EVALUATION OF SOIL MOISTURE IN A WATER HARVESTING SYSTEM WITH SUPPLEMENTAL BUBBLER IRRIGATION SYSTEM

BY

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The University of Arizona, 1985

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Water harvesting may be defined as the process of decreasing the infiltration of a large area by changing its properties and collecting runoff from this area for beneficial use. Water harvesting for agriculture offers great promise of utilizing precipitation to increase food production. Water harvesting systems, when properly designed, will provide sufficient runoff water to replenish the entire root zone with soil moisture, then enable crops to tolerate long drought periods.

The objectives of this study were (i) to obtain information about soil moisture content in a water harvesting system, (ii) to estimate the water collected by the water harvesting system, (iii) to estimate water use by the plants, (iv) and finally to establish a water balance for a fig orchard in a micro-catchment area . This information would allow improvements in the design of water harvesting systems for use as supplemental irrigation.

TO MY PARENTS WHO MADE IT ALL POSSIBLE

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CHAPTER ONE

INTRODUCTION

Water harvesting may be defined as the process of decreasing the infiltration of a large area by changing its properties and collecting runoff from this area for beneficial use. Water harvesting for agriculture offers great promise of utilizing precipitation to increase food production. Water harvesting systems, when properly designed, will provide sufficient runoff water to replenish the entire root zone with soil moisture, then enable crops to tolerate long drought periods.

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CHAPTER 2

LITERATURE REVIEW

Water Harvesting in the Past

Water harvesting defined by Currier as " the process of collecting natural precipitation from prepared watersheds for beneficial use " is not new. It was practiced as early as 4500 B.C. by the people of Ur and later by the Nabateans and the people from the Middle East. Evenari (1971) described water harvesting systems in the Negev desert which are thought to have been built nearly 4,000 years ago. These systems involved building contour ditches to collect and carry water to the fields. In some regions of the world, in ancient times Roman villas and cities were planned to take advantage of rain water for drinking and air conditioning. Also, in the hills above Bombay in India, the early buddhist monastic cells had a series of gutters and cisterns cut into the rock to provide domestic water on a round-the-year basis. These early water harvesting techniques used natural materials such as soil crusts or rock surfaces to increase runoff from precipitation (U.N.E.P. 1979).

More recently, collection and storage of runoff from the roofs of houses are practices still used in many regions of the world. In 1956, " roaded catchments ",in which the soil is graded into a series of parallel roadways , have been installed to collect water for farm supplies (Myers 1974).

Despite its benefits, current research in water harvesting started in the 1950's. The most significant development in the 1950's was the work of Lauritzen in introducing plastic and artificial rubber membranes for the contruction of catchments and reservoirs. In 1959, the U.S. Water Conservation Laboratory began to investigate water repellent materials. In the 1960's, sprayable asphaltic compounds, plastics and metal films, soil compaction and clay dispersion, and field fabricated asphalt-fiberglass membranes were used to reduce infiltration in catchment areas. Also, research programs in water harvesting done at the University of Arizona (Cluff, 1974) related to the use of soil sealing with sodium salts. Cluff indicated as the result of a research project that the two catchment methods: compacted earth and compacted earth sodium treated are cheaper than any other method when soils are easy to compact. Moreover, these two treatments are more likely to be used for agricultural purposes because of the presence of considerable sediment in the water collected.

In the following sections, water harvesting characteristics and methods will be presented. Also, increasing and estimating runoff by different processes or treatments will be evaluated. Finally, some soil moisture measurement methods will be defined.

Water Harvesting Characteristics

Runoff Efficiency

The performance of a water harvesting system as a water source is directly related to the relative impermeability of the catchment apron. To determine the quantity of water that can be collected from a given rainfall, the runoff efficiency of the catchment surface must be known. The runoff efficiency can be defined as the percent of precipitation collected. It is also the equivalent depth of runoff water divided by the precipitation depth expressed in percent. The runoff efficiency can be determined by construction of an isolated plot or catchment area bordered on all sides with runoff collected and measured at the lower end. The surface of the isolated plot should have the same characteristics as the catchment area (i.e. treatment, slope, and length).

Catchment cultivated area ratio

Another important concept in understanding water harvesting systems is the catchment to cultivated area ratio (C.C.A.R). The C.C.A.R required is determined by the runoff efficiency of the catchment area, the crop moisture requirements, and the expected quantity and distribution of precipitation.

Water Quality

The quality of water obtained from catchments is not ordinarily a problem for irrigation or for livestock, but it must be considered when the water is to be consumed by humans. Water obtained from soil catchments may contain suspended and colloidal material dangerous for human life.

Water Harvesting Methods

Runoff Farming Water Harvesting (R.F.W.H.)

This method is practiced in Wadi Auda, Israel. Runoff farming water harvesting is based on flash floods. It is applied under two different systems: a diversion system and a damming system. Under the diversion system, a long channel diverts the flood to a cultivated area; it is usually sufficient to support the water consumption of the plants. The damming system supplies water to the crops from a large reservoir behind a dam. When the reservoir is full, pumps are started to pump water through pipes to a large number of sprinklers, which spread water over the crops.

Microcatchment Water Harvesting (M.C.W.H.)

The microcatchment is a very small watershed (100 to 300 m^2) designed to collect runoff for the consumptive use of a single tree (Evenari et al 1971). The M.C.W.H. is practiced in North Africa, Afghanistan, Australia, India, Israel, Mexico, and Pakistan (see Fig 1).

Roaded Catchment Water Harvesting (R.C.W.H.)

Widely practiced in western Australia, roaded catchment water harvesting consists of a series of parallel compacted roads with exaggerated camber which join to make V-shaped channels that discharge into a collector drain at the lower end (Fig 2) (Boers and Ben Asher 1979).

Roaded catchments promote runoff by the reduction of depression and infiltration losses (Laing 1980). The most important factors involved are:

-increasing surface slope

-surfacing with suitable clay soil

-compacting and smoothing the surface by rolling

-removing weed growth

-maintaining a steady gradient along road channels and collecting drains to a reservoir.

These examples of water harvesting methods were developed in arid regions. However, the list is far from complete. The National Academy of Science (1974), Burdass

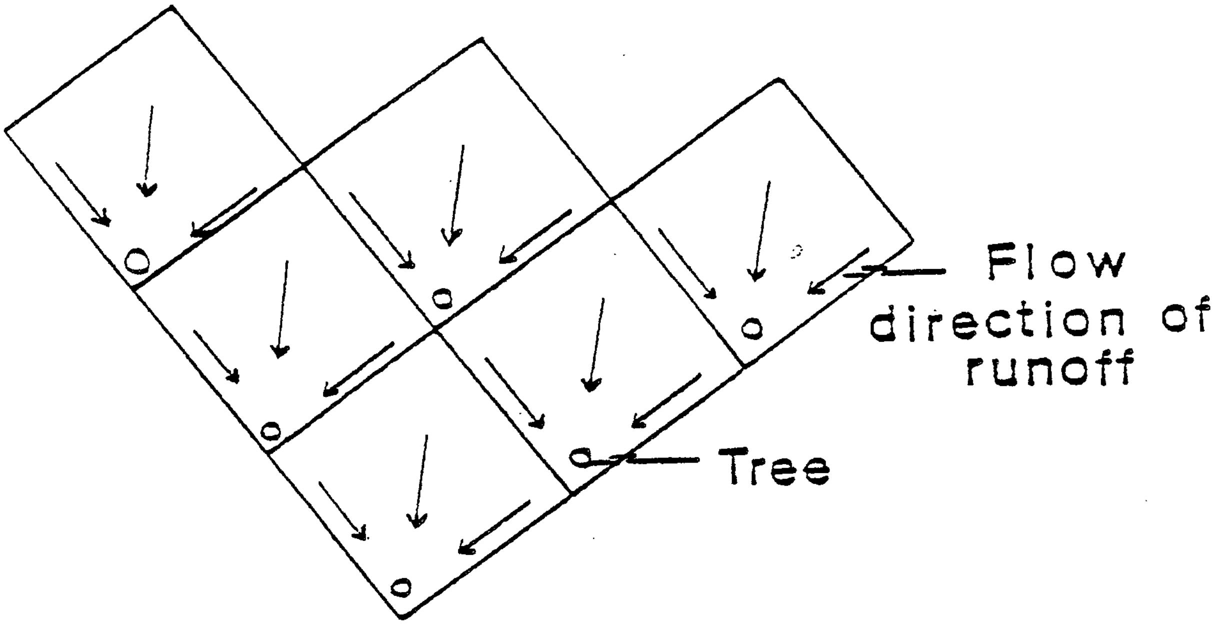

Figure 1 Diagram of Microcatchment Water harvesting System

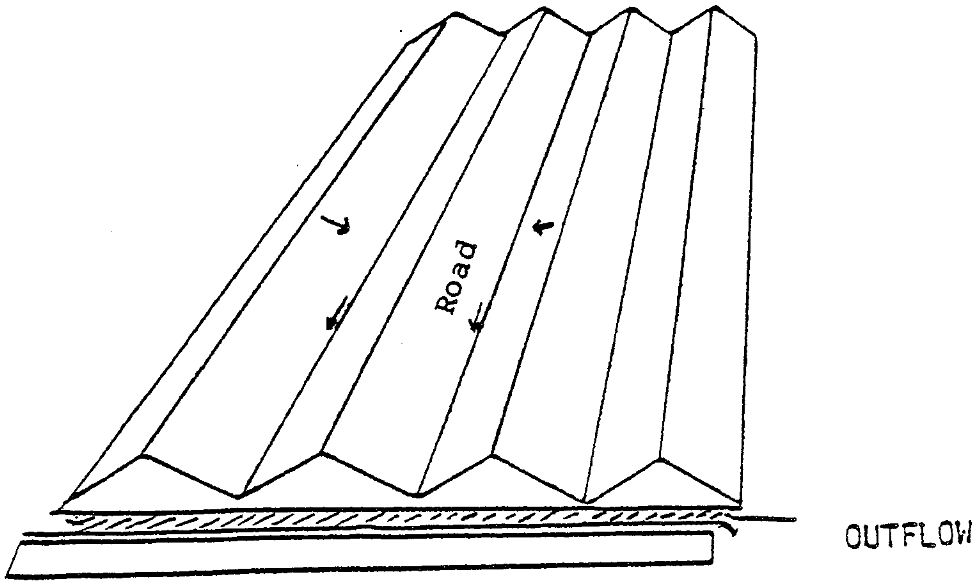

Figure 2 Idealized Roaded-Catchment Water harvesting System

(1978), Lanchow Institute of Glaciology and Desert Research (1978), and Nabhan (1979) have described or developed other methods to survive which involve water harvesting.

Increasing runoff efficiency

Vegetation removal

A relatively inexpensive method of increasing runoff is to remove vegetation. However, the runoff efficiency is usually low with this method, and may vary greatly with storm, season, or year (Boers and Ben-Asher, 1979.

Land smoothing and clearing

Smoothing and clearing are probably the oldest water harvesting treatments, dating back more than 4,000 years (Evenari et al 1971). The process consists of grading, smoothing, and sometimes of compacting the soil surface. The efficiency of the runoff is largely dependent upon the soil type. Coarse and sandy soils with high permeability are usually unsuited for this treatment. Finer soils with significant nonexpanding-type clays can be smoothed and compacted to increase water yields (Frith 1974, Hollick 1974).

Compaction

The effect of compaction on the soil is essentially to decrease the permeability because of the reduction of size and number of pores. On a plot 2.8 x 2.0 m at 4% slope, Hillel et al. (1966) found that compaction of a loam soil in the Negev increased runoff by 25% over smoothing and clearing.

Compacted earth catchments represent most of the water harvesting systems in Australia (Laing 1981). More than 3,500 "roaded catchments" are in use in Australia. Laing (1981) studied roaded catchments in South West Australia. His plots were V-shaped with a 20 m long central drain at 2.5% slope. The plots were 6 by 20 m long and were compacted by six passes of a 6-ton rubber-tired roller after watering to optimal water content on loamy sand with 10% kaolinitic clay. The annual runoff averaged 43% (38 - 46%).

Also Laing and Prout (1974) studied a plot 7.5 m wide and 30 m long. The slope of the plot was nearly 1.5% and the side slope was approximately 10%. The treatment was smoothed, compacted clay which was transported from a nearby borrow pit, and placed as a compacted blanket 8 cm thick using a two-wheeled scoop behind a wheeled tractor. During placement of the clay blanket, many tractor movements were required. Some leveling of the clay surface was necessary to give the final finish. Runoff measurements were calculated by water level differences in the reservoir. The mean runoff volumes for the Summer-Autumn 1972, Winter 1972, Spring 1972, and Winter 1973, were 2.95 mm (4%), 19.25 mm (26.5%), 7.25 mm (17.3%), and 12.25 mm (29.2%) respectively.

Wax treated soil surfaces

A relatively new water harvesting treatment is the application of paraffin wax to soils to create a water-repellent catchment surface. The first two paraffin-wax-treated water harvesting catchments were installed at the U.S. Water Conservation Laboratory's Granite Reef test site in summer 1972 (Fink, Frasier, and Cooley, 1980). The first plot was rectangular and small (10 m^2) with 5% slope and the second was a 200 m^2 ridge and furrow plot with 3% longitudinal and 10% lateral slopes. Soil surfaces were cleared, sloped, smoothed, and sprinkled several times to compact the soil. The paraffin wax was hand spread atop the small and large plots at 0.73 and 0.68 kg/m^2 respectively. Solar energy melted the wax into the soil and created a water repellent catchment. An average runoff efficiency for the two catchments was 87% for 7 years. However, both laboratory and field tests indicated that the wax treatment was most successful on sandy soils containing less than 20-25% clay plus fine silt. (Fink, Frasier, and Cooley 1980). Frasier, Cooley, and Griggs (1979) evaluated the runoff efficiency of paraffin wax treated catchments (0.7 kg/m^2) on field sized plots at the Granite Reef test site. The catchment area was a rectangular "V" with 197 m^2 at 10 % slope. The runoff efficiency obtained was 88%. It was believed that insufficient wax had been applied for the soil type.

Asphalt treatment

Another treatment to increase runoff is the application of asphalt. Kowsar, Mehdizadeh, Vaziri, and Boersma (1978) studied the survival and growth of trees in a water harvesting system. The plot was a 2 m wide terrace on contour lines at 5 m intervals leaving a 3 m wide watershed area between terraces. These plots were sprayed with asphalt at the rate of 1 l/m^2. Although the seedlings planted on the asphalt treated plots showed higher rates of survival than those on the control plots, the differences were not statistically significant.

A combination of asphalt polypropylene and asphalt fiberglass was studied by Frasier, Cooley, and Griggs (1979). A square plot having 200 m^2 was treated with asphalt polypropylene and had a 5% slope. The period of treatment was 0.2 years. The runoff efficiency after reaching threshold rainfall was 100%. Another plot treated with asphalt fiberglass (chopped fiberglass matting and cationic asphalt emulsion, 1.5 kg asphalt/m^2) was rectangular with 180 m^2 area. The slope was 5%. The runoff efficiency after reaching threshold rainfall was 97%.

Other scientists studied the effect of asphalt treated areas. Cluff (1974) studied the effect of asphalt-plastic-asphalt-chipcoated treatments to increase the runoff from a 1/2 acre catchment on the Papago Indian Reservation. The efficiency of the catchment was between 85-95% with an estimated life of 10-11 years.

Sodium Treated Compacted earth

Effective results have been obtained when a sodium chloride treatment is coupled with clearing, shaping, and compaction (Cluff 1974). A sodium treated compacted earth catchment has been tested on an acre site at the Page Experimental Ranch (now Oracle Agricultural Center, 50 km north of Tucson). The soil classification is loam with 45% sand, 33% silt, and 22% clay. Five tons of granulated sodium salt was added with a fertilizer spreader. The granulated salt was mixed into the upper 1 to 2 inches and the soil surface smoothed with a rotating tractor-drawn rock rake. The efficiency of the catchment was between 40-70% with an indefinite estimated life. Maintenance consisted of weed removal and recompaction as needed.

Dutt and McCreary (1974) worked on sodium treated catchment areas. The principle was to minimize infiltration which allows reducing the catchment area. The methods were (1) increasing the "exchangable sodium percentage"; (2) breaking down the soil structure; (3) eliminating vegetative cover; and (4) reducing depression storage. The treatment consisted of (1) removal of the vegetation, (2) clearing and smoothing the area to about 2-4% slope; (3) reducing the soil structure in the surface by rototilling, (4) adding 5 tons/acre of salt to the surface with a fertilizer spreader and compacting the soil after two 0.4 inch rainstorms. During the period of July 1, 1971 to December 30, 1971, 6.76 inches of runoff was collected from 14.23 inches of rainfall for a runoff efficiency of approximately 50% (47.5).

Field methods for measuring soil moisture

Gravimetric Method

This method involves weighing a sample of moist soil, drying it to a constant weight at a temperature of 105 to 110°C, and reweighing to determine the amount of water lost by drying. The results are commonly expressed as the ratio of mass of water lost to mass of dry soil. It is also convenient to express soil water contents on a volumetric basis, i.e. the ratio of soil water volume to the total soil volume. The volumetric method is subject to errors because of difficulties in obtaining accurate soil volumes. It is also laborious and time-consuming (Hillel 1980, ASAE 1980).

Electrical Resistance

This method takes advantage of the fact that the electrical resistance of certain porous materials such as gypsum, nylon, and fiberglass is related to their water content. When these blocks with suitable embedded electrodes are placed in moist soil, they absorb soil moisture until equilibrium is reached. The electrical resistance in the blocks is determined by their moisture content. The relationship between the resistance reading and the soil moisture content percentage can be determined by calibration. This method provides reasonably accurate moisture readings over the range of 1 to 15 atmospheres suction (Brady, 1974).

Neutron Scattering

The application of neutron scattering to the estimation of soil water content involves three processes:

(i) fast neutron emission from a radioactive source

(ii) moderation of the neutrons to thermal velocities by collisions in the soil medium, and back-scattering towards the instrument

(iii) selective detection and counting of thermal neutrons at a point close to the source

The first and third of these are determined by the instrument designer. Also, the moderation process can be strongly dependent on the soil bulk density (i.e. the weight of dry soil in a given volume) and chemical composition. In addition, the first two of the processes combine to generate a "cloud" of thermal neutrons in dynamic equilibrium within 1 - 2 m of the source (Glasstone and Edlund, 1957).

A proportion of the fast neutrons, emmitted from the source and passing through a given small volume of soil, collide with hydrogen nuclei and suffer scattering which reduces their kinetic energy and alters their direction of motion. The result is that the gauge reading increases with total hydrogen compounds (or equivalent water content). To avoid any significant effect of chemical composition of the soil upon the gauge reading, field calibration of the probe is required (Kirkham et al, 1973).

Supplemental water in a Water Harvesting System

Supplemental water for irrigation which is additional water supplied through an irrigation system to the plants is essential for maximum crop production. In India, Krantz (1979) found that the addition of as little as 5 cm of water more than doubled the production for several crops, including corn. Also, Mielke and Dutt (1981) worked with supplemental irrigation of grapes at the University of Arizona's Page - Trowbridge Experimental Ranch (now Oracle Agricultural Center). They applied supplemental water to the plants through a spitter irrigation system from excess runoff stored in reservoirs. The amount applied as supplemental water ranged from a low of 36 liters per plant in 1976 to a high of 65.5 liters per plant in 1978. June and September required the highest amount of supplemental water. July and August had lower requirements for supplemental water because of higher rainfall. When the amount of rainfall and runoff (average 370 liters per plant) occurring are taken into consideration, supplemental irrigation amounted to about 18 percent of the total water that infiltrated in the soil at each plant.

CHAPTER 3

EXPERIMENTAL STUDY

Background

The experiment was conducted at the Oracle Agricultural Center (O.A.C) where a runoff farming research area was established in 1969. The O.A.C. is located about 50 km north of Tucson (see Figure 3). The elevation is about 1100 m above mean sea level. Rainfall maps of the area place it in the 300-400 mm range. The runoff farming area consists of a number of salt treated compacted-earth catchments to harvest rainfall, and crops grown with the harvested water. The catchment in the study area was prepared in the early 1970'S . The soil classification is a loam (see appendix A). The soil surface was cleared, smoothed, and then compacted. The catchment slope is in two directions. The slope is about 2% and 3% along the short and long axis respectively.

Experimental Design

Fig trees (Ficus carica) were planted in microcatchment basins in 1979. V-shaped berms limited the catchment for each tree. Three sub-plots separated by berms provide for

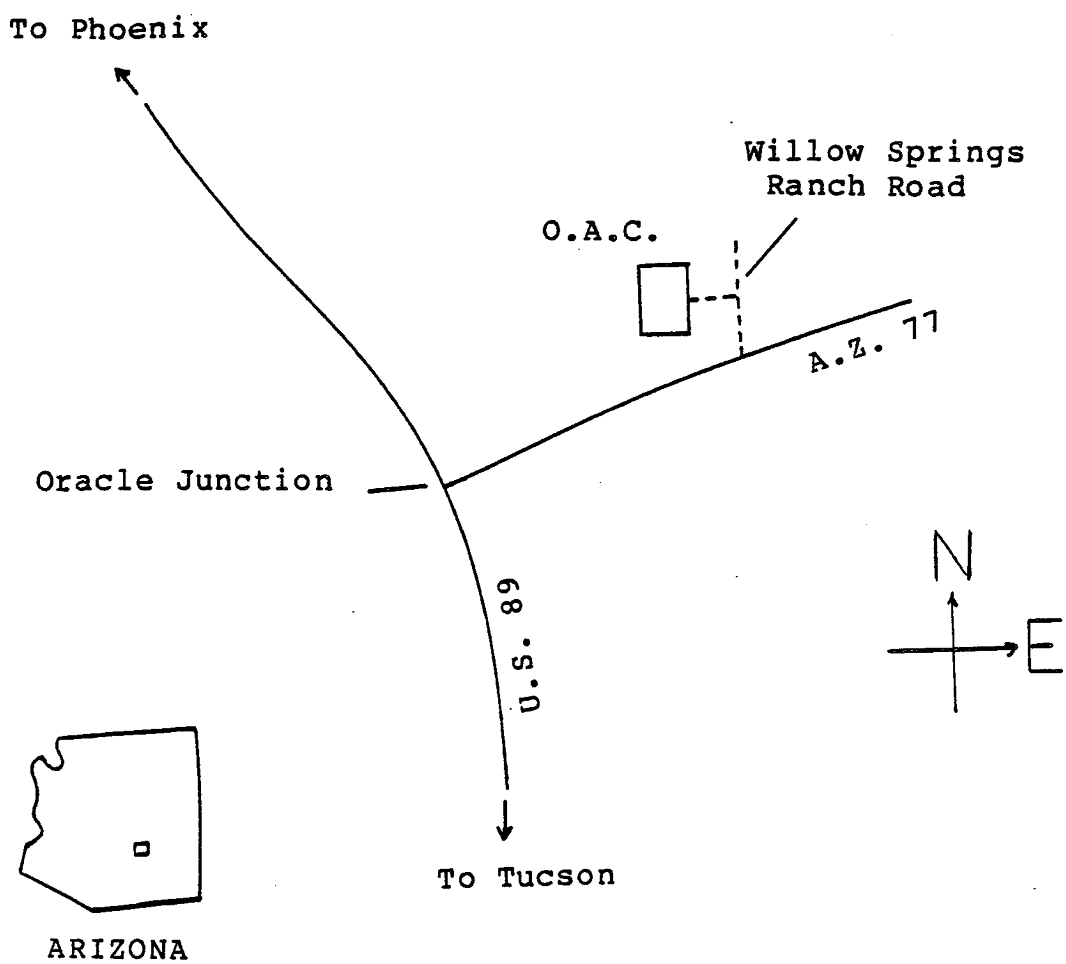

Figure 3 Map of the location of the Oracle Agricultural Center

different catchment size and tree spacing (Figure 4). Two neutron probe access tubes were placed in each subplot. Soil moisture measurements were taken at 30, 45, 60, and 90 cm depth.

First sub-plot: Six trees were selected in this subplot for the study. The dimensions of the berms in this sub-plot are shown in Figure 5a. The height of the berms after compaction was 45 cm. Spacing between trees along the short axis of the basin was 10.2 meters. Along the long axis, the spacing between the trees was 10 meters (see Figure 6a).

Second sub-plot: Six trees also were selected from this area. The dimensions of the berms limiting the microcatchment basins are shown in Figure 5b. The average spacing between trees was 10.6 meters along the short axis of the basins and 7.25 meters along the long axis (see Figure 6b).

Third Subplot: Six trees also were selected for this study. The dimensions of the berms limiting the microcatchment basins are shown in Figure 5c. The spacing between trees in these basins was 7.5 meters along the short axis and 6.3 meters along the long axis (see Figure 6c).

Design and layout of irrigation system

During April, May, and June, the trees need an additional source of water. Runoff collected in the

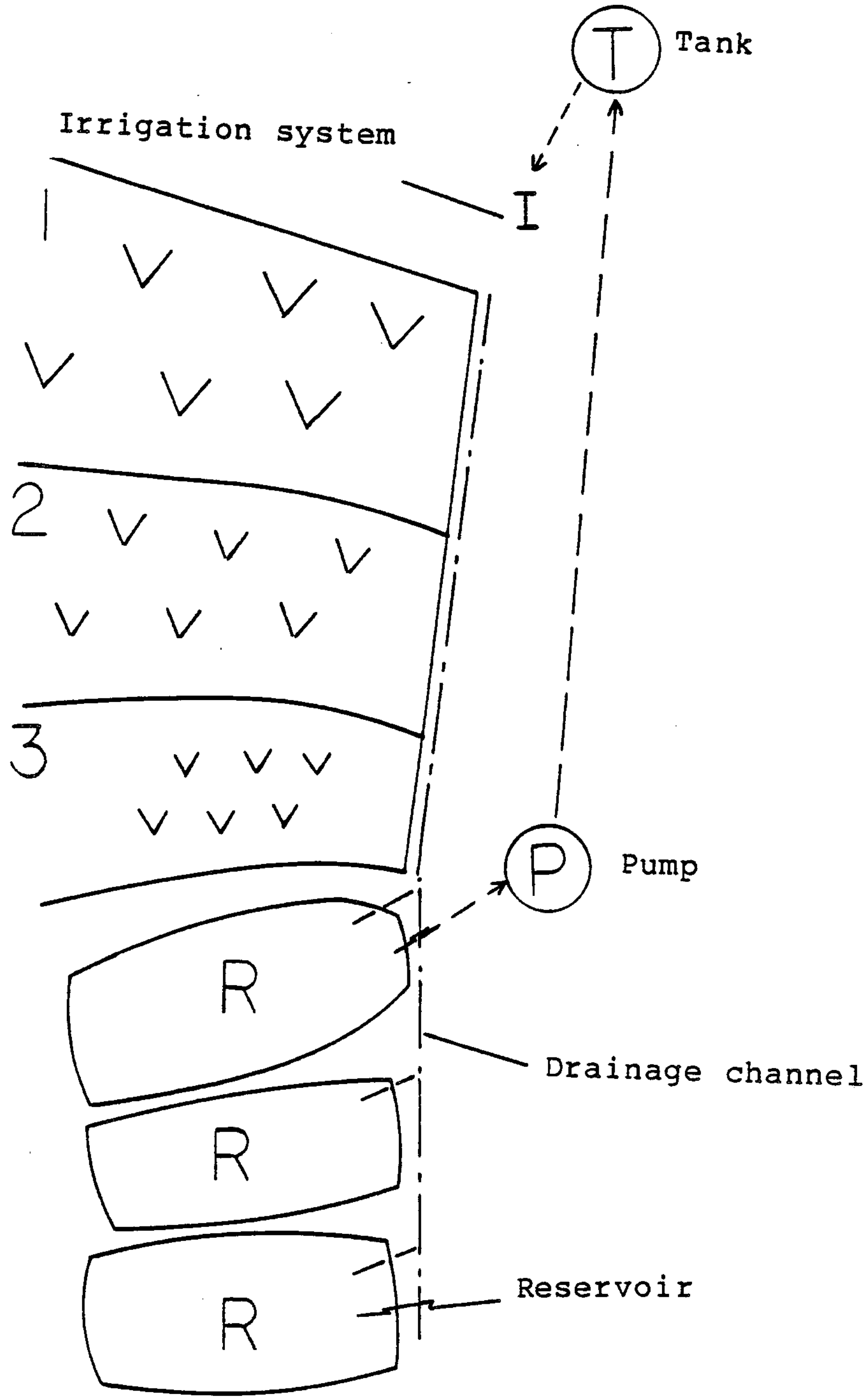

Figure 4 Schematic of the experimental area

reservoirs was pumped to the metal storage tank. A low-pressure bubbler irrigation system was used to water the figs. During drought periods, additional water from the tank was supplied through PVC pipes to each tree. Three submain pipes were connected to a PVC pipe. A valve and water meter were placed at the beginning of each connection. Laterals connect the submain pipes to the trees. The water meter at each subplot and the valves at the end of each lateral allowed us to determine the amount of water supplied to each tree by the irrigation system. Details of the bubbler irrigation system are given in Figure 7.

Calibration of the neutron probe

The probe was calibrated by obtaining the readings of the instrument for a range of independently determined values of the soil moisture content. The relationship between the readings and the soil moisture provides the calibration curve. In this case, a calibration equation was determined

$$\theta = bn + a \qquad (3\text{-}1)$$

where θ (cm^3 / cm^3) is the volumetric content of free water (water released on drying at 105°)

n is the ratio of the count rate in the soil to the count rate under standard conditions.

b is the calibration coefficient

a is the intercept constant

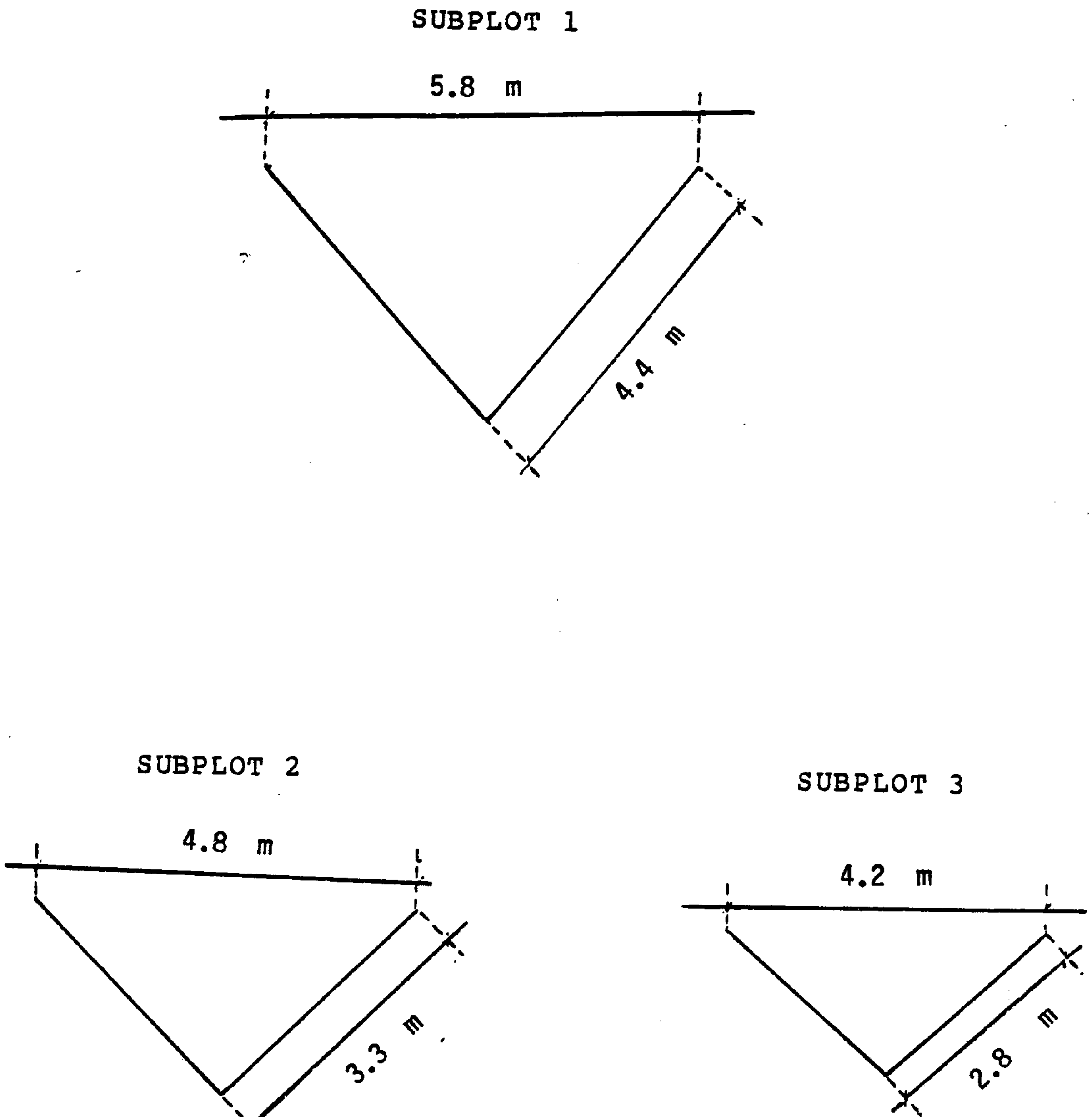

Figure 5 Berm dimensions

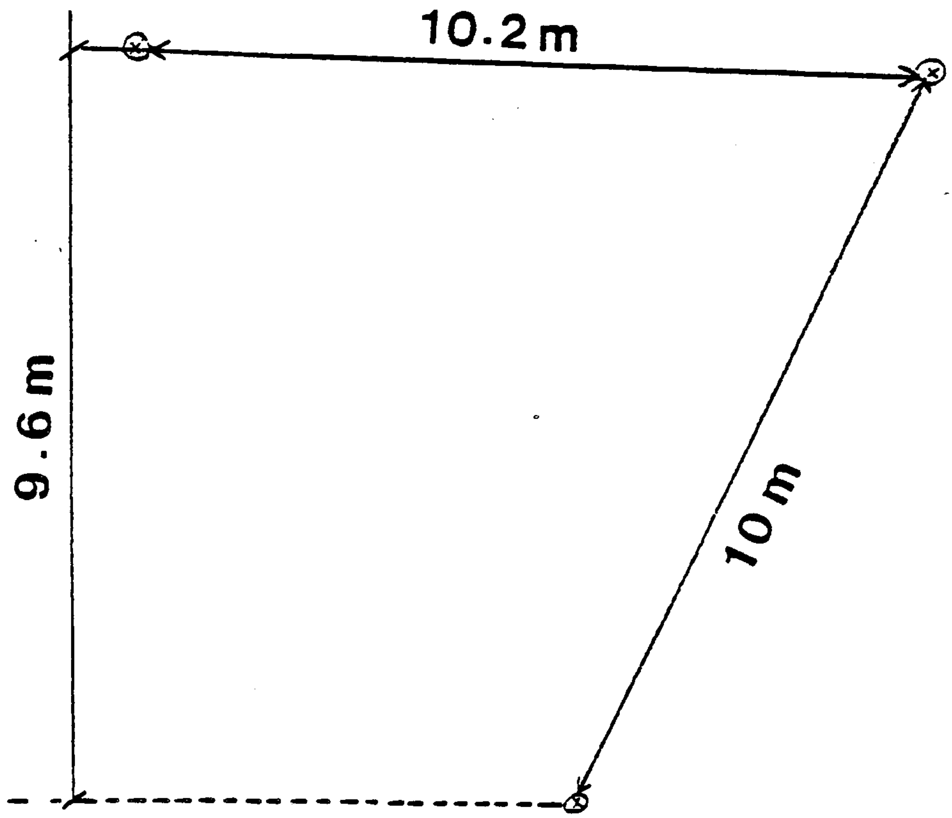

Figure 6a Space between trees, subplot 1

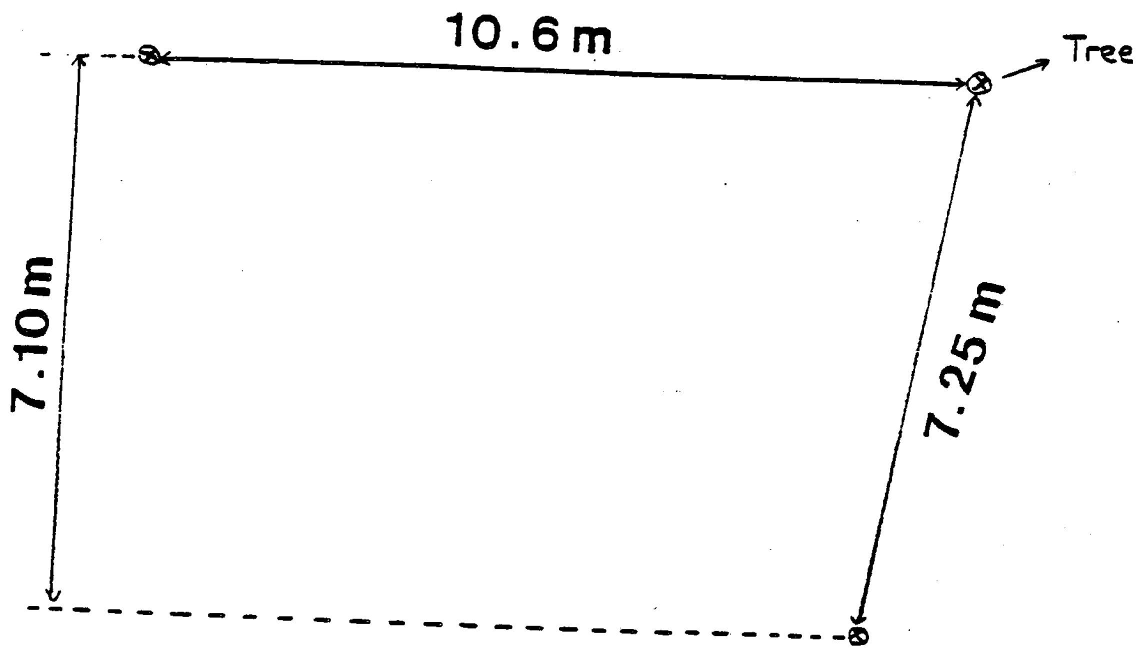

Figure 6b Space between trees, subplot 2

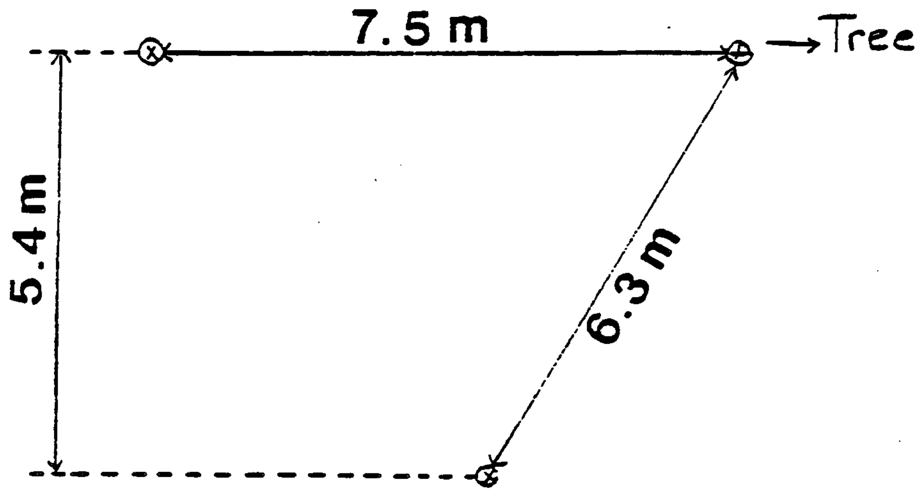

Figure 6c Space between trees, subplot 3

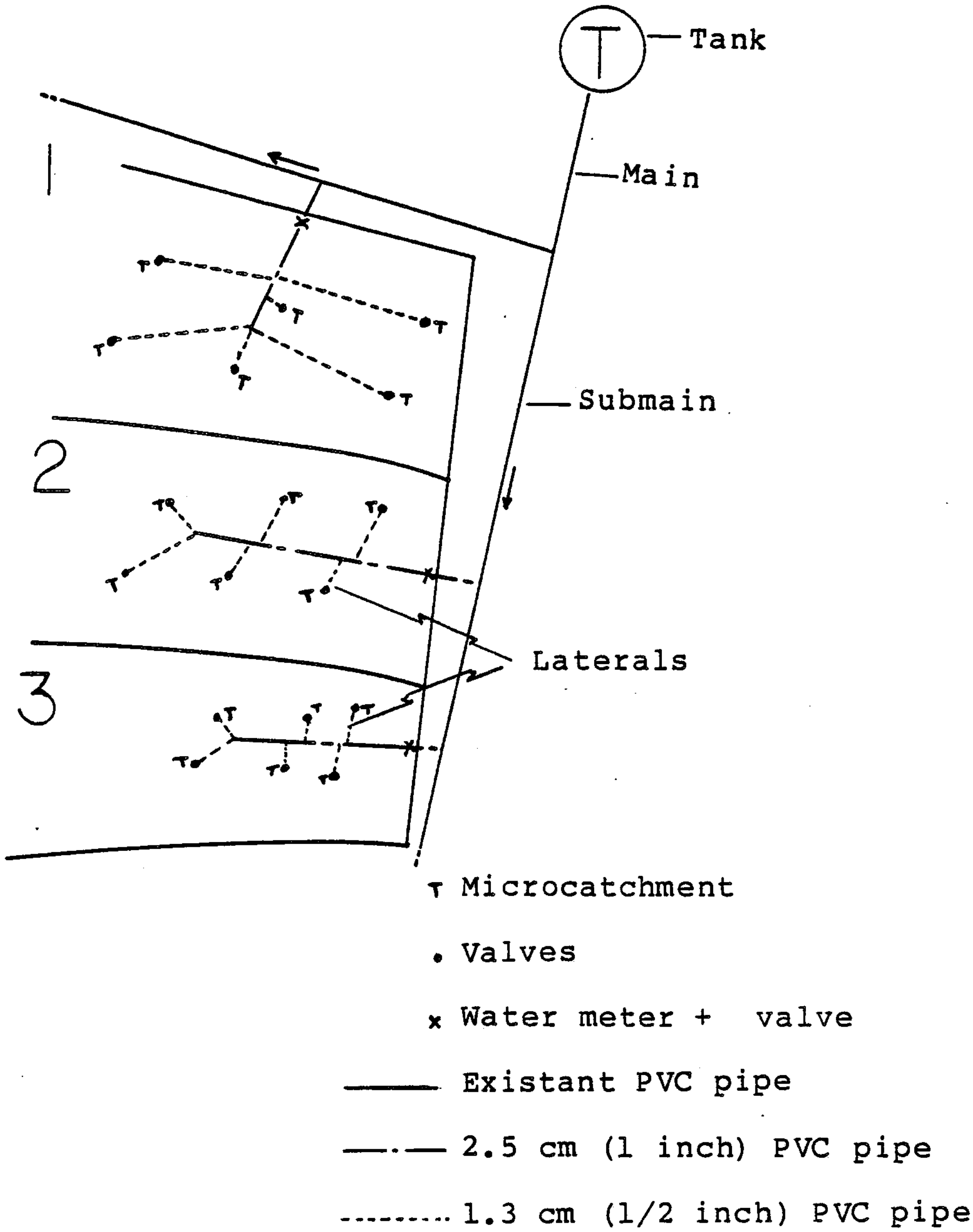

Figure 7 Irrigation system layout

The count rate depends largely on θ , but it is also affected by other soil properties such as the dry bulk density of the soil, the volumetric content of constitutional hydrogen, various other chemical components of the soil, and the soil solutions (Rode 1965).

The process for the calibration was laborious. The gravimetric method was used to determine the soil moisture content. A sample of moist soil, taken in cores of known volume from the field, was weighed, then dried in an oven at a temperature of 105^{o} for a period exceeding 24 hours, then weighed again. The moisture lost by heating represents the soil moisture in the moist soil. Calibration data and curves are given in appendix B. Bulk density also was determined using this equation:

$$\text{Bulk density} = \underset{(g)}{\text{dry soil}} \;/\; \underset{(cm^3)}{\text{soil sample volume}} \qquad (3\text{-}2)$$

Finally the soil moisture (θ) was evaluated using the following equation:

$$\theta\ (cm^3\ /\ cm^3) = \underset{(g)}{H_2O} * \underset{(g/cm^3)}{\text{bulk density}} \;/\; \underset{(g)}{\text{dry soil}} * \underset{(g/cm^3)}{H_2O\ \text{density}} \qquad (3\text{-}3)$$

Schedule of soil moisture measurements

Soil moisture measurements were taken at least once a week for the three subplots at 30, 45, 60, and 90 cm depth from March 14 to September 14, 1984.

Rainfall data

The rainfall data collected are shown in Table 1. During the period from March 14 to September 14, the months of higher rainfall were August (187.7 mm) and July (143 mm). The months of lower rainfall were March (no rain) and May (4.3 mm).

Runoff calculations

The assumption was made that 40 percent of the rainfall was captured as runoff water by the microcatchment which is the approximate runoff efficiency of a compacted earth sodium treated apron. The runoff values are shown in Table 1. Rainfall less than 10 mm was assumed to produce no runoff.

Irrigation data

The tree in subplot 1 was irrigated on June 5. The volume applied for the tree A1P1 (area 1, plant 1) was 475 liters. The wetted area was 8.5 m^2. The amount of water applied through the bubbler irrigation system in equivalent depth for subplot 1 is 56 mm. For the tree A2P3 in subplot 2, the volume of additional water applied was 290 liters on June 5. The wetted area was 5.3 m^2. Then, the amount of

Table 1. Rainfall and runoff data

DATE	RAIN (mm)	RUNOFF (mm)
March	no rain	-
April Ø9	29.2	11.7
April 3Ø	9.7	-
May 14	1.Ø2	-
May 15	.51	-
May 16	2.8	-
June 26	.51	-
June 29	23.4	9.3
July Ø6	6.4	-
July Ø7	17.8	7.1
July Ø9	16.Ø	6.4
July 11	3.5	-
July 13	2.5	-
July 16	6.9	-
July 17	1.3	-
July 18	14.2	5.7
July 19	15.2	6
July 2Ø	1.3	-
July 23	31.7	12.7
July 24	6.1	-
July 3Ø	13.7	5.5
August Ø6	7.1	-
August 1Ø	17.8	7.1
August 13	48.3	19.3
August 14	22.8	9.1
August 15	1.3	-
August 17	57.1	22.8
August 2Ø	5.8	-
August 22	4.1	-
August 23	2.5	-
August 27	7.4	-
August 28	12.7	5.1
August 29	.7	-
September Ø5	.76	-
September 12	3.6	-
Sebtember 14	1.3	-

supplemental water added to the tree in subplot 2 in equivalent depth is 55 mm. Finally, 230 liters were applied through the bubbler irrigation system to the tree A3P3 in subplot 3 on May 31. The wetted area was 4 m^2. The amount of supplemental water added to the tree in equivalent depth is 57.5 mm.

<u>Consumptive use data</u>

Pan evaporation data provided a measurement of the integrated effect of radiation, wind, temperature, and humidity on evaporation from a specific open water surface (Doorenbos and Pruitt, 1977)

The reference crop evapotranspiration (ETo) can be obtained from

$$ETo = Kp \cdot Ep \qquad (3-4)$$

where Ep = pan evaporation in mm.

Kp = pan coefficient

The pan coefficient was assumed to be 65 percent (from March to September, 1984). Reference crop evapotranspiration then was computed for the five month period April to August. The results are in Table 2. The crop evapotranspiration can be found by:

$$ETcrop = Kc \times ETo \qquad (3-5)$$

Where Kc is the crop coefficient. The crop coefficient takes into account the crop characteristics, time of planting, stage of crop development, and general climatic conditions (Doorenbos and Pruitt, 1977).

Since there are no data available on crop coefficient for figs in the area, it was assumed to be equal to the crop coefficient for citrus. The values of Kc are given in Table 2.

The estimation of evapotranspiration for the fig orchard is given in Table 2 using the following formula

$$(ET)figs = (Kc)figs \times Kp \times Ep \qquad (3-6)$$

where Ep = pan evapotranspiration

Kp = pan coefficient

Kc = crop coefficient

Table 2. Estimated ET for Fig trees.

	APRIL	MAY	JUNE	JULY	AUGUST
Ep mm/day	8.3	10.2	13.1	7	7.8
Kp	.65	.65	.65	.65	.65
Kc	.6	.6	.55	.55	.55
ET (Figs) mm/day	3.2	4	4.7	2.5	2.8
ET (Figs) mm/month	96	116	141	77.5	86.8

CHAPTER 4

DISCUSSION OF RESULTS

Soil moisture versus depth

Soil moisture profiles are given in Figure 8 for the three subplots (A1, A2, A3) for seven days which are March 14, April 12, May 11, June 12, July 13, August 10, and September 14, 1984. The curves will be analyzed for each subplot individually.

In subplot 1, the maximum soil moisture occurred at 60 cm depth for all days during the seven months. The minimum soil moisture occurred on March 14, April 12, May 11 at 30 cm depth and on June 12, July 13, August 10, and September 14, at 90 cm depth.

In subplot 2, the maximum soil moisture occurred at 60 cm depth for March 14, April 12, May 11, June 12, July 13, and at 90 cm on August 10. The minimum soil moisture occurred at 30 cm depth on March 14, April 12, May 11, June 12, July 13, September 14 and at 45 cm depth on August 10.

In subplot 3, the maximum soil moisture occurred at 60 cm depth on March 14, April 12, May 11, June 12, July 13,

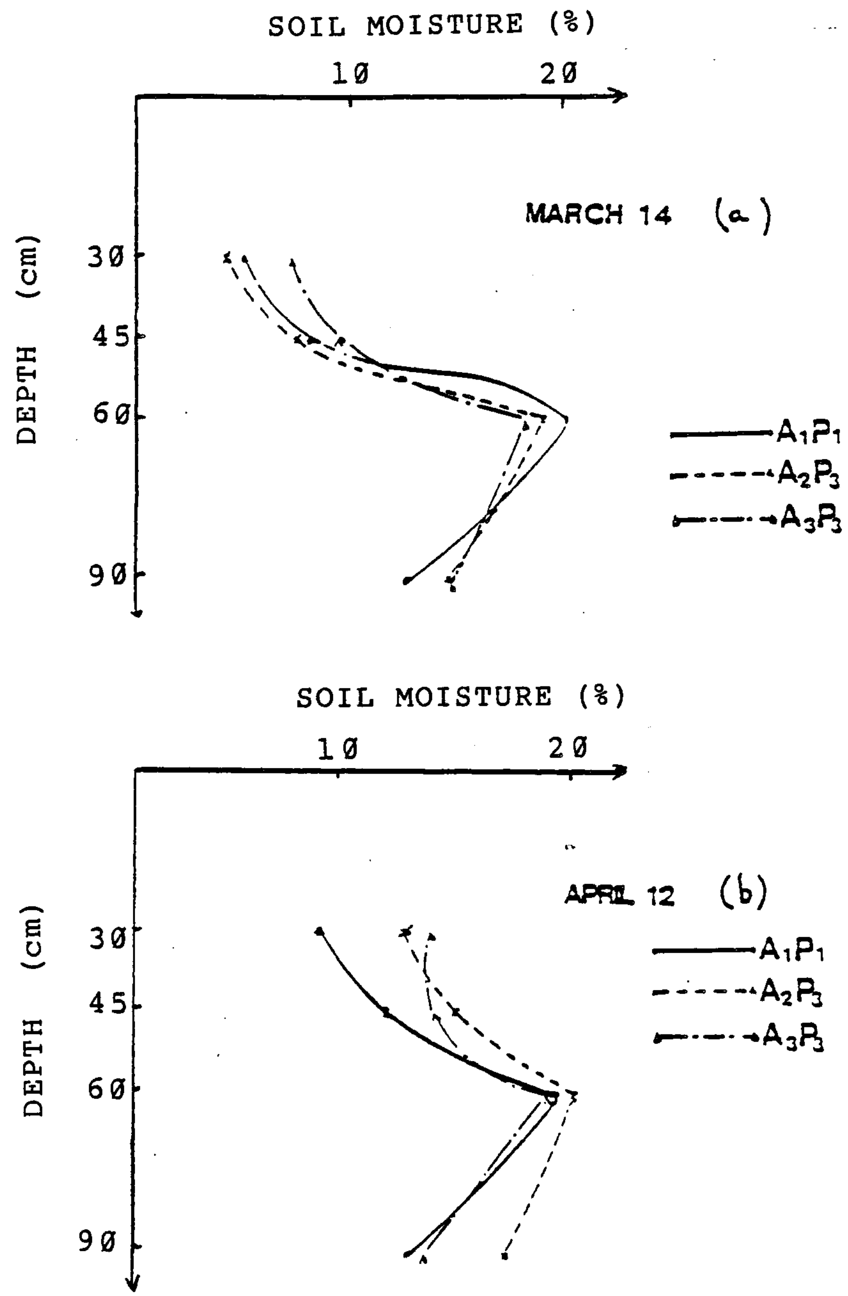

Figure 8 Soil moisture variation with depth for the three subplots and seven days during the 1984 growing season

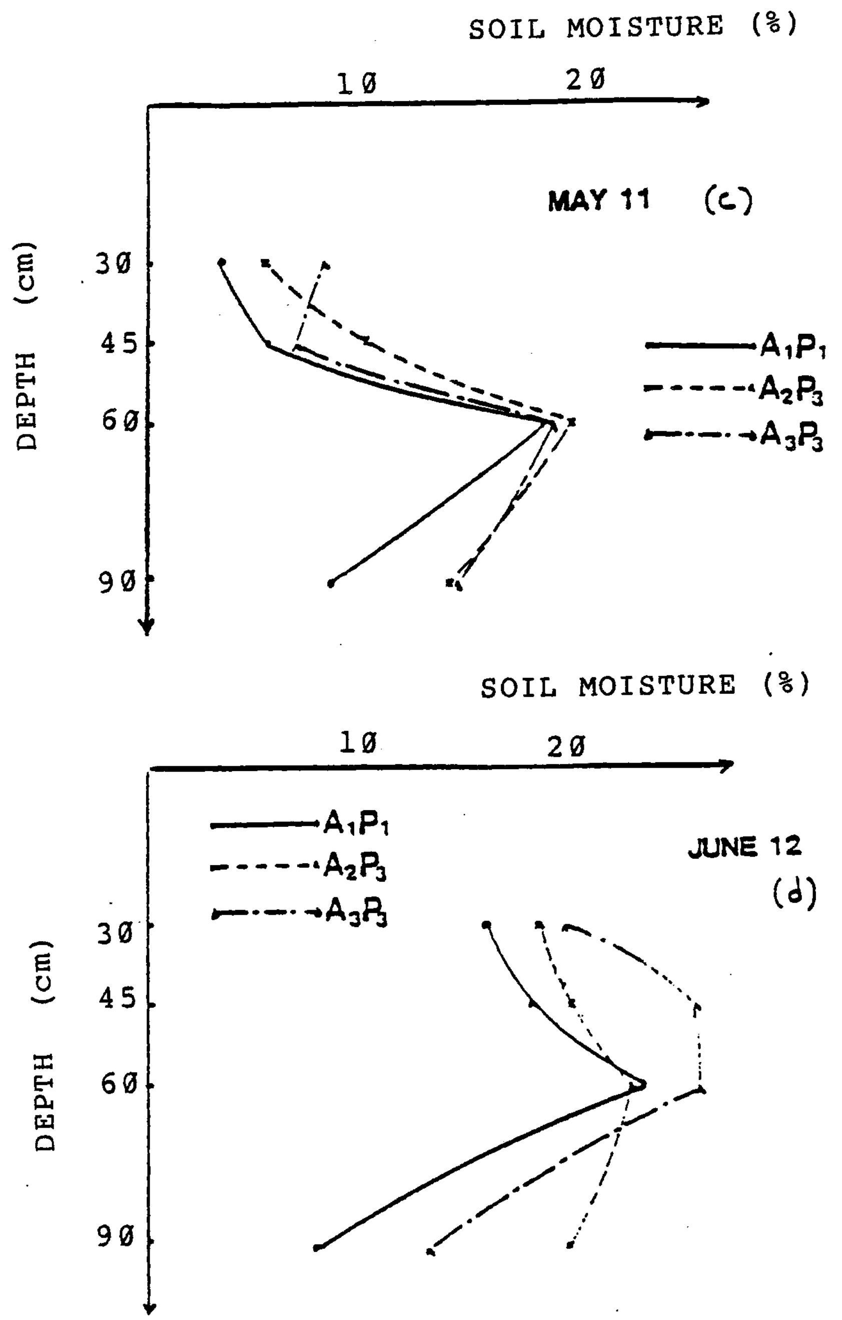

Figure 8 (con't)

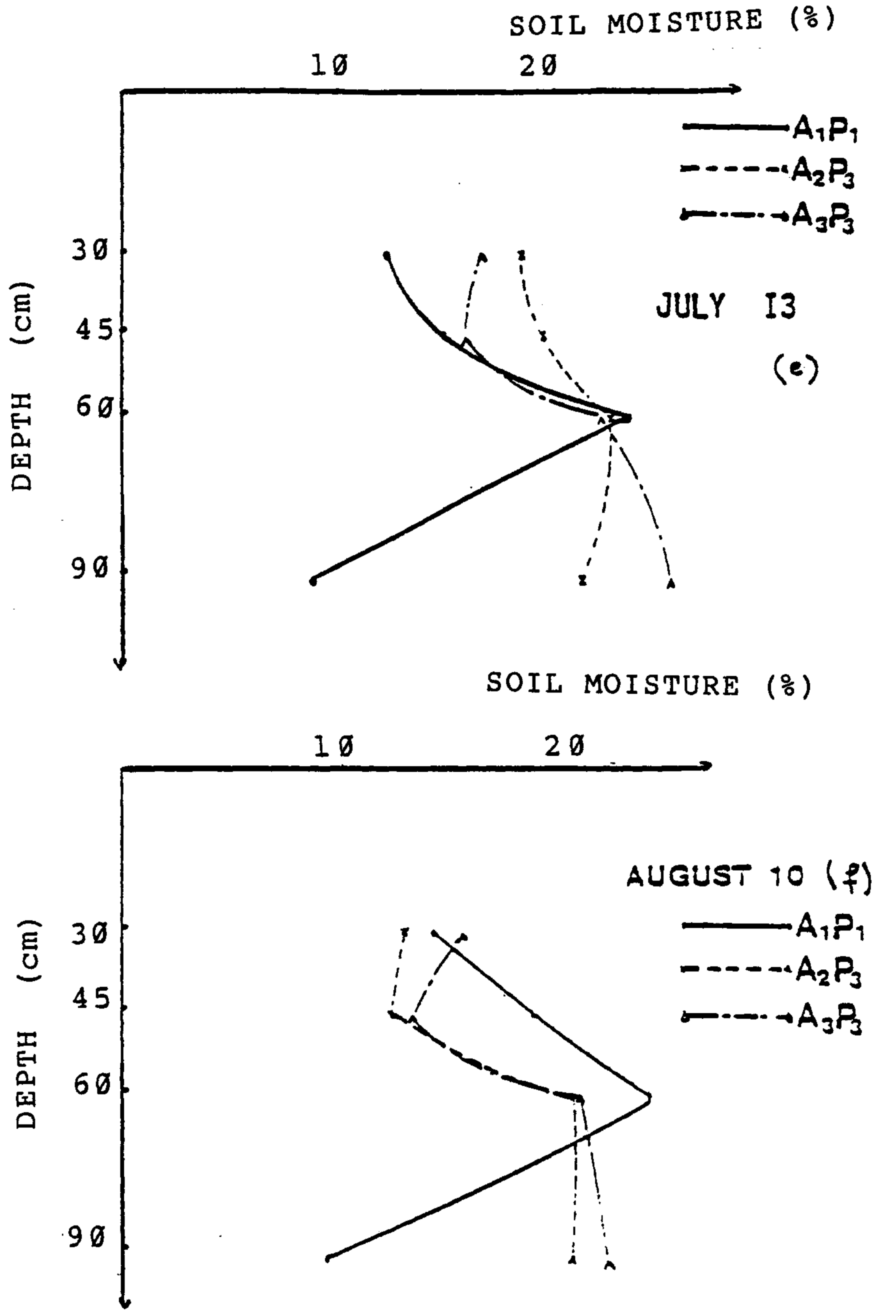

Figure 8 (con't)

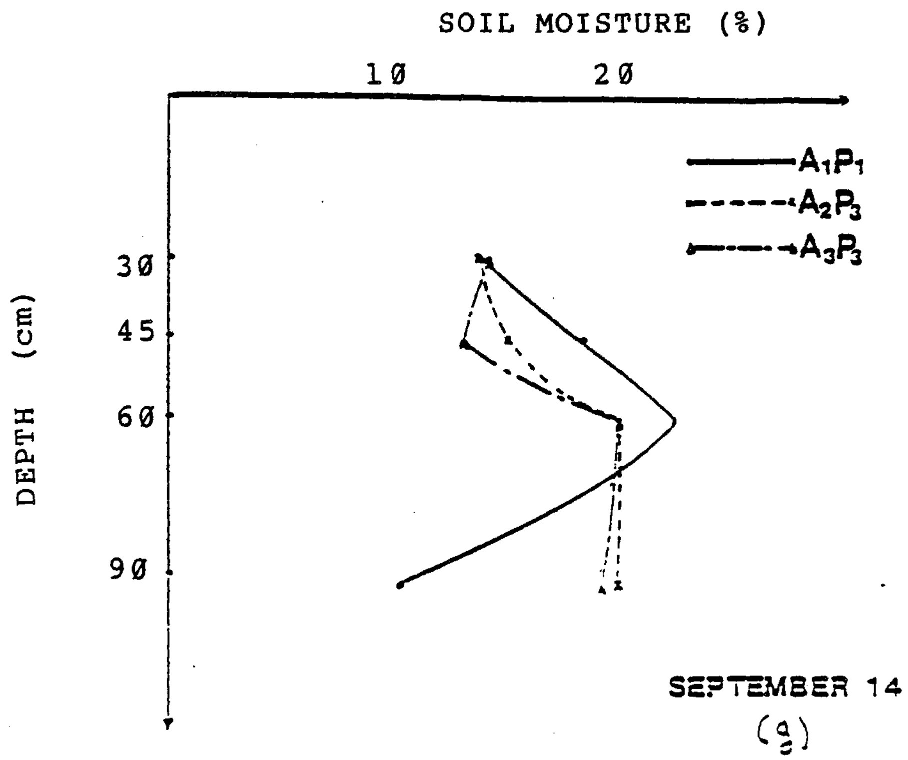

Figure 8 (con't)

September 14, and at 90 cm depth for August 10. The minimum soil moisture occurred at 30 cm depth on March 14, 45 cm depth on May 11, July 13, August 10, and September 14 and at 90 cm depth for April 12 and June 12.

Soil moisture in percent versus time

For each subplot, one location was selected to study the relationship of soil moisture in percent (cm^3 / cm^3) with time at 30, 45, 60, and 90 cm depths. The locations selected in the three subplots are represented by A1P1, A2P3, and A3P3 in the first, second, and third subplot, respectively.

Variation of soil moisture with time at 30 cm depth

The graphs of soil moisture versus time at 30 cm depth for A1P1, A2P3,and A3P3 are represented in Figure 9. In general, the shapes of the three curves are similar. At 30 cm depth, the soil moisture for the third subplot with the close spacing is the highest. At this depth, the first subplot with the large spacing has the lowest moisture content. The critical period for the first subplot seems to be from March to May where the soil moisture content averaged about 5 percent. From June to September, the soil moisture content averaged about 15 percent.

For the second subplot, the critical period when the plants need additional water is from March to May. The soil moisture content averaged about 6 percent. From June

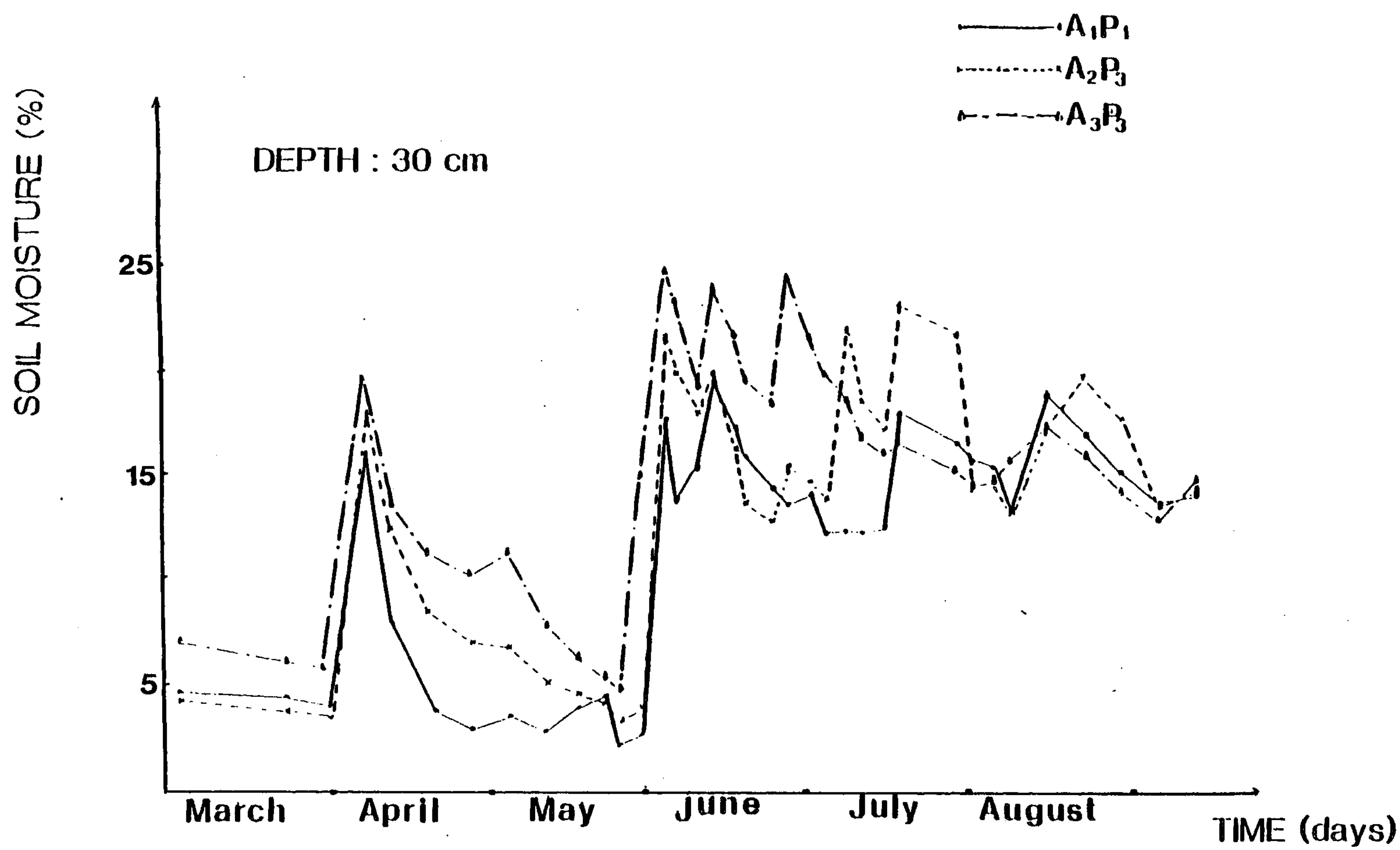

Figure 9 Variation of soil moisture with time at 30 cm depth

to September, the soil moisture increased due to rainfall or irrigation and averaged about 17 percent. This subplot had the highest soil moisture content for a short period from July 10 to August 14.

The third subplot has more soil moisture than the other subplots during the months of March, April, May, and June. The highest soil moisture content for this subplot was 24 %.

Variation of soil moisture with time at 45 cm depth

Soil moisture content versus time at 45 cm depth is shown in Figure 10 for A1P1, A2P3, A3P3 in the first, second, and third subplots, respectively. The soil moisture content is higher during June, July, August, and September than in March, April, and May. The critical period for the first subplot is during March, April, and May. The soil moisture content averaged about 6 percent. From June to September, the soil moisture content averaged about 17 percent. For the second subplot, the critical period was only during March and May where the soil moisture content averaged about 7 and 10 percent respectively. From June to September, the soil moisture content averaged about 18 percent. The critical period for the third subplot was during March and May when the soil moisture content averaged about 8 percent.

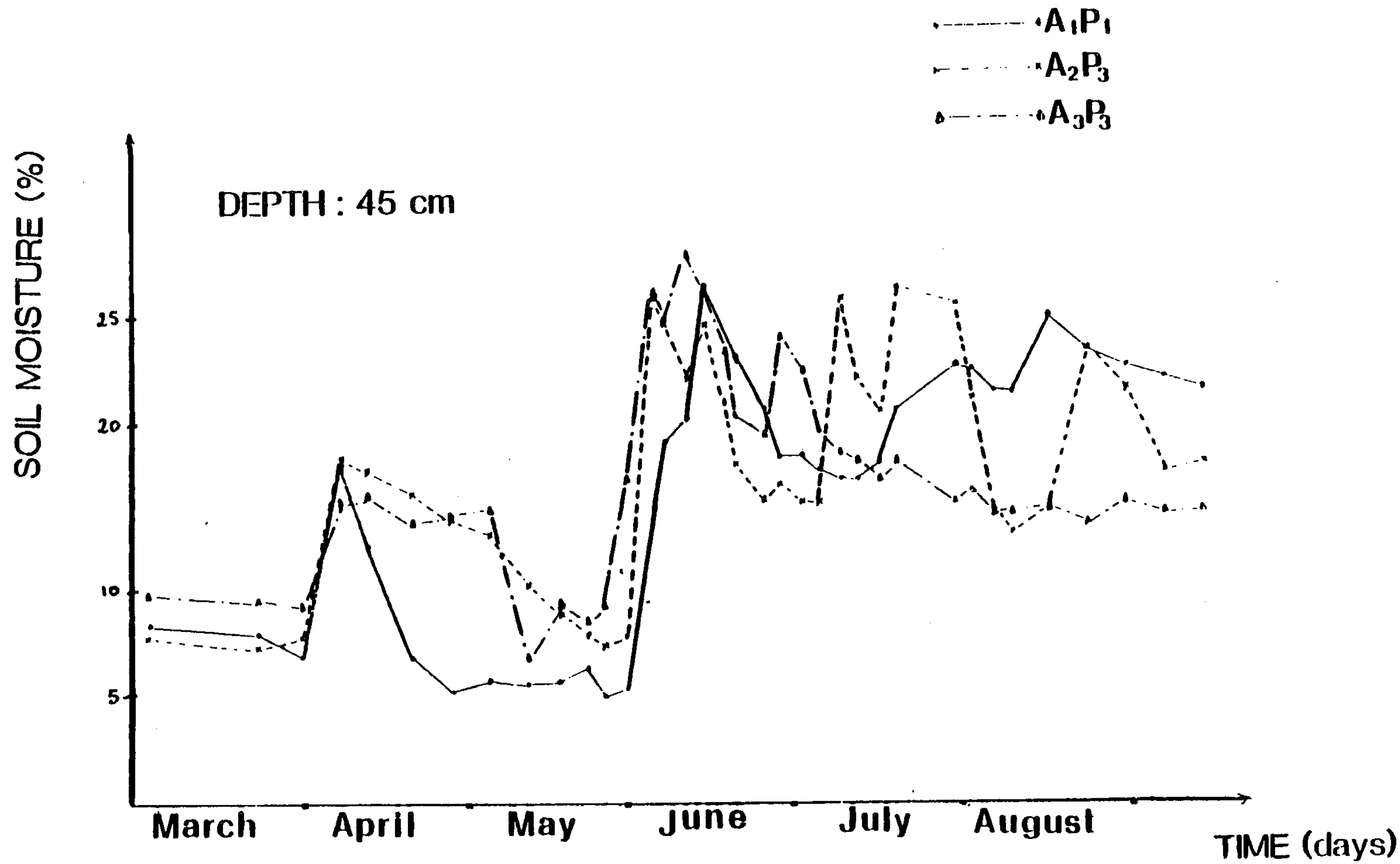

Figure 1Ø Variation of soil moisture with time at 45 cm depth

Variation of soil moisture with time at 60 cm depth

The graph representing the soil moisture content versus time at 60 cm depth for A1P1, A2P3, A3P3 for the first, second, and third subplots is shown in Figure 11. The variation of soil moisture with time between the three curves is very low compared to the curves at 30 and 45 cm depths. For the first subplot, the curve from March to June is almost flat. During this period, the soil moisture content was decreasing with time. The variation of soil moisture was only 2 percent. The soil moisture content averaged about 19 percent. From June 15 to September 14, the soil moisture content averaged about 24 percent. For the second subplot, from April 10 to May 20 the soil moisture content increased from 19 to 20 percent then decreased to 16.5 percent. Also, the soil moisture content averaged 19 percent from March to June and 21 percent from July to September. The soil moisture content in the third subplot averaged 18.5 percent from March to June and 21 percent from July to September.

Variation of soil moisture with time at 90 cm depth

The soil moisture content versus time at 90 cm depth for A1P1, A2P3,and A3P3 for the first, second, and third subplots is represented in Figure 12. For the first subplot, the soil moisture content averaged at 9.5 percent

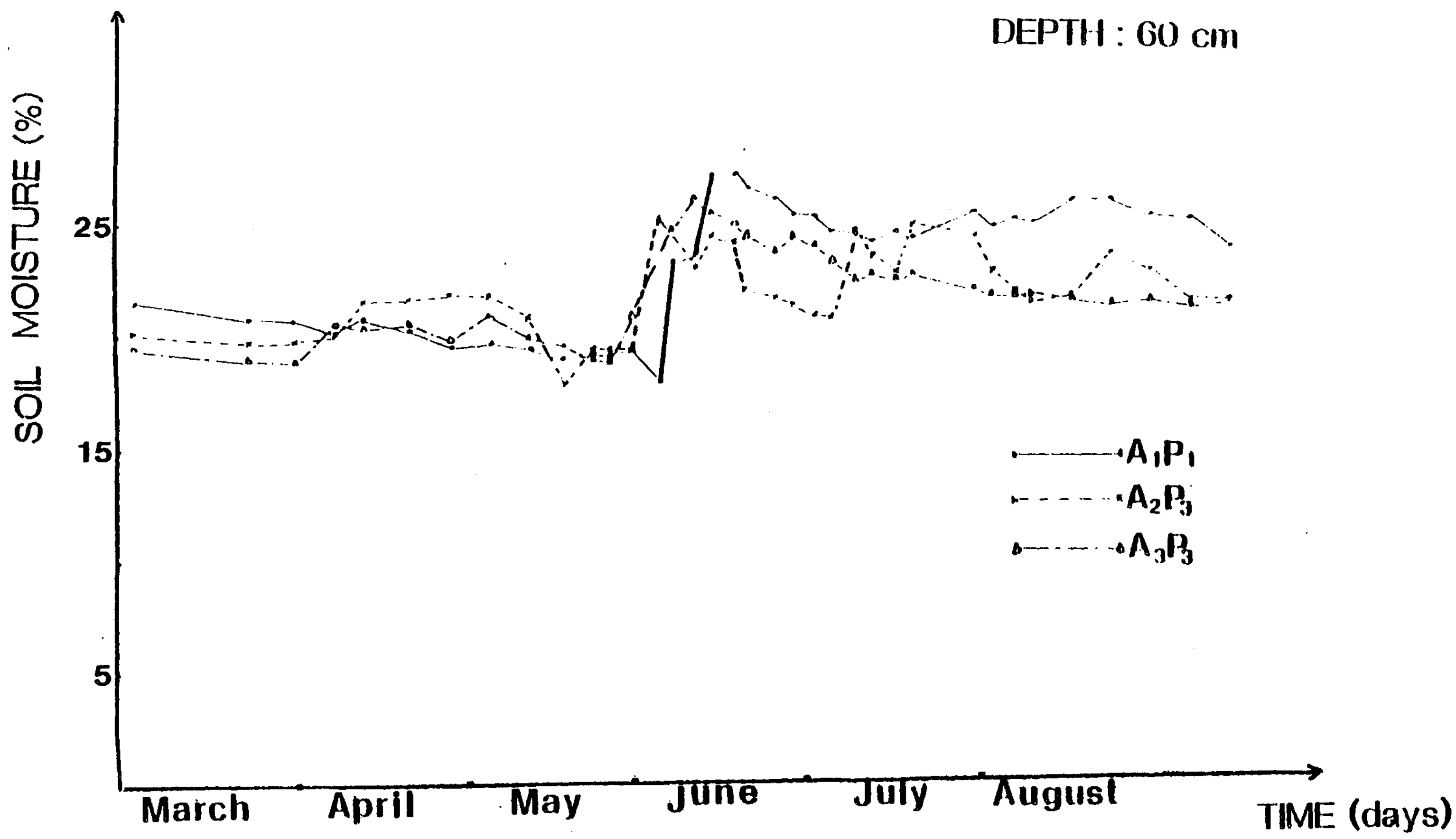

Figure 11 Variation of soil moisture with time at 6Ø cm depth

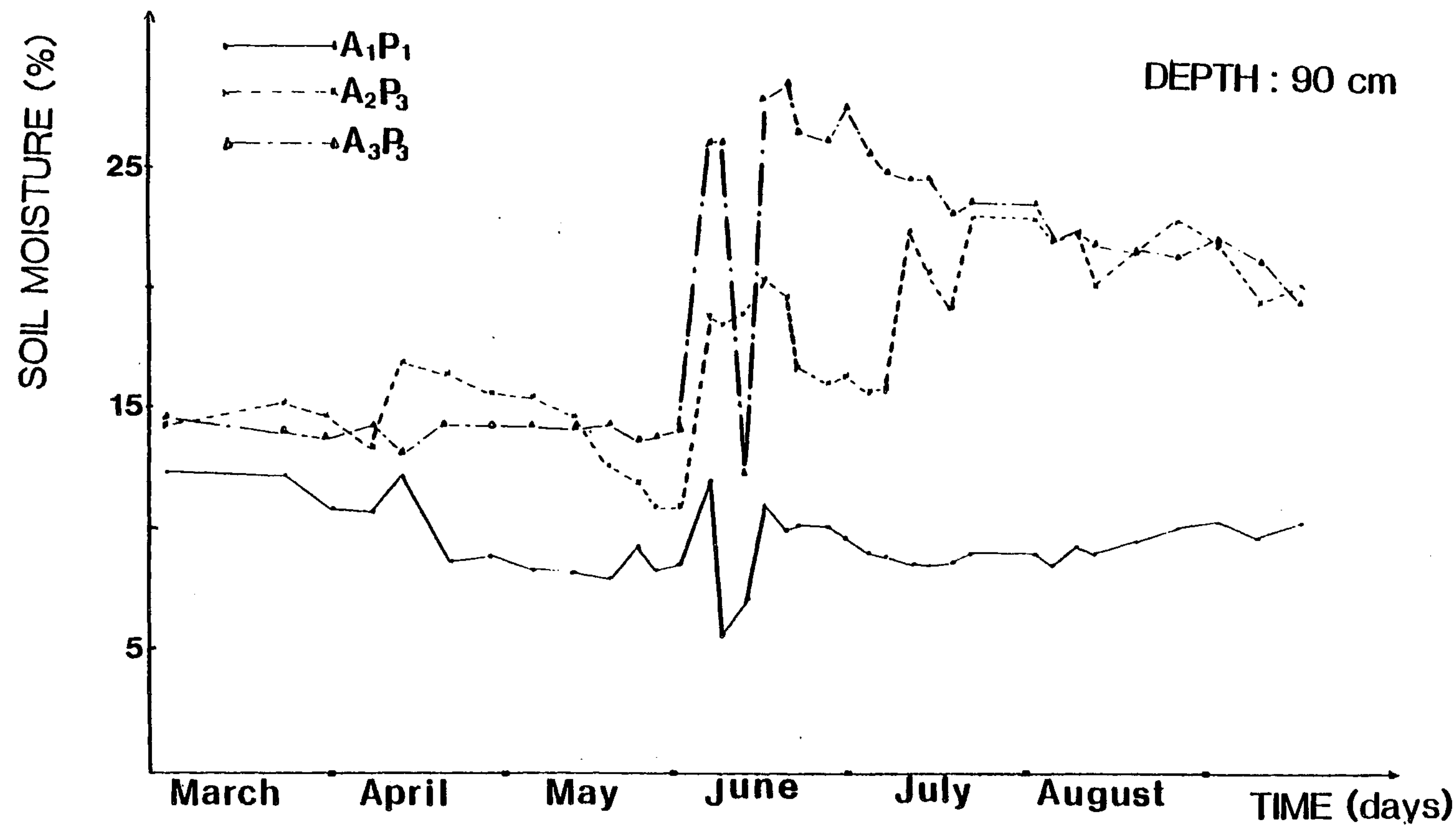

Figure 12 Variation of soil moisture with time at 90 cm depth

from March to September with 12 percent and 5.5 percent the highest and lowest soil moisture contents, respectively. For the second subplot the curve representing soil moisture content with time is characterized by many fluctuations. The highest soil moisture content was 23 percent occurring in July and 11 percent the lowest, occurring in May. During the first period (March to May) the soil moisture content was lower than during the second period (June to September). From March to May, the soil moisture content in the third subplot was relatively stable (14 percent). From May 28 to June 8 the soil moisture content increased from 14 percent to 26 percent due to additional water through irrigation. Then from June 15 to September 14, the soil moisture decreased from 26 to 20 percent.

<u>Soil moisture in equivalent depth versus time</u>

Soil moisture in equivalent depth (θ) was determined for the three subplots and the total soil depth using the following equation:

$$\theta(\text{mm}) = \theta\ (\%) * d\ (\text{mm}) \qquad (4\text{-}1)$$

where d represents the depth of the soil layer in mm.

Subplot 1: Soil moisture content, rainfall, and irrigation in mm versus time (March to September, 1984) for subplot 1 is shown in Figure 13. From March 14 to 31, the soil moisture content decreased by 3.5 mm mainly due to evapotranspiration losses. From March 31 to April 9, the soil moisture content increased by 51 mm in which 22 mm of water were supplied by runoff. From April 7 to April 28, the soil moisture content decreased by 61 mm mainly due to evaporation. During May, the soil moisture content was relatively stable. The losses of water through evaporation were compensated by 14 mm of rainfall. During June, the soil moisture content increased by 107 mm due to a 56 mm of additional water supplied by bubbler irrigation system. From June 15 to June 29, the soil moisture content decreased by 38 mm due to evaporation. From July 13 to July 20, the soil moisture content increased by 23 mm due to rainfall. From July 20 to August 7, the soil moisture content increased by 2.8 mm and then decreased by 6.5 mm despite 58.5 mm of rainfall. From August 7 to August 17, the soil moisture content increased by 19.6 mm due to 90 mm of rainfall during that period. From August 17 to September 14, the soil moisture content decreased by 26mm despite 57 mm of rainfall on August 17.

SUBPLOT 2: Soil moisture, rainfall, and irrigation in mm versus time (March to September, 1984) for subplot 2 are shown in Figure 14. From March 31 to April 9, the soil moisture content increased by 51.8 mm in which 22.6 mm of water were supplied by runoff. From April 12 to May 25, the soil moisture content decreased by 64 mm mainly due to evaporation. On June 5, 54 mm of additional water supplied

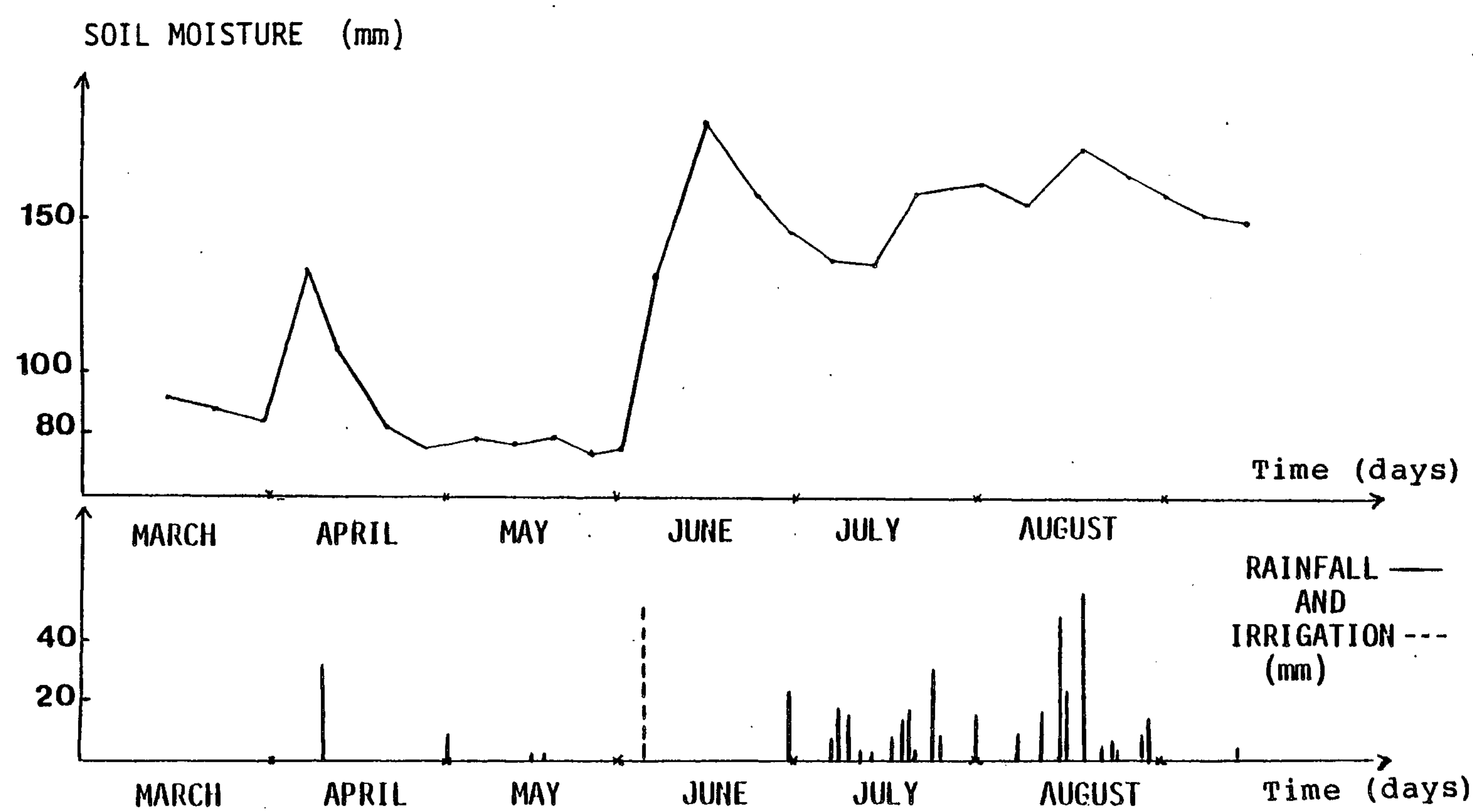

Figure 13 Soil moisture, rainfall, irrigation versus time for subplot 1 (1984)

through the bubbler irrigation system increased the soil moisture content by 117mm. From July 6 to July 20, the soil moisture content increased by 75 mm due to 85 mm of rainfall during that period. From July 31 to August 7, the soil moisture content decreased by 45 mm despite 8mm of rainfall on August 6. From August 7 to August 24, the soil moisture content increased by 31 mm due to nearly 150 mm of rainfall during that period. Then, from August 24 to September 7, the soil moisture content decreased by 54 mm despite 21.5 mm of rainfall during that period.

SUBPLOT 3: Also, soil moisture, rainfall, and irrigation in mm versus time (March to September, 1984) for subplot 3 is shown in Figure 15. From March 14 to March 31, the soil moisture content decreased by 8 mm due to evaporation. From March 31 to April 7, the soil moisture content increased by 55 mm in which 25.8 mm were supplied by runoff. From April 7 to May 25, the soil moisture decreased by 59.2 mm due to evaporation. On May 31, an additional 58.6 mm of water supplied through the bubbler irrigation system increased the soil moisture content by 150 mm of water. From June 29 to September 14, the soil moisture content decreased by 84 mm despite over 150 mm of rainfall in August.

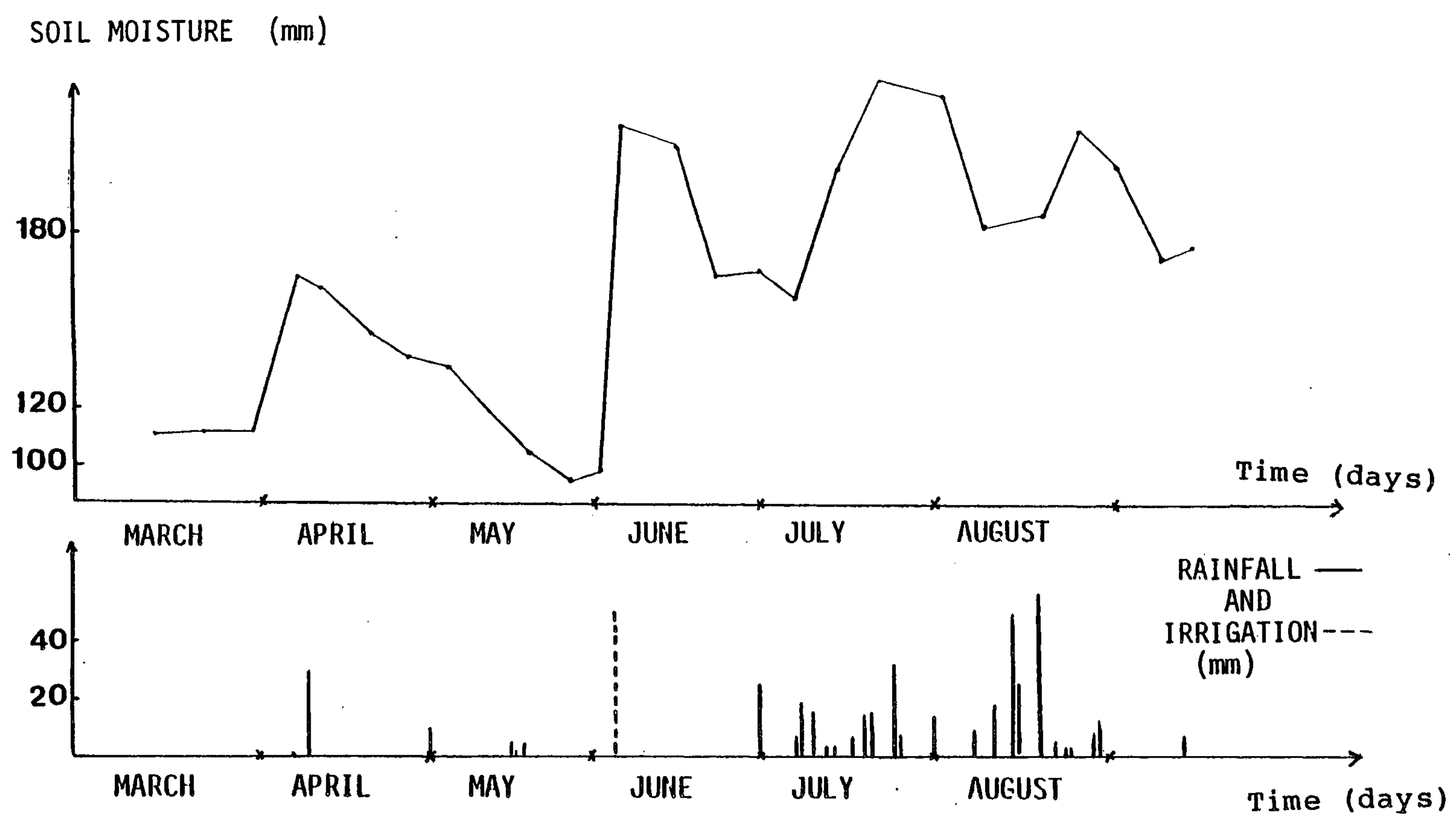

Figure 14 Soil moisture, rainfall, irrigation versus time for subplot 2 (1984)

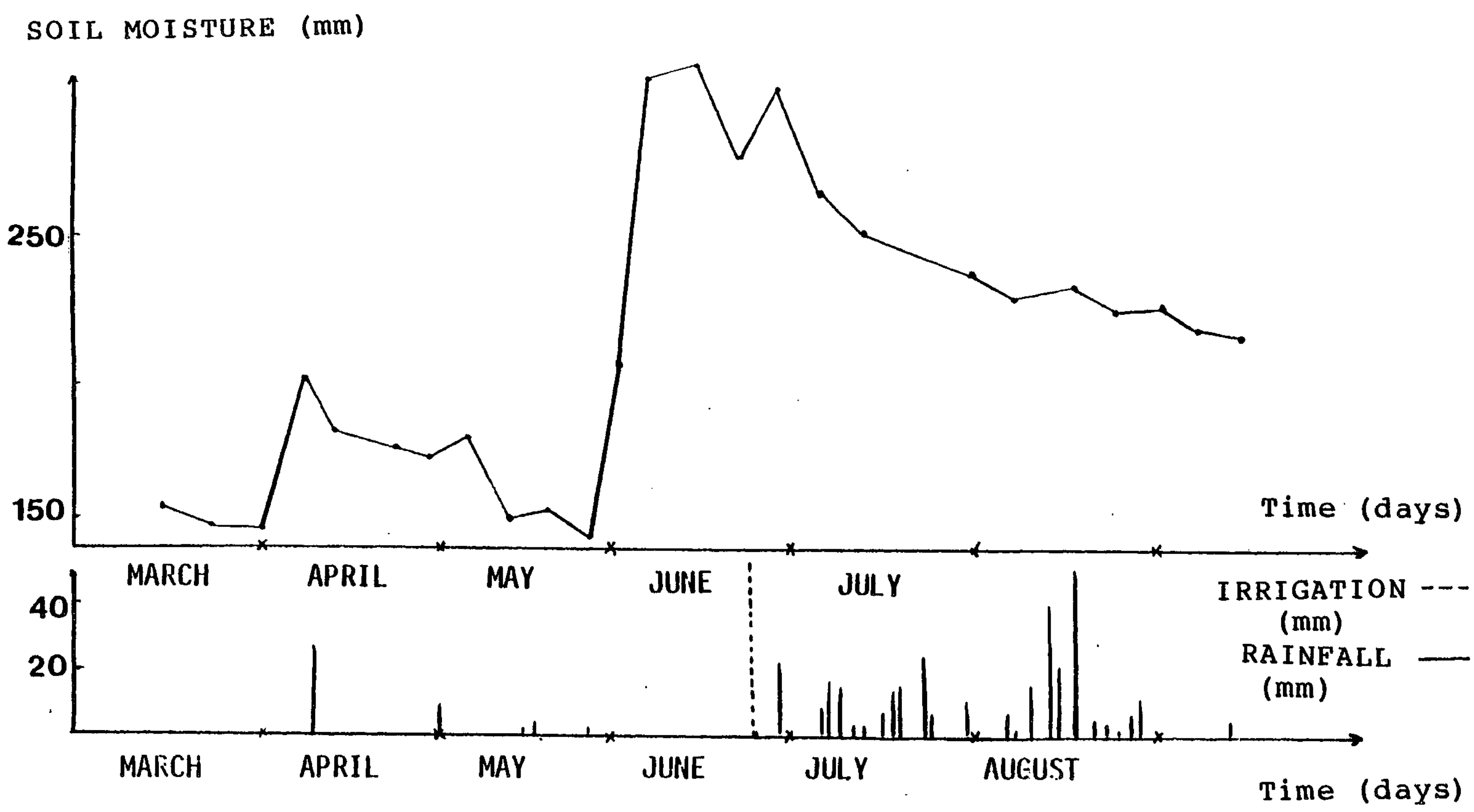

Figure 15 Soil moisture, rainfall, irrigation versus time for subplot 3 (1984)

Seasonal water balance

The water balance analysis is given in Table 3. The rainfall in the microcatchment area is shown in column 3. Rainfall (m^3) = Rainfall (m) * Microcatchment Area (m^2).

The runoff (RO) was calculated in column 4. Runoff = Ø.4 * Rainfall * area

In column 5, the runoff concentrated area which represents the wetted area of the captured water from runoff is listed. The difference in runoff concentrated area for the different subplots is due to the difference in microbasin areas.

The rainfall received into the runoff concentated area (RCA) calculated in column 6: Rr = RCA * Rainfall.

The irrigation data are listed in column 7.

The potential evapotranspiration (ETP) is shown in column 8. The difference in ETP for the different plots is due to the difference of the runoff concentrated area which provides different evaporation values.

The water stored in the root zone (S) was calculated in column 9 assuming no deep percolation and ground water movement. S = Rr + Ro + Irr - ETP

The results show that the highest amount of water stored in the root zone was in the first subplot which is explained by the largest area of its apron. The minimum amount of water stored in the root zone was in the third subplot because of its low apron area.

	RAINFALL mm	MICROCATCHMENT AREA m^2	RAINFALL m^3	RUNOFF (Ro) m^3	RUNOFF CONC. AREA m^2	RAINFALL m^3/tree	IRRIGATION (Ir) m^3	ET (Figs) m^3	WATER STORED m^3
SUBPLOT 1	403.3	87	35	14	19.4	7.8	.475	10	22.3
SUBPLOT 2	403.3	57.1	23	9.2	11	4.4	.29	5.7	13.9
SUBPLOT 3	403.3	36	14.5	5.2	7.6	3	.23	4	9.1

Table 4 Water balance for the three subplots

Interpretation of results

The results have been interpreted using the graphs: soil moisture versus depth and soil moisture versus time. The graphs,soil moisture versus time at various depths for the three subplots show that there is accumulation of soil moisture at 60 cm depth in the first subplot , and at 60 to 90 cm depth in the second subplot. The third subplot has the highest soil moisture content at 90 cm depth.

The graphs of rainfall and irrigation versus time for the three subplots (Figure 13, 14, and 15) explain why the soil moisture content is higher during June, July, and August than March, April, and May. The additional water supplied to the trees through the bubbler irrigation system on May 31 is responsible for the high increase of soil moisture content in early June at all depths except for the first subplot at 90 cm depth because of the impervious layer. The water applied may not have infiltrated equally throughout the area. A concentration of this water in the vicinity of the access tube would explain the high soil moisture readings.

The graphs of soil moisture versus depth for the three subplots and seven days during the 1984 growing season show that there is accumulation of moisture for the three subplots at 60 cm depth. This is explained by the soil profile (See Appendix A). The soil is a Whitehouse sandy loam. The top 30 cm of the soil is mostly a granular, sandy loam which is permeable and has a low moisture holding capacity. However, from 30 to 50 cm depth the soil is a brown, friable sandy clay loam. From 50 to 70 cm the soil is a dark red clay which has a high capacity of moisture retention. This explains the high soil moisture content at 60 cm depth.

In the first subplot, an impervious layer consisting mostly of clay is located at 80 cm depth which explains the low soil moisture content at 90 cm depth. In the second subplot, the impervious layer is located at 100 cm depth which explains the accumulation of soil moisture in the layer between 60 and 90 cm depth. However, the soil moisture content at 30 and 45 cm depth is low because of the high permeability and low moisture retention of the sandy loam at these depths. In the third subplot the impervious layer is located at 120 cm depth. A dark red clay layer with low permeability and a high soil moisture retention is located between 50 and 90 cm depths, which explains the accumulation of soil moisture content at these depths.

Soil moisture in equivalent depth versus time (March to September, 1984) for the three subplots is represented in Figures 14, 15, and 16. The 29.2 mm of rainfall on April 9 provided the highest increase in soil moisture in subplot 3 and the lowest in subplot 1. However, subplot 1 has the highest microcatchment area and subplot 3 the lowest. This may be explained by the presence of rills in subplot 1 and 2 due to erosion. Small channels divert the water from the microcatchment to the drainage channel. Evaporation losses in subplot 1 were higher than in subplot 3. This is explained by the reduction of the catchment area in subplot 3. The rainfall in July and August provided a higher increase of soil moisture content in subplot 2 than in subplot 1. However, it seems to have no effect on subplot 3.

Also, soil moisture in equivalent depth versus time was used to estimate the evapotranspiration losses from Figs for the three subplots during March 14 to May 29 and June 6 to September 14. The evapotranspiration was computed using the following equation:

$$ET = \text{rainfall} - SM \qquad (4\text{-}2)$$

where SM represents the variation of soil moisture content. ET is the evapotranspiration of Figs.

In subplot 1, the loss of water through evapotranspiration was 603.1 mm (Table 4). The runoff concentrated area was 19.4 m^2. Then, the evapotranspiration was 11.6 m^3. In subplot 2, the evapotranspiration was 607.8 mm (Table 5). The runoff concentrated area was 11 m^2. Then, the loss of water through evapotranspiration from March 14 to May 29 and June 6 to September 14 was 6.7 m^3. In subplot 3, the evapotranspiration was 694.7 mm (Table 6). The

Table 4 : Evapotranspiration losses in mm for Figs during March 14 to May 29 and June 15 to Sept 14, 1984 in subplot 1

Period	SM	R	ET
March 14-31	-7.7	-	7.7
April 1-9	+51.3	29.2	13.5
April 10-27	-60.8	-	60.8
April 28-May 4	+3	9.7	6.7
May 5-11	-2.8	-	2.8
May 12-19	+2.5	4.3	1.8
May 20-29	-6.2	-	6.2
June 15-29	-38.1	.5	47.9
June 30-July 13	-8.9	69.6	92
July 14-21	+23.13	38.9	27.5
July 22-31	+2.8	51.5	66.7
August 1-7	-6.5	7.1	13.6
August 8-18	+19.6	90.2	128.9
August 19-Sept 14	-26.1	95.1	127

ET(total)= 603.1 mm

Table 5 : Evapotranspiration losses in mm for Figs during March 14 to May 29 and June 6 to Sept 14, 1984 in subplot 2

Period	SM	R	ET
March 14-31	+1.25	-	8.5
April 1-9	+51.8	29.2	13.5
April 10-May 29	+69.8	14	83.8
June 6-22	-50.9	-	50.9
June 23-29	+1.3	23.9	31.9
June 30-July 6	-9.1		9.1
July 7-20	+75.1	67.8	19.8
July 21-August 7	-51.9	59.9	130
August 8-24	+34.1	157.2	181.4
August 25-Sept 7	-43.8	21.6	70.5
Sept 8-14	+4.9	13.4	8.4

ET(total)= 607.8 mm

Table 6 : Evapotranspiration losses in mm for Figs during March 14 to May 29 and June 15 to Sept 14, 1984 in subplot 3

Period	SM	R	ET
March 14-31	-8.3	-	8.3
April 1-9	+55.2	29.2	13.5
April 10-27	-30.2	-	30.2
April 28-May 4	+5.9	9.7	3.8
May 5-11	-27	-	27
May 12-19	+1.5	4.3	2.8
May 20-29	-9.3	-	9.3
June 15-22	-31.7	-	31.7
June 23-29	+24.8	23.9	41.8
June 30-July 6	-35.6	-	35.6
July 7-13	-13.9	46	72.5
July 14-20	-4.4	37.6	53.7
July 21-31	-9.1	52.8	80.1
August 1-7	-8.3	7.1	15.4
August 8-17	+4.1	97.3	151.5
August 18-24	-7.3	69.5	76.8
August 25-31	+1.1	20.8	24.8
Sept 1-7	-7.9	.8	8.8
Sept 8-14	-2.2	4.9	7.1

ET(total) = 694.7 mm

runoff concentrated area was 7.6 m^2. The evapotranspiration in m^3 was 5.2.

The evapotranspiration computed using the variation of soil moisture with time are nearly similar to those estimated in the water balance analysis. However, the amount of water stored in the soil using the soil moisture versus time curves and water balance analysis are different. In subplot 1, the soil moisture versus time curve shows that 1.1 m^3 were stored in the soil compared to 12.1 m^3 in the water balance analysis. Also, in subplots 2 and 3, the soil moisture versus time curves showed that the amount of water stored in the soil were Ø.7 and Ø.4 compared to 8.2 and 5 m^3 in the water balance analysis. This may be explained by the low rate of infiltration of water into the soil assumed high in the water balance analysis.

The difference of amount of water stored in the soil computed from the soil moisture curves and the amount computed from the water balance analysis can be attributed to the following factors:

The formation of rills in the microcatchments due to erosion collects the runoff water and conveys it out of the microbasins. This reduces the amount of water collected in the microbasins from runoff by nearly 25 percent which in the case of subplot 1 represents 3.5 m^3. Also, in the three subplots, the rate of infiltration was low due to the formation of a thin impervious layer around the tree. This allows the water to concentrate on the surface and increases the amount of evaporation. Therefore, an additional losses from evaporation from free water surfaces should be taken into consideration. The rate of additional water losses is expected to be nearly 3.5 mm/day during a period of 60 days (July and August when the rainfall is high). Then, for subplot 1, where the runoff concentrated area is 19.4 m^2, the additional water losses from free water surface evaporation is 4 m^3. An another loss of water assumed to be equal to zero in the water balance analysis may be deep seepage at depth over 100 cm. The bed of clay at 90 cm depth with a conductivity of 1 mm/day allows, in the case of subplot 1 (runoff concentrated area is equal to 19.4 m^2) and for a 6 month period, a loss of 3.5 m^3 of water through deep seepage. Finally, assumptions made in the water balance analysis may be another source of error. The runoff considered to be 40 percent of the rainfall may be overestimated. Also, some reading errors might have been made during soil moisture measurements or rainfall data collection.

Obviously, the magnitude of these additional losses of water assumed to be equal to zero in the water balance analysis explains the different values obtained in computing the amount of water stored in the soil using the water balance analysis and the soil moisture curves. Additional reseach would be needed to permit a more accurate comparison.

The information from this research will allow us to use the irrigation system more efficiently. The amount of additional water supplied by the irrigation system will decrease from the first to the third subplot. Also, increasing the frequency of irrigation and decreasing the flow rate of the irrigation will be more efficient because of the high permeability in the upper layer of the soil.

The choice of the crop for the first subplot should be reviewed. The figs are not suitable for the first subplot because of the need of the fig roots to use soil moisture at 100 to 120 cm depth. However, the soil moisture content for the first subplot is concentrated at 60 cm depth. Also, an impervious layer located at 80 cm depth limits the root development of the Fig trees.

The design of the system could be improved by increasing the catchment area in the first subplot resulting in an increase of the net runoff. Also, reducing the length and increasing the width will reduce the effect of erosion on steep slopes and increase the runoff efficiency.

The results of this study could be used in designing a similar water harvesting system. A detailed soil analysis including an evaluation of soil moisture characteristics would be necessary to determine the depths and amounts of soil moisture storage . This will provide better information for selecting the crop and designing the supplemental irrigation system.

CHAPTER 5

SUMMARY AND CONCUSIONS

Summary

The study provided an evaluation of soil moisture in a water harvesting system with supplemental bubbler irrigation. The advantages of this type of crop production are obvious such as low cost, increase in availability of water, increase in crop production, and better use efficiency of water by supplemental irrigation system.

Soil moisture data were taken at different depths (3Ø, 45, 6Ø, 9Ø cm) during a six month period using the neutron probe. The analysis was based on variations of soil moisture with time and depth in the three subplots with different size, tree spacing, and water applied. The analysis of soil moisture versus depth showed that there was accumulation of soil moisture for the three subplots at 6Ø cm depth. This was explained by the presence of a dark red clay with low permeability and high moisture retention.

The analysis of soil moisture versus time showed that the first subplot has the lowest soil moisture content at all depths except at 6Ø cm depth and the second subplot the highest soil moisture content at 45 cm depth. The third subplot has the highest soil moisture content at 90 cm depth. However, the water balance analysis, with an estimation of the evapotranspiration from the Figs, showed that the first subplot received the highest amount of water and the third subplot the lowest amount of water.

Also, the analysis of soil moisture versus time compared with the rainfall data confirmed that March and April required the highest amount of supplemental water and July and August the lower requirements of supplemental water for the year 1984.

All the trees observed in this study have gained considerable growth. The additional water supplied by the bubbler irrigation system after a drought period during March, April, and May has been very effective for the plants in terms of development. But, no yield or growth studies have been done in this research.

Conclusions

The analysis of soil moisture versus time and depth provides a reasonable basis for the design of water harvesting microcatchments. It provides necessary information for estimating the catchment area and the additional amount of water needed by the plants. The water balance was insufficient in providing information relating to the design of the system. Additional measurements and observations of runoff, evaporation, and deep percolation should be done for accurate water balance analysis.

To get higher runoff efficiency, maintenance of the apron from erosion is essential. Erosion control will avoid the transport of soil from the land by running water. Weeds must be removed from the catchment to increase the net runoff. Maintenance of berms, slope, drainage channels, and supplemental irrigation systems will surely increase the efficiency of the water harvesting system.

Another study which could be done to complement this research is the evaluation of soil moisture in a water harvesting system with supplemental irrigation and different treatments of the catchment apron. Additional detailed, accurate information of variables such as runoff and losses of water due to evaporation, deep percolation, and erosion is needed.

APPENDIX A

Oracle Agricultural Center soil

The soil was a Ustollic Haplargid, fine, mixed, Whitehouse sandy loam. The soil has an unusually deep, permeable A1 horizon overlying a very deep, slowly permeable, heavy textured prismatic B horizon. The soil was slightly acidic (pH 6.5) at the surface, pH increased with increasing depth until a value of 8.2 was found at the lowest depth observed.

The top layer was a dark red brown granular sandy loam overlying a reddish brown sandy clay loam. A dark red clay, strongly prismatic, is found under these two layers. Deeper, an impervious clay layer is found (Billy, 1970).

Soil characteristics

SOIL TEXTURE (at the surface)			SOIL CLASSIFICATION
sand (%)	silt (%)	clay (%)	LOAM
45	33	22	

APPENDIX B

calibration data and curves

Subplot 1

depth (cm)	wet soil (g)	dry soil (g)	can (g)	dry soil (g)	H O (g)	B.D (g/cm^3)
30	171.4	157.1	48.9	108.2	14.3	1.77
45	174.8	158.2	48.5	109.7	16.6	1.8
60	180.4	164.3	49.5	114.8	16.1	1.88
90	144.6	138.1	49.6	88.5	6.5	1.45
120		NOT COLLECTED				
30	157.9	141.2	48.4	92.8	16.7	1.52
45	164.9	151.1	47.3	103.8	13.8	1.7
60	174.9	160.0	49.8	110.2	14.9	1.8
90	162.3	153.0	47.5	105.5	9.3	1.73
120		NOT COLLECTED				
30	161.9	146.8	48.7	98.1	15.1	1.6
45	150.2	134.6	49.0	85.6	15.6	1.4
60	154.8	137.6	47.5	90.1	17.2	1.47
90	164.9	153.5	49.0	104.5	11.4	1.71
120		NOT COLLECTED				
30	176.1	163.3	49.3	114.0	12.8	1.87
45	156.0	130.0	50.0	80.0	26.0	1.31
60	161.5	145.4	49.0	96.4	16.1	1.58
90	175.1	160.6	48.2	112.4	14.5	1.84
120		NOT COLLECTED				

Subplot 2

30	169.4	155.1	49.0	106.1	14.3	1.74
45	172.9	158.7	48.1	110.6	14.2	1.81
60	164.0	151.2	49.3	101.9	12.8	1.67
90	155.6	143.3	47.3	96.0	12.3	1.57
120		NOT COLLECTED				
30	165.8	152.4	48.1	104.3	13.4	1.7
45	157.2	145.6	46.8	98.8	11.6	1.62

60	177.2	162.7	49.7	113.0	14.5	1.85
90	169.0	152.1	48.6	103.5	16.9	1.69
120	157.4	145.8	46.8	99.0	11.6	1.62
30	166.7	154.3	49.6	104.7	12.4	1.71
45	174.0	160.1	49.8	110.3	13.9	1.8
60	171.3	156.8	47.0	109.8	14.5	1.79
90		NOT COLLECTED				
120		NOT COLLECTED				
30	158.3	145.5	48.6	96.9	12.8	1.59
45	172.4	157.1	49.1	108.0	15.3	1.77
60	169.5	154.8	48.7	106.1	14.7	1.74
90	165.0	155.7	48.6	107.1	9.3	1.75
120		NOT COLLECTED				
Subplot 3						
30	169.3	154.6	48.9	105.7	14.7	1.13
45	172.3	156.6	48.5	108.1	15.7	1.77
60	176.3	159.5	49.5	110.0	16.8	1.8
90	159.8	140.6	49.6	91.0	19.2	1.49
120	172.2	155.4	48.6	106.8	16.8	1.75
30	172.4	157.1	48.4	108.7	15.3	1.78
45	158.8	145.8	47.3	98.5	13.0	1.61
60	178.9	162.0	49.8	112.2	16.9	1.84
90	173.9	154.2	47.5	106.7	19.7	1.75
120	169.1	160.4	47.8	112.6	8.7	1.84
30	161.8	148.2	48.7	99.5	13.6	1.63
45	149.3	139.9	49.0	90.9	9.4	1.49
60	137.6	129.2	47.5	81.7	8.4	1.34
90			NOT COLLECTED			
120			NOT COLLECTED			
30	174.9	160.0	49.3	110.7	14.9	1.81
45	170.9	156.9	50.0	106.9	14.0	1.75
60	166.4	150.5	49.0	101.5	15.9	1.66
90	165.0	143.0	48.2	94.8	22	1.55
120			NOT COLLECTED			

CALIBRATION CURVES

AT 30 CM DEPTH

$Y = 0.3051 * X - 0.03959$ where Y represents the soil moisture content and X represents the count rate ratio

The correlation coefficient is equal to Ø.874

AT 45 CM DEPTH

Y = Ø.373 * X - Ø.1156 where Y represents the soil moisture content and X represents the count rate ratio

The correlation coefficient is equal to Ø.626

AT 6Ø CM DEPTH

Y = Ø.1747 * X + Ø.067Ø9 where Y represents the soil moisture content and X represents the count rate ratio

The correlation coefficient is equal to Ø.4Ø9

AT 9Ø CM DEPTH

Y = Ø.3959 * X - Ø.1784 where Y represents the soil moisture content and X represents the count rate ratio

The correlation coefficient is equal to Ø.731

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