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Determining the Transportation Rate of Peach Trees Under Two Trickle Irrigation Regimes

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IMPROVED WATER AND NUTRIENT MANAGEMENT THROUGH HIGH-FREQUENCY IRRIGATION

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Volume 3: Determining the Transporation Rate of Peach Trees Under Two Trickle Irrigation Regimes

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ABSTRACT

The scientific design and management of a modern irrigation system requires that the designer or manager have knowledge of site and plant criteria such as infiltration, drainage, soil fertility, plant water needs, and plant production under varying conditions. With modern trickle systems water control is very precise and thus precise information on irrigation needs of a crop allow for the optimal use of water supplies.

Work has been conducted on the effects of trickle irrigation on peach trees in North Central Texas. Initial data relating trickle irrigation amounts to total production, peach size, and plant growth have indicated that trickle irrigation may provide benefits that would offset costs of the irrigation system and water. Previous work however has related these benefits only to the amount of water applied through irrigation and did not consider the total water use of the tree.

Research was undertaken to determine the transpiration rate of peach trees under two trickle irrigation regimes. To determine the transpiration rate a volume of soil around the test trees was instrumented with neutron access tubes. Soil moisture depletion was measured weekly. A soil water balance was conducted equating evapotranspiration to the sum of the change in the soil moisture content (a decrease being positive) plus irrigation applied, plus any rainfall that occurred in the period.

For this work runoff and flux across the measurement zone boundaries was assumed zero. Estimates of evaporation from the soil surface were made using a two-stage evaporation process along with values of potential evapotranspiration made with the Penman (1956) equation. The estimates of evaporation from the soil surface were subtracted from total evapotranspiration to give estimates of the transpiration of the peach trees.

Estimates of transpiration were not consistent from one measurement period to the next. Errors in the estimation of evaporation from the soil surface directly affect the estimate of transpiration. During latter stages of a rain-free period an estimate of transpiration was made which should not have been influences by the low values of evaporation from the soil surface that existed. This method of estimating transpiration has many errors and can be much improved upon by using a method such as a lysimeter to estimate transpiration more accurately.

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CHAPTER I

INTRODUCTION

The use of trickle or drip irrigation systems for crops with small plant densities (500 plants per hectare), such as an orchard may reduce water and energy requirements. Other advantages of a drip/trickle irrigation system include: high degree of water control which reduces pest, weed, and disease problems; precise control of water and aeration conditions in the root zone; the ability to use small yield wells; and increased yields due to more effective use of water. The reduction of water and energy use with properly designed and managed trickle systems results from the slow application of water to the soil volume, the small surface wetted during an irrigation (thereby reducing surface water evaporation), and the low pressures required in a trickle system (generally less than 150 kPa).

Work by Reeder et al. (1979)* on trickle-irrigated peaches indicated additional advantages of trickle irrigation. These advantages included more pounds of fruit in the desired larger sizes, increased trunk growth, and greater potential productivity with trickle irrigation when compared to sprinkle irrigation. In comparing trickle treatments with different irrigation rates a trend was evident with higher trickle irrigation rates providing for increased fruit size and production. This research showed promise for the use of trickle irrigation on a peach orchard, but the results of the study could only be related to the irrigation amounts applied. The results were inconclusive since the total water use of each treatment was unknown (changes in the soil moisture storage were not measured). Therefore the researchers could interpret their data with only the water applications being known while the actual water use by the peach trees remained unknown.

It thus became necessary to determine the actual transpiration rate of peach trees under different irrigation regimes. The determination of the transpiration rate provides the basis for relating yield and plant growth characteristics to the total water use of a treatment.

Objective

The objective of this research was to determine quantitatively the transpiration rate of two trickle irrigation treatments in a peach orchard of North Central Texas.

Steps taken to achieve the objective were:

1. to determine the soil water content during the growing season under peach trees being trickle irrigated,
2. to calculate a running soil water balance during the growing season, and
3. to find the individual components of ET, E (surface water evaporation) and T (plant transpiration).

The objective of this research was attained by applying a soil water balance formula to the irrigation treatments and solving for ET. The water balance formula is (Tanner, 1967),

$$ET = \Delta SM + P + I - R - D \tag{1}$$

where

ET = evapotranspiration, mm
ΔSM = change in soil moisture, mm
P = precipitation, mm
I = irrigation, mm
R = runoff, mm
D = deep percolation, mm

Equation (1) is useful only if all the parameters except one can be controlled or measured, with the unknown parameter being the solution of the water balance. If facilities and equipment are not available for measuring or controlling all of these unknowns, then they must be estimated.

CHAPTER II

LITERATURE REVIEW

The research work done in the determination of transpiration covered many subjects of which a few are of primary importance. A literature review was conducted on several of these areas. These topics included: previous ET studies on peach trees, root and soil moisture distribution studies under trickle irrigation, the calculation of potential ET, the estimation of surface soil moisture evaporation, and the use of the neutron soil moisture method for the determination of the soil moisture content.

Root and Soil Moisture Distribution

Earl and Jury (1977) conducted tests on water movement from trickle sources under cropped soil conditions. They found that for a constant weekly irrigation volume, the plot irrigated once per week had much greater horizontal and vertical distribution than a similar plot irrigated three times per day. They found this had a pronounced effect on root development with the root system being more evenly distributed in the once per week irrigated plot than the daily irrigated plots where roots were concentrated under the emitter.

Observations in an apple orchard under trickle irrigation showed that soil moisture distribution in the orchard varied greatly. The greatest variability was between the rows rather than along the line of emitters (Groot Obbink and Alexander, 1977). Levin et al. (1974) in a trickle irrigated apple orchard found horizontal distribution of irrigation water was limited to approximately 117 cm (46 in), with the wetted area of the orchard being limited to only 35 to 65 percent of the total orchard area.

Willoughby and Cockroft (1974) observed the root changes of peach trees under trickle irrigation. They found the greatest concentration of live roots 300 to 600 mm (12 to 14 in) from the emitter. They pointed out that poor aeration retarded root growth along with killing some roots directly beneath the emitter. Bartholic et al. (1976) found most of the water removed by a peach tree was from the surface 0.61 m (2 ft).

ET Studies of Peach Trees

Bartholic et al. (1976) used a soil water balance based on soil moisture depletion measurements to determine the ET of a sprinkler irrigated peach orchard in Florida. The calculated ET was 0.7 of the pan evaporation in the orchard during the summer and 0.3 pan in the fall when the trees were bare and the orchard grass cover had died. During the month of May (drought month) they recorded a maximum ET of 15.4 cm (6 in) and a pan evaporation of 24.5 cm (9.6 in). The minimum ET was in January when an ET of 3.9 cm (1.6 in) and a pan evaporation of 6.4 cm (2.5 in) was recorded. Buchanan and Harrison (1974) found that the ET in a trickle irrigated peach orchard varied from 2.0 mm (0.08 in) per day at pre-bloom to a value of 5.1 mm (0.2 in) per day at harvest. Harrison et al. (1976) found that ET in a trickle irrigated peach orchard varied from 1.0 mm (0.04 in) in February and

March up to 4.3 mm (0.17 in) per day in May prior to harvest, but dropped back down to 2.5 mm (0.10 in) per day immediately after harvest.

Surface Evaporation and Potential ET

While the soil water balance will provide estimates of ET, it is also desirable to separate ET into its individual components and to also know the potential ET (PET) at the site. To separate ET into its components, evaporation (E) from the soil surface and transpiration (T) from the plant canopy, would involve the calculation of either E or T. Evaporation from the soil surface can be estimated. The general method for accounting surface evaporation is a two-stage method (Ritchie, 1972; Richardson and Ritchie, 1973; Tanner and Jury, 1976). In stage one, the surface is always wet, so evaporation is limited only by the evaporative potential of the atmosphere. In stage two, the surface evaporation is restricted by the soil water content near the surface and the water transmission characteristics of the soil. The point at which evaporation from the soil surface enters stage two is defined by an upper limit of cumulative evaporation from an initially wet soil (U). An initially wet soil will evaporate water from the surface at the potential rate until U is reached at which time evaporation from the surface enters stage two. Stage two cumulative evaporation can be approximated by

$$Es_2 = \alpha t^{\frac{1}{2}} \qquad (2)$$

where α is a constant dependent on the hydraulic properties of the soil in mm/day$^{\frac{1}{2}}$, and t is time in days since the start of stage two evaporation. Ritchie (1972) lists values for the upper limit of cumulative evaporation from an initially wet soil and the stage two soil constant for four soil types. Since these constants are dependent upon the soil water holding capacity and soil water transmissibility characteristics of the soil, the constant will vary with varying soil types.

In computing surface evaporation it is necessary to know the potential ET at the soil surface. The evaporation from the soil surface would equal the PET rate when the evaporating surface is wet. This places no constraints upon the transport of water to the soil surface. Thus, the PET can be defined for any evaporation surface by its radiative and aerodynamic properties and the local micrometeorological conditions (Van Bavel, 1966). Many methods to calculate PET exist, but those methods most used are the methods of Penman (1956), Van Bavel (1966), and Priestley and Taylor (1972). Potential evapotranspiration equations have been used extensively in computer programs developed to estimate plant transpiration and evaporation from the soil surface using climate, crop and soil data. Ritchie (1972) used the Penman combination equation which neglects soil heat flow with an empirical wind function as presented by Penman (1956). Richardson and Ritchie (1973) used the Penman (1956) equation in their model. They originally used the combination equation of Van Bavel (1966), but found that it gave values of PET higher than the measured evapotranspiration when the plants in their study were evaporating at the potential rate.

Neutron Soil Moisture Method

Changes in soil moisture storage may be measured by several techniques, but the neutron method had several advantages over other techniques. Visvalingam and Tandy (1972) discussed the theory of operation of the neutron moisture meter. The neutron moisture method measures the soil moisture content by measuring the hydrogen content in the soil with fast neutrons. Advantages of the neutron soil moisture method found in Van Bavel et al. (1961), Visvalingam and Tandy (1972), and Tanner (1967) are:

1. soil moisture is measured regardless of its physical state;
2. measurements can be taken at any depth;
3. measurements are made on the same soil throughout the year (i.e., it is non-destructive sampling);
4. measurements at short time intervals allow for detection of rapid soil moisture change;
5. the water volume fraction is measured directly; and
6. measurements of soil moisture involve a large volume of soil.

In using a neutron moisture probe to determine soil moisture, Calder (1976) pointed out several difficulties which may occur:

1. thermal effects on the probe count rate,
2. errors in neutron probe depth location,
3. errors in neutron probe random counting,
4. random areal variability of root-water

extraction, and

5. random areal variability of net-rainfall distribution.

The accuracy of the neutron method depends upon the derivation of a regression curve relating neutron counts to moisture content. Basically two methods of calibration exist: laboratory and field. In a laboratory calibration, a prepared large volume of soil at a set moisture content is measured to achieve a neutron count. Several containers of soil at different moisture contents are measured to provide the data necessary for the regression curve. In a field calibration, counts are taken at the field site. The moisture content of the soil is then determined by some other direct method, usually gravimetric sampling. The laboratory method of calibration is the most accurate of the two methods, however the field method is often preferred due to its practicality.

CHAPTER III

METHODS AND PROCEDURES

Description of Test Plots and Treatments

The research was conducted at the Texas Fruit Research and Demonstration Station, Montague, Texas. The site is operated by the Texas Agricultural Experiment Station. Two test plots were installed on nine-year-old Redglobe peach trees in the spring of 1978. The trickle irrigation system had been in place since 1973 with the orchard being divided into several different irrigation regimes. Treatment I consisted of one emitter per tree. Water was applied at one-half the calculated consumptive use rate. The calculated consumptive use rate was set as six-tenths of the total pan evaporation for one week (Kenworthy, 1972). The irrigation water applied was calculated for the area covered by the tree canopy (determined to be approximately twenty percent of the orchard surface area with a 9m by 9m tree spacing). The irrigation water was then applied the following week. The treatment plots were irrigated daily in midsummer and four times a week when lower irrigation amounts were needed. Irrigations were timed to start in late afternoon so as not to interfere with neutron measurements. Treatment II consisted of two emitters per tree supplying water at the calculated consumptive use rate.

These two treatments were chosen based on the results of work by Reeder et al. (1979). Their work showed that trees with Treatment II irrigation had a higher crop potential (based on length of budstick and number of flowerbuds per budstick) than would Treatment I. The total irrigation applied to the trickle irrigation treatments was not reported along with pan evaporation. This work suggested that Treatment II provided sufficient irrigation water to meet the plant needs for good production. It was hypothesized that Treatment I would give a water deficit with a resulting decrease in production.

The trees were spaced 9 m by 9 m (30 ft by 30 ft) with east-west rows. Irrigation lateral lines were 15 mm (½ in) polyethylene with 0.91 mm (0.36 in) inside diameter microtubes. Emitters were approximately 0.9 m (3 ft) from the base of the tree on one or two sides depending upon the number specified per tree. The soil profile consisted of a sand layer approximately 24 cm in depth. Below the sand layer the profile consisted of heavy clay.

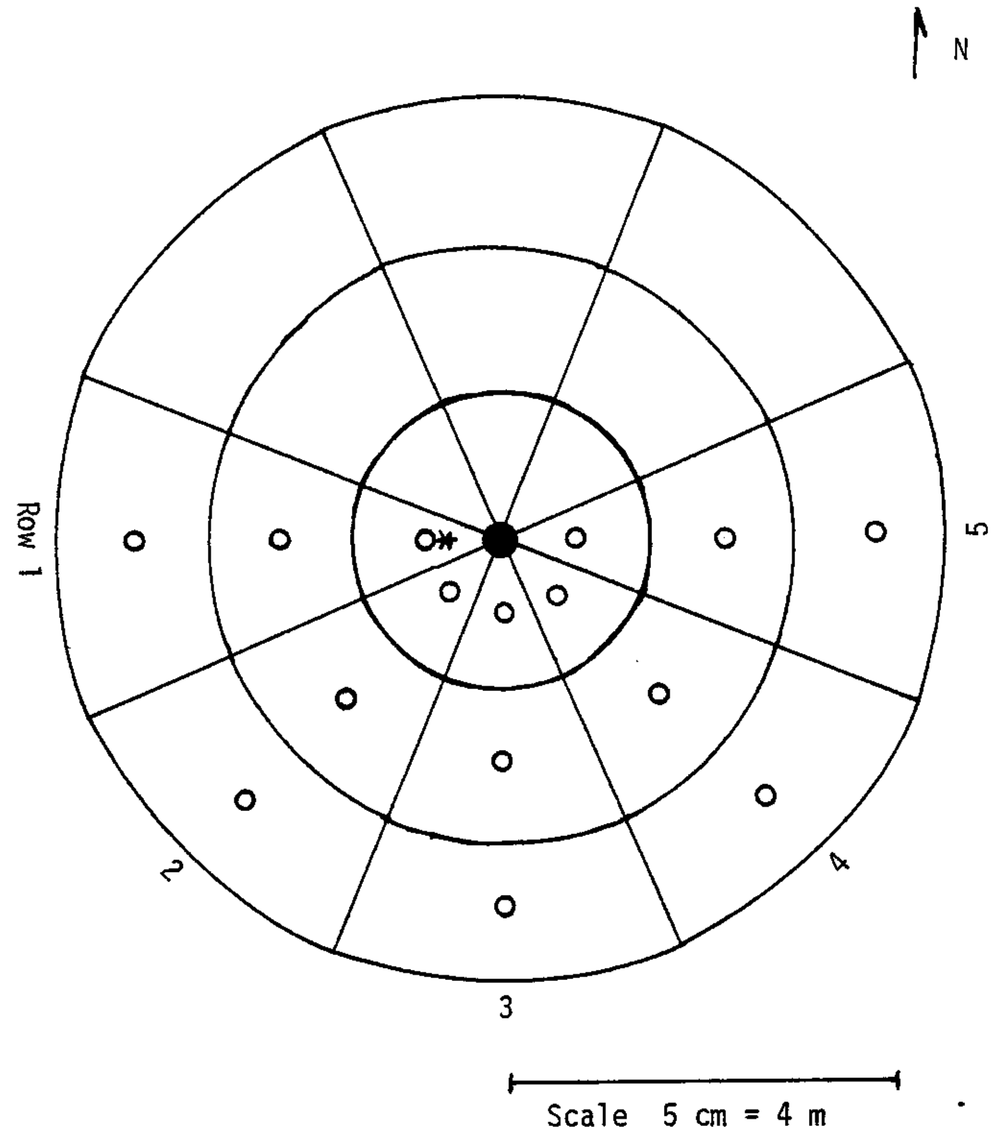
The emitter flow rate was approximately 6.3 liter/hour (2.5 gpm). The emitter flow rate was checked throughout the irrigation season. The irrigation schedule was adjusted to account for differences in the emitter flow rate. The trickle system was fully automated and controlled by time clocks. The time clocks were set to provide the irrigation timing to apply the calculated irrigation required. Irrigation water was supplied from a shallow (less than 33 m) ground water well. Water was pumped from the well into a surface storage pond. Separate pumps were used for the trickle system. The groundwater well was low-yielding and could not keep up with high irrigation demands at some times in the irrigation season.

Instrumentation

Thin-wall aluminum access tubing with an outside diameter of 4 cm (1.6 in) was installed to a depth of approximately 160 cm (63 in). Treatments I and II were each instrumented with fifteen neutron tubes in five rows of three tubes each. The tubes were laid out in a semicircle on the south side of the tree with the first and fifth rows placed along the tree row and the second, third, and fourth rows extending out at forty-five degrees, ninety degrees and one-hundred thirty-five degrees from the tree row (see Figure 1 for a description of the experiment plot layout). Only one-half of the soil volume was instrumented around these trees. It was assumed during the course of the field work that the water distribution, movement, and uptake was symmetrical around the tree row. This was necessary to reduce the number of measurements to be recorded. The three tubes in each row were placed 0.76 m (2.5 ft), 2.29 m (7.5 ft), and 3.81 m (12.5 ft) from the tree base. Neutron readings were taken at 10 cm (3.9 in) increments from 10 cm (3.9 in) to the 150 cm (59 in) depth inclusive.

The large number of neutron tubes and readings taken were necessitated by the wetting pattern from a trickle source. To observe the three-dimensional pattern developed from a trickle source, neutron access tubes were placed so that changes in moisture content could be measured with respect to depth, distance from the source, and location around the source.

The moisture content at each depth was determined from the appropriate calibration curve of the neutron probe using the count rate



○ Neutron access tubes

● Tree

✱ Emitter

Fig. 1. Plot layout.

(actual counts to standard counts). The moisture content found was on a percent volume basis. The total water volume at a depth was calculated by multiplying the moisture content at the depth in question by the appropriate volume of soil that the moisture content was determined to represent. That volume was the area around the tree that the tube in question represented times the thickness of the measurement volume (5 cm (2.1 in) on either side of the probe center for the 20 cm to 150 cm depths). At the 10 cm (4 in) position the thickness of the volume was taken to be the 10 cm (4 in) above the probe center plus the 5 cm (2 in) below. The total water volume in the measurement zone was found by integrating the water content over the area and depth.

Climatological Measurements

Weather data were collected at a weather station located on the experiment station approximately 400 m from the test plots. Daily maximum and minimum temperatures were recorded with thermometers mounted in a standard U.S.W.B. cotton-region shelter approximately 1.5 m above the soil surface. Free water surface evaporation was recorded from a U.S.W.B. three-cup anemometer equipped with a totalizing recorder. The anemometer was located approximately 61 cm above the soil surface at the evaporation pan. Total daily solar radiation was measured with an Eppley pyranometer (model 8-48, instrument constant 11.79 x 10^{-6} J (W/m^2)) coupled to a LI-COR LI-510 integrator. Daily rainfall was measured by a U.S.W.B. standard 20.3 cm (8 in) diameter rain gauge.

Neutron Probe Calibration

The neutron probe was field calibrated on April 26, 1979, adjacent to the treatment plots. Several aluminum access tubes were installed alongside the two-emitter plot. One of the tubes was used as installed. The remaining tubes were installed and had a small border built around them so that the neutron tube was in the center of a 1.2 m (4 ft) diameter basin. One basin was flood irrigated with 5.1 cm (2 in) of water and the other basin was flooded with 10.2 cm (4 in) or water. This, it was hoped, would provide a sufficient variation in soil moisture content to provide for the development of calibration curves. Neutron readings (counts per minute) were taken at 10, 14, 40, 50, 60, and 74 cm depths. This provided data for two calibration lines; one curve for the sand layer and one for the clay. Simultaneously with the neutron reading, an undisturbed core sample was taken at the same depth within 12.7 cm of the access tube. Soil moisture on a volume basis and bulk density were determined by gravimetric analysis. The calibration data obtained on this date was of a high moisture content (compared to the actual field data) and did not cover a sufficient range of moisture contents so as to provide a calibration curve over a wide range of moisture conditions. Therefore, additional neutron probe measurements along with volumetric soil samples were obtained on July 24, 1979, when low values of soil moisture content were present. The data from these two dates provided data points over a range of soil moisture contents comparable to the soil moisture contents observed in the field data. The neutron probes used in this research were Troxler N105A probes with a Am-Be source in an aluminum shield, operated with a Troxler Model 600 portable scaler.

Calculation of Potential ET

For the purpose of this research a method was needed for calculating PET using only the basic meteorological data of: 1) daily maximum and minimum temperatures, 2) daily solar radiation, 3) average dew point temperature, and 4) daily wind run at a known height. Therefore the Penman (1956) combination equation was used.

The Penman (1956) equation may be written

$$PET = (\Delta RN + \gamma Ea) / (\Delta + \gamma) \qquad (3)$$

with values of Ea given by

$$Ea = 0.262\ (e_a - e_d)\ (1 + 0.0061\ U_2) \qquad (4)$$

where,

Δ = the slope of the saturated vapor pressure curve, mb/°c

γ = the psychrometric constant, mb/°c

RN = net radiation, mm/day

Ea = a measure of the drying power of the air, mm/day

e_a = the saturation vapor pressure, mb

e_d = the actual vapor pressure of the air, mb

U_2 = the wind speed at 2m, km/day

This equation neglects soil heat flux. This is due to the fact that calculations are made over a 24-hour time period, and that over this period the net soil heat flux is assumed to be zero.

Estimation of Surface Soil Moisture Evaporation

Soil surface water evaporation takes place in two stages: the constant and falling rate stages as outlined by Ritchie (1972). In stage one, when the soil is wet, the evaporation rate at the surface (E_{s1}) is equal to the PET at the surface, until a cumulative stage one evaporation limit (U) is reached. Therefore for stage one,

$$E_{s1} = PET \qquad 0 \leq E_{s1} \leq U \tag{5}$$

In stage two, the evaporation from the soil surface is dependent on the hydraulic characteristics of the soil and becomes less with higher cumulative evaporation. The falling rate stage evaporation (E_{s2}) can be expressed as

$$E_{s2} = \alpha t^{\frac{1}{2}} \tag{6}$$

where α is a soil water evaporation parameter dependent on soil water transmission characteristics expressed as mm per square root of time in days and t is the time after the beginning of stage two expressed in days. Due to the sandy surface layer, values for α and U were selected from the empirical values Ritchie presented to be 3.34 mm/day$^{\frac{1}{2}}$ and 6 mm, respectively. In the application of these equations to the field conditions that existed, the orchard surface was divided into three area classifications for which separate stage one and stage two evaporation rates were calculated. The first area to be considered was the surface area of the peach orchard wetted by the emitter (s). This surface was almost continually wetted (depending upon the exact irrigation schedule) and thus nearly always stayed in stage one. This area was under the peach canopy and was therefore shaded during part of the day. The second area to be considered was the remaining area under the tree canopy with a reduced PET, but was subject to wetting only through rainfall. The third and largest surface area was the area outside of the tree drip line. This area was completely bare and had a minimum amount of shading in early morning and late afternoon.

CHAPTER IV

RESULTS

To reach the final objective of determining the transpiration rate of two trickle irrigation regimes an orderly sequence of steps was undertaken beginning with the calibration of the neutron probe to the final determination of transpiration. The sequence began with the determination of appropriate calibration curves for the neutron probe. Using these calibration curves the soil moisture depletion could be calculated from the calculated field data. The next step was to measure ET. The measurement of ET is accomplished using two primary methods: 1) the water balance method; and 2) microclimatological methods. The water balance methods include measurements or controls from natural catchment hydrology, and soil water depletion sampling. For this research the soil water balance was calculated by soil water depletion measurements made by the neutron method, with ET being the sum of the measured soil moisture depletion in the profile, irrigation, and rainfall.

The next step was the estimation of surface soil moisture evaporation using the Penman equation to calculate PET and a two-stage empirical process for estimating the evaporation of the surface soil water. Using the measured value of ET and the estimated value of E and subtracting the value of E from ET, the final step is achieved; the solution for plant transpiration. These steps will now be discussed in more detail.

Neutron Probe Calibration Curves

Figure 2 shows the results of the neutron probe calibration curve for the sand layer (0-25 cm). The sand layer corresponds also to the measurement zone in which there is a significant loss of fast neutrons to the atmosphere, thus biasing the calibration curve. The calibration procedure resulted in a calibration equation for the surface zone (sand layer) of:

$$\theta s = 0.02 + 0.30 * CR \tag{7}$$

where

θs = soil moisture content, fraction volume basis

CR = count ratio (ratio of measurement count to standard count).

Figure 2 also gives the neutron probe calibration curve for the clay layer (25-150 cm). All measurements in this zone were deep enough to be unaffected by the loss of neutrons to the atmosphere. The calibration equation for the clay zone was:

$$\theta s = -0.09 + 0.51 * CR \tag{8}$$

The intercept value for the sand layer calibration curve is most definitely wrong. However it would be in the range of error in the calculation of the curve from gravimetric sampling. A negative number as the intercept is in agreement with the theory of operation of the neutron probe. A negative slope was obtained for the clay layer, thus properly reflecting the influence of background hydrogen on the count ratio. At a zero moisture content the meter would still record the effects of background hydrogen and this is reflected in the

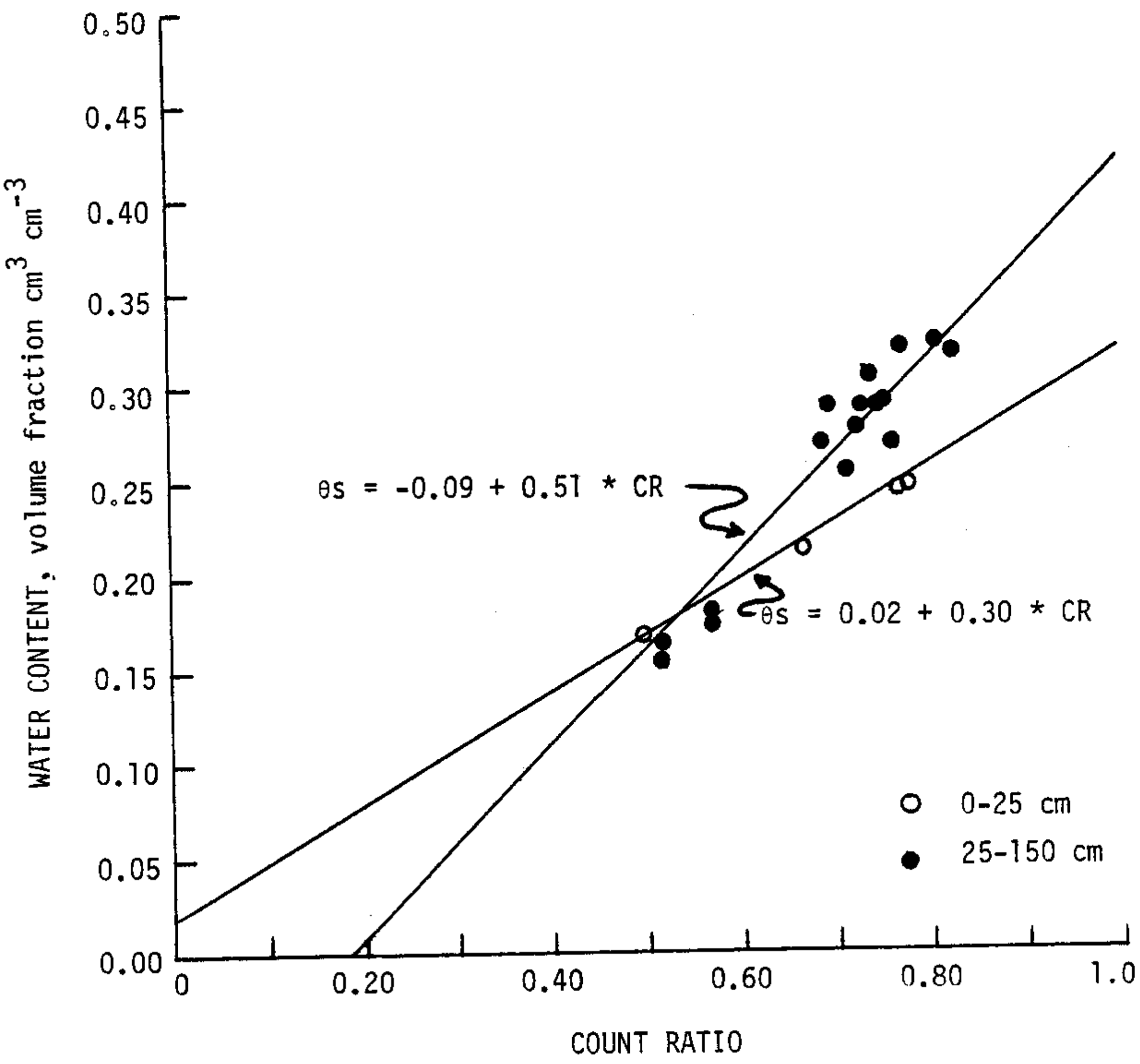


Fig. 2. Calibration curve for neutron soil moisture probe.

calibration curve for the clay layer.

Soil Water Depletion

Neutron probe measurements were begun in mid April of 1978 and continued throughout the growing season. Table 1 presents the results of the neutron probe measurements for Treatment I. As can be seen, the total soil moisture in the profile runs from a high of 383 mm on Julian day 102 to a low of 303 mm on day 202. The soil moisture slowly increases from then until it reached 318.2 mm on day 236. This occurrence is due to the fact that from day 195 to day 202 a rain-free period existed. Thereafter several rainfall events were recorded with a resulting increase in soil moisture. The soil moisture in the top 35 cm varied from a high on day 102 with 81.0 mm, decreased to 42.2 mm on day 202, and then increased to 54.6 mm on day 236. This again shows the extraction that occurred during the rain-free period, with an increase in surface soil moisture with the return of rainfall events after day 202. The soil water depletion data also shows that the soil moisture in the 125 cm to 155 cm layer varied from 76.8 mm to 74.9 mm. This slight change helps support an assumption of negligible deep percolation since a constant total soil moisture indicates either no changes or else a constant flux across this layer. For a clay soil the field capacity would be approximately 30 percent. This would give a water contentat field capacity of 90 mm for this layer. The values for this layer are below 90 mm so that gravity drainage can be ruled out. This result and the limited quantity of water applied by the trickle emitter provides high confidence in the

Table 1. Soil Moisture Depletion. Treatment I.

Julian Day	
103	Total Soil Water = 383.0 mm Soil Water Layer 1 = 81.0 mm Soil Water Layer 2 = 84.8 mm Soil Water Layer 3 = 70.7 mm Soil Water Layer 4 = 71.1 mm Soil Water Layer 5 = 75.4 mm
137	Total Soil Water = 360.7 mm Soil Water Layer 1 = 65.2 mm Soil Water Layer 2 = 77.9 mm Soil Water Layer 3 = 69.7 mm Soil Water Layer 4 = 73.0 mm Soil Water Layer 5 = 74.9 mm
157	Total Soil Water = 357.9 mm Soil Water Layer 1 = 70.7 mm Soil Water Layer 2 = 71.7 mm Soil Water Layer 3 = 67.3 mm Soil Water Layer 4 = 72.7 mm Soil Water Layer 5 = 75.6 mm
163	Total Soil Water = 351.8 mm Soil Water Layer 1 = 69.3 mm Soil Water Layer 2 = 69.8 mm Soil Water Layer 3 = 65.3 mm Soil Water Layer 4 = 72.1 mm Soil Water Layer 5 = 75.4 mm
177	Total Soil Water = 322.6 mm Soil Water Layer 1 = 48.2 mm Soil Water Layer 2 = 62.7 mm Soil Water Layer 3 = 62.7 mm Soil Water Layer 4 = 72.7 mm Soil Water Layer 5 = 76.4 mm
179	Total Soil Water = 319.6 mm Soil Water Layer 1 = 47.5 mm Soil Water Layer 2 = 61.3 mm Soil Water Layer 3 = 63.8 mm Soil Water Layer 4 = 71.6 mm Soil Water Layer 5 = 75.5 mm

Table 1. (continued)

Julian Day	
195	Total Soil Water = 308.4 mm Soil Water Layer 1 = 44.2 mm Soil Water Layer 2 = 58.4 mm Soil Water Layer 3 = 58.5 mm Soil Water Layer 4 = 71.8 mm Soil Water Layer 5 = 75.5 mm
200	Total Soil Water = 303.7 mm Soil Water Layer 1 = 42.0 mm Soil Water Layer 2 = 55.3 mm Soil Water Layer 3 = 58.2 mm Soil Water Layer 4 = 72.1 mm Soil Water Layer 5 = 76.0 mm
202	Total Soil Water = 303.0 mm Soil Water Layer 1 = 42.2 mm Soil Water Layer 2 = 55.0 mm Soil Water Layer 3 = 57.8 mm Soil Water Layer 4 = 72.1 mm Soil Water Layer 5 = 75.9 mm
209	Total Soil Water = 309.2 mm Soil Water Layer 1 = 47.9 mm Soil Water Layer 2 = 55.4 mm Soil Water Layer 3 = 57.7 mm Soil Water Layer 4 = 71.9 mm Soil Water Layer 5 = 76.4 mm
223	Total Soil Water = 311.3 mm Soil Water Layer 1 = 50.3 mm Soil Water Layer 2 = 55.7 mm Soil Water Layer 3 = 56.8 mm Soil Water Layer 4 = 71.7 mm Soil Water Layer 5 = 76.5 mm
236	Total Soil Water = 318.2 mm Soil Water Layer 1 = 54.6 mm Soil Water Layer 2 = 57.2 mm Soil Water Layer 3 = 57.2 mm Soil Water Layer 4 = 72.5 mm Soil Water Layer 5 = 76.8 mm

assumption of negligible deep percolation. However, the possibility of upward movement into the profile exists and remains a possible complicating factor in the results of this work. Since it was not possible to quantitatively show there is no upward movement present, the assumption was made that this variable was indeed zero. Table 1 also shows that in the 95 to 125 cm layer, the total soil moisture only changed 1.9 mm. This supports an absence of water extraction or deep percolation through this deeper zone. Therefore for Treatment I, soil moisture measurements indicate that the area of water movement exists in the 0-95 cm layer.

The soil moisture depletion for Treatment II is shown in Table 2. Measurements for Treatment II were not started until day 137. The total soil moisture varied from a high of 395.4 mm on day 163 to a low of 315.8 mm on day 209. From this point the moisture increased to 336.6 mm on day 236. Treatment II follows the pattern seen in Treatment I where soil moisture decreased until the end of the dry spell at which point the soil moisture slowly increases. The 125 to 155 cm layer varied in soil moisture from 83.0 to 79.1 mm or a difference of 3.9 mm. This was less than a 5 percent change and supported the assumption of negligible flux. The variation of the 95-125 cm layer from 74.1 to 79.0 mm was a 6.6 percent change and was considered to be an acceptable change. This change in the 95-125 cm layer indicates there is more movement into and out of the 95-125 cm layer in Treatment II than in Treatment I.

A contour plot of the change in soil moisture for access tube rows 1 and 5 for Treatment I between days 165 and 200 is shown in

Table 2. Soil Moisture Depletion. Treatment II.

Julian Day	
137	Total Soil Water = 374.3 mm Soil Water Layer 1 = 76.9 mm Soil Water Layer 2 = 78.2 mm Soil Water Layer 3 = 65.9 mm Soil Water Layer 4 = 74.2 mm Soil Water Layer 5 = 79.1 mm
157	Total Soil Water = 395.3 mm Soil Water Layer 1 = 87.9 mm Soil Water Layer 2 = 78.8 mm Soil Water Layer 3 = 68.7 mm Soil Water Layer 4 = 78.2 mm Soil Water Layer 5 = 81.7 mm
163	Total Soil Water = 395.4 mm Soil Water Layer 1 = 85.7 mm Soil Water Layer 2 = 78.7 mm Soil Water Layer 3 = 69.1 mm Soil Water Layer 4 = 79.0 mm Soil Water Layer 5 = 82.9 mm
165	Total Soil Water = 382.0 mm Soil Water Layer 1 = 80.1 mm Soil Water Layer 2 = 76.1 mm Soil Water Layer 3 = 67.1 mm Soil Water Layer 4 = 77.6 mm Soil Water Layer 5 = 81.1 mm
177	Total Soil Water = 359.6 mm Soil Water Layer 1 = 62.7 mm Soil Water Layer 2 = 70.9 mm Soil Water Layer 3 = 64.0 mm Soil Water Layer 4 = 79.0 mm Soil Water Layer 5 = 83.0 mm
179	Total Soil Water = 351.9 mm Soil Water Layer 1 = 60.4 mm Soil Water Layer 2 = 68.8 mm Soil Water Layer 3 = 62.4 mm Soil Water Layer 4 = 77.7 mm Soil Water Layer 5 = 82.0 mm
195	Total Soil Water = 329.3 mm Soil Water Layer 1 = 52.5 mm Soil Water Layer 2 = 61.2 mm

Table 2. (continued)

Julian Day	
	Soil Water Layer 3 = 57.0 mm Soil Water Layer 4 = 76.5 mm Soil Water Layer 5 = 82.1 mm
200	Total Soil Water = 319.0 mm Soil Water Layer 1 = 49.8 mm Soil Water Layer 2 = 58.4 mm Soil Water Layer 3 = 54.0 mm Soil Water Layer 4 = 75.6 mm Soil Water Layer 5 = 81.2 mm
202	Total Soil Water = 316.4 mm Soil Water Layer 1 = 49.0 mm Soil Water Layer 2 = 57.4 mm Soil Water Layer 3 = 53.4 mm Soil Water Layer 4 = 75.4 mm Soil Water Layer 5 = 81.3 mm
209	Total Soil Water = 315.8 mm Soil Water Layer 1 = 51.9 mm Soil Water Layer 2 = 56.7 mm Soil Water Layer 3 = 52.0 mm Soil Water Layer 4 = 74.6 mm Soil Water Layer 5 = 80.6 mm
220	Total Soil Water = 325.2 mm Soil Water Layer 1 = 62.7 mm Soil Water Layer 2 = 56.7 mm Soil Water Layer 3 = 51.3 mm Soil Water Layer 4 = 74.3 mm Soil Water Layer 5 = 80.3 mm
222	Total Soil Water = 324.9 mm Soil Water Layer 1 = 62.0 mm Soil Water Layer 2 = 56.7 mm Soil Water Layer 3 = 51.4 mm Soil Water Layer 4 = 74.5 mm Soil Water Layer 5 = 80.4 mm
236	Total Soil Water = 336.6 mm Soil Water Layer 1 = 68.6 mm Soil Water Layer 2 = 61.0 mm Soil Water Layer 3 = 52.5 mm Soil Water Layer 4 = 74.1 mm Soil Water Layer 5 = 80.3 mm

Figure 3. This plot shows the changes that occurred between days 163 and 200. Day 163 was the beginning of the dry period and day 200 was three days before any additional rainfall. In this plot, the extraction and surface drying are evident. Also on the side of the tree opposite the emitter the extraction is greater than on the emitter side which is moderated by the constant inflow of water to the soil. The extraction pattern illustrates that the top 50 cm of soil is the zone of most significant extraction. The lower limit of extraction is about 80 cm.

Rows 2 and 4 are plotted in Figure 4. Extraction is present in the top 50 cm again but is much less in row 4 than was present in rows 1 and 5. Row 2 which is close to the emitter has very little net extraction. Figure 5 is a plot of row 3 with the data of row 3 duplicated since symmetry about the tree row is assumed. The extraction by roots was greatest near the tree and diminished outward from the tree base. The extraction occurred in the top 80 cm. A higher concentration of roots was indicated near the base of the tree than at the outer access tube. This suggests that root development is greatest near the tree base and in the tree row where there was no tillage.

Treatment II, rows 1 and 5, is plotted in Figure 6 for the interval between days 163 and 200 (the dry period). The profile indicates a very extensive and uniform extraction pattern throughout the profile down to a depth of 90 cm. This contrasts sharply with the one-sided extraction that occurred for Treatment I. Another extensive extraction pattern similar to the one in Figure 6 for rows 2 and 4 is

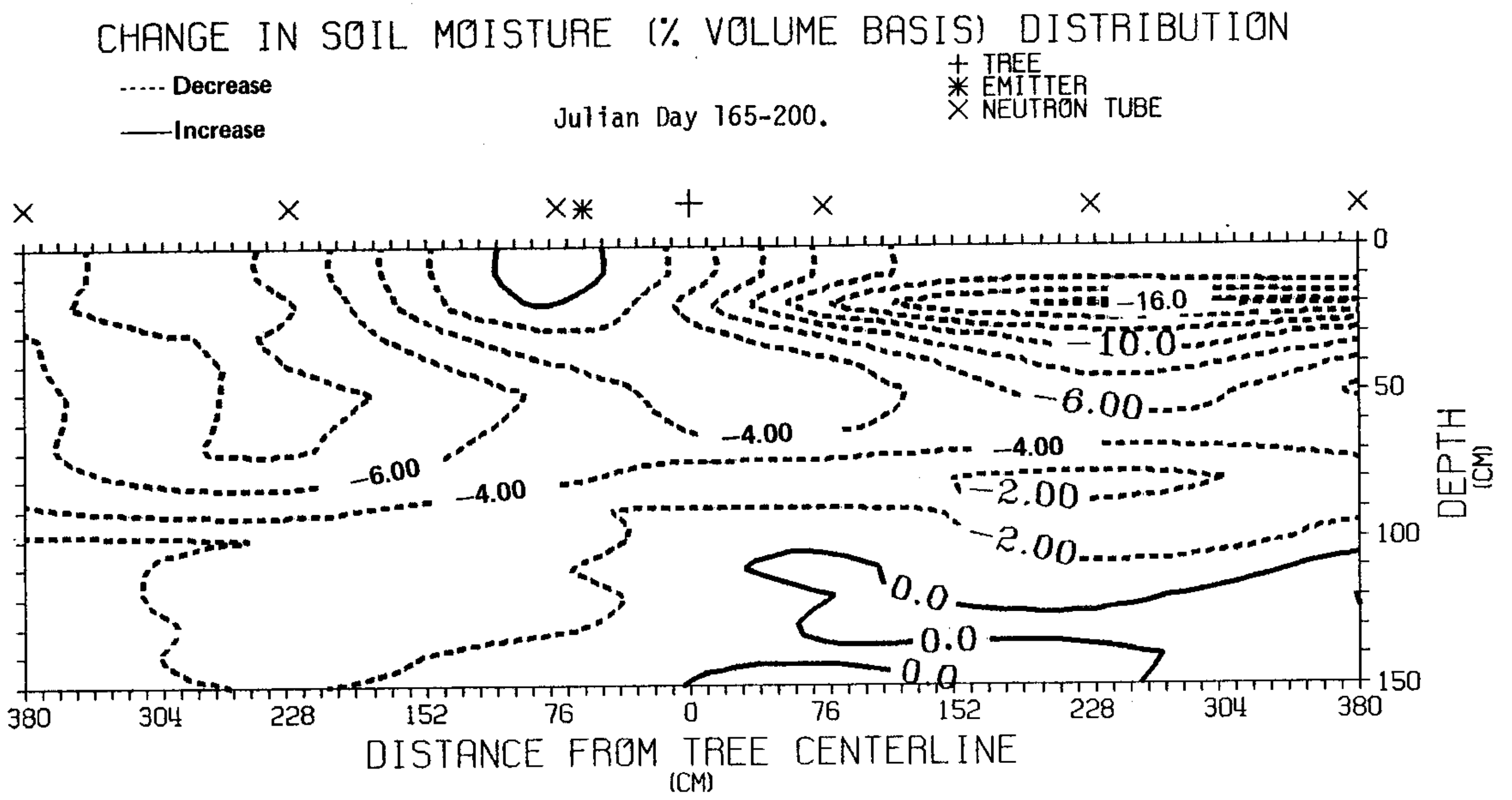


Fig. 3. Treatment I. Soil moisture profile. Row 1-5.

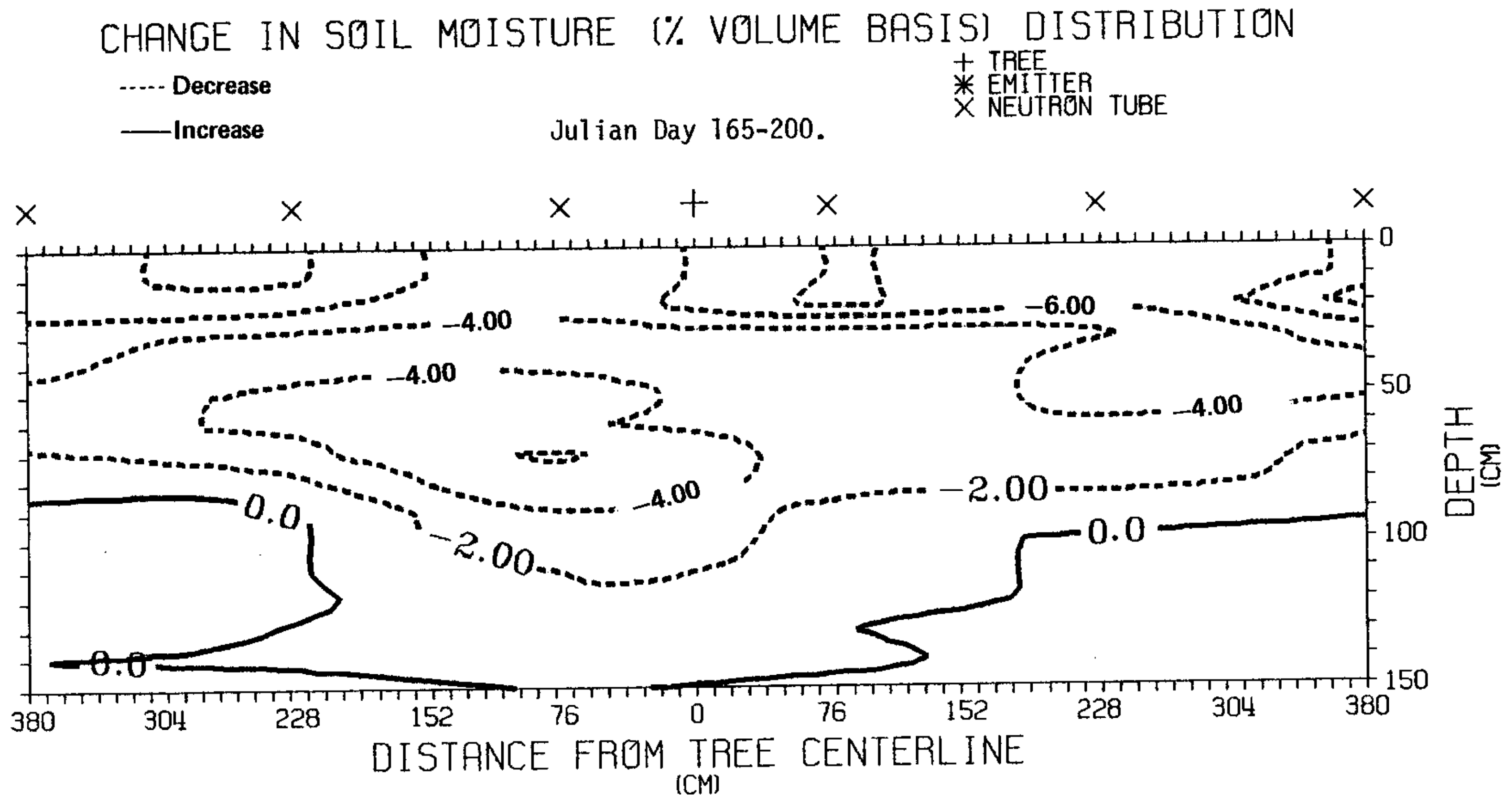


Fig. 4. Treatment I. Soil moisture profile. Row 2-4.

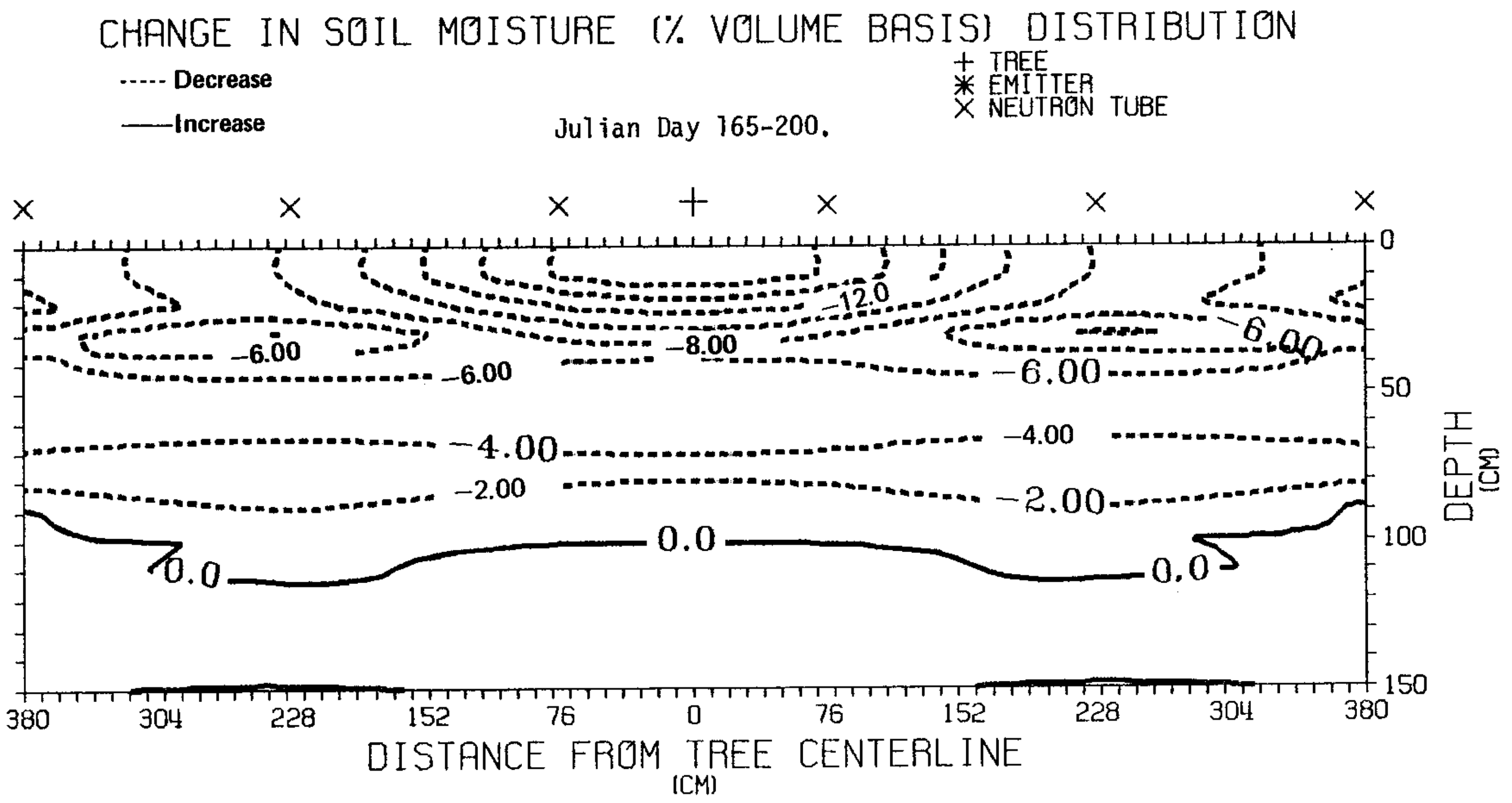


Fig. 5. Treatment I. Soil moisture profile. Row 3-3.

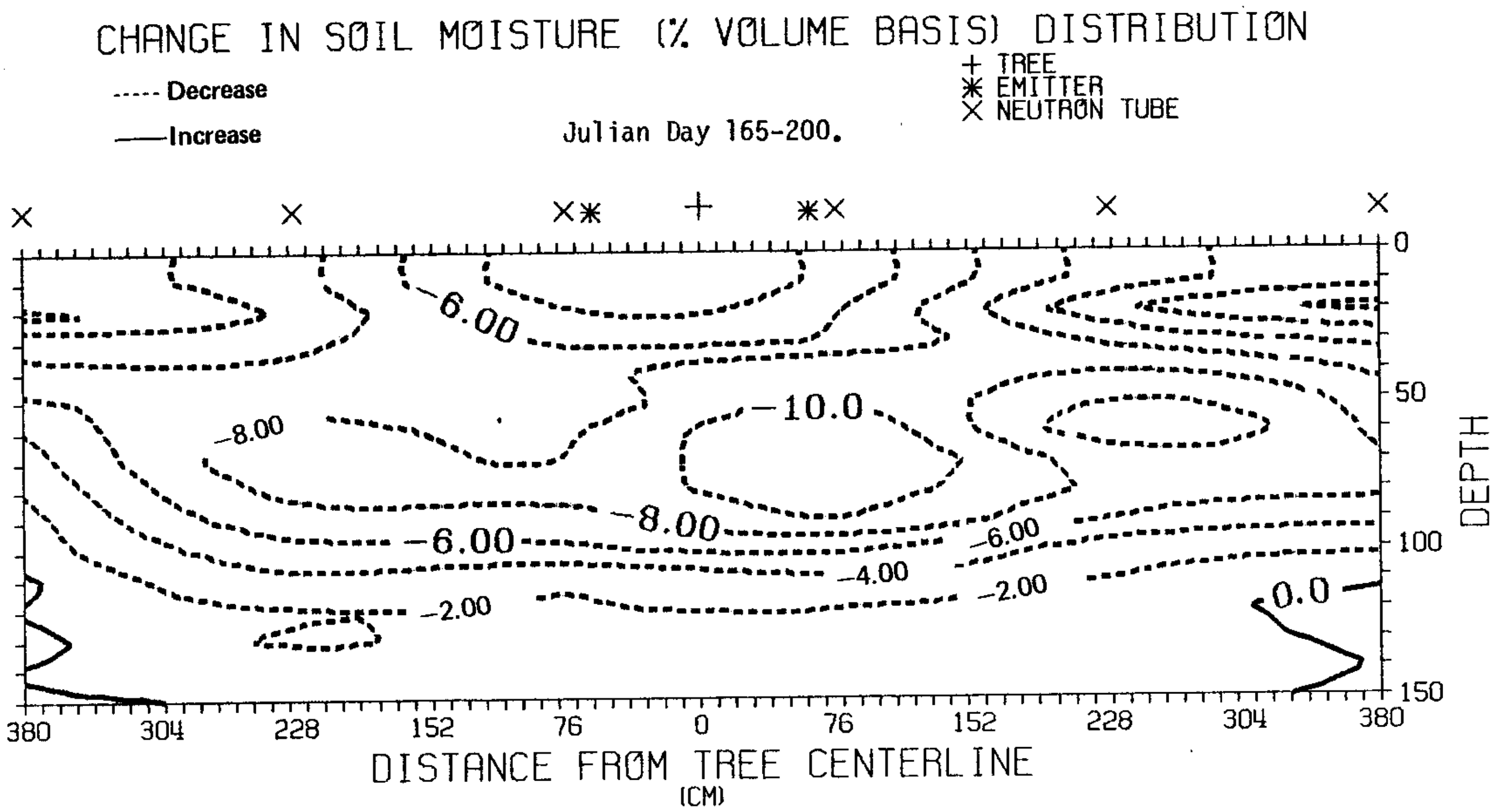


Fig. 6. Treatment II. Soil moisture profile. Row 1-5.

in Figure 7 , with the same pattern repeated in Figure 8 for row 3. These figures show a much more uniform and greater extraction pattern in Treatment II than in Treatment I.

Soil Water Balance

Measurements of the changes in soil moisture along with rainfall and irrigation records were used in the soil water balance equation. For this work the total of rainfall, irrigation, and change in soil moisture was considered to be the total ET of the test plot. The results are presented in Table 3 for Treatment I and Table 4 for Treatment II. A rain-free period of thirty-eight days occurred between days 163 and 202. During this period Treatment I had a soil moisture depletion of 53.5 mm and received 46.8 mm of irrigation. This resulted in a total ET for the period of 100.3 mm or a daily ET rate of 2.57 mm/day. Treatment II had a soil moisture depletion of 79.0 mm and had an irrigation total of 93.6 mm for a total ET of 172.6 mm and a daily ET rate of 4.43 mm/day. For this same thirty-eight day period the Penman PET was 232.6 mm or 6.1 mm/day. These figures indicate the difference in water use between the two treatments. Treatment II extracted approximately 25 mm of stored soil moisture more than Treatment I. The larger extraction amounts of Treatment II are most likely directly related to the greater development of roots and thus the more efficient system for using stored soil moisture.

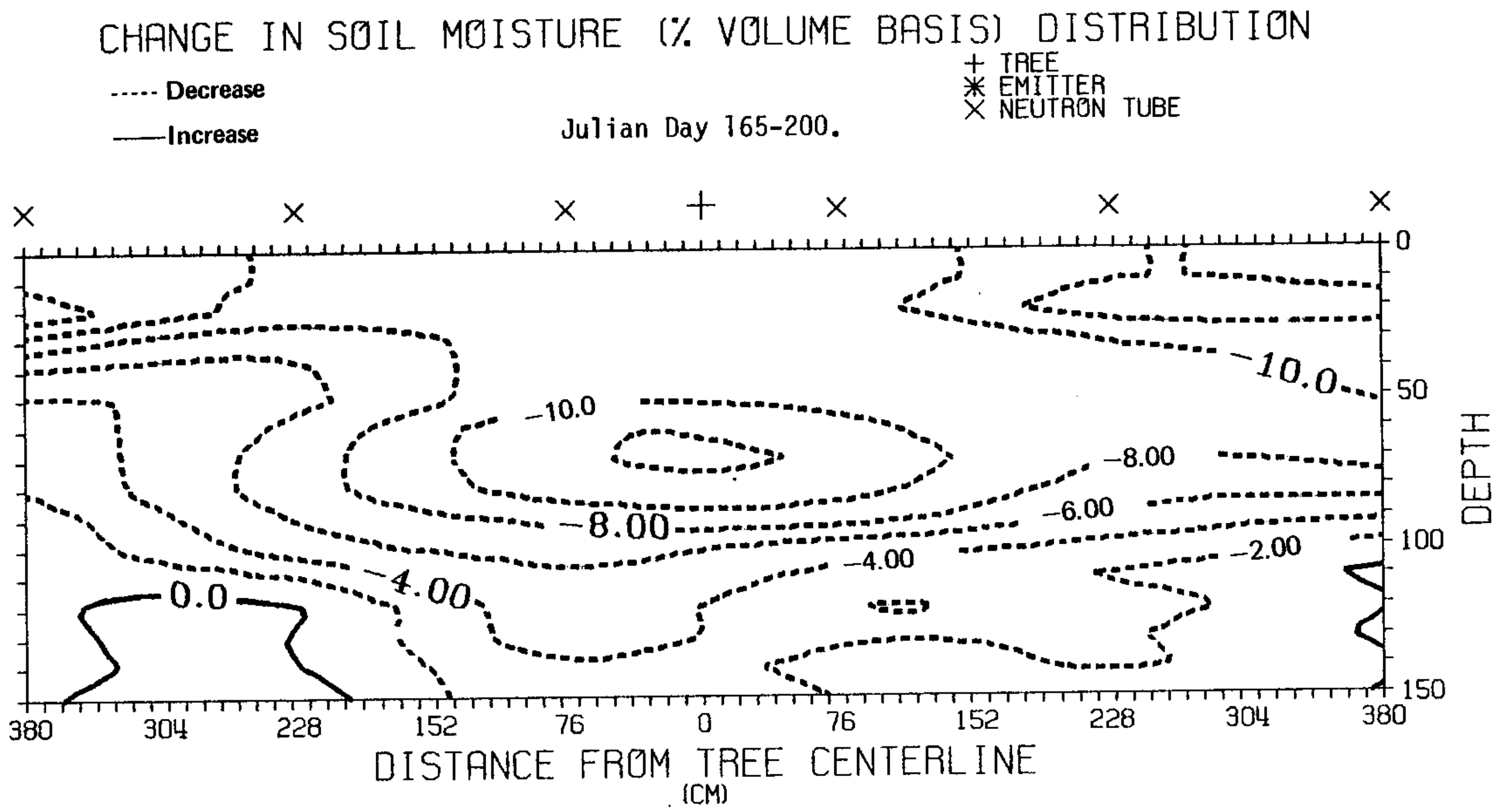


Fig. 7. Treatment II. Soil moisture profile. Row 2-4.

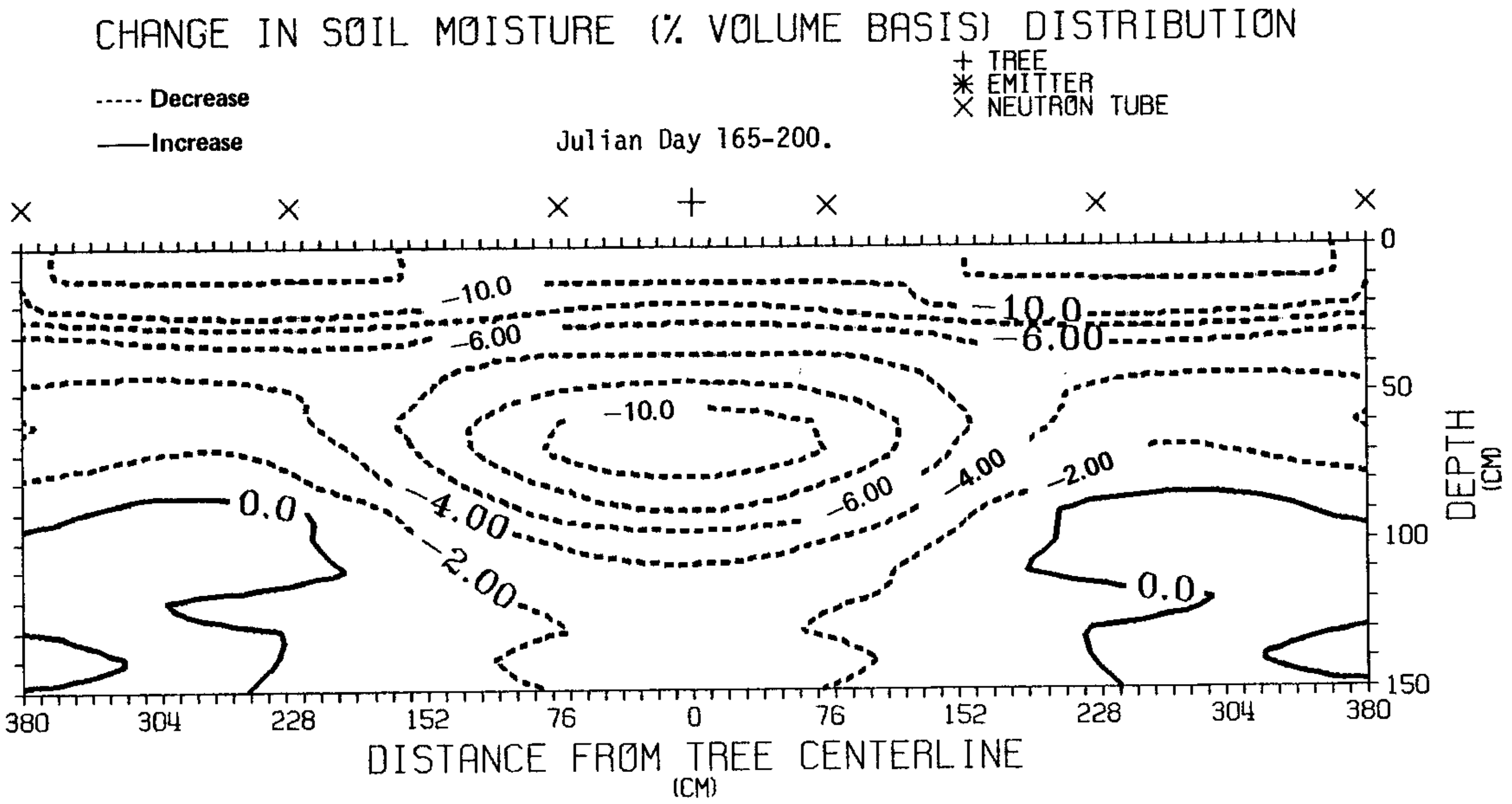


Fig. 8. Treatment II. Soil moisture profile. Row 3-3.

Table 3. Field Soil Water Balance. Treatment I.

Period (Julian Day)	Days (#)	Change in Soil Moisture (mm)	Irrigation (mm)	Rainfall (mm)	ET (mm)	Avg. ET (mm/day)
159-165	6	- 6.1	0.0	25.7	31.8	5.3
165-181	16	-32.2	19.1	0.0	51.3	3.2
181-195	16	-11.2	17.3	0.0	28.5	1.8
195-202	7	- 5.4	10.4	0.0	15.8	2.3
202-209	7	+ 6.2	5.5	18.8	18.1	2.6
209-223	14	+ 1.9	16.6	32.0	46.7	3.3
223-236	13	+ 7.1	0.0	78.7	71.6	5.5
236-264	28	-23.3	0.0	18.8	42.1	1.5

Table 4. Field Soil Water Balance. Treatment II.

Period (Julian Day)	Days (#)	Soil Moisture (mm)	Irrigation (mm)	Rainfall (mm)	ET (mm)	Avg. ET (mm/day)
159-165	6	+ 0.1	0.0	25.7	25.6	4.3
165-181	16	-44.0	38.2	0.0	82.2	5.1
181-195	16	-22.1	34.6	0.0	56.7	3.5
195-202	7	-12.9	20.8	0.0	33.7	4.8
202-209	7	- 0.6	11.0	18.8	30.4	4.3
209-223	13	+ 9.1	27.6	32.0	50.5	3.9
223-236	14	+11.7	2.8	78.7	69.8	4.9
236-264	28	-35.3	0.0	18.8	54.1	1.3

Estimation of Evaporation from the Soil Surface

The evaporation from the soil surface was estimated using the Penman (1956) equation and a two stage evaporation process as previously outlined. Due to assumptions made in the calculation process a brief sensitivity analysis was performed to determine the effects of these assumptions on the results. Table 5 contains some of the inputs to the estimation (columns 2-4), the intermediate results (columns 5-6), and the final results (columns 7-10).

As was mentioned previously, the evaporation rate beneath the canopy will be reduced to below the potential in the unshaded region due to the diurnal changes in shading that occur. Due to shading the radiation beneath the canopy was assumed to be twenty-five percent of the daily net radiation total for areas one and two. To test the sensitivity of estimated evaporation to this assumption, calculations were also made using ten percent of the net total daily radiation. For Treatment I using 25 percent of net radiation (NR) the evaporation from the surface totalled 17.3 mm. For 10 percent of RN the evaporation totalled 16.2 mm or a difference of 6.6 percent in estimated evaporation for a 150 percent change in RN. This is due to the stage one evaporation process. No matter what the PET rate is, evaporation will stay in stage one only until U is reached. This will take only a few days for either .25 RN or .10 RN in area three. Therefore evaporation is in stage two which is regulated only be the soil properties and the number of days since stage two began. While area one is almost constantly in stage one evaporation, the area wetted by the emitter is small compared to the remaining area.

Table 5. Sensitivity Analysis of Estimated Evaporation from the Soil Surface.

						Evaporation from the Soil Surface using TMIN			
				PET		Treatment I		Treatment II	
Julian Day	Net Radiation mm	Rain mm	Irrigation Calculated Rate mm	TMIN mm	TMIN -2.8°c mm	.25 RN mm	.10 RN mm	.25 RN mm	.10 RN mm
164	0.8	24.4	0.0	0.8	0.8	0.65	0.62	0.60	0.62
165	5.9	0.0	0.0	4.8	4.9	3.47	3.30	3.47	3.30
166	7.3	0.0	0.0	5.9	6.0	2.46	2.25	2.46	2.25
167	7.0	0.0	3.5	5.6	5.8	1.38	1.27	1.44	1.27
168	7.5	0.0	3.5	6.1	6.4	1.26	1.04	1.16	1.04
169	6.7	0.0	3.5	5.4	5.3	1.08	0.87	0.99	0.87
170	7.0	0.0	3.5	5.7	5.9	0.96	0.82	0.90	0.82
171	7.1	0.0	3.5	5.7	5.9	0.85	0.76	0.83	0.76
172	6.0	0.0	3.5	4.9	5.1	0.77	0.70	0.76	0.70
173	7.4	0.0	3.5	6.1	6.1	0.73	0.70	0.75	0.70
174	8.0	0.0	0.0	6.6	6.7	0.69	0.68	0.73	0.68
175	8.1	0.0	0.0	6.7	6.8	0.62	0.68	0.64	0.68
176	7.8	0.0	0.0	6.6	6.8	0.63	0.66	0.68	0.66
177	7.9	0.0	3.5	6.6	6.7	0.60	0.66	0.66	0.66
178	7.5	0.0	3.5	6.1	6.2	0.57	0.62	0.62	0.62
179	7.2	0.0	3.5	5.9	6.0	0.55	0.57	0.59	0.58

Area three comprised approximately 75 percent of the orchard surface area. The surface area wetted by an emitter was approximately 5 percent of the orchard area. Therefore a two emitter tree had a surface area wetted by irrigation of 10 percent of the orchard area. The remaining unaccounted orchard area is area two. The surface area wetted by an emitter is a low percentage of the total orchard area and thus cannot weight evaporation from the soil surface. Area three comprising 75 percent of the area will weight the result heavily.

Also, because of a lack of instrumentation, dew point temperature was not recorded. In its place, minimum temperature was used. This substitution would be acceptable in the fall and spring months but will definitely be off in the summer, when dew point temperature will be below the recorded minimum. Therefore the calculation of evaporation was made with the minimum temperature reduced by an arbitrarily selected value of 2.78°c. The difference of lowering the minimum temperature several degrees so that it more closely approximates dew point temperature in the calculation of evaporation from the soil surface is almost negligible as is seen in the results. Therefore it is possible to use the results of any of these calculations with a good degree of confidence.

Estimation of the Water Use by the Trees as Transpiration

It is also of interest to determine the breakdown of ET into its two components. For this purpose the calculated estimates of Es are subtracted from ET to leave only transpiration. Table 6 gives the data for Treatments I and II. These data reflect that surface

Table 6. Evaluation of Transpiration.

		Treatment I				Treatment II			
Period (Julian Days)	Rainfall mm	ET mm	Es mm	T mm	Avg. T mm/day	ET mm	Es mm	T mm	Avg. T mm/day
159-165	25.7	31.8	10.5	21.3	3.6	25.6	10.5	15.1	2.5
165-181	0.0	51.3	17.2	34.1	2.1	82.2	17.3	64.9	4.1
181-195	0.0	28.5	6.4	22.1	1.6	56.7	7.3	49.4	3.5
195-202	0.0	15.8	2.7	13.1	1.9	33.7	3.2	30.5	4.4
202-209	18.8	18.1	12.2	5.9	0.8	30.4	12.2	18.2	2.6
209-223	32.0	46.7	15.0	31.7	2.3	50.5	12.9	37.6	2.7
223-236	78.7	71.6	24.4	47.2	3.6	69.8	24.2	45.6	3.5
236-264	18.8	42.1	23.2	18.9	0.7	54.1	22.1	32.0	1.1

evaporation is a major fraction of total ET and needs to be considered independently of transpiration.

For Treatment I during the period between days 181 and 195 the average transpiration was 1.6 mm/day. During this same time period, Treatment II had an average transpiration rate of 3.5 mm/day. For this same period the irrigation rates for Treatments I and II were 1.3 and 2.6 mm/day, respectively.

It would appear that while the trees are primarily dependent upon the irrigation system for water, they are also able to use the stored soil moisture. For this fourteen day period Treatment I obtains 18 percent of its total transpiration from the stored soil moisture while Treatment II obtains 25 percent of its transpired water from the soil moisture storage (these numbers are calculated on the basis that all irrigation water is transpired).

The general results for transpiration are inconclusive. Between days 159 and 165 the transpiration rate of Treatment I exceeds the transpiration rate of Treatment II. This phenomenon is repeated between days 223 and 236. The exact reasons and ranges for this are unknown. For any one treatment the values for transpiration are very random. Values for the three rain-free periods are more consistent.

CHAPTER V

DISCUSSION

Starting with the measurement of soil moisture depletion over time by use of a neutron soil moisture meter, a soil water balance of two trickle irrigation regimes was equated using soil moisture depletion, irrigation and rainfall to total ET. Evaporation from the soil surface was estimated and subtracted from ET to give an estimated value of transpiration. A discussion of the results of various aspects of the work is now desirable.

Measurements of the soil moisture depletion for Treatment I revealed that the soil moisture extraction taking place occurred from 0-95 cm in depth. For Treatment II extraction was evident from 0-125 cm. Contour plots of the neutron data for Treatment I had evidence of extraction in the upper depths (0-80 cm) with this extraction being greater on the side of the tree opposite the trickle emitter. For Treatment II the extraction pattern is not limited to one side of the tree but is uniform below the emitters and between them. This occurrence could be explained by a larger root distribution in Treatment II then in Treatment I caused by a larger wetting pattern from the emitters in Treatment II which results in the ability of Treatment II to use stored soil moisture to a greater extent than Treatment I. This raises the question of varied root zone difference due to differences in the number of emitters and quantity of water applied. The seemingly larger root pattern of Treatment II would allow the extraction of nutrients (especially micronutrients) from a larger soil volume. Thus design of an irrigation system to wet a larger soil volume may be beneficial.

Measurement of the soil moisture depletion was based on the assumption that there was no flux across the bottom or sides of the measurement profile. This assumption cannot be qualified and it is noted that the possibility of a flux across one or more of the boundaries is possible. The experiment in question was not equipped to quantify the value of any flux that existed.

The ET was calculated for each of the two treatments. Between days 159 and 264 Treatment I received 68.9 mm of irrigation, 174.0 mm of rainfall, and had a soil moisture depletion of 63.1 mm for a total ET of 306.0 mm. Treatment II received 137.8 mm of irrigation, 174.0 mm of rainfall and had a soil moisture depletion of 94.0 mm for a total ET of 405.8 mm. This is a 33 percent difference between irrigation treatments. In Treatment I, irrigation accounts for only 23 percent of the total ET. In Treatment II the irrigation amount is 34 percent of the total water use. This information points at the probability that the irrigation treatments are not a sufficiently large fraction of the total water use to heavily influence performance. This also shows the capability of both treatments to utilize stored soil moisture. Also, Treatment I had a soil moisture depletion 36 percent less than Treatment II. This is probably due to two facts. One is that TreatmentII's total soil moisture was higher than Treatment I's at the beginning of the season. This would allow for greater extraction. Also Treatment II provided a larger wetted volume from the trickle source as compared to Treatment I, thus providing for a

CHAPTER VI

CONCLUSIONS

Two trickle irrigation regimes on peach trees were studied for one season. A soil water balance was performed on each treatment. Treatment II was irrigated at the calculated rate (measured pan evaporation times the surface area inside the drip line of the tree multiplied by a replenishment factor of 0.6) through two emitters, and Treatment I received one-half the calculated rate distributed through one emitter. The research conducted herein did not provide sufficient data to accurately determine the irrigation needs of peach trees or their performance in terms of yield under two trickle irrigation regimes. Specific conclusions include:

1. Treatment II may have had a more extensive root distribution than did Treatment I as observed through moisture extraction patterns.
2. The tree in each Treatment was able to obtain moisture stored in the root zone.
3. Treatments I and II had an ET rate considerably higher than their irrigation rates.
4. The ET rates of each treatment was still below the PET rate.
5. Estimates for the transpiration rate of Treatments I and II are 1.6 mm/day and 3.5 mm/day, respectively.

CHAPTER VII

RECOMMENDATIONS FOR FUTURE RESEARCH

This research also indicated areas of future research and design criteria for future research. Recommendations for future study include:

1. to achieve a higher degree of water control to allow researchers to limit the water available to the trees (rainfall is a random variable),
2. to increase the irrigation amount supplied (4 emitters, twice the calculated rate, would be advisable),
3. the determination of stress criteria in peach trees such as leaf temperature, leaf water potential, stomatal resistance, or leaf water content,
4. the development of crop coefficients for peach trees based on stress factors listed above,
5. the study of root development and water extraction in relation to emitter spacing, number, and discharge, and
6. the determination of irrigation timing and amounts based on stress levels of the tree.

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APPENDIX A

Supplementary Data

TABLE A-1

Neutron Probe Calibration Data

Surface, 0-25 cm

Line of Best Fit, $\theta s = 0.295 * CR + 0.0196$ $r^2 = 0.996$

Count Ratio, CR (Actual/Standard)	Water Content, θs (cm^3/cm^3)
.501	.168
.681	.218
.760	.246
.780	.249

Subsurface, 25-150 cm

Line of Best Fit, $\theta s = 0.509 * CR - 0.0926$ $r^2 = 0.843$

Count Ratio, CR (Actual/Standard)	Water Content, θs (cm^3/cm^3)
.763	.271
.733	.289
.746	.289
.732	.282
.713	.256
.699	.293
.741	.305
.689	.270
.753	.290
.775	.320
.828	.317
.810	.324
.517	.165
.517	.156
.566	.182
.566	.181