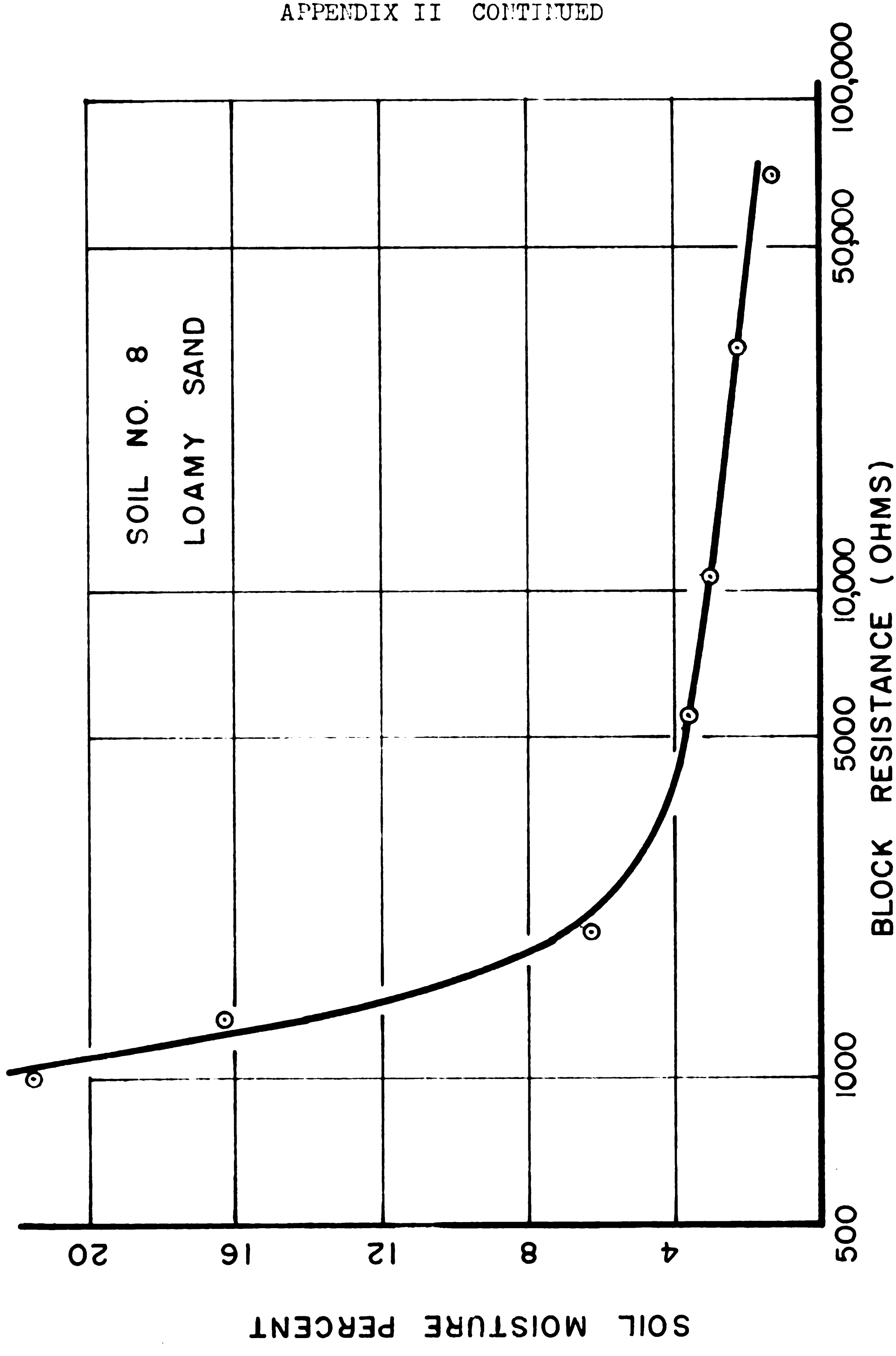


FIGURE 36 CALIBRATION CURVE FOR SOIL NO. 8

APPENDIX II CONTINUED

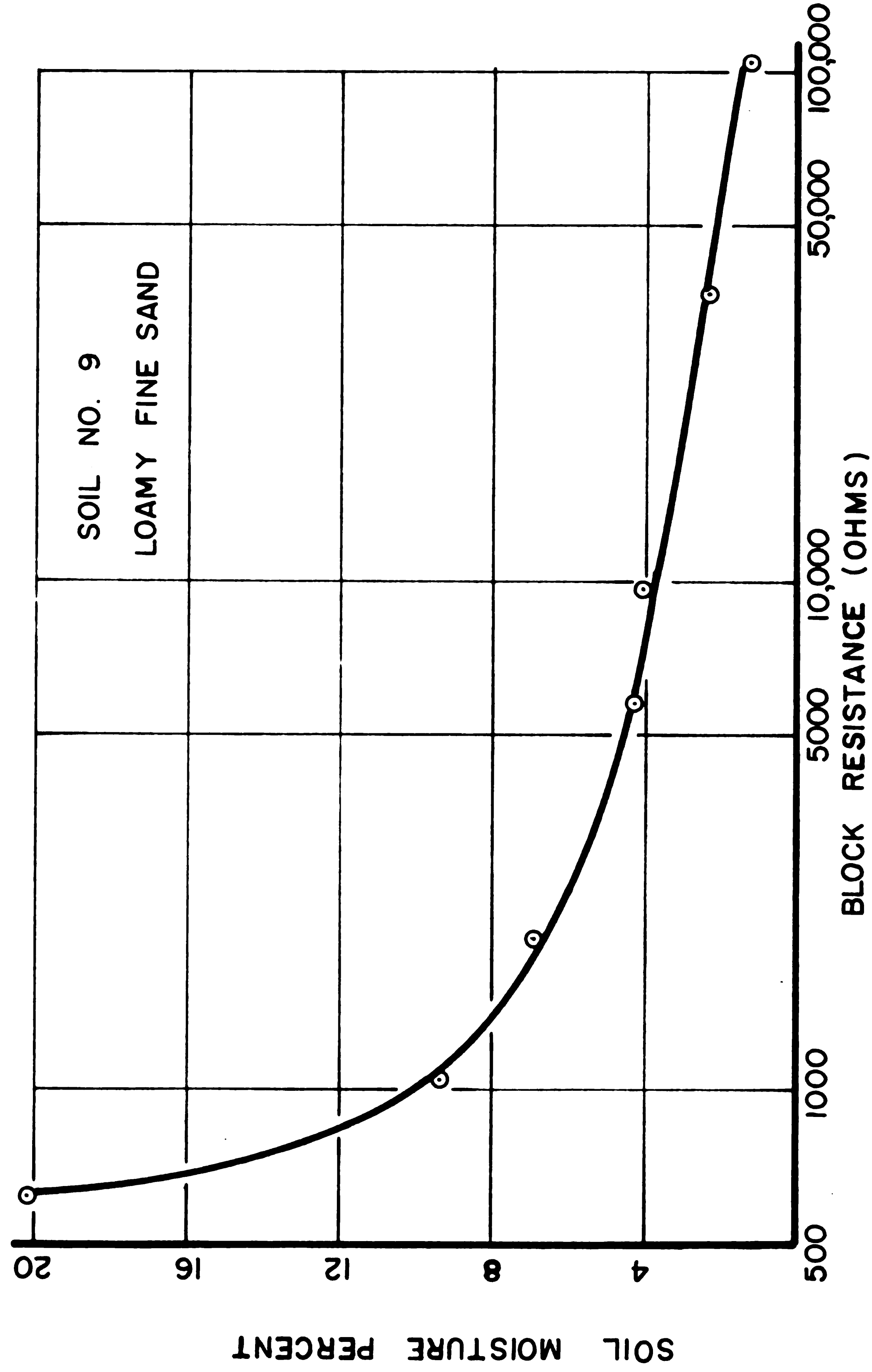


FIGURE 37 CALIBRATION CURVE FOR SOIL NO. 9

APPENDIX II CONTINUED

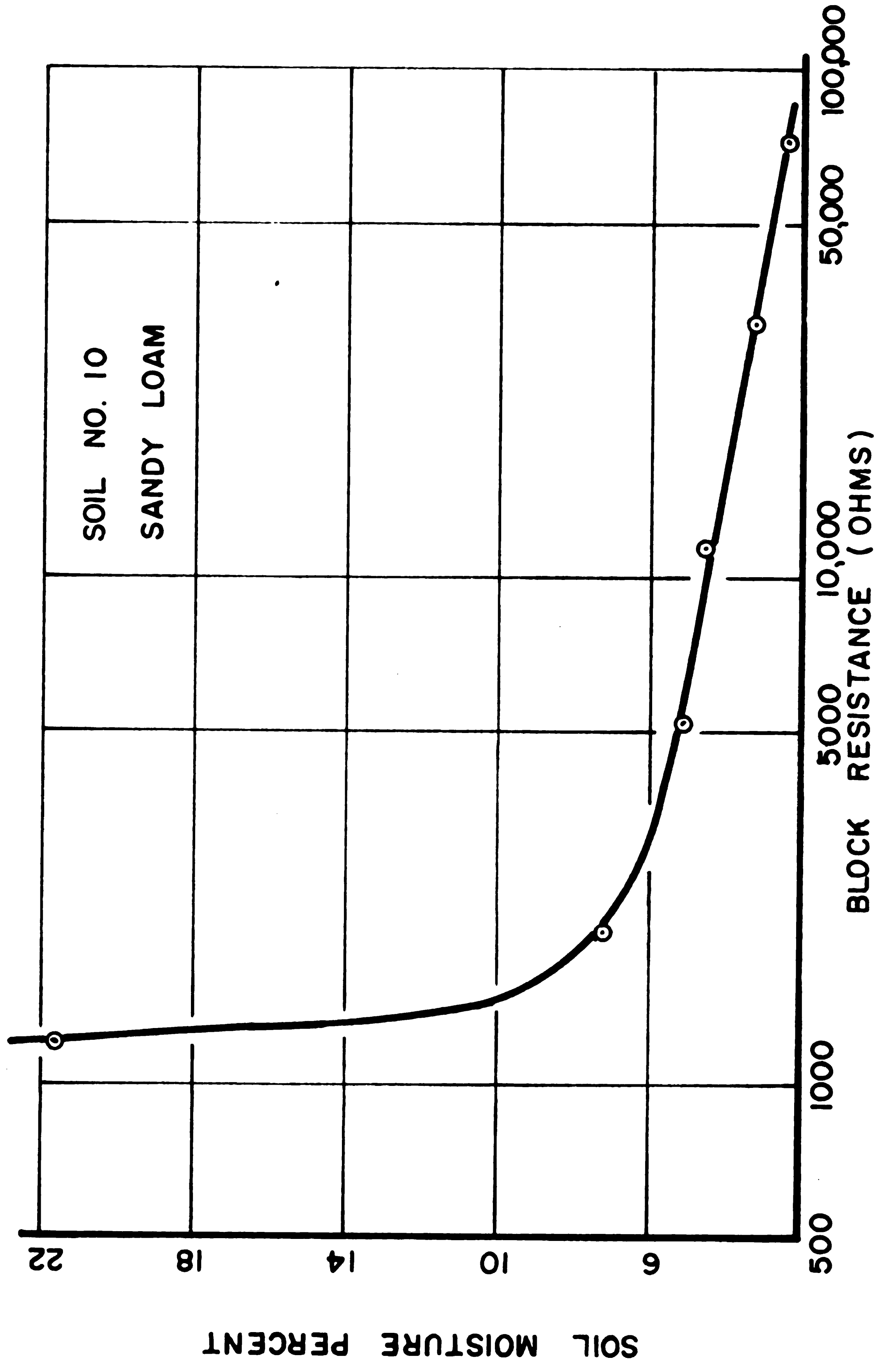


FIGURE 38 CALIBRATION CURVE FOR SOIL NO. 10

APPENDIX II CONTINUED

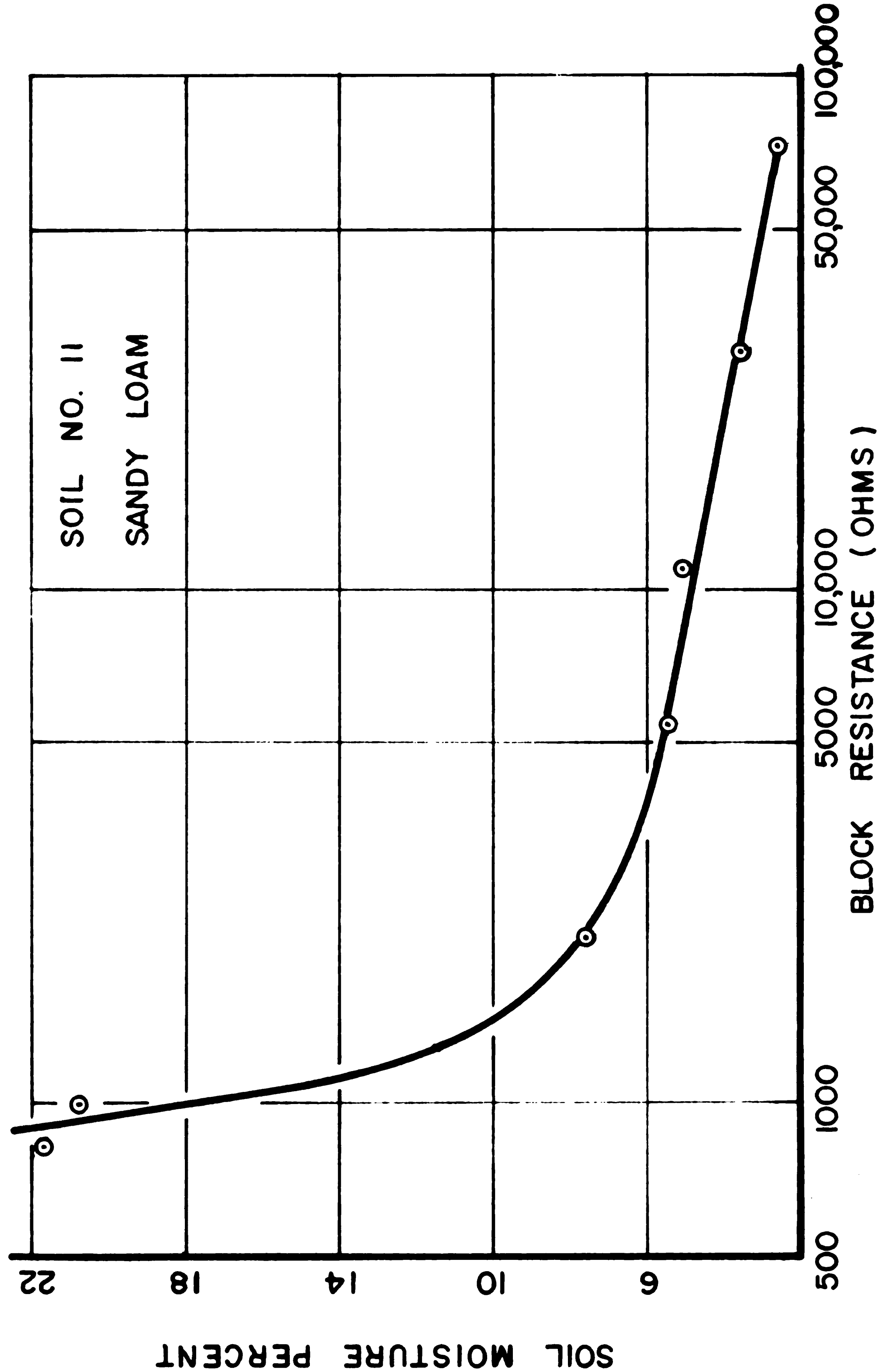


FIGURE 39 CALIBRATION CURVE FOR SOIL NO. 11

APPENDIX II CONTINUED

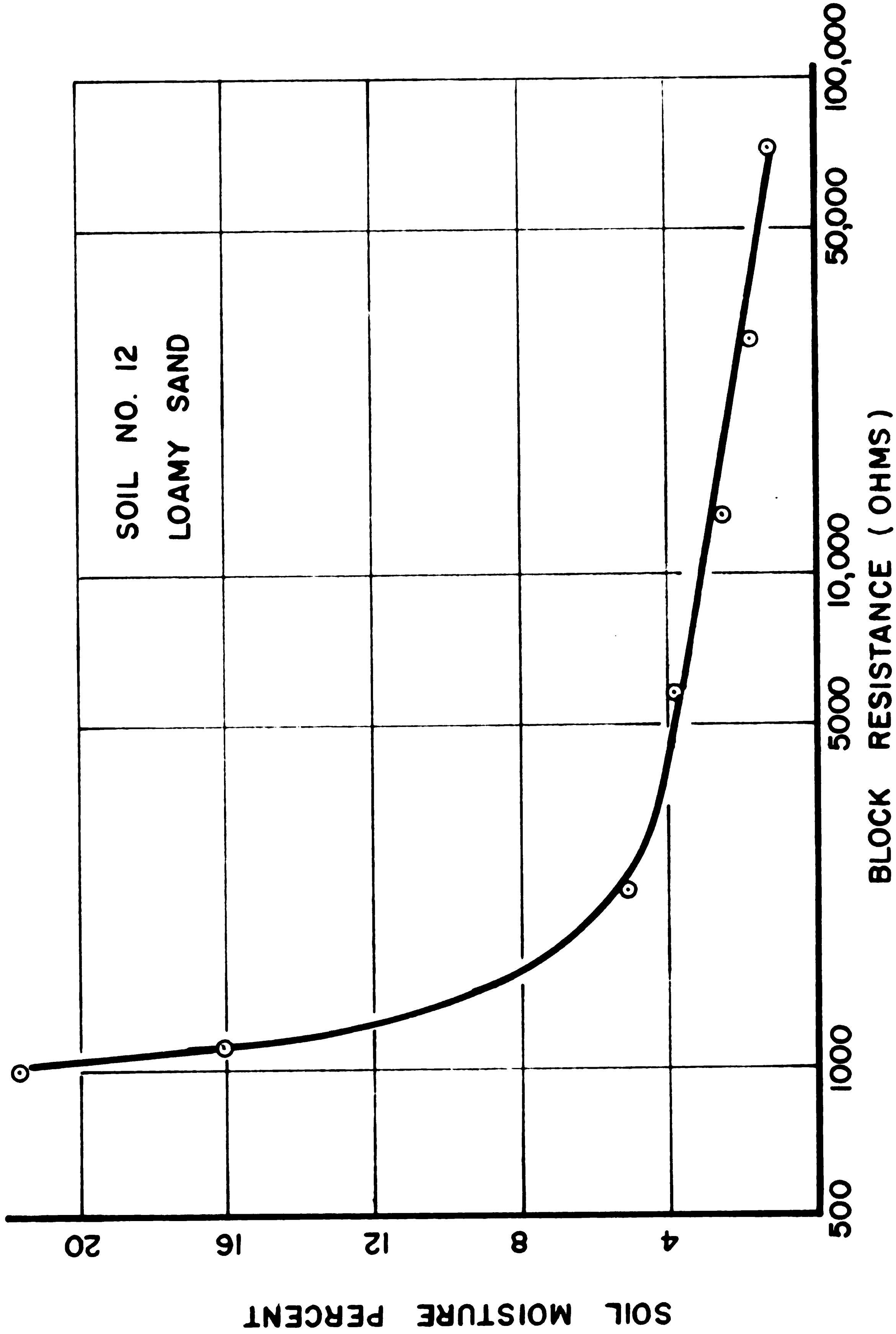


FIGURE 40 CALIBRATION CURVE FOR SOIL NO. 12

APPENDIX II CONTINUED

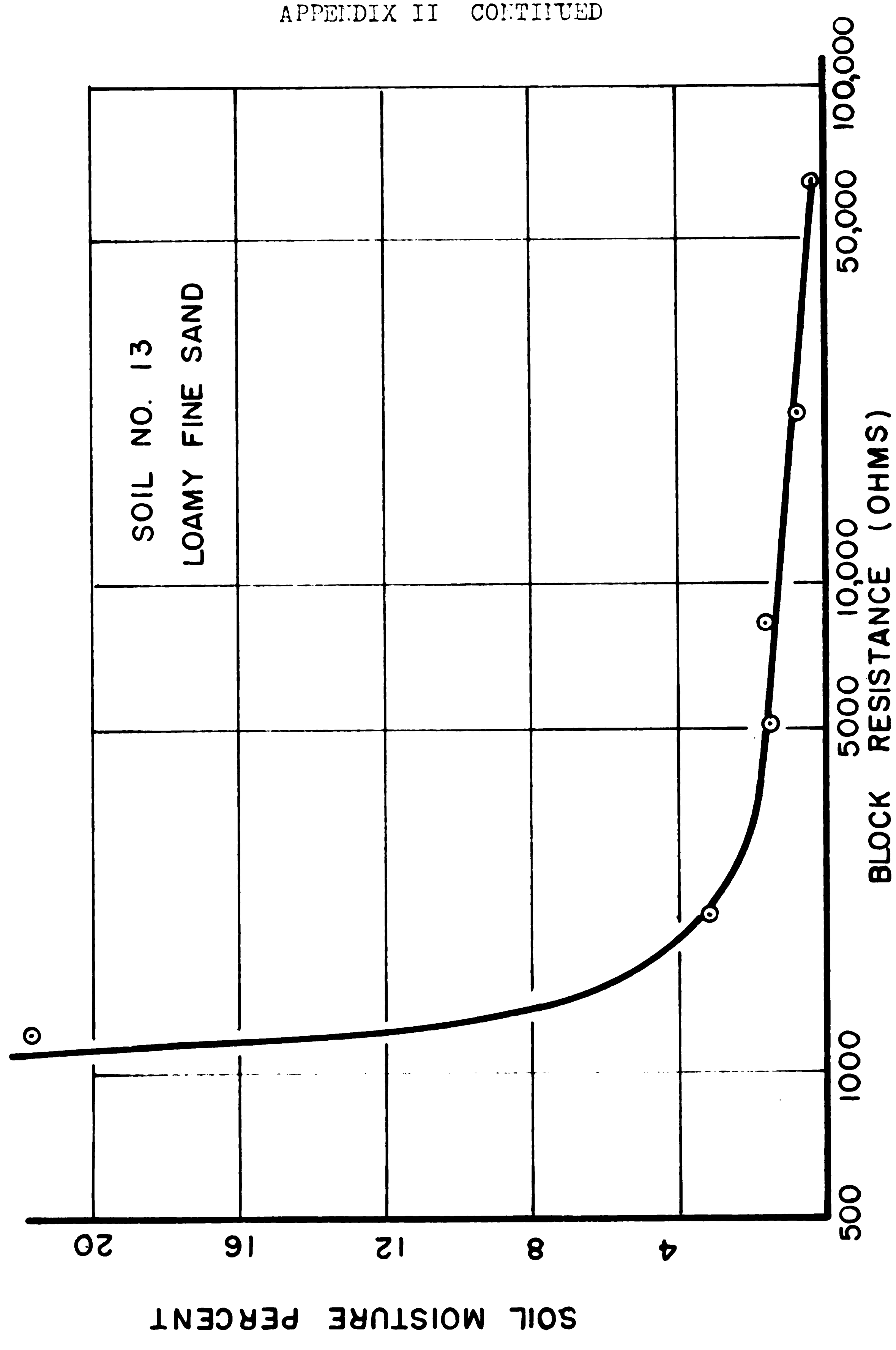


FIGURE 41 CALIBRATION CURVE FOR SOIL NO. 13

APPENDIX III

PORTION OF FIELD DATA APPLES - TREE 2

DATE	DEPTH	A				B			
		RESIST	TEMP	C' RESIST	% M	RESIST	TEMP	C' RESIST	% M
	1	1150	63	1050	12.4	1540	64	1420	11.1
8-20	2	1500	63	1360	11.2	960	64	900	13.6
	3	34,000	62	29,000	4.0	4800	63	4350	9.1
	1	1600	61	1420	11.0	2500	62	2250	9.9
8-23	2	1960	62	1750	10.4	1260	63	1150	12.0
	3	39,000	61	32,200	3.9	5800	62	5100	8.9
	1	2050	60	1770	10.4	3250	62	2850	9.6
8-27	2	3750	60	3220	9.5	1800	62	1620	10.6
	3	48,000	60	39,000	3.8	7500	62	6600	8.6
	1	3000	63	2710	9.6	3900	63	3520	9.3
8-30	2	6500	63	5800	8.8	2400	63	2200	10.0
	3	50,000	63	44,000	3.7	8700	63	7700	8.4

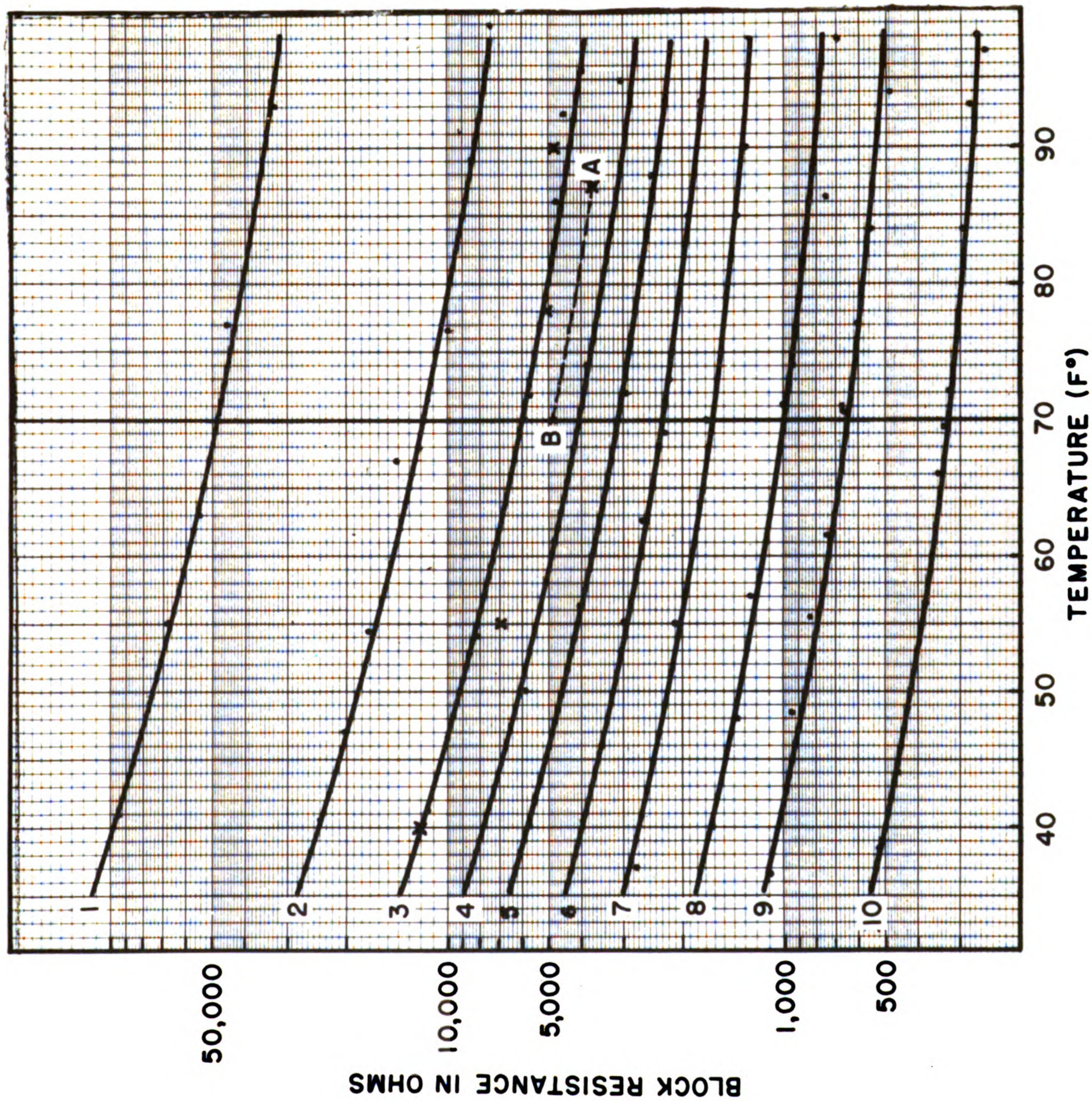
APPENDIX III CONTINUED:

DATE	DEPTH	C				D			
		RESIST	TEMP	C' RESIST	% M	RESIST	TEMP	C' RESIST	% M
8-20	1	1200	62	1080	12.3	920	63	840	14.2
	2	12,200	62	10,500	8.1	8100	63	1650	10.6
	3	98,500	61	81,00	3.4	72,000	61	60,000	3.6
8-23	1	1700	61	1510	10.8	1200	62	1080	12.3
	2	18,600	61	15,800	7.7	2350	61	2050	10.0
	3	97,000	60	78,000	3.4	70,000	60	57,000	3.6
8-27	1	1850	60	1620	10.6	1200	61	1060	12.4
	2	33,000	60	27,200	7.1	4100	60	3520	9.3
	3	97,000	60	78,000	3.4	72,000	60	58,000	3.6
8-30	1	1700	63	1550	10.8	940	64	870	13.8
	2	40,000	62	34,000	6.8	6700	62	5900	12.8
	3	97,000	61	80,000	3.4	77,000	61	64,000	3.5

APPENDIX IV

TEMPERATURE CORRECTION FOR MOISTURE BLOCKS

(From Ref. 4)



APPENDIX V

SAMPLE CALCULATION - INCHES OF WATER PER FOOT OF SOIL

$$\text{Percent Water} = \frac{\text{Weight of Water}}{\text{Weight of Soil}} \times 100$$

$$\text{Weight of Water} = \frac{\text{Percent Water} \times \text{Weight of Soil}}{100}$$

$$\text{Inches of Water/foot} = \frac{\text{Percent Water}}{100} \times \frac{\text{Weight of Soil (grams)}}{\text{Volume of Soil (cu. in.)}}$$

$$\times \frac{\text{cu. cm}}{\text{gram}} \times \frac{\text{cu. in}}{\text{16.4 cu. cm}} \times \frac{\text{12 in.}}{\text{ft.}}$$

$$\text{Inches of Water/foot} = \frac{12.4}{100} \times \frac{\text{571.0 (grams)}}{\text{21.2 (cu. in.)}} \times \frac{\text{1c.c.}}{\text{gram}} \times \frac{\text{cu. in.}}{\text{164 c. c.}}$$

$$\times \frac{\text{12 in.}}{\text{ft.}}$$

$$= 12.4 \times 571.0 \times .0345$$

$$= 2.44 \text{ in./ft.}$$

The depth of water for each foot of soil was calculated, using the percent moisture at that position. The depth of water for each foot was then added giving a total of the threefoot depth. This was done for each of the four block locations, A, B, C and D, around the tree. The amount of water for the four locations, was then averaged to give a representative depth of water for the tree. This data was then plotted to give the moisture use curves. Figure 10-18.

APPENDIX VI

PORTIONS OF DATA SHOWING WATER AVAILABLE - TREE 2

Location		A		B		C		D	
Date	Depth	Inches of H_2O / Foot	Total H_2O Available	Inches of H_2O / Foot	Total H_2O Available	Inches of H_2O / Foot	Total H_2O Available	Inches of H_2O / Foot	Total H_2O Available
8-20	1	2.44	5.45	2.19	6.66	2.42	4.69	2.80	4.89
	2	2.21		2.68		1.59		2.09	
	3	.80		1.79		.68		.72	
8-23	1	2.16	4.99	1.95	6.06	2.13	4.33	2.42	5.11
	2	2.05		2.36		1.52		1.97	
	3	.78		1.75		.68		.72	
8-27	1	2.05	4.68	1.89	5.68	2.09	4.17	2.44	4.99
	2	1.87		2.09		1.40		1.83	
	3	.76		1.70		.68		.72	
8-30	1	1.89	4.36	1.83	5.45	2.12	4.14	2.72	5.94
	2	1.73		1.97		1.34		2.52	
	3	.74		1.65		.68		.70	
9-4	1	1.72	3.94	1.62	5.15	1.87	3.83	2.07	4.31
	2	1.50		1.91		1.28		1.56	
	3	.72		1.62		.68		.68	
9-7	1	2.09	4.19	1.46	4.70	1.75	3.71	1.87	4.01
	2	1.38		1.66		1.28		1.46	
	3	.72		1.58		.68		.68	

APPENDIX VII

TOTAL WATER ADDED AND USED

date	Average Inches H_2O/3 ft.	Rainfall Inches	Total H_2O Available	H_2O Used since Previous Reading
8-20	5.42	.47	5.89	.85
8-23	5.12	.09	5.21	.77
8-27	4.88	.35	5.23	.33
8-30	4.97		4.97	.26

APPENDIX VIII

Evapotranspiration for 9th week (September 3-8) East Lansing

Temperature = 66° F.

σTa^4 = 14.71 (66° F. Appendix XI)

E_a ≐ 16.8 (Appendix X,B)

E_d = Percent RH (ea) = 52(16.8) = 8.74

$\frac{n}{N}$ = 77.0 percent

N = 12.95 hr. sunrise to sunset

r = .2 for vegetation

Wind = 57.4 m.p.d. @ 25' x $\frac{(\text{Log } 6.6')}{\log 25}$ = 33.6 m.p.d. at 6.6'

Solar energy = 462.0 gm-cal./cm^2 / day

$H_t = R_c - R_b$

R_c = (1-2) (pyroheliometer)

$R_b = \sigma Ta^4 (.56 - .092 \text{ ed})(.1 = 9 \frac{n}{N})$

R_b = 14.71 (.56 - .092 x 2.96)(.1 + .9 x .77)
= 14.71 (.288)(.793)
= 3.36

R_c = .8 x 462 = 370
= 370 cal/cm^2 x $\frac{1}{590 \text{ cal./gm of } H_2O}$ x $\frac{1}{\text{gm/cc}}$ = .627 cm
= .627 cm x 10mm/cm = 6.27 mm of H_2O evap.

H_t = 6.27 - 3.36
= 2.91

L_a = .65 (1 + .0098 x 33.6)
= .65 (1.329)
= .864

$$S = \frac{L_a}{L_a + .16}$$
$$= \frac{.864}{1.024}$$
$$= .842$$

APPENDIX VIII CONTINUED

$$D = \frac{N}{24} + \frac{1}{\pi} \text{Sin } N\,\pi/24$$
$$= \frac{12.95}{24} + .318 \sin \frac{12.95}{24} (\pi)$$
$$= .54 + .318 \sin 83$$
$$= .54 + .318\ (.99)$$
$$= .54 + .3145$$
$$= .855$$

$$E_a = .35\ (1 + .0098\ U_2)\ (e_a - e_d)$$
$$= .35\ (1.329)\ (8.06)$$
$$= 3.75$$

$$E_t = \frac{\Delta\ Ht + .27\ Ea}{\Delta + .27/SD}$$
$$= \frac{.58 \times 2.91 + .27 \times 3.75}{.58 + \frac{.27}{.855 \times .842}}$$
$$= \frac{1.69 + 1.012}{.58 + .374}$$
$$= \frac{2.702}{.954}$$

E_t = 2.635 mm/day

P.E.= .1036 in./day

Act. E_t = .75 x .1036 = .0778

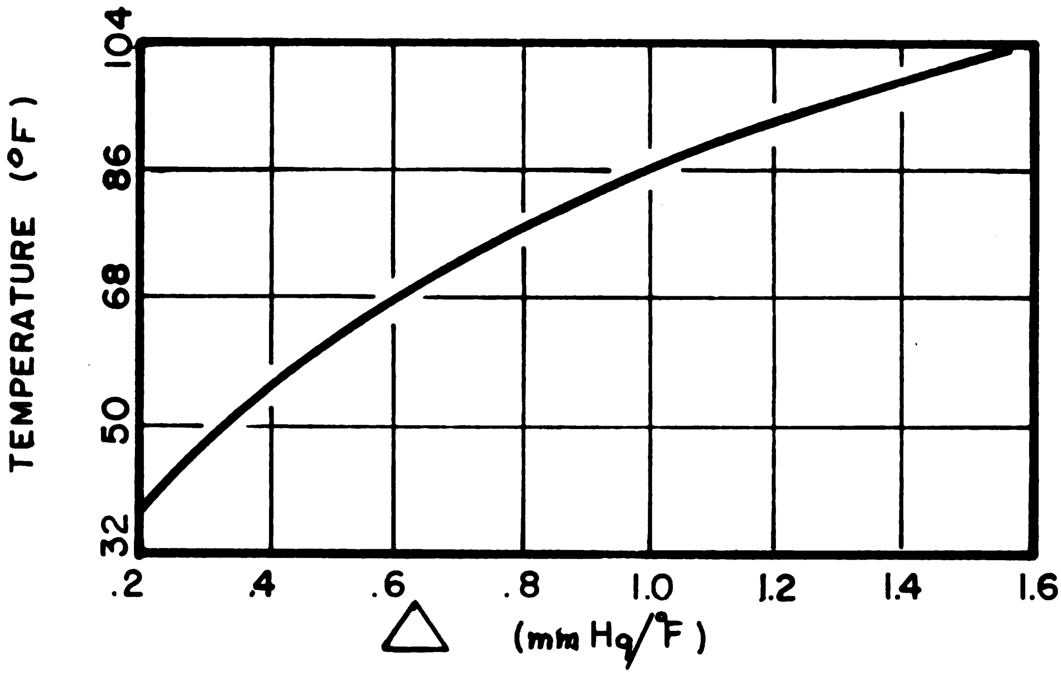
Act. E_t is rounded off to .078 as the data does not justify .0000 accuracy.

APPENDIX IX

Climatic Data:

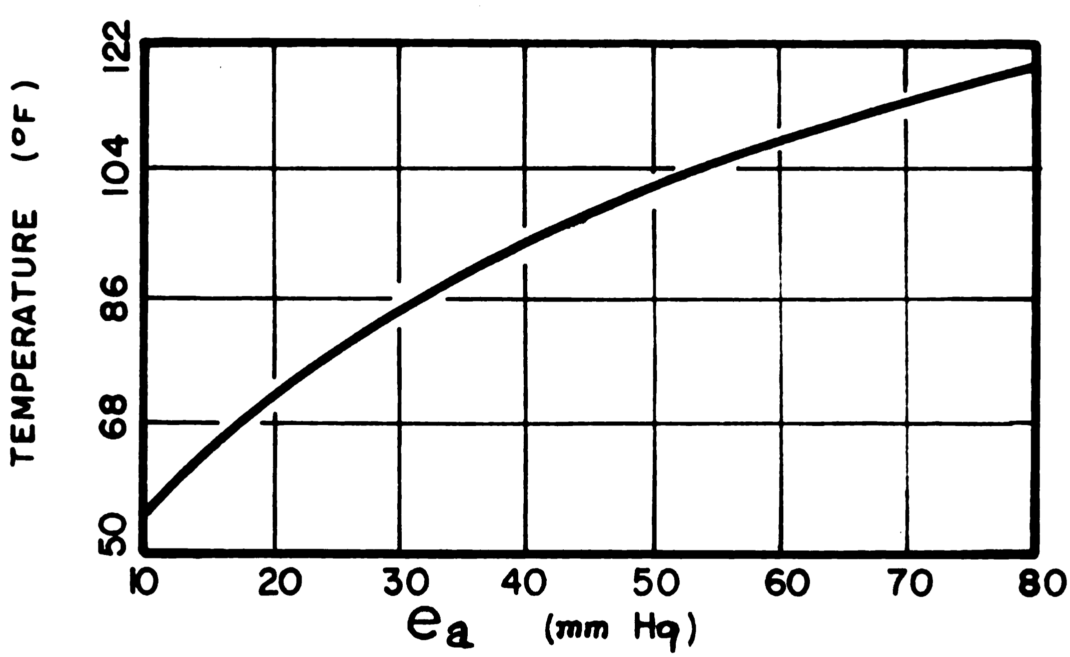
Week	Radiation gm-cal/cm²	Ra mm H_2O /day @ 43° lat.	$\frac{n}{N}$	N	t	R.H.	u_n MPD	actual Et in./day
1 7-9 7-14	522.8	16.3	71.4	15.10	69	64	97.3	.116
2	488.4	16.0	61.7	14.92	66	57	47.4	.098
3	572.5	15.6	84.4	14.70	70	50	66.0	.119
4	407.4	15.2	57.1	14.45	67	62	52.6	.083
5	431.9	14.8	65.8	14.17	70	63	55.8	.101
6	472.8	14.2	70.6	13.88	72	55	60.0	.103
7	422.0	13.7	66.3	13.60	60	50	56.8	.081
8	421.0	12.8	70.6	13.28	72	62	58.4	.082
9	462.0	12.2	77.0	12.95	66	52	57.4	.078
10	360.7	11.4	54.4	12.63	62	61	52.6	.059
11	352.7	10.8	68.7	12.28	52	54	78.7	.044
12 9-24 9-30	459.5	10.0	93.7	11.95	56	44	53.0	.055

APPENDIX X



A. TEMPERATURE VS. SLOPE OF SATURATED VAPOR PRESSURE CURVE.

(FROM REFERENCE 6.)



B. TEMPERATURE VS. SATURATION VAPOR PRESSURE.

(FROM REFERENCE 6.)

APPENDIX XI

Temperature °F	σT_a^4 mm H_2O/day*
35	11.48
40	11.96
45	12.45
50	12.94
55	13.45
60	13.96
65	14.62
70	15.09
75	15.65
80	16.25
85	16.85
90	17.46
95	18.10
100	18.80

* Heat of vaporization was assumed to be constant at 590 cal/gm of H_2O

(reference 6)

Thesis, M.S.
1960

Robert H. Wilkinson

DATE	ISSUED TO