Irrigation Management For The Sierra Nevada Foothills Of California

prepared for the

United States
Department of the Interior
Bureau of Reclamation

by the

Cooperative Extension Service
University of California
El Dorado County

June 1981

IRRIGATION MANAGEMENT
FOR THE
SIERRA NEVADA FOOTHILLS
OF CALIFORNIA

by

Dick Bethell, Elias Fereres, Richard Buchner and Ronald Mansfield

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PREPARED FOR

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COOPERATIVE EXTENSION SERVICE
UNIVERSITY OF CALIFORNIA
EL DORADO COUNTY

FARM & HOME ADVISOR'S OFFICE
311 Fair Lane, Placerville. California 95667
Phone 916/626-2468

December 18, 1980

Mr. Gordon Lyford
Contracting Officer's Technical Representative
Water and Power Resources Service
2800 Cottage Way, Room W-2212
Sacramento, CA 95825

Dear Gordon:

This manuscript represents the final draft of the irrigation management manual prepared under Contract No. 0-07-20-X0134 between the University of California Cooperative Extension in El Dorado County and the Water and Power Resources Service.

We would like to express our appreciation for your assistance and excellent cooperation during the conduct of this work.

Sincerely yours,

Dick Bethell

Dick Bethell
Farm Advisor

DB/b
Encl.

COOPERATIVE EXTENSION WORK in AGRICULTURE & HOME ECONOMICS, United States Department of Agriculture & University of California Cooperating

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SUMMARY

"Irrigation Management for the Sierra Nevada Foothills" was prepared by the University of California Cooperative Extension in El Dorado County under contract with the United States Water and Power Resource Service. It culminates several years of crop irrigation research and five years experience with the El Dorado Irrigation Management Service (IMS).

Farmers, consultants, irrigation districts and government agencies can use this publication as a general reference on foothill irrigation practice and in developing irrigation management programs. The text points out how farmers can do their own irrigation management, but major focus is on how to conduct a program similar to the El Dorado IMS.

Special attention is given to computer scheduling of irrigations for specific sites, using weather data and crop curves adjusted to reflect slope, elevation and cover crop influences. Procedures used in developing and conducting this irrigation management program are presented in the text and appendix or are referenced so that others are able to utilize the accumulated El Dorado IMS experience.

The El Dorado IMS has become a reasonably accurate, economical and quickly delivered irrigation scheduling program for small-sized farms and irrigation units in an area of unusual variability in crop

water requirements.

However, the water budget potential of the irrigation management program has yet to be fully implemented by completing irrigation system analysis work and teaching growers how to efficiently use their systems. One more season of public input is needed to have the program receive a high level of commercial adoption.

Five years have already been devoted to building this model IMS. It must be taken to completion to provide a positive image of irrigation management program success for those starting new programs.

IRRIGATION MANAGEMENT
FOR THE
SIERRA NEVADA FOOTHILLS OF CALIFORNIA

INTRODUCTION

"How often do I irrigate?" and "How much water do I apply?" As California's population increases, these questions will have to be answered more precisely to cope with water scarcity and higher water costs. Rising energy costs and water pollution problems provide further motivation for efficient irrigation.

Past improvements in irrigation practice on foothill farms have always been accompanied by striking improvements in crop performance. In the future, more advanced irrigation technology will be adopted to further improve water utilization and reduce water costs. However, the major benefit of more efficient irrigation will, again, be better crop performance.

Many of the first foothill farms were non-irrigated. Eventually, water was diverted from canals built for mining and applied to crops by furrows. The dramatic results concentrated foothill agriculture along these old waterways. Later, furrows were zigzagged or doubled in number for even better results. Next came sprinkler irrigation, rapidly replacing furrows -- when growers witnessed a profound response to improved distribution uniformity.

The drought of 1976-77 forced a reassessment of foothill irrigation needs and practices. The Water and Power Resources Service, at the request of the District, assisted the El Dorado Irrigation District initiate an irrigation management service (IMS) program for farmers in 1976. Because the District had additional questions on crop water requirements, the University of California Cooperative Extension conducted studies on orchard water use in El Dorado County. The results were used to adapt and calibrate the IMS program to be sensitive to the highly variable foothill environment. These experiences demonstrated that local standard irrigation practices were frequently inadequate or excessive. Few farms were found that could not benefit financially by using a complete irrigation management service.

An irrigation management service (IMS) has three basic functions:

1. Schedule irrigations to obtain optimum plant performance.
2. Determine the amount of water required to refill the soil profile at any time.
3. Evaluate how long to operate the irrigation system to replace depleted moisture.

While individual farmers can perform all of these functions, the El Dorado IMS has been developed to quickly and accurately provide the first two functions by feeding weather data into a computer programed to give site specific irrigation recommendations. This has helped growers conserve water, even when irrigating to obtain optimum crop performance.

The El Dorado IMS has started performance analyses of irrigation systems to achieve maximum water use efficiency. Evaluations made to date show about 20 to 30 percent of irrigations are efficiently applied. Only after system evaluations are completed, can accurate water budget irrigation be realized.

The various foothill communities have differences in amounts and availability of water, water costs and power requirements for irrigation. Despite these differences irrigation management technology can be adopted to provide substantial benefits for nearly all irrigated farms. At the same time, the broader concerns of society; water conservation, economical food production, preservation of water quality and reduced energy consumption are all optimally served.

While adoption of improved irrigation methodology may be done to save on water, labor or energy costs, farmers should bear in mind however that higher and more consistent crop yields usually accompany improved irrigation practices.

This publication is written for individual farmers, agricultural consultants, water managers and water districts. Its purpose is to provide the information necessary for selection and operation of irrigation management programs to fit the individual and collective needs of water users throughout the Sierra Nevada foothills. Where possible, complex explanations or detailed procedures are left to the end of a topic section or have been placed in the appendix. General assistance in irrigation management or interpretation of this information may be obtained from local farm advisors of the University of California Cooperative Extension Service or local representatives of the United States Soil Conservation Service. Water districts interested in initiating IMS programs should contact the United States Water and Power Resources Service for assistance. For evaluation of irrigation practices and establishment of irrigation scheduling programs on specific farms, well-trained, commercial water management consultants are also available.

WHAT IS IRRIGATION SCHEDULING

The basic purpose of irrigation is to supply plants with water as needed to obtain optimum yield and quality of a desired plant constituent. Irrigations should be applied before the soil water content decreases enough to stress the plant and reduce yield and/or quality of the crop.

It is impossible to recommend a universally applicable irrigation schedule. Crop irrigation requirements and crop responses to irrigation vary with soils, types of plants, stage of growth and weather conditions.

Crops differ in their tolerance to the depletion of soil water before irrigation. A crop such as paddy rice responds favorably to frequent irrigations and even to continuous submergence. Some crops such as potatoes and most winter vegetables require moist conditions and suffer if more than 40 to 50 percent of available soil water is depleted before irrigation is applied even though the evaporative conditions are not severe. Other crops, such as small grains (especially during maturation stage), alfalfa, fruit trees and a number of crops which develop deep and well-branched root systems, may show little reduction in yield until nearly all of the available water has been depleted in the soil depth from which extraction has been most rapid.

It must be emphasized, however, that irrigation programs for specific crops should vary according to the prevailing conditions of weather and soil. Factors that determine the supply of water available to crops, and affect crop water-use rate, must be considered in determining irrigation schedules. Accordingly, before an irrigation program is planned, the local situation should be analyzed in terms of soil, plant, climatic and management factors.

(1) Soil factors: Soil structure, texture, depth, mechanical impedance, infiltration rate, internal drainage rate, aeration, moisture retention characteristics, ground water table conditions, temperature and fertility are soil factors of concern in evaluating foothill soils. Most foothill soils are loams and normally have good performance characteristics for most soil factors. Soil depth is usually the most important factor to consider in scheduling irrigations for deep-rooted crops. The majority of foothill tree and vine crops are grown on soils that are less than 5 feet in depth and, because of lack of soil water storage capacity, they require a high scheduling frequency. Soil surveys developed by the U.S. Soil Conservation Service are available for foothill soils of Amador, El Dorado, Mariposa, Nevada, Placer and Yuba counties. Soil water storage can be estimated from these surveys. Where surveys are not available, on site investigations employing soil tubes may be made.

(2) Climatic factors: Climatic factors that influence scheduling are temperature, solar radiation, wind, humidity, day length, length of growing season and diurnal fluctuations. The highly variable terrain and elevation of the Sierra foothills can have large effects on many of these climatic factors and require careful evaluation in scheduling.

(3) Plant factors: Plant factors include crop varieties, rooting characteristics, age, drought tolerance, growth stages critically affected by water stress, organs or plant constituents to be harvested, effect of water stress on quality of harvested product and the length of the growing season. Information on the influence of plant factors on irrigation scheduling of certain crops may be

available through the farm advisor's office.

(4) Management factors: The principal management factors include method of water delivery, irrigation scheduling in relation to critical growth periods, amount of water applied each irrigation, fertilizer application, crop protection measures, cultivation practices, dates of harvesting, and dates of planting and resultant plant population. Covercrop management in tree and vine crops can also strongly influence scheduling needs. Orchard irrigation scheduling must be coordinated with other practices, especially with crop protection and harvesting.

Scheduling Procedures

Individual farmers use a number of ways to schedule irrigations to avoid crop stress and yet minimize irrigation labor. Watching covercrop plants for stress and checking soil color have long been used for scheduling irrigations. These simplified methods seldom meet season-long water requirements without some crop stress or wasted water, since there is no indication of how much water to apply.

Farmers can more reliably schedule irrigations by following (1) a water budget procedure or (2) by monitoring soil moisture with water sensing devices. The water budget procedure can be used to answer how much to irrigate as well as when to irrigate. Since both rainfall and irrigation water are considered to be stored in the soil, the root zone can be visualized as a reservior for water to be used by the crop. If the capacity of that reservior (the volume of soil water available to the crop) and the rate of water use are known, then the amount of soil water for any given day can be calculated. It is also possible to determine the date of the next irrigation and the amount of water to be applied.

The water budget procedure is similar to keeping a bank account balance. If the balance on a given date is known and dates and amounts of subsequent withdrawals are known, the balance can be calculated at any time. Most important, the time when the account will be overdrawn can be determined, so that overdraft (plant stress) is avoided.

The starting point often is after a thorough wetting of the soil by irrigation or winter rains which bring the soil reservior to full capacity. If this is not the case, the initial balance must be determined by direct measurement. Daily quantities of water used by the crop are subtracted until the soil water is reduced to the allowable depletion point or where the plant begins to show signs of stress. At that point an irrigation should be applied with a net amount equivalent to the accumulated daily use since the last irrigation. The soil reservior is thus recharged to full capacity, and the depletion cycle begins again. Figure 1 illustrates an example. The following sections explain how to determine soil water reservior capacity and water use rates for making water budget calculations.

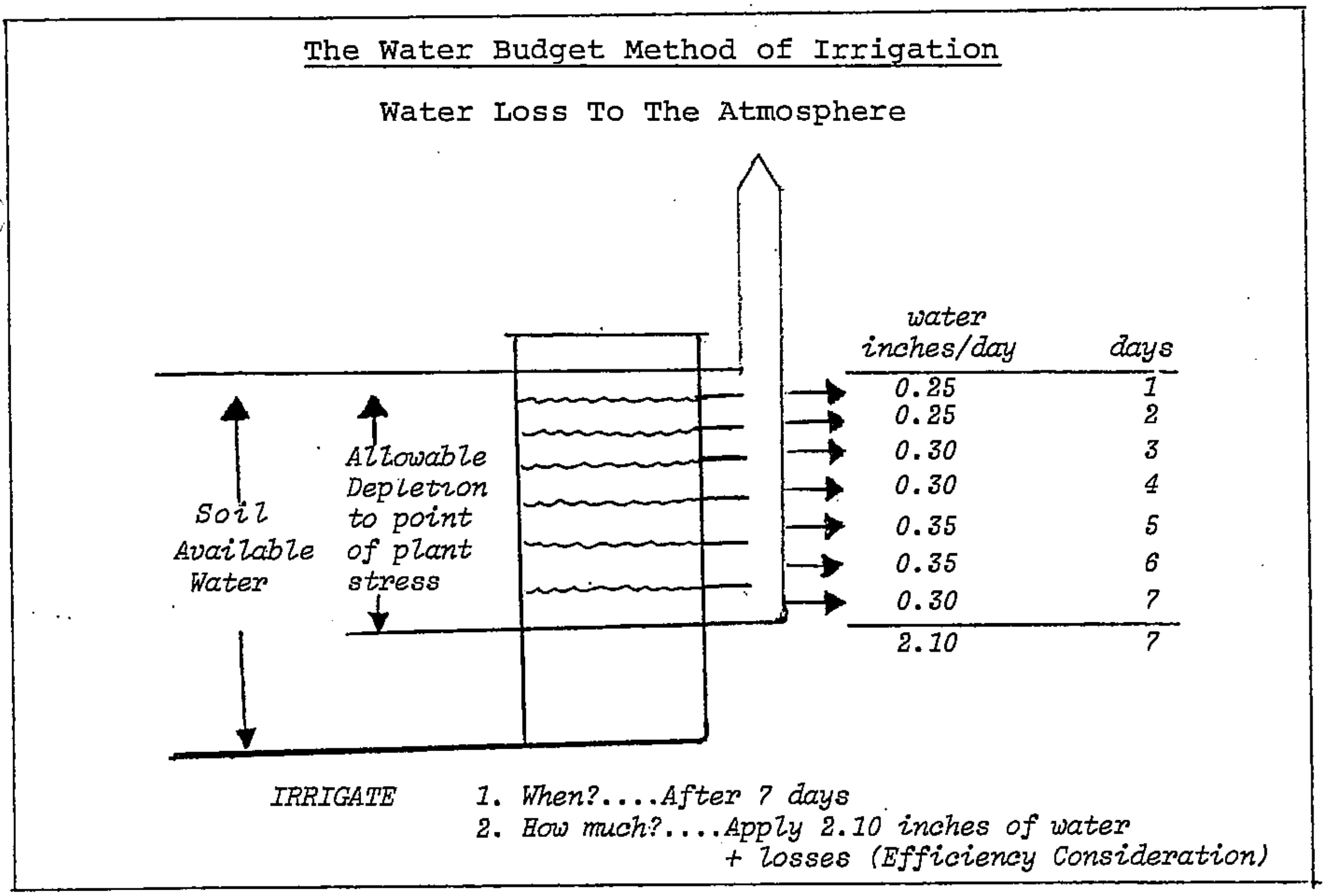

Figure 1. A visual presentation of the water budget method of irrigation.

Water Sensing Devices can be used for scheduling irrigations by themselves, but are most effective when used in conjunction with the water budget procedure. Soil moisture sensing devices have been used for several decades. Among them, tensiometers are the instruments most commonly employed. Gypsum blocks are also used on a limited basis. These devices register the status of water in the soil, generally in terms of soil tension, at the depth in the soil at which the device is placed. Their use is based on keeping soil water tension below the level causing adverse plant stress. However, the level of tension varies with depth of placement and use of these instruments must be correlated with crop needs and site conditions. U.C. Leaflet 2264, Questions and Answers About Tensiometers, provides information on the use of tensiometers for irrigation scheduling. It may be obtained at U.C. Cooperative Extension Offices.

The neutron probe and the pressure bomb can also be used for scheduling irrigations. The soil water content can be measured directly with a neutron probe once the probe has been calibrated for a particular soil. This device is most effectively employed by irrigation consultants. Purchase price and training and licensing requirements make ownership impractical for most foothill farmers.

The pressure bomb measures the tension of the water held within plants. Research over the past 15 years has correlated many water stressed plant physiological responses to leaf water tensions. While the pressure bomb can be effectively used for scheduling irrigations, costs and data deficiencies have limited its adoption.

All the above instruments are useful in establishing an irrigation management program. They will be discussed in greater detail in the section on Scheduling Procedures.

WATER REQUIREMENTS IN THE FOOTHILLS
AS INFLUENCED BY
ELEVATION, TERRAIN AND CROP

WATER REQUIREMENTS - EVAPOTRANSPIRATION

Water is lost from a cropped field in two ways: (1) direct evaporation of water from the soil surface and (2) transpiration, which is the loss of water vapor from plant leaves. This combination of evaporation from the soil and transpiration by the plant is called evapotranspiration (ET). This is the *"crop water requirement"* -- the amount of water actually used by the growing crop.

However, the process of delivering water to the farm and applying it to the land involves loss by runoff or percolation below the root zone. These losses can be minimized through good conservation practices, but they are difficult to eliminate and must be included to determine the *"irrigation water requirement"*. In general: Irrigation Requirement = ET - Effective Rainfall + Irrigation System Losses.

In the north and central parts of California effective rainfall supplies an appreciable portion of the crop needs in normal years. While some rain may fall after the crop is planted, most is stored in the soil from pre-season rains. Farmers need to estimate the amount of rainfall stored at the beginning of the season, as it is too important to be ignored.

Figure 2 shows the water received and potential losses at the farm level during and after irrigation. If the losses are kept to a minimum, most of the applied water goes to meet the ET demand.

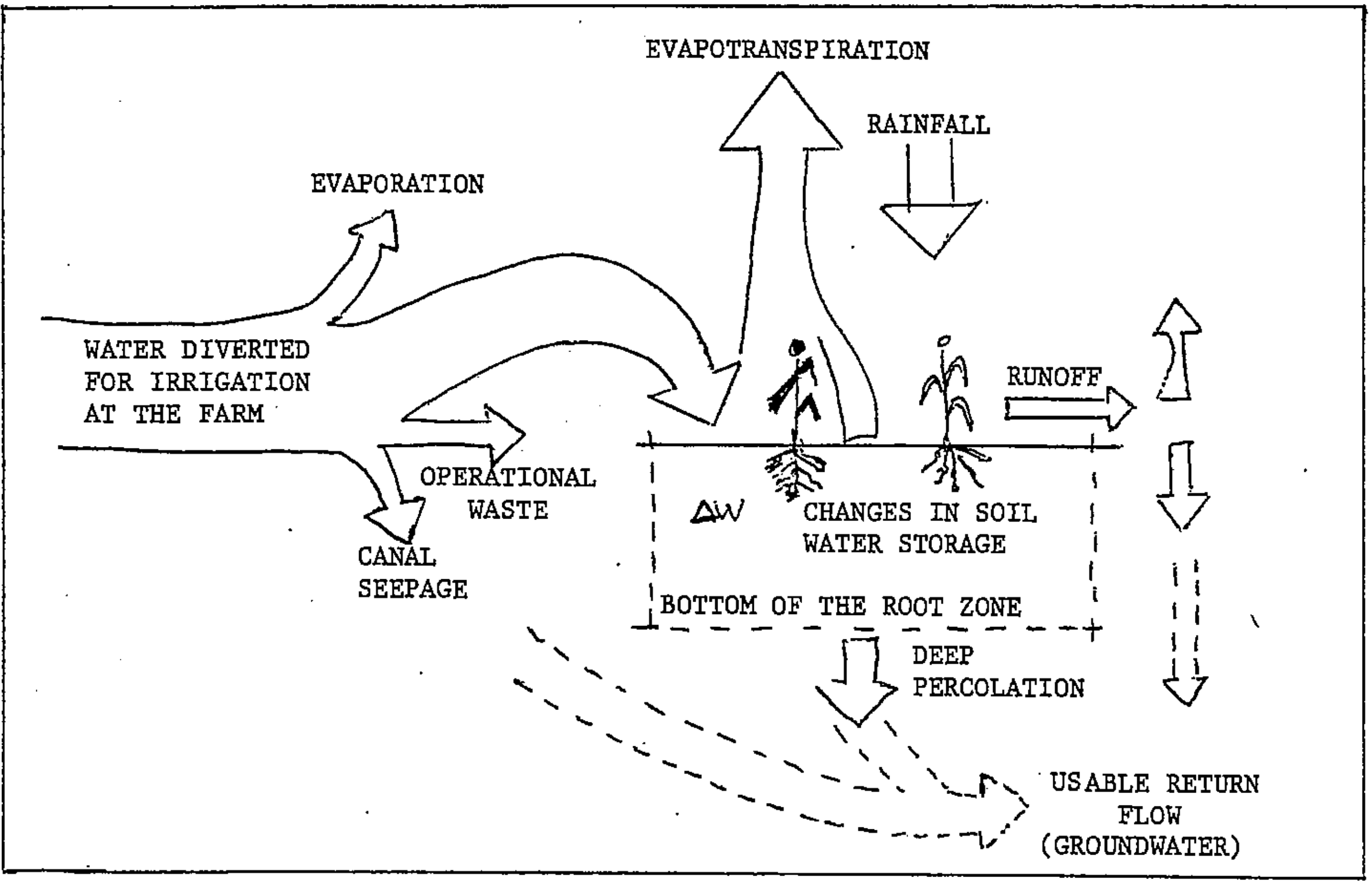

Figure 2. The water balance of a field

WHAT CONTROLS ET?

Evaporation requires energy. If field and foliage surfaces are wet, the amount of water vaporizing and moving into the atmosphere is determined mostly by the energy available from solar radiation. Thus solar radiation is the main climatic factor that determines the ET rate, although air temperature, humidity, and wind also affect it. ET rates are thus highest in summer when daily radiation and temperatures are high. Exceptionally low relative humidity and high winds increase ET rates above normal.

The most significant plant factor affecting ET is undoubtedly the degree of ground cover. Many crops do not totally shade the ground especially during their early stages of growth, and evaporation from dry soil surface between plants is very low. In such cases, the ET rate is essentially determined by the area of leaf surface that is intercepting sunlight, or, to put it another way, the percent of soil surface shaded by the crop. For this reason, ET for row crops in the early growth stages and for many orchards and vineyards is significantly less than the maximum ET. As growth increases, ET reaches its maximum with nearly complete ground cover. ET measurements indicate that when the percent of ground shaded by the crop is above 70 to 80%, full ground cover and full ET rate can be assumed.

Evaporation from the wet soil immediately after an irrigation is very close to full cover ET, but as the soil dries this water loss is drastically reduced. Thus, frequency of irrigation plays an important role in determining evaporation losses directly from the soil, especially when all the soil surface is wetted.

VARIATION IN FOOTHILL WATER REQUIREMENTS

In undulating foothill terrain the variability in microclimate through the growing season can be extreme resulting in variable evapotranspiration rates. Differences in environmental factors of slope, exposure, elevation and wind patterns create these microclimates and their resulting evapotranspiration rates. ET rates decrease with increases in elevation. They decrease on north facing slopes and to a lesser extent on east facing slopes. Most foothill farms are on mountain ridges that are oriented from east to west and gradually descending towards the Pacific Ocean. This orientation mainly creates north and south facing slopes. Ridge tops experience higher ET rates than wind-sheltered draws or valleys.

The lowest ET rates are to be found, then, on north slopes of high elevation, wind-sheltered farms. In contrast, southwest slopes on exposed ridges of low elevation farms produce the highest ET rates.

Keep in mind the important role of vegetation interception of solar radiation in determining ET. Differences in cultural practices such as orchard cover crop management, plant spacing and training and pest attack all take part in influencing ET. Environmental factors taken collectively result in each crop situation being unique in its ET requirements under foothill conditions.

Experimental work on pears and apples in El Dorado County (California Agriculture, Vol. 33 #10) demonstrated that seasonal orchard water use can be expected to vary from less than 20 inches in a northerly exposed orchard without a cover crop at 3,500 feet, to more than 40 inches for a fully exposed orchard with a cover crop at 1,500 feet elevation. These observations have clearly shown that each foothill farm should be irrigated as its environmental conditions require and not by an assumed average rate as sometimes is practiced in valley situations with uniform climate. Table 1 illustrates the measured monthly crop water use for two El Dorado County pear orchards. Notice the differences in monthly and seasonal water use totals. Pear orchard A has a much higher monthly and seasonal water requirement than orchard B because A is located at 1,500 feet elevation on a warm south slope and the orchard floor is covered by a vigorously growing cover crop. Orchard B uses much less water due to its north facing location at 2700 feet elevation and clean cultivation practice.

	Jan	Feb	Mar	Apr	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Total
ORCHARD A			1.0	3.5	5.4	8.3	9.5	8.8	5.9	2.4			44.8
ORCHARD B			.7	1.7	3.6	5.5	6.3	5.8	3.9	1.6			29.1

Table 1. Monthly water use in two foothill pear orchards with different environmental conditions.

Environmental factors affecting ET cannot always be readily quantified by estimation as there are many interrelated influences. Table 2 presents best available estimates on how these factors might individually affect the ET of a given site. The ET effect is presented as a percentage of the ET potential of a standard known site, which in this case is the Jensen-Haise ETP estimate based on the Water and Power Resources Service weather station located at Folsom, California. (See Page 19)

ELEVATION	FOLSOM WEATHER STATION - NO SLOPE	SLOPE DIRECTION		COVERCROP	
		North	South	None	Heavy
500 -1000	100	*	*	*	*
1000-1500		95	110	80	115
1500-2000		85	105	75	110
2000-2500		80	100	70	105
2500-3000		70	90	65	95
3000-3500		65	85	60	85
3500-4000		60	80	55	70

Table 2. This table shows the relative influence of elevation, slope and covercrop on plant water use rates as these environmental factors change as compared with the Folsom reference point.

Tables 1 and 2 are based on the assumption that soil moisture content was adequate at all times for an optimum ET rate for the crop in question.

*NO DATA COLLECTED

If the soil is allowed to dry until plant stress occurs, then the ET rate becomes restricted. Plants accomplish this by closing stomata (leaf pores) in response to the stress, which decreases water lost to the atmosphere. This slows water use, crop growth, and can cause other detrimental plant responses, depending on the degree of stress. A reduced ET rate may be important in manipulating certain crops such as wine grapes to obtain desirable berry size or sugar level. During water short years or in water short areas, reduced ET rates can be managed to give maximum plant performance with the water available.

ESTIMATING WATER REQUIREMENTS - ET

Several techniques are available for estimating ET under foothill conditions. The most direct and accurate method is to use a *neutron moisture probe* to periodically measure the soil water content. Water used between measurements can be added to give the ET for the time period involved.

Date of Reading	Third ft. Water	Second ft. Water	First ft. Water	Total Water
7/03/79	4.20	3.25	3.20	10.65
7/10/79	3.85	2.85	2.75	9.45
	.35	.40	.45	1.20

Table 3. Example of orchard water use for 7 days in July.

In table 3 neutron probe measurements were taken at the 1st, 2nd and 3rd foot seven days apart and showed that ET was 1.20 inches over the period. The depth of rooting for each site must be determined to get an accurate estimate of plant water use. This example assumes the rooting depth is three feet. For more information on neutron probe use see Irrigation Scheduling Procedures.

Weather Estimation of Crop ET

Although ET can be accurately measured by the neutron probe, the method is slow and time consuming due to the need for numerous field measurements and calculations. A suitable alternative is to use weather data to estimate the potential ET (ETP). This may be done by (1) ETP estimates from water surface evaporation or (2) ETP estimates from mathematical equations using weather data.

There is a good correlation between crop ET and evaporation from a free water surface. The standard water surface commonly used is the U.S. Weather Bureau Class A evaporation pan located in an irrigated pasture.

Two mathematical equations or models are commonly used to predict ETP: The Jensen-Haise equation, using solar radiation and mean air temperature, and the more complex Penman equation that uses solar radiation, air temperature, dewpoint and wind speed as input.

The relationship of the ETP from an evaporation pan or mathematical formula to that of actual crop ET under any particular set of circumstances is expressed as a number -- the *"crop coefficient" (Kc)*.

$$Kc = \frac{\text{Actual Crop ET}}{\text{Potential ET (ETP)}}$$

This number varies with different crops, with the stage of growth and with different climates, but otherwise it is assumed to be the same in different locations with similar climate. Thus, if a season-long set of crop coefficients (a crop coefficient curve) is experimentally determined for one crop in a given location, it can be used there and in other similar areas and in other years to estimate the actual ET for that crop. All that is needed are evaporation potential determinations from either pan, Penman or Jensen-Haise calculations for the period in question and the appropriate Kc values for the stage of growth of a given crop.

For example, on the 8th of August at the maximum stage of growth for the season the Kc of an orchard is .85 and the potential ET is .352 inches of water. The crop ET is calculated as follows:

$$\text{Crop ET} = \text{Kc} \times \text{ETP}$$

$$\text{Crop ET} = .85 \times .35 \text{ inches} = .29 \text{ inches}$$

Crop ET calculations can be made rapidly by this method to provide daily soil moisture status without the need of field moisture measurements. Future soil moisture status can be predicted from current and/or historical weather data. Projected dates of irrigation and irrigation amounts to be applied can be recommended. This procedure is more thoroughly discussed in Scheduling Procedures section. The actual ET of the crop can be determined by either neutron probe or gravimetrical sampling of the soil. Measured ET is divided by measured or calculated ETP to give the crop Kc. For example, if on a given day orchard ET is .21 inches/day by the neutron probe method and ETP by the evaporation pan is .280 inches/day then:

$$\text{Kc} = \frac{\text{Actual Crop ET}}{\text{Potential ET (ETP)}}$$

$$\text{Kc} = \frac{.21}{.28} = .75$$

Crop Curves

A set of crop coefficients collected over a season may be plotted against time to develop a seasonal crop curve (Figure 3.) Crop curves show the crop coefficient (Kc) of ETP for any time through the growing season. The Kc value for the apple crop in

Figure 3 on the first day of June is .68. If the evaporation pan ET is .34 on the same day, ET for the apple block is .34 x .68 or .23 inches.

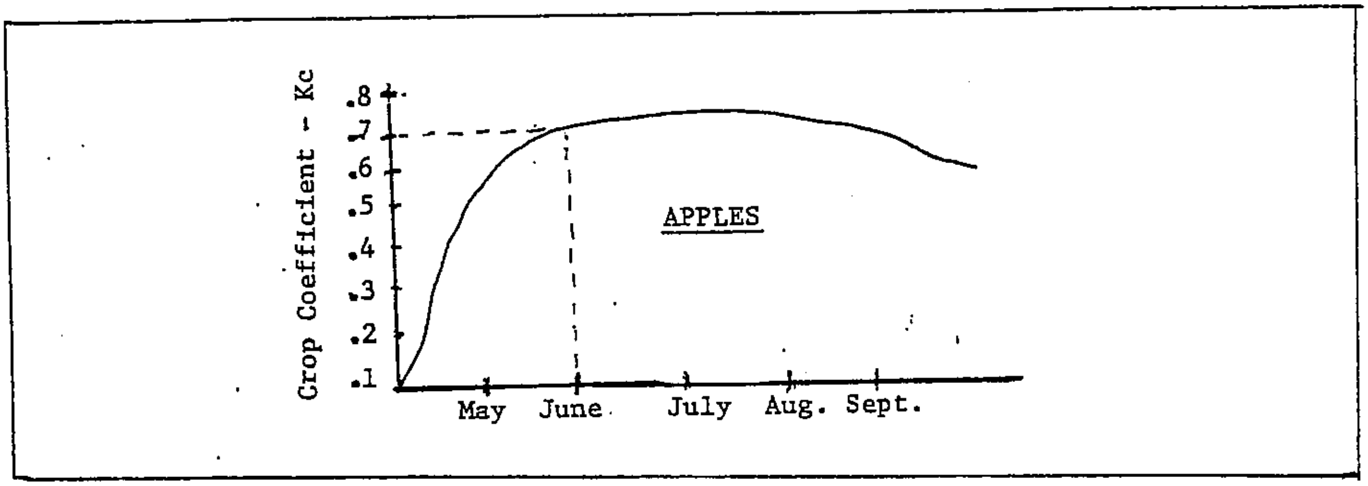

Figure 3. Crop curve developed for water use in a foothill apple orchard.

Site Specific Crop Curves

Usually one crop curve per crop is adequate to calculate accurate crop ET estimates over a uniform area. However, large variations in microclimate are encountered in undulating foothill terrain making it difficult to base ET estimates on one crop curve without serious errors. To solve the problem of this variability, empirical crop curves reflecting essential site characteristics have been developed based on soil moisture depletion data obtained at various sites over the four years of the IMS program. They are based on the following four factors: crop, cover crop practice, crop exposure and elevation. Cover crop practice is treated either as full cover crop or no cover crop. In reality these extremes are seldom realized. Exposure is divided into those crops sloping north and those crops that slope toward the south or are flat. Elevation is grouped into three 1000 foot increments; 1000' to 2000', 2000' to 3000' and 3000' to 4000 feet. Crops that have been studied are pears, apples, stone fruits, grapes, pasture and Christmas trees. By evaluating each crop according to site characteristics, specific curves can be assigned to the crop reflecting the variability in ET as induced by site factors. For example, see Figure 4 for the crop curve of an El Dorado County apple orchard at 2,500 foot elevation with a heavy cover crop and a southern exposure. For comparison, consider Figure 5, which is the crop curve of an El Dorado County apple orchard at 2,500 feet with no cover crop on a north facing slope. Notice that the apple orchard in Figure 4 has a much higher crop curve and water requirement than the apple orchard in Figure 5.

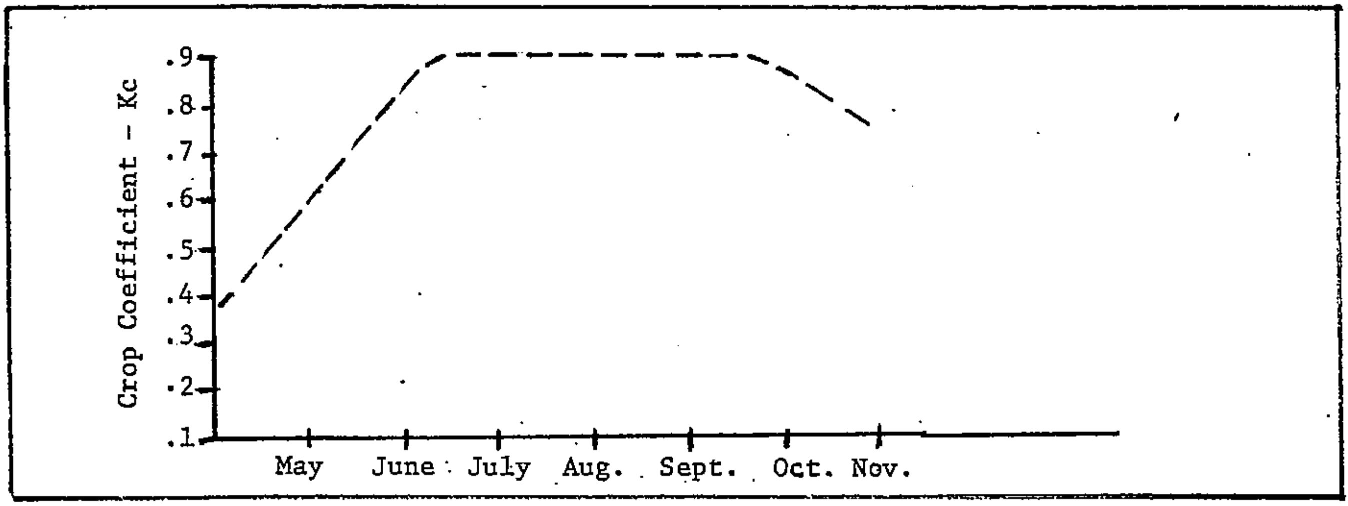

Figure 4. A crop curve developed for a mature apple orchard at 2500 feet elevation, heavy cover crop and on a south slope.

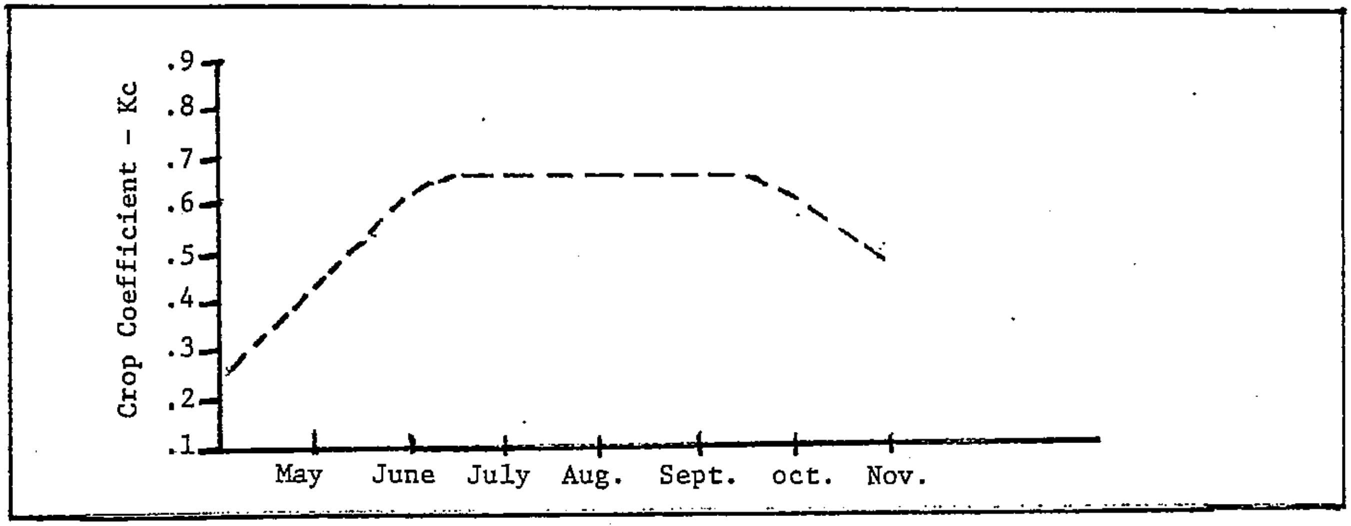

Figure 5. A crop curve developed for a mature apple orchard at 2500 feet elevation, with no covercrop and on a north slope.

Site specific crop curves are used in the same manner as any other crop curves to predict crop ET by multiplying Kc x ETP. Verification of the accuracy of the adjusted curve for a specific site can be done by sampling soil moisture to verify predictions. (described in Scheduling Procedures.)

WATER REQUIREMENTS OF FOOTHILL CROPS

Each crop has its own peculiar pattern of water need over the season and in the foothills this pattern varies with site and management factors. How then does a farmer know how much water he will need to supply his various crops? First, the total season requirement of a crop does not vary greatly from year to year -- normally not more than ten percent. The farmer must supply then:

> The crop water requirement (ET) —— minus —— any rain effectively used —— plus —— any water lost during irrigation.

Table 4 shows the best estimates of crop water requirements for major foothill crops. The amounts of water shown are the amounts needed to produce desirable size, quantity and quality of the plant constituent harvested. Plants can be encouraged to use more water by increasing the scheduling frequency and total supply. This higher water consumption can lead to reduced quality, excessive vegetative growth, disease, increased costs and in some cases, lower yields. The amounts in Table 4 allow for crop water needs after harvest in the case of perennial crops, especially orchards which accumulate food reserves for the following spring.

	Inches of Water Required Per Season				
Elevation	Pear-Apples	Stone Fruits*	Wine Grapes	Pasture	Christmas Trees
500 -1000	**	**	**	50	**
1000-1500	**	**	22	46	**
1500-2000	44	44	18	43	**
2000-2500	39	39	15	**	9
2500-3000	36	36	13	**	7
3000-3500	33	33	10	**	6
3500-4000	31	31	**	**	6

Table 4. Estimates of crop water requirements as they relate to elevation changes. These figures reflect average slope and orchard conditions.

Covercrop practice and slope direction are two other important factors that need to be assessed in determining water requrements as they relate to elevation changes. The effect of other factors such as method of irrigation and soil depth (which influences irrigation frequency and therefore evaporation) should be considered in the analysis of a specific site.

Orchard Water Requirements

Pear and apple orchards have been found to range in orchard water use from less than 20 inches to more than 40 inches as shown in Table 5. Orchard characteristics that largely determine ET are: percent of leaf cover, elevation, slope, and cover crop practice. Leaf cover percent is a measure of how much radiation is intercepted by the trees. Mature orchards develop foliage rapidly on leafing

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*Early maturing stone fruit may not require full ET rates after harvest.

** No data collected.

and reach maximum ET in five to eight weeks. Stone fruit ET is similar, but once the crop is harvested deficit irrigation may be practiced without serious effect on next year's crop. Pin-pointing the degree of this deficit is the object of several current irrigation studies in California.

Elevation	Inches of Water Required Per Season			
	South Slope		North Slope	
	Covercrop	No Cover	Covercrop	No Cover
500 -1000	*	*	*	*
1000-1500	47	33	40	29
1500-2000	43	30	35	24
2000-2500	39	26	31	21
2500-3000	36	24	28	19
3000-3500	31	21	24	16
3500-4000	*	*	*	*

Table 5. Estimates of orchard water use as they relate to the site factors of elevation, slope direction and covercrop practice.

Wine Grape Water Requirements

Information on wine grape water requirements is limited by lack of experience and by lack of definitive data on performance of wine grape varieties in relation to quality. 1979 and 1980 El Dorado Irrigation Management Service records showed vineyard water use ranging from 22 inches at 1300 feet elevation to approximately 10 inches at 3000 feet elevation -- but with varietal differences. This is a marked contrast to seasonal ET's of over 30 inches in the hotter grape districts.

* No Data Collected.

The lower water use in vineyards compared to orchards (see figure 6.) is due to (1) less interception of light, especially in the first half of the growing season and (2) much less influence generally from covercrops and (3) grower practice of deficit irrigation towards harvest slowing vine growth.

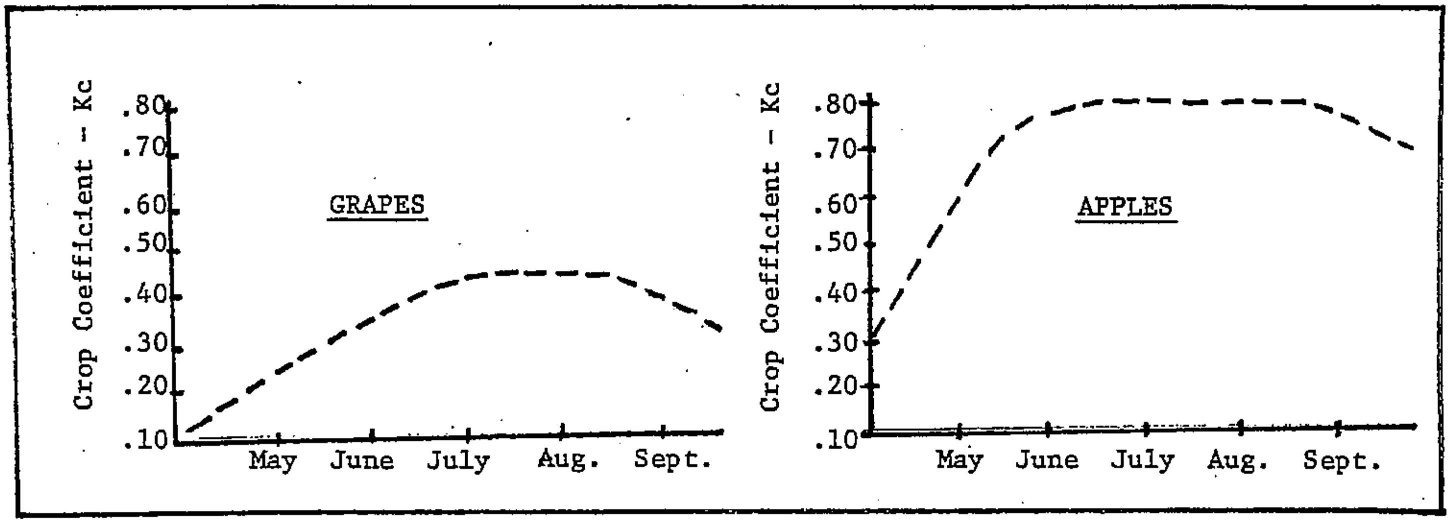

Figure 6. Crop curves for grapes and apples show vineyard water use increasing at a much slower rate and peaking at lower use rates.

Grapevines are severely pruned each winter to less than 100 buds per vine. Vineyard water use crop curves show a gradual increase in water use from leafing out until the vine canopy is fully developed in mid to late summer. Orchard trees have a large framework with many thousands of buds that quickly develop a canopy of leaves in the spring. As a consequence there is little need for early irrigations in vineyards, unless covercrops have depleted water supplies. Most vineyards are well-cultivated early and covercrops are slow to reestablish without frequent irrigation. Table 6 presents tentative estimates of vineyard water requirements. Further investigations are being conducted to gain a better understanding of these interesting findings.

Elevation	Inches of Water Required Per Season			
	South Slope		North Slope	
	Covercrop	No Cover	Covercrop	No Cover
500 -1000	- - - - - - No Data Collected - - - - - - -			
1000-1500	31	22	26	19
1500-2000	26	18	21	14
2000-2500	22	15	17	12
2500-3000	20	13	15	10
3000-3500	15	10	12	7
3500-4000	- - - - - - No Data Collected - - - - - - -			

Table 6. Estimates of vineyard water use as they relate to the site factors of elevation, slope direction and covercrop practice.

Christmas Tree Water Requirements

Christmas tree water requirements are subjected to substantial variables. Species, elevation, presence of overstory and irrigation practice are factors that have confused the Christmas tree water requirement picture. Species that make more than one flush of growth a season, such as Monterrey pine, respond to frequent irrigation. The firs which dominate foothill plantings make effective tree growth with one growth flush a season. This flush of growth can occur successfully with a small amount of water. However, irrigated trees will adapt to use much more water if it is availalbe. Frequent irrigation will foster covercrop growth and greatly increase the water requirement. An overstory of mature trees also increases the water requirement. Because of these complexities and lack of data, Table

7 shows only Christmas tree water requirements for fir trees as related to elevation.

Elevation	Inches of Water Required Per Season
Below 2000	No Data Available
2000 - 2500	9
2500 - 3000	7
3000 - 4000	6

Table 7. Seasonal water requirements for fir Christmas trees.

SOIL WATER STORAGE

After rainfall or irrigation, water tends to drain into deeper soil layers. Drainage is rapid at first, but after one to several days -- depending on soil type, layering, etc. -- drainage decreases to a very slow rate, so that for practical purposes it may be neglected. At this point, soil moisture in the root zone may be considered in storage; it can be depleted only by plant transpiration or surface evaporation from soil. This upper limit of water storage in the root zone is called *"field capacity" (FC)*.

Similarly, a practical lower limit may be defined as the soil water content below which severe crop water stress and permanent wilting develops. This lower limit has been defined as the *"permanent wilting percentage" (PWP)*. While plants may remove some water below this level, such extraction has little or no significance in irrigated agriculture, although it may be crucial for plant survival.

The difference between FC and PWP is termed *available water (AW)*. Table 8 presents the AW of various soil types. Once the AW value per foot of soil depth is known, the total depth of water available, and thus the capacity of the soil water reservoir, can be obtained by multiplying the AW value per foot of soil by the root zone depth. AW also may be estimated by applying a known limited amount of water to the soil when the profile water content is near PWP and observing the depth of wetted soil.

	Available Moisture	
	Range Inches/Foot	Average Inches/Foot
Very Coarse to Coarse Textured Sand	0.5 - 1.25	0.90
Moderately Coarse Textured Sandy Loams and Fine Sandy Loams	1.25 - 1.75	1.50
Medium Texture - Very Fine Sandy Loams to Silty Clay Loam	1.50 - 2.30	1.90
Fine and Very Fine Texture - Silty Clay to Clay	1.60 - 2.50	2.10

Table 8. Available water for various soil types.

ALLOWABLE DEPLETION

As the soil water reservoir is depleted, there is no reduction in ET for a considerable period. However, ET starts to decrease before the PWP level is reached. This lower ET generally does not increase water use efficiency because it is likely to reduce yield. In these cases, farmers should irrigate most crops before the root zone water content reaches a level that restricts ET. This critical depletion level depends on several factors -- plant factors (rooting density and developmental stage), soil factors (AW and soil depth), and climatic factors (current ET rate). Therefore, no single level can be recommended for all situations. For deep-rooted perennial crops on fine-textured soils under mild weather conditions, the depletion level may reach 80 percent or more of the available water without reducing ET. On the other hand, with low rooting densities and high evaporative demand, depletion levels of 40 to 50 percent may reduce the rate of crop growth. The amount of soil moisture at which desirable plant production becomes reduced may be called the *refill point (RP)* for irrigation purposes. The difference between Refill Point and FC is the amount of water available for optimum crop production and is termed the *allowable depletion (AD)*. Once this quantity of water has been determined for a specific field, the water budget method can be used to schedule irrigations. This is done by subtracting the daily ET from the allowable depletion, starting when the soil is at field capacity. If the field has an allowable depletion of 2.5 inches of water and the average daily ET is .25 inches, an irrigation would be necessary in ten days to refill the soil reservior.

Under foothill conditions allowable depletions are frequently low. This is largely due to insufficient soil depths for water storage, but in some cases is due to shallow rooting characteristics of the crop involved. Generally speaking the allowable depletion is about half of the available soil moisture. Available soil moisture can be estimated from Soil Conservation Service Soil Survey publications produced for most Sierra foothill counties. The information on soil properties shown in Table 9 at the end of this section was taken from the "El Dorado Area Soil Survey".

Orchards in the El Dorado County Irrigation Management Program had a range of allowable depletions from 2.0 to 4.5 inches with an AD of 2.8 being the most typical.

Fir Christmas trees demonstrate the variability in allowable depletion tolerated by different crops. After achieving their early summer flush of growth, they can use nearly all the available water in the soil without reduction in performance.

The allowable depletion for wine grapes may vary with the season. IMS experience in El Dorado County shows that vineyard depletions of no more than 2 to 3 inches favor proper plant growth rate in the early to mid-summer time period. Thereafter, greater depletions slow vine growth without reducing desired crop performance.

Allowable depletions are best selected by conducting research on crop responses to irrigation as was done for pears and apples in El Dorado County. Experienced observations combined with the use of soil moisture sensing methods can provide reasonably accurate allowable depletion figures for other crops. (See Irrigation Scheduling Procedures section).

TABLE 9. ESTIMATED PROPERTIES
OF THE
EL DORADO AREA SOILS

Soil series and map symbols	Depth to bedrock (feet)	Depth from surface of typical profile (inches)	USDA texture	Available water holding capacity (inches per inch of soil)
Acidic rock land: AaF. Properties too variable to be estimated.				
Ahwahnee: AcC, AdD, AdE..........	2.0-3.5	0-8	Coarse sandy loam........	0.11-0.13
		8-26	Heavy coarse sandy loam..	0.13-0.15
		26	Weathered granodiorite.	
Aiken: AfB, AfB2, AfC, AfC2, AfD, AgD........................	4.0-5.0	0-15	Loam....................	0.15-0.17
		15-35	Clay loam...............	0.17-0.19
		35-72	Clay....................	0.15-0.17
Argonaut: AkC, AlD, AmD..........	1.5-3.5 (2.0-4.0 in AlD)	0-10	Gravelly loam and gravelly silt loam......	0.10-0.12
		10-30	Clay....................	0.14-0.16
		30	Metaandesite.	
Argonaut: AnB....................	2.0-3.5	0-11	Clay loam...............	0.18-0.20
		11-40	Clay....................	0.14-0.16
		40	Gabbrodiorite.	
Argonaut, seeped variant: AoB.....	2.0-3.5	0-8	Loam....................	0.13-0.15
		8-17	Silty clay loam.........	0.18-0.20
		17-32	Clay....................	0.14-0.16
		32	Slate.	
Auberry: ArB, ArC, ArD, AsC, AtD, AtE, AuD..................	3.5-5.0+ (2.0-3.5 in AuD).	0-13	Coarse sandy loam........	0.11-0.13
		13-36	Coarse sandy clay loam...	0.14-0.16
		36-56	Coarse sandy loam........	0.11-0.13
		56	Granodiorite.	
Auburn: AwD, AxD, AxE, AyF.......	1.0-2.0	0-14	Silt loam...............	0.16-0.20
		14	Metamorphic rock.	

Table 9. Estimated properties of the soils - continued.

Soil series and map symbols	Depth to bedrock (feet)	Depth from surface of typical profile (inches)	USDA texture	Available water holding capacity (inches per inch of soil)
uburn, heavy subsoil variant: AzE.	0.5-20	0-27	Cobbly clay loam and very cobbly clay loam	0.08-0.10
		27	Slate.	
oomer: BhC, BhD, BkD, BkE, BkF, BpC, BpD, BrE	2.0-4.5	0-13	Gravelly loam	0.15-0.17
		13-52	Gravelly clay loam and gravelly sandy clay loam	0.15-0.17
		52	Basic Schist.	
haix: CcE, CcF	2.0-3.5	0-34	Coarse sandy loam	0.10-0.12
		34	Granodiorite.	
hawanakee: ChE	1.0-2.0	0-16	Coarse sandy loam	0.10-0.12
		16	Granodiorite.	
ohasset: CkD, ClE	3.5-5.0+	0-15	Sandy loam or cobbly sandy loam	0.10-0.12
		15-46	Loam or cobbly loam	0.14-0.18
		46	Andesite.	
CmB, CmC, CmD, CoC, CoE	3.5-5.0+	0-14	Cobbly loam or loam	0.13-0.17
		14-46	Cobbly clay loam or clay loam	0-14-0.18
		46	Andesite.	
rozier: CrE	2.0-3.5	0-16	Cobbly loam	0.13-0.15
		16-36	Cobbly clay loam	0.14-0.18
		36	Andesite.	
elpiedra: DeE	1.0-2.0	0-12	Clay loam	0.16-0.18
		12	Serpentine.	
iamond Springs: DfB, DfC, DfD, DgE	2.0-4.0	0-9	Very fine sandy loam and loam	0.13-0.16
		9-40	Clay loam	0.17-0.19
		40	Metadacite.	
iamond Springs, grayish subsoil variant: DmD, DmE	3.0-5.0	0-5	Gravelly sandy loam	0.09-0.11
		5-25	Loam	0.15-0.17
		25-48	Gravelly loam and gravelly sandy loam	0.10-0.14
		48	Rhyolitic tuff.	
lied land: GuF. Properties too variable to be estimated.				

Table 9. Estimated properties of the soils - continued

Soil series and map symbols	Depth to bedrock (feet)	Depth from surface of typical profile (inches)	USDA texture	Available water holding capacity (inches per inch of soil)
Holland: HgB, HgC, HgD, HhC, HkE, HkF	3.5-5.0+	0-21	Coarse sandy loam	0.10-0.12
		21-45	Sandy clay loam	0.14-0.16
		45-59	Coarse sandy loam	0.10-0.12
		59	Granodiorite.	
Horseshoe: HrC, HsE	5.0	0-30	Gravelly loam (gravelly mucky loam surface layer in places	0.13-0.15
		30-50	Gravelly clay loam	0.15-0.17
		50-70	Very gravelly clay loam	0.08-0.10
Hotaw: HtE	2.0-3.5	0-22	Coarse sandy loam	0.10-0.12
		22-35	Sandy clay loam	0.14-0.16
		35	Granodiorite.	
Iron Mountain: ImE	0.5-2.0	0-12	Cobbly sandy loam	0.08-0.10
		12	Andesite.	
sephine: JrC, JrD, JsE, JtC, tD, JtE, JuE, JuF, JvD	3.5-5.0	0-14	Silt loam (gravelly loam in places)	0.16-0.18
		14-33	Silty clay loam	0.16-0.18
		33-50	Very gravelly silt loam	0.07-0.09
		50	Slate.	
Loamy alluvial land: LaB. Properties too variable to be estimated.				
Mariposa: MaD, MbE, MbF, McE, McF.	1.5-2.5	0-26	Gravelly silt loam	0.12-0.14
		26	Slate.	
Maymen: MfF	0.5-1.5	0-9	Gravelly loam	0.12-0.14
		9	Slate.	
McCarthy: MhE	2.0-3.5	0-38	Very cobbly loam	0.10-0.12
		38	Andesite.	
Metamorphic rock land: MmF. Properties too variable to be estimated				
Mixed alluvial land: MpB. Properties too variable to be estimated.				

Table 9. Estimated properties of the soils - continued

Soil series and map symbols	Depth to bedrock (feet)	Depth from surface of typical profile (inches)	USDA texture	Available water holding capacity (inches per inch of soil)
usick: MrC, MrD, MsC, MtE	4.0-5.0+	0-12	Sandy loam	0.12-0.14
		12-42	Heavy clay loam and sandy clay	0.16-0.18
		42-60	Sandy loam	0.11-0.13
erkins: PeD	4.0-5.0+	0-13	Gravelly loam and cobbly loam	0.12-0.14
		13-46	Cobbly clay loam and cobbly clay	0.15-0.17
		46	Weathered granodiorite.	
erkins, moderately deep variant: PgB	2.0-3.5	0-12	Gravelly loam	0.12-0.14
		12-37	Very gravelly sandy clay loam	0.08-0.10
		37	Metabasic rock.	
lacer diggings: PrD. Properties too variable to be estimated.				
scue: ReB, ReC, ReD, RfC, RfD, RfE, RgE2	3.5-5.0+	0-10	Sandy loam	0.12-0.14
		10-34	Sandy clay loam	0.15-0.17
		34-66	Weathered gabbrodiorite..	
escue, clayey variant: Rk	3.5-5.0+	0-40	Clay	0.16-0.18
erpentine rock land: SaF. Properties too variable to be estimated.				
haver: SbB, SbC, SbD, ScC, SdE..	3.5-5.0+	0-51	Coarse sandy loam	0.10-0.12
		51	Granodiorite.	
ierra: SfC2, SfD2, SgC, ShD, ShE.	3.5-5.0+	0-22	Sandy loam and loam	0.15-0.17
		22-44	Clay loam	0.18-0.20
		44-72	Sandy clay loam	0.14-0.16
ites: SkC, SkD, SkE, SoE, SrE, SrF	3-5-50+	0-14	Loam and stony loam	0.14-0.16
		14-21	Clay loam	0.16-0.18
		21-53	Clay	0.15-0.17
		53-69	Clay loam	0.16-0.18
		69	Schist.	
SsC, SsD, SsE	3.5-5.0+	0-12	Clay loam	0.16-0.18
		12-70	Clay	0.15-0.17

Table 9. Estimated properties of the soils - continued

Soil series and map symbols	Depth to bedrock (feet)	Depth from surface of typical profile (inches)	USDA texture	Available water holding capacity (inches per inch of soil)
Sobrante: SuC, SuD, SwD...........	2.0-3.0	0-11	Silt loam...............	0.18-0.20
		11-24	Clay loam...............	0.18-0.20
		24	Basic schist.	
Tailings: TaD. Properties too variable to be estimated.				
Wet alluvial land: WaB. Properties too variable to be estimated.				
Whiterock: WhE..................	0.5-1.0	0-8	Gravelly silt loam.......	0.12-0.14
		8	Slate.	

IRRIGATION SCHEDULING PROCEDURES

HISTORICAL CONSIDERATIONS

Most irrigation scheduling and the amounts of water applied on foothill farms have been strongly influenced by irrigation district policies, former and current, of supplying water on a continuous flow basis. Under this method farmers order a seasonal supply of water. It is delivered continusously from season's start to end at a fixed flow rate measured in miner's inches.* The standard recommendation for an acre of orchard and pasture was 1/2 miner's inch for the irrigation season. This rate of flow provided 3 to 3½ acre feet for pastures over their respective growing seasons. Sprinkler systems were designed to handle this or slightly lower flow rates. The consequence was a locked-in irrigation schedule that over-irrigated during cool weather and failed to meet peak plant use under the high evaporative demand of midsummer condtions.

Observant farmers, recognizing the critical role of water in crop development, constructed farm ponds and reservoirs to achieve flexibility in irrigation scheduling. They watched covercrop plants for stress or checked soil color as a method to assess the need for increased frequency of irrigation. At best these efforts seldom accomplished optimum irrigation efficiency.

The increasing costs of water development and distribution plus the growing "scarcity" of water Statewide will tend to bring supplying water onto a daily demand basis. Water provided and

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* a miner's inch continuous flow equals 11.25 gallons per minute, 1/40 cubic feet per second and 1.0 acre foot every 20 days.

priced on demand use will encourage water conservation and adoption of better irrigation management programs.

ALTERNATIVE METHODS OF PRACTICING IRRIGATION MANAGEMENT

An irrigation management program (IMP) can be conducted with only the most basic information necessary to estimate crop water needs. On the other hand, an IMP can be developed into a reliable, precision management tool through in-depth measurement and analysis of all factors involved in irrigation management. For example, the simplest IMP might require a farmer using his shovel to determine soil moisture and irrigation timing, while the most sophisticated IMP will make use of sensitive instrumentation, computer programs and specialists to provide a highly accurate, site specific, predictive approach to all aspects of crop irrigation.

Approach I

The simplest irrigation management program involves observations and best estimation of the factors that determine irrigation scheduling. This approach requires simple visual observations of soil and plant conditons. Digging into the soil in several locations provides an indication of texture, structure and rooting depth, as well as the extent these factors vary. Observation of these characteristics enables a farmer to determine available soil moisture for his soil types from soil survey guides. By using the "feel" method, soil moisture content at any specific time can be estimated. This technique involves manipulating a soil sample in the hand and comparing the feel with a chart description* of feel versus moisture content. Field capacities may be obtained during the dormant season and compared to samples taken under drier conditions to determine soil moisture depletion. Irrigation effectiveness may be checked by sampling the soil profile a few days after irrigation to determine depth and uniformity of wetting.

An awareness of the effect of weather on water use rates is important to this type of irrigation management program. Irrigation scheduling may be improved by considering daily high and low temperatures and the relative amount of wind.

This type of irrigation program while not highly accurate can be easily and inexpensively conducted by the farmer. However, this approach is subject to errors such as; sampling soil moisture from shaded areas, sampling areas without cover crop where one is generally present, sampling a small area, or sampling to only a shallow depth. Although general in nature, this approach practiced conscientiously will increase a farmer's ability to manage irrigation practices. To provide more precision to this basic approach with minimal expense a farmer can replace his shovel with a soil sampling tube, as a faster and easier way to estimate soil moisture. An additional purchase of a few tensiometers could greatly enhance ability to irrigate adequately by monitoring soil moisture tensions in the crop's root zone.

For example: he may have 2 tensiometers in an orchard placed at 18 and 30 inch depths. After the third irrigation of the season he observes that the 18 inch instrument reads 70 and the 30 inch

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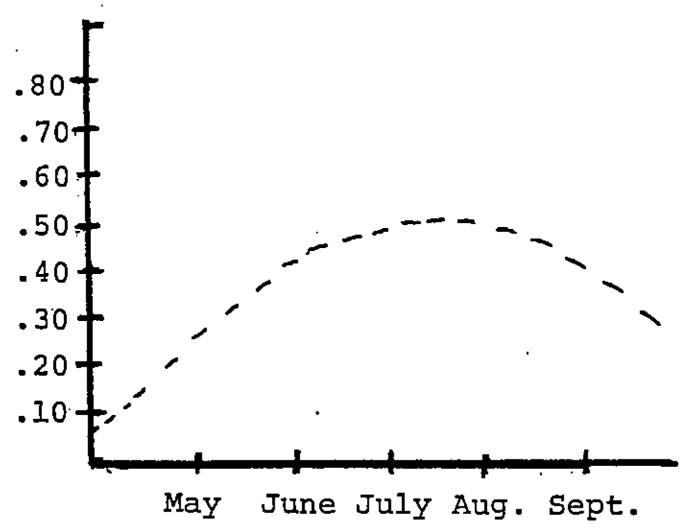
* The "feel" chart is located in this section after the soil tube discussion.

reads zero. Rather than assume no water extraction at 30 inches, he checks with a soil tube. He encounters dry soil at 2 feet. The last irrigation was not adequate and the deeper tensiometer dried out and went "off scale". He now has a better estimate of his allowable depletion and increases the length of irrigation for the orchard to refill the root zone with water.

Approach II

A second, more effective, type of irrigation management program can be developed from the basic approach outlined above through addition of a water budget bookkeeping system. With the previous method the soil texture and rooting depth have been determined and allowable depletion has been estimated. With the appropriate crop curve taken from the appendix of this guide and an estimate of the daily ETP, the amount of water remaining in the soil can be calculated for any given date. Many newspapers publish the daily ETP. This ETP figure or one obtained by other methods is multiplied by the crop curve coefficient for the appropriate stage of growth to obtain the crop water used for that day (ET). A record of daily crop water use from the last irrigation can be logged to determine when the next irrigation will be due.

For example: A grape grower has enough water remaining in his farm pond to refill the soil with four inches of water -- just enough on an average season to get through harvest. From past experience he knows a soil moisture depletion of four inches will slow vine growth without causing foliage loss from dryness. He records the daily ETP found in the local newspaper and multiplies it by 0.5 taken from the crop curve shown in Figure 7, starting with his last irrigation on July 9.



Date	ETP from paper (in.)	Crop Coefficient	Crop ET (in.)	Cumulative ET (in.)
July 10	.28	.5	.14	.14
July 11	.32	.5	.16	.30
July 12	.26	.5	.13	.43

Figure 7. Wine grapecrop curve and ET calculations for a specific farm.

When his cumulative crop ET is 4 inches on August 4, he applies the irrigation and just refills the soil.

This second irrigation management approach is more precise than Approach I, but requires more time and record keeping. The increased effort is justified when the seasonal water supply is limited or when irrigation can significantly affect management or crop results. For example:

- Delaying overhead sprinkler irrigation to get maximum benefit from a codling moth spray applied on apples.
- Irrigating wine grapes to achieve optimum quality without unnecessarily sacrificing yield.

Approach III

This sophisticated irrigation management program develops a high degree of precision. The factors involved in crop water use are carefully measured and entered into a computer programed to predict irrigations for specific sites. The initial costs of data collection and computer programing are high. However, efficient use of labor eventually makes program operation economical.

Field capacities and allowable depletions are determined by correlating plant stress thresholds obtained from tensiometers or from pressure bomb evaluations of foliage with actual soil moisture content measured at the same time by the neutron probe method or by gravimetic sampling of the soil. These data and the appropriate crop curve are entered into a computer, which has been programed to make water budget calculations to predict the next irrigation date. Field checks are made prior to the irrigation to verify accuracy of predictions and make adjustments if necessary.

A computer "printout" can be delivered to the farmer by a variety of methods showing him the dates and amounts required for the next round of irrigations (see Farmer Communication at the end of this section). To insure this third method works properly, the irrigation system(s) must be analyzed to determine operational efficiency. Then, the time required to operate the irrigation system can be included on the "printout". Once the farmer has been motivated to apply his irrigations according to recommendations, field checks can be reduced to occasional spot checking during the season so any deviation in computed and actual soil moisture levels can be corrected.

This irrigation management approach not only provides accuracy and economy, but frees the farmer from record keeping and computation chores while insuring maximum yields and profits. This program is best handled by trained consulting personnel working with a large number of farms.

SOIL MOISTURE EQUIPMENT USE UNDER FOOTHILL CONDITIONS

There is a wide selection of devices for sensing moisture and crop response to moisture status. An individual farmer would choose to use, at most, only a few of these. Irrigation management programs operated on a broader scale tend to favor one or more monitoring methods over others. Any one of these tools seldom precisely duplicates the information provided by any of the other tools. Used collectively they often compliment each other in providing insight on achieving the most effective irrigation program possible. While only some of the equipment available is discussed here, irrigation management consultants should become familiar with all available equipment.

Equipment List

Each major piece of equipment necessary for irrigation management is underlined and followed by its use or need. Below each piece of equipment are the detailed lists of tools or materials necessary for efficient equipment use.

1. Neutron Moisture Probe - Used for measuring soil moisture content.
    a. NRC license for probe and certification film badges for probe readers.
    b. Locked storage cabinet or closet with radiation signs externally visible.

c. Carrying case for probe transport.

d. Probe battery chargers.

e. 2" galvanized steel pipe for access tubes, variable lengths.

f. No. 11 rubber stoppers, bolts, nuts and washers (¼ x 2½ USS) and 2" x 2" x 1/4" steel squares for sealing off access tube ends.

g. Bright red spray paint for painting access tube caps and site location stakes.

h. Stakes and flagging for site location.

i. Suction pump to remove water from tubes.

j. Water bucket and access tube section for probe calibration checks.

k. Access tube extraction equipment.

l. 2" diameter power auger to drill holes for access tubes.

m. Slide hammer and tamping bar for inserting access tubes.

2. <u>Tensiometers</u> - for measuring soil water tension.

a. Suction pump and test gauge for removing air from instrument verifying gauge accuracy.

b. 1/2" section of pipe and a hammer to provide a hole for tensiometer installation.

c. Tensiometer slide hammer as an installation method for dry soil. See appendix for diagram.

d. Water container for refilling instruments.

3. <u>Soil Sampling Tube</u> - for evaluating soil types, uniformity and estimating moisture content.

a. Spare tips.

NOTE: *Neutron probes are radioactive devices. Rules and regulations of the Nuclear Regulatory Commission must be observed.*

4. Soil Core Sampling Equipment - for measuring gravimetric water content and bulk density of soil:

   a. Oven for drying soil samples.

   b. Scale for weighing soil samples.

   c. Sample cans to transport samples.

5. Pressure Bomb - to evaluate plant water tension.

   a. Pressurized nitrogen gas for the pressure bomb.

   b. Single edge razor blade, water bottle and towels.

   c. Magnifying glass.

6. Equipment to Evaluate Efficiency of Sprinkler Systems - to carefully monitor applied water.

   a. Irrigation catch cans to determine applied water at soil surface.

   b. One liter graduated cylinder to measure water volume.

   c. Pitot tube for pressure checks at the sprinkler nozzle.

   d. 25' of 1/2" plastic hose, stopwatch, and suitable container to measure sprinkler flow rate.

7. Weather Station* - to monitor weather conditions.

   a. Instrument shelter house.

   b. Maximum - minimum thermometer to calculate average daily temperature.

   c. Wet bulb - dry bulb temperature apparatus to calculate relative humidity.

   d. Radiometer to measure solar radiation.

   e. Class A evaporation pan - to measure daily evaporation from a standard water surface.

   f. Rain gauge.

   g. Anemometer - to measure wind speed.

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* Weather instruments selected depend upon the ETP method used.

Neutron Moisture Probe

A neutron moisture meter is based upon the principle that "fast" neutrons that collide with the hydrogen atoms present in water molecules are converted to "slow" neutrons. A radioactive source of "fast" neutrons and a detector of "slow" neutrons are built together into a probe that is lowered to various soil depths using an access tube, where readings are taken that can be correlated with the soil water content.

Soil water content on a volume basis can be measured directly with a neutron probe once the probe has been calibrated for a particular soil. (See appendix). The ratio between the counts obtained in the soil to a standard count taken with the probe inside its case correlates linearly with the volumetric soil water content. Calibration lines have been developed for some soil types in California.

The neutron probe allows for measurement of the water content of the soil profile. If the measurements are taken after a thorough irrigation, the upper limit of water storage in the root zone (field capacity) can be defined. The allowable depletion, however, must be determined by other means as water is absorbed by plant roots following a water potential gradient irrespective of the actual soil water content. Tensiometers or gypsum blocks placed near the neutron access tubes may be used to determine the allowable depletion. The pressure bomb could also be used to determine the allowable depletion in conjunction with the neutron probe. The soil water depletion over the profile is a good estimate of ET losses provided that deep percolation losses are minimized or accounted for. Some recommendations have advocated using the neutron probe reading of the first foot to determine the allowable depletion or refill point assuming that most of the water extraction occurs in the first foot. This, however, does not seem to fit a variety of field situations where the neutron probe has been used. Once the allowable depletion has been defined, the neutron probe may be used to determine when to irrigate and how much to apply. Plotting the water content data vs. time allows for projection of the next irrigation date, assuming that no drastic changes in ET will occur (see Figure 8). The amount to be applied will be obtained directly from the graph and has to be corrected for the application losses in the irrigation system.

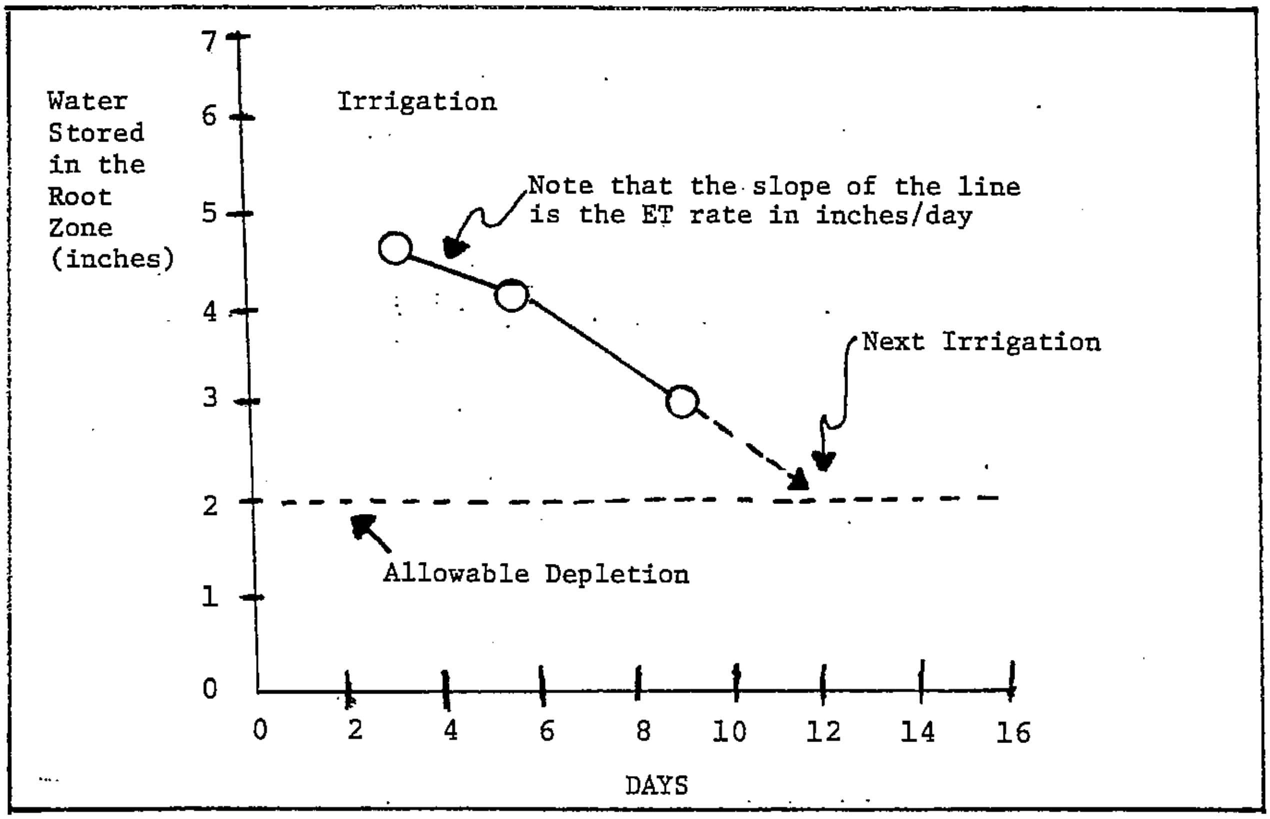

Figure 8. Soil water content of the root zone measured with a neutron probe plotted as a function of days after irrigation.

Use of the neutron probe for soil moisture checks requires installation of a soil access tube. Access tubes are 2-inch galvanized steel pipe with the soil end of the pipe crimped and a #11 rubber stopper bolted into the end to prevent water from entering the tube. The top of the tube is also sealed with a cap made from a #11 rubber stopper bolted to a 2" square steel plate. The metal plate provides easy removal of the cap for neutron probe moisture checks. Cap tops should be painted, usually red, to prevent rust and make them easier to locate. With the cap removed, the probe is placed on the access tube. The measuring probe is lowered into the access tube and measurements are taken at the desired depths. Work in El Dorado County indicates accurate moisture checks can be made at 9", 18", 30" and 42" depths to represent respectively the first four feet of soil. Each depth measurement reading is converted to inches of water per foot of soil by using the calibration line described in the appendix.

Access tubes are installed by augering a two-inch hole vertically into the soil profile. The depth of the hole should correspond to the length of the access tube. Holes augered deeper than tube length will cause an air space at the lower end which may produce faulty deep readings. Each tube is pounded into the hole with a special slide hammer (see appendix). The tube should be pounded entirely into the soil with approximately 1/2" protruding above ground surface. This helps to keep water, soil and debris out of access tubes. Throughout the installation process soil disturbance should be minimized.

This installation technique works well in soils that can hold shape. However, in sandy soils and in particularly wet areas, another installation method may be desirable. It may be necessary to use a casing, hand dig tubes or hammer tubes in without a bottom stopper and remove the dirt from the interior.

Neutron probes are expensive, costing approximately $3500. Being radioactive, they are regulated by the government and their use requires licensing.

Tensiometer

The function of a tensiometer is to tell when an irrigation is needed. A tensiometer measures the force with which soil particles hold soil moisture. Various crops may achieve optimum performance when irrigated at different soil moisture tensions. Irrigation should be applied just before plant water stress reduces desired performance. Irrigations applied far in advance of moisture stress will waste water and may result in excessive vegetative growth or other problems.

Tensiometers consist of a closed water column with a porous ceramic cup at lower end and a vacuum gauge and water filler orifice at the upper end. The clay cup is placed into the soil to a depth or depths selected to best monitor the bulk of the active root zone. For deep rooted crops, tensiometers are usually placed into both the upper and lower portions of the root zone. The shallow unit is used to determine when to irrigate and the deeper instrument is used to determine the adequacy of root zone wetting. 18 and 30 to 36 inches are the depths used to monitor mature foothill orchards and vineyards.

As the soil dries, a partial vacuum develops inside the tensiometer that is read on the gauge. Progressively drier soil increases the vacuum force (soil moisture tension) and the gauge reading rises. When soil is irrigated, soil moisture tension is reduced and the vacuum is partially released effectively lowering the gauge reading. Most tensiometer gauges are calibrated with graduations from

0 to 100 centibars (cb.). A tensiometer effectively operates between 0 cb. (saturated soil) and 80 cb. with a 10 cb. reading normally representing field capacity for foothill soils. At 80 cb., 25 to 50 percent of the available soil moisture may remain for plant use, but plants will become increasingly stressed in extracting this moisture down to permanent wilting point (PWP). Up to 80 cb. tensiometers provide accurate means of monitoring soil moisture availability. Tensions above 80 cb. cause the gauge to go "off scale" giving inaccurate readings.

Tensiometers are easily installed in a hole prepared by driving a metal rod or pipe into the soil to the desired monitoring depth. Outside diameters of this tool and the tensiometer body must match to insure close contact fit between the ceramic cup and the soil. The tensiometer should be slowly and firmly pushed to the bottom of the prepared hole taking care to avoid forcing or twisting the instrument. Twenty-four hours after installation, data collection can begin.

In newly planted orchards, the tensiometer tip should be placed in the root ball since optimum soil moisture conditions here are vital to tree survival. After several months, the tensiometer can be reinstalled near the drip line of the growing tree. Subsequent moves may occur annually during the rapid growth period and less frequently thereafter so that the tensiometer will remain where roots are heavily concentrated -- which would normally be midway between the trunk and dripline. In newly planted vineyards, the tip should be no more than 6 to 8 inches away from the vine to best monitor the small soil volume surrounding its roots. After several months the instrument can be reinstalled one foot away from the vine. Annual moves of one foot can be made in the second and third years. In mature vineyards tensiometers should be located equi-distant from two vines within a row.

With crops under furrow irrigation, place instruments near enough to the furrow so that water will be certain to reach them. With sprinkler irrigation, place tensiometers where they can "see" the sprinkler; that is where water from the sprinkler is not blocked by a post, tree trunk, branch, leaves, vines, etc. With drip irrigation, place them 6 to 12 inches away from the emitter.

Frequency of instrument reading through the irrigation season depends on the rate of water used in relation to the supplying capacity of the root zone soil being monitored. Initially, at least three readings should be taken between irrigations to develop familiarity with the rate of soil moisture tension increase. Readings should remain frequent enough so that the change from one reading to the next is not more than 20-30 cb. This frequency will insure that prolonged periods of plant water stress will not go undetected. Frequent readings insure that reliable data is collected. A serious problem resulting from infrequent instrument readings is the zero or "off scale" reading caused by dry soil pulling all water out of the tensiometer. This problem and freeze damage caused by low winter temperatures freezing moisture in the vacuum gauge causing inaccurate readings are the major reasons that farmers discontinue tensiometer use. Instrument maintenance such as adding water and checking vacuum gauges can be performed when frequent reading schedules are maintained. Then damaged or malfunctioning instruments can be replaced with a minimum data loss.

The cost of a commercially made tensiometer ranges from $30 to $50. This cost will vary according to manufacturer and with the size and number of instruments purchased. To economize where many tensiometers are needed, component parts can be purchased and assembled for about half the commercial cost. Construction directions are included in this manual's appendix section. Additional tensiometer information is available in University of California Cooperative Extension leaflet #2264.

Soil Sampling Tubes

The soil tube is a very useful tool for conducting irrigation management in the foothills. It may be used to:

- Determine the depth of penetration of a rain or irrigation.
- Estimate the moisture content of the soil.
- Check the soil depth and soil texture in calculating water storage capability of the root zone.
- Evaluate the variability of a field when selecting a representative location for placement of other monitoring devices or when designing an irrigation system.

A soil tube is a hollow metal tube or rod with a handle. The bottom has a cutting tip. Tubes 3 to 5 feet in length are recommended for foothill farms.

When the tube is pushed into the soil, a soil core is collected. The core can be viewed and felt to determine soil structure and moisture content. The whole soil profile can be inspected by taking core samples at progressively deeper points. From analysis of the texture and depth, a rough estimate of moisture holding capacity of the profile can be made (see the soil water storage section). The soil moisture depletion in inches can also be estimated at the time of sampling, using the "feel" guide on the next page.

Samples are quickly taken when the soil is moist -- about 2 minutes for a 3 foot core sample. However, it may be impractical to sample rocky or dry soils. The Oakfield Soil Sampler and the Lord Soil Sampler are two commonly used soil tubes. They each sell for about $60.

Gravimetric Soil Sampling

The gravimetric soil sampling technique is used to measure the actual water content of the soil at any given time. It is a laborious and time consuming technique and therefore, its primary use in irrigation management is to calibrate other soil moisture monitoring devices.

Equipment required for sampling includes: Special soil core sampling equipment for collecting undisturbed soil cores of known volume, collection cans, scales for weighing samples and a drying oven. Care must be taken such that exact volume samples are obtained. Each soil core sample is field weighed to prevent errors from premature drying, then oven dried and reweighed. By following the calculation techniques outlined in the appendix, actual inches of water per foot of soil can be calculated and paired to neutron probe, tensiometer or gypsum block data to obtain accurate calibration curves.

When instruments are being calibrated, samples must be collected in close proximity to these instruments and at the exact depths that readings are taken. Instruments must be read at the time of sampling for accurate pairing with the samples. Samples should be

APPEARANCE RELATIONSHIP CHART

This chart indicates approximate relationship of soil moisture deficiency between field capacity and wilting point. For more accurate information the soil must be checked by drying samples.

Moisture Deficiency in./ft.	SOIL TEXTURE CLASSIFICATION				Moisture Deficiency in./ft.
	Coarse (loamy sand)	Sandy (sandy loam)	Medium (loam)	Fine (clay loam)	
	(field capacity)	(field capacity)	(field capacity)	(field capacity)	
.0	Leaves wet outline on hand when squeezed.	Appears very dark, leaves wet outline on hand, makes a short ribbon.	Appears very dark, leaves a wet outline on hand, will ribbon out about one inch.	Appears very dark, leaves slight moisture on hand when squeezed, will ribbon out about two inches.	.0
.2	Appears moist, makes a weak ball.				.2
.4	Appears slightly moist sticks together slightly.	Quite dark color, makes a hard ball.	Dark color, forms a plastic ball, slicks when rubbed.	Dark color, will slick and ribbons easily.	.4
.6		Fairly dark color, makes a good ball.	Quite dark, forms a hard ball.	Quite dark, will make thick ribbon, may slick when rubbed.	.6
.8	Dry, loose, flows thru fingers. (wilting point)	Slightly dark color. makes a weak ball.	Fairly dark, forms a good ball.		.8
1.0		Lightly colored by moisture, will not ball.		Fairly dark, makes a good ball.	1.0
1.2		Very slight color due to moisture. (wilting point)	Slightly dark, forms weak ball.	Will ball, small clods will flatten out rather than crumble.	1.2
1.4			Lightly colored, small clods crumble fairly easily.	Slightly dark, clods crumble.	1.4
1.6			Slight color due to moisture, small clods are hard. (wilting point)		1.6
1.8				Some darkness due to unavailable moisture, clods are hard, cracked. (wilting point)	1.8
2.0					2.0

Field Method of Approximating Soil Moisture (Deficiency) for Irrigation; Transactions of the American Society of Agricultural Engineers, Vol. 3, No. 1, 1960; John L. Merriam, Professor, California Polytechnic State University, San Luis Obispo, California.

collected over a wide range of soil moisture conditions to most accurately correlate moisture levels from field capacity to the permanent wilting point.

Fortunately, once an instrument has been calibrated for a given soil type, the process does not need to be repeated. See the appendix for more information on developing calibration curves.

Plant Pressure Bomb

The pressure bomb provides rapid field measurement of internal plant water status. It consists of a chamber that is connected to a nitrogen or air source at high pressure. A leaf or branch is cut from the plant and introduced in the chamber with the cut end protruding out. Pressure is then raised inside the chamber to force the xylem sap to move towards the cut end. When the sap starts bubbling at the cut end, the pressure inside the chamber as indicated by the pressure gauge is recorded.

Timing of irrigation may be determined by using the pressure bomb provided that data exist on the responses to various levels of plant water potential for a particular crop. Measurements with the pressure bomb should be taken preferably before dawn when the plant is in equilibrium with the soil and movement of water from the soil into the plant is minimal. Research has shown that predawn measurements of plant water potential correlate very well with measurements of soil water potential. Under situations of relatively constant evaporative demand, such as in the summers of the Central Valley of California, measurements of water potential between noon and 3:00 P.M., give a good indication of the minimum water potential value (maximum reading in the pressure bomb). These values should also correlate well with measurements of soil water.

The pressure bomb is basically a research tool which may be used to diagnose water management problems. However, it can also be used successfully for scheduling irrigations provided that research and local experimentation is carried out to develop appropriate recommendations. The approximate cost of the instrument is $1,200 to $1,500 depending on the model desired.

Weather Instruments

Crop water use is largely dependent upon local weather. All irrigation management programs need to evaluate climatic factors on water use. The factors that need to be measured are determined by the sophistication of the scheduling service. The most sophisticated method requires daily measures of: (1) Solar radiation, (2) maximum and minimum temperatures, (3) wet and dry bulb temperatures (dewpoint) and (4) wind run. A rain gauge is necessary to determine rainfall amounts. Not always necessary, but often desirable is a class A evaporation pan. Shelters, stands and fences are necessary for station setup. Individual weather instruments have unique installation and monitoring methods.

In some irrigation areas accurate weather data for irrigation scheduling is available from existing stations and can be easily obtained. However, if suitable stations are not located in the area it may be desirable to develop a weather station. Site selection for a weather station is critical. Weather instruments must be located in an exposed area similar to farm conditons. Weather station location may also depend upon monitoring convenience and available land. A good compromise between ideal location, convenience and available land usually determines the station location.

Weather instruments are limited because they monitor the weather only at the station site. Climatic conditions are highly variable and the station may not monitor the same weather conditions and microclimates as are present in various farm situations. Station monitoring is labor intensive and the instrument costs are high, but accurate data for crop water use calculations will be obtained.

SITE SELECTION FOR FIELD MONITORING

Repetitive soil moisture checks with a neutron moisture probe, tensiometers or gypsum blocks require selection of permanent monitoring stations or locations. Each station monitors or samples a very small volume of soil, therefore proper placement of the monitoring station is essential to accurately reflect soil moisture conditions for an entire irrigation block. The unique nature of every foothill farm demands a field evaluation of soil and plant factors and geographic characteristics for selection of a truly representative monitoring station for irrigation scheduling.

Soil factors which must be analyzed are texture, structure and depth. These factors determine moisture intake rate, water storage capacity and effective plant rooting depths, which in turn affect crop water use rates. Soil tube examination of farm fields can quickly determine soil characteristics as well as soil uniformity throughout the block. Small atypical areas of compacted, shallow or poorly drained soil must be identified and avoided to ensure that the data collected accurately represents each field.

Otherwise, a monitoring station should be located in an area estimated to be on the lower side of the average available water holding capacity for the field. For example, in a field with a soil profile ranging in depth from 30 inches to 60 inches a monitoring station should be located in a shallower area. This area will have a low water storage capacity requiring more frequent irrigations for optimum plant performance. Meeting moisture requirements at this location will assure that adequate moisture conditions will exist in other areas of the field. Frequently a single field may be large enough to contain areas exhibiting very different characteristics. In such cases, instruments should be used to evaluate the water needs of these different areas. Tensiometers are useful for this and can be placed in areas of suspected variation for 2 to 3 irrigation cycles. Soil tension readings may be compared to neutron probe readings or other tensiometers to better quantify deviations within farms and fields. Field experience and familiarity with the characteristics of various soils are invaluable in determining the number and location of monitoring stations.

Crop characteristics and cover crop practice combine to influence the rate of water use for any well-irrigated field. Evaluation of the size, maturity and vigor of all vegetation must be made in selecting the monitoring site. The site plant should be typical of or slightly better than the majority of plants in the field and must be surrounded by other healthy plants. Examples of <u>improper</u> site selection which may result in collection of inaccurate data follow:

1. An excessively vigorous cover crop is present around the monitoring site, but not prevalent throughout the

block, or vice versa. Water use rates then would appear higher or lower than expected.

2. Planting blanks or open spaces exist next to a monitoring site. Roots have larger volume of soil to explore resulting in lower root density and lower use rate at the monitoring site.
3. Symptoms of disease, injury, or decay are present on the nearest plant. These situations would probably result in lowered water use rates.
4. A site located at the end of a row or on the edge of a block may receive poor irrigation coverage resulting in restricted water use rates, or if adequate irrigation is received, lack of root competition would cause lower root densities resulting in lower use rates.

   NOTE: Native plants outside an orchard or vineyard may have extensive root systems that can remove water from the outer portion of the field resulting in higher than expected use rates.

The major geographic characteristic used in site selection is the direction   the field faces. The direction of slope influences the amount of sunlight that enters a field and indirectly determines the air temperature of the block. Fields with a south facing slope are considerably warmer and consistantly higher water users than fields with a northern slope. Fields with eastern or western slopes have water use rates falling between these extremes. Change in slope between fields, or within a single field will require separate monitoring stations to determine the degree of influence on water use rates. In undulating terrain, fields often contain two other geographic characteristics: (1) fully exposed ridgetop areas and (2) more sheltered slopes or protected areas of low ground. After soil and vegetation characteristics have been assessed, it is more accurate to locate the monitoring station on higher ground because increased air movement on higher ground will result in higher use rates than in more sheltered areas. Measuring the soil moisture in a fully exposed area assures adequate soil moisture throughout the balance of the field. For optimum field performance, irrigation should be scheduled to the areas of highest water use. However, if over-irrigation occurs in other parts of the field, nozzling adjustments should be made.

In mature orchards or vineyards a new monitoring station ideally consists of one or two tensiometers and a neutron probe access tube. When a single tensiometer is used, it is placed at a depth of 18 inches. This depth best reflects irrigation scheduling requirements for the upper portion of the root zone. The neutron probe determines the adequacy of the irrigation for the lower portion of the root zone. When two tensiometers are used, they are placed into the upper and lower portions of the root zone, usually at depths of 18 and 30 to 36 inches respectively. Neutron access tubes are usually three feet deep although longer tubes may be installed where crops are known to be deeply rooted.

In new orchards or vineyards the soil volume containing the active root zone is very small and can be most effectively monitored with a tensiometer. Monitoring with a neutron probe should not be attempted on young trees until root development is sufficient to envelop an access tube by more than a foot in any direction from the center of a measurement.

In non-bearing orchards, it may be necessary to relocate instruments as trees enlarge to positions further from the trunk. Once trees mature, the station should be located at a point midway between the tree trunk and the dripline. Whether this location is more representative than positions closer to the trunk or dripline will be the subject of a study to be initiated in 1981.

In vineyards, tensiometer monitoring of the active root zone is recommended during vineyard establishment. After the third year, the root zone should be sufficiently large to allow permanent positioning of monitoring equipment equi-distant between vines within the vine row. The suitability of this location under various training methods will be tested in 1981.

Wetting characteristics of an irrigation method should be considered in monitoring station selection. Instruments in fields under furrow irrigation should be located near enough to the furrow so that irrigation water will reach them. With sprinkler irrigation, monitoring sites must be placed in areas of good water uniformity. Dry areas from sprinkler shadows should be avoided. Drip irrigation requires that instruments be placed in the wetted zone approximately 6 to 12 inches away from the emitter.

When installing more than one type of instrument at a station, it is necessary to place them far enough apart so they do not influence each other. Yet they should be close enough together to measure similar soil conditions. This spacing is particularly important with tensiometers and neutron probe access tubes. If tensiometers are too close to access tubes, the neutron probe will read the water in the tensiometer. Placing instruments slightly more than one foot apart is a good compromise. Avoid placing stations in equipment driverows where breakage or soil compaction may be encountered. Stations should also be clearly marked with colorful stakes or ribbons for additional protection.

COMPUTER IRRIGATION SCHEDULING

Is computer scheduling of irrigations for foothill farms practical? Yes, definitely! Computers can provide fast and economical predictions of irrigation needs and sometimes the need for pest treatment. Currently, most computer efforts require a high degree of expertise to develop and operate. Eventually, new, low-cost equipment and simplified programs will enable farmers to conduct their own computer scheduling of farm operations.

How the Computer Works

A number of computer programs have already been written for irrigation scheduling. The simpler ones can be adapted for use in small computers. Most of these irrigation programs use the water budget method for scheduling.

Specific irrigation site information intially entered into the computer includes:

Allowable depletion

Crop curve (Kc)

Site adjustment factor (Sa) (When needed.)

Field identification including crop, field name or number and farm name.

An accurate estimate of soil moisture when ET calculations are started.

The computer has previously been programed with the appropriate mathematical equations (Penman, Jensen-Haise, etc.) for making calculations. Daily weather is then added to obtain the ET of the individual site from the following formula:

$$\text{Crop ET} = \text{ETP} \times \text{Kc} \times \text{Sa}$$

ETP is calculated from the weather data. Kc is the seasonal water use curve for the crop. Sa, the site adjustment factor, corrects differences in site water use from those of the weather station (unless the weather station is located at the site.) NOTE: in the appendix, crop curves with site adjustments built into them have been developed for some foothill crops to reflect elevation and slope direction influence on water use.

The computer subtracts the daily ET from the soil moisture reservior and maintains an account of the field water balance. When the sum of daily ET equals allowable depletion, an irrigation is needed. Any irrigations or effective rainfall* must be entered into the computer to have an accurate budget of the water supply.

The computer predicts future irrigation dates based on forecast water use and the actual past weather as they relate to the water balance of the field. Predictions can be up-dated any time to reflect condition changes.

Computed information can and should be rapidly transmitted to farmers by one of the methods discussed in the following section. The sample "printout" in that section shows the information provided to farmers participating in the El Dorado IMS. This printout reports two items that may not be included in other IMS printouts. First, accumulated codling moth trap catches appear on the printout,

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*Effective rainfall - that amount of rain added to the soil moisture that wasn't lost to deep percolation or evaporation.

enabling growers to see when moth spray needs may conflict with irrigation. Second, the number of hours to operate the irrigation system are given to effectively refill the soil moisture depletion. This later information requires a system analysis and programing of the computer to make computations based on the irrigation system's ability to supply water.

Is Computer Scheduling Accurate?

Computers must have complete and correct data to make accurate predictions. The 1979 El Dorado IMS program obtained this accuracy from weekly neutron probe checks used to up-date actual soil moisture levels. This labor intensive program was accurate but too costly for general farm adoption. The program also failed to fully utilize the computer's ability to predict accurately without frequent soil moisture checks.

Twenty orchards were tested in last half of the '79 season to determine if neutron probe checks could be spaced further apart. Overall results indicated this could be done; however, predictions of irrigation dates were uniformly early. Other refinements were needed.

First foot correction - It was decided that early predictions probably meant the neutron probes were not measuring all the available soil water. The logical point of error was in the first foot, since neutrons could escape to the atmosphere at this depth. Gravimetric samples were collected to test for actual water in the soil at two levels within the first foot. Tentative results suggest El Dorado soils need a correction of 1.8 times the first foot neutron probe reading. (See Table 10.)

Soil Series	Average First Foot Correction
Boomer	1.35 dn = dg
Josephine	1.76 dn = dg
Auberry	1.84 dn = dg
Aiken	2.03 dn = dg
	1.75 average correction

dn = neutron depletion

dg = gravimetric depletion

Table 10. Comparison of gravimetric and neutron probe depletions of the first foot of four soils showing the needed correction for the neutron probe depletion.

Verification of computer scheduling based on weather - In 1980 a procedure was followed to verify the accuracy of computer predictions made without actual soil moisture up-dates. Farm fields were still monitored frequently with the neutron probe. However, actual moisture levels were not entered into the computer. Only irrigation dates and daily weather were entered, allowing the computer to predict soil moisture status. The measured depletions were then compared with computed depletions. Selected graphs of the comparisons are shown in the appendix.

This was done for all farms that had well-established field capacities and allowable depletions. Analysis of the data shows that computers can accurately predict soil moisture depletions given only daily weather and irrigation dates when site adjustments are accurate. Approximately 20 percent of the El Dorado sites achieved a high degree of predictive accuracy in 1980. Predicted soil moisture status did not deviate from measured soil moisture status by more than two days at any time during the season. Another 50 percent achieved predictions within acceptable limits, but lacked a consistant pattern of prediction over the season. Thirty percent of the sites had serious predictive errors due to various site problems.

The major site problems were;

The computer was not programed with an accurate allowable depletion or site adjusted crop curve. For example, the site was calibrated with a neutron soil tube that was too shallow to completely reflect the root zone.

Weather at the site and the weather station differed, such as in rainfall or wind patterns.

Cultural practices changed site water use. For example, the covercrop was disced or allowable depletion was exceeded, slowing ET.

Water distribution problems occurred so that the profile was not refilled during irrigation or else was wetted between irrigations. This could be caused by: blocked or plugged sprinklers, low line pressure, short sets, line breaks and other system malfunctions.

Irrigation dates were not accurately determined and recorded for entry into the computer.

Most of these problems can be spotted by experienced personnel and accounted for in making computer predictions safe and accurate for all sites.

Safeguards for Computer Accuracy

Nearly everyone has either experienced or heard of computer blunders. How can they be avoided in computer irrigation scheduling? Actually such errors are usually human errors. Well-trained, alert personnel will spot errors that result in abnormal irrigation predictions. When a prediction looks strange, personnel will still have to spot check fields to analyze the source of problem.

Farmer interest and cooperation is important in making the computer system work accurately. Close supervision of irrigations and recording of irrigation dates and other cultural events greatly improve computer accuracy. The prediction, after all, is only a guide for the farmer. He must actually decide when to irrigate and apply the irrigation.

A scheduling board for plotting all future irrigations and past irrigations provides a useful check on what is really happening. Irrigation managers should develop such a fail-safe method of scheduling so that they can sleep comfortably during irrigation season.

COMMUNICATION

Communication has several vital functions in an irrigation management program. Through good communication:

- Farmers will understand the program and incorporate it into their farm management system.
- Farmers can make management decisions based on irrigation predictions well in advance of carrying out farm practices.
- Program costs can be minimized by having the farmer report irrigation dates and hours of operation and tillage dates to irrigation consultants.
- Awareness and concern for better irrigation practices are stimulated.
- When written, a record is provided for future reference.

Sound irrigation management depends on farmer understanding of irrigation management concepts and on going communication between the farmer and the irrigation consultants. Water management is not a complex confusing program. It is a simple water budget procedure. By eliminating the mystery of irrigation scheduling through good communication, the farmer can understand the goals and the benefits of the program. After all, the farmer is the decision maker and must integrate irrigation management information into his total farm program.

Farmer Communication with Consultants

Consultants must know when irrigations occur and for how long, to update irrigation predictions. Also, they must know when certain cultural practices occur, such as discing or mowing. As previously mentioned, these practices reduce crop ET. Irrigation consultants could regularly visit sites to monitor and record these events; however, this procedure is time consuming and therefore expensive. Irrigation managers can provide this kind of service, but only at an increased cost to growers. An inexpensive solution is to have growers inform consultants when irrigation or cultural changes have occurred. Communication can be by any method convenient to growers and consultants. The El Dorado County IMS has had very good results with a farm irrigation record form, see Figure 9.

FIELD #1			FIELD #2		
Irrig. Date	Hours	Mow or Disc Date	Irrig. Date	Hours	Mow or Disc Date
8/17/80	12	-	8/21/80	36	8/25/80
8/29/80	12	-	9/ 8/80	34	-
9/ 7/80	12	-	9/25/80	48	-

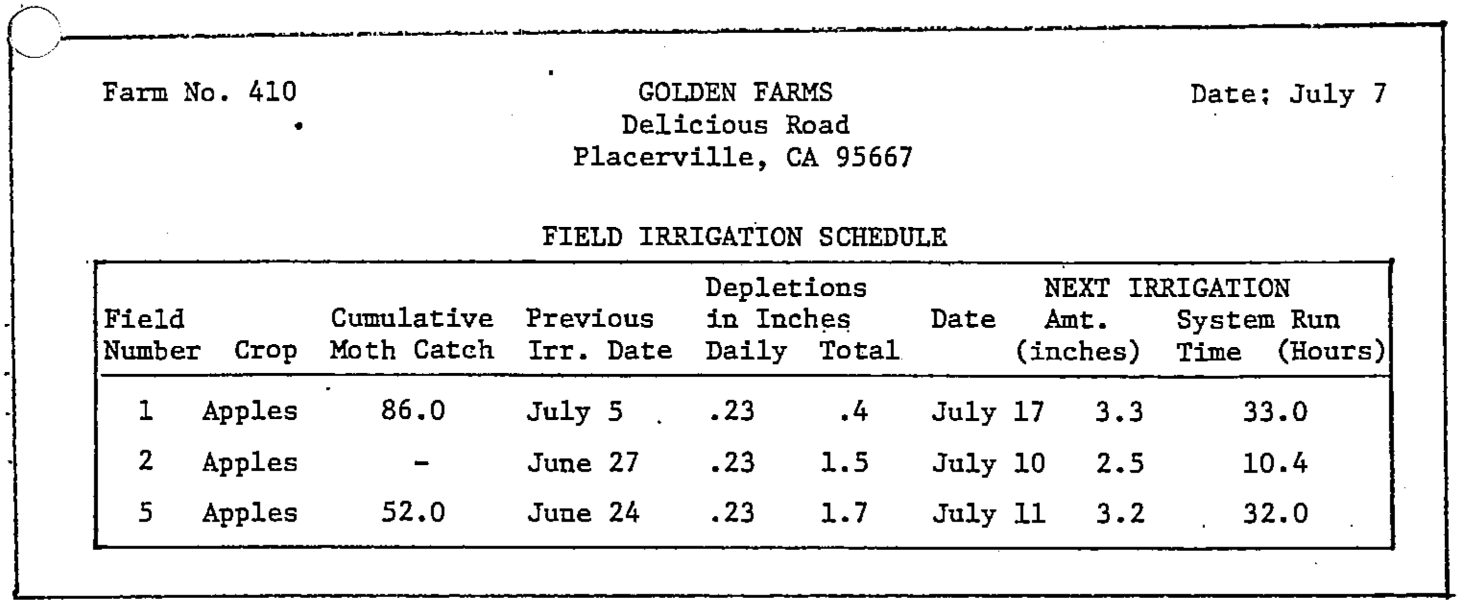
Figure 9. Farm irrigation record. Notice how field 1 has all 12 hour run times. This is for a portable sprinkler system. Field #2 is an overhead system which has been run to just refill the soil profile.

The farm irrigation record is located in a convenient place for easy access by farmers and consultants. The farmer records irrigations and other activities as they are completed. At regular but convenient intervals, consultants review the record and determine which fields may need an actual moisture depletion check. For example: a consultant checks an irrigation record and notices that a field received a short irrigation. Being suspicious that this may be an inadquate irrigation, the consultant makes a soil depletion check and finds a residual depletion of 1.20 inches. The grower is notified of the problem and a decision to re-irrigate to satisfy the depletion is made. Another option would have been to apply the next irrigation earlier than usual. The farm irrigation record allows consultants to concentrate on farm irrigation problems without making numerous field checks. Another advantage of the farm irrigation record is that accurate field data is available at a glance.

This system of communication depends upon farmers keeping farm records up-to-date and accurate.

Irrigation Consultant Communication With Farmers

Primary communication between consultants and farmers for the El Dorado IMS is through weekly computer printouts (see Figure 10.) They contain predicted irrigation dates for all fields made the same day the printout is mailed. Consistent weekly reporting is important because farmers need to know when their recommendations will arrive. This makes it possible for farmers to rely on irrigation communication. By knowing when recommendations will arrive, they can delay other management decisions and incorporate irrigation into a total management scheme. If imminent irrigation problems became evident, farmers are contacted immediately at the farm or, if unavailable, later by phone.



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Farm No. 410                   GOLDEN FARMS                        Date: July 7
                               Delicious Road
                            Placerville, CA 95667

                          FIELD IRRIGATION SCHEDULE

                                      Depletions              NEXT IRRIGATION
Field          Cumulative  Previous   in Inches       Date     Amt.     System Run
Number  Crop   Moth Catch  Irr. Date  Daily  Total           (inches)  Time  (Hours)

  1    Apples     86.0     July 5      .23     .4    July 17    3.3       33.0
  2    Apples      -       June 27     .23    1.5    July 10    2.5       10.4
  5    Apples     52.0     June 24     .23    1.7    July 11    3.2       32.0
```

Figure 10. An El Dorado IMS computer printout.

Other communication methods used in El Dorado County include: IMS newsletters as supplements to weekly farm soil moisture status reports to keep farmers aware of program changes and improvements. Farmer meetings and workshops conducted to demonstrate equipment and monitoring techniques. These meetings provided a chance for IMS personnel and farmers to become better acquainted and promoted a better understanding of program abilities, needs, and goals. Finally, and of utmost importance, personal contact was made with the farmer as often as possible, especially in the field. Farmers became acutely aware of irrigation deficiencies when actually shown the problem. Seeing dry soil collected with a soil sampler at the second foot of the soil profile leaves little doubt that the last irrigation was inadequate. Conversely, the irrigation consultant may have a problem field that is not being predicted properly by computer scheduling. By discussing the problem with the farmer, he may learn the source of the problem from the farmer's experience. This type of personal contact provides information exhanges that help program personnel and farmers work together to eliminate errors and problems.

Farmers doing their own irrigation management need to keep themselves fully informed of field irrigation needs. Good record keeping is vital. Farmers should faithfully record irrigation dates to alert themselves when moisture checks should be taken next.

If tensiometers are used, records again are important. Data can be plotted against time to predict irrigation dates. For example, (see Figure 11.) on August 17 following an irrigation, a grower checks his 18" tensiometer and finds a reading of 5 cb., indicating that water penetrated at least 18". Four days later on August 21, he checks the same instrument and finds a 15 cb. reading. With these

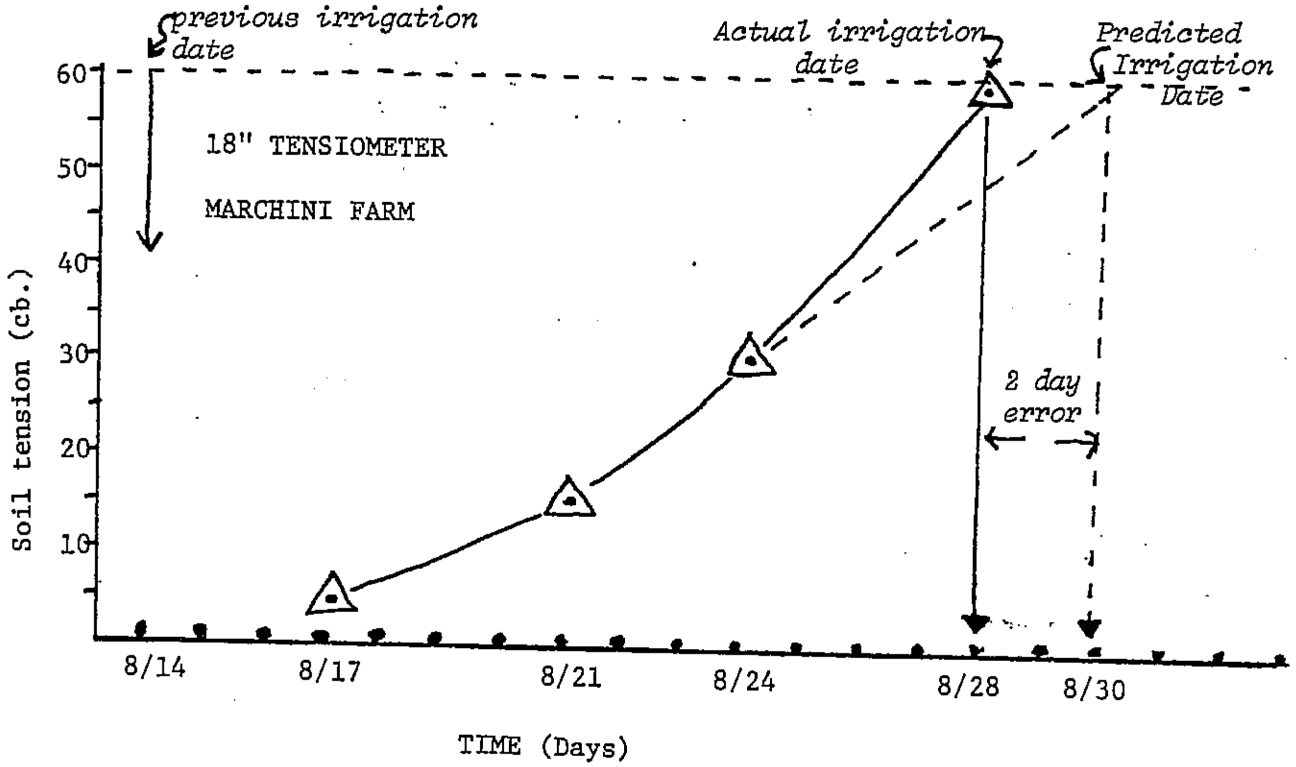


Figure 11. This graph shows how tensiometer readings can be used to approximate the irrigation date. Note that we assume a straight line and consistent weather conditions which in this case has resulted in an error of two days (data from 1978 Marchini test #7)

two readings he could draw a line through the points until it intersects the 60 cb. irrigation line. This would be an initial prediction of the irrigation date. However, this initial prediction could be risky because of weather changes. To verify his prediction, the grower waits for three days and again checks the instrument on August 24. This check gives him a 30 cb. reading. Predicting ahead as he did before indicates that he should irrigate on August 30. On this predicted date the farmer again checks the tensiometer and finds a higher-than-predicted reading. Thinking about the discrepancy, he notes that it had been a hotter than usual week. He begins the irrigation cycle and records the date.

If a farmer selects the water budget irrigation management approach, record keeping is more involved. However, improved irrigation accuracy may justify this effort. See the water budget discussion in the What Is Irrigation Scheduling section to see how budget records are kept. This procedure of record keeping and irrigation date calculations provides individual growers with a method for accurately predicting irrigation dates and amounts. Another advantage to accurate record keeping is that growers, farm advisors and irrigation consultants can review the record and evaluate field problems as related to irrigation practice.

FOOTHILL IRRIGATION METHODS

Sprinkler irrigation is the major method used to irrigate undulating foothill terrain. Some drip and furrow irrigation are also used. Sprinkler irrigation systems are either portable or solid set. If solid set, the sprinklers may be either under or over-tree.

Sprinkler systems are well adapted to the undulating terrain, and variable soil types found on foothill farms. Sprinkler operation requires relatively large amounts of pressurized water which must be clean enough to prevent sprinkler clogging. Each sprinkler normally requires 2.0 to 10.0 gallons of water each minute. Water pressures of 35 to 60 pounds per square inch are required to operate sprinklers. In many foothill locations the supply of water is limited and water may not be available under pressure. In cases where water is limited, drip irrigation may be the preferred method of irrigation. Pumps can be used to develop pressure in these situations, however pumping is expensive if water needs to be lifted to the irrigation site.

Most of the sprinkler systems on foothill farms are supplied by irrigation districts from ditches or pressurized pipelines. Those farms served by ditches often can take advantage of gravity to gain adequate pressure for sprinkler operation. One pound per square inch pressure is gained from each 2.3 feet of elevation drop. Therefore, 92.27 feet of vertical drop develops 40 psi of sprinkler line pressure.

Portable Sprinkler Systems

Movable sprinkler systems require a permanent underground main line with hydrants on riser pipes spaced periodically for attachment of the portable lateral lines. Sections of portable pipe (jumpers) may be run parallel to the main line to reduce the need for frequent hydrant placement. The portable lateral lines are connected to the jumpers with elbow or tee couplers. In orchards, standard practice consists of irrigating every other row with irrigation durations of 12 to 24 hours and water applications of 3 to 5 inches. During the next irrigation cycle, the lines are placed in the alternate rows.

The advantages of movable systems are:

1. Less expensive than solid set sprinkler systems.
2. Little wetting of fruit and foliage in orchards that may be disease susceptible.

Disadvantages and limitations associated with movable systems include:

1. High labor costs to move them through fields.
2. A set period of time is needed to complete an irrigation cycle.
3. Little, if any, crop frost protection or cooling capability.
4. High maintenance requirement.

Movable systems should be designed to apply water uniformly and to move through the field fast enough to apply sufficient water to meet peak ET demand. If a field requires water on a ten day interval at peak demand, the system must be capable of covering the field in 10 days. If possible, main lines should disect the field so that the lateral sprinkler lines may be rotated around the field avoiding the need to transport a line back after completing an irrigation.

Uneven sprinkler application is a problem where laterals are placed on rolling terrain that varies in elevation from the beginning to the end of the line. Flow controls and/or nozzle changes may be necessary on some or all pipe sections.

A common problem in managing portable sprinklers is the failure to start the first irrigation cycle of the season early enough so that the water reaches the last tree rows in the cycle before stress occurs. If lines are started when the first row needs water, then all following rows will be irrigated late.

Two other common problems are excessive application rates and lack of application uniformity. Excessive rates are caused by nozzle wear or higher than normal line pressure. Poor uniformity is caused by nozzle wear, sprinkler malfunctions and system leakage. Regular system maintenance more than pays for itself in water savings and improved crop performance.

Permanent Under-Tree Sprinklers

Permanent under-tree sprinkler systems are desirable where frost protection requirements are low. Sprinklers are usually placed in every other tree row and centrally located at every other space between trees in the row on 12" risers. Water is delivered to sprinklers through a system of buried main lines and distribution laterals. When sprinklers are located between trees, cross-cultivation is usually impossible and is replaced by strip spraying of the row with herbicide.

Solid set, under-tree irrigation has the advantages of;

1. Low labor requirement for operation.
2. Flexibility in timing of applications, if mainline has adequate capacity.
3. Little wetting of fruit and foliage in orchards that may be disease susceptible.
4. Sprinklers can be reached for repairs or modifications.

The disadvantages and limitations of solid set under-tree systems are:

1. High initial cost due to distribution pipe, sprinkler numbers and installation costs.
2. Not adapted for closely spaced orchards, hedge row plantings or vineyards.
3. Frost protection is only 3 to 5 degrees.

Permanent Over-Tree Sprinklers

Permanent over-tree sprinkler irrigation systems are desirable when micro-climate modification is needed for frost protection or field cooling. These systems are permanently installed such that sprinklers are placed above the tree or vine canopy on risers. Water is delivered to sprinklers through a system of buried main lines and distribution laterals into plastic risers supported by a vine stake in vineyards or 1/2 inch to 3/4 inch galvanized pipe risers supported by tree scaffold limbs in orchards.

The advantages of permanent-set, over-tree sprinklers are:

1. Low labor requirement for operation.
2. Flexibility in timing of applications if mainline has adequate capacity.
3. Can provide more frost protection and cooling.
4. Dust washed off of foliage, aiding mite suppression.

The disadvantages and limitations include;

1. High initial cost due to distribution pipe, sprinkler numbers, metal riser pipe and installation costs.
2. Sprinklers in orchards difficult to reach for repairing clogged or malfunctioning sprinklers.
3. Wind can interfere with efficiency of water application.
4. Low application rates for frost control, which may make irrigations excessively long.
5. Over-tree water application can wash pesticide residues off foliage and contribute to disease development.

With permanent sprinkler installation spacing is critical. Sprinklers must be located such that uniformity of water distribution is adequate. The 1979 over-tree sprinkler tests indicate good uniformity for several well-designed overhead systems in El Dorado County. However, poor coverage can result where ground is water shadowed by a dense tree canopy and when operating pressure and/or water flow is reduced.

System efficiency checks in 1979 for several solid-set sprinkler systems have shown that 85 to 95 percent of the applied water actually reaches the ground. This range represents acceptable application loss for overhead irrigation. A vineyard irrigation test indicated that interrupting irrigation reduced irrigation efficiency. In this test irrigating for three consecutive nights at 9 hours per night was compared to irrigating continuously for 27 hours. Soil surface evaporation may have been greater with interrupted irrigation. This result requires further investigation.

1979 IMS data showed many growers failed to operate overhead systems long enough to refill the soil profile.

Drip Irrigation

Drip irrigation systems are well-suited for hedge row crops and vineyard use, when frost protection is not required or practical. Drip systems may also be used in orchards, but require strip weed control to keep emitters visible for checking.

Drip irrigation systems are designed for continuous or periodic slow applications of water (1/2 to 2 gal/hr.) to the soil surface near each plant. A buried main line is used for water transport to surface laterals and emitters located at each plant. The water is filtered and line pressure is controlled at the head of a system.

Drip irrigation can be used most effectively where water is limited or soil is shallow. Only about 15 percent of the soil surface is wetted which results in small evaporation losses. Emitters are designed to apply a specific amount of water. One to several emitters may be used per plant to apply just enough water to meet ET requirements.

Advantages of drip systems are:

1. Drip irrigation can be operated efficiently when water is limited.
2. Drip systems can be relatively inexpensive to install and operate, although some systems can be very expensive particularly if extensive filtration equipment, fertilizer injection equipment and expensive emitters are used.
3. Weed problems are reduced due to dry soil surface between emitters.
4. Fertilizers can be easily applied through drip systems.
5. Irrigations do not interfere with other orchard practices.
6. Soil moisture fluctuation can be reduced.

Disadvantages and limitations with drip systems include:

1. Clean water is necessary to prevent emitter clogging; where clean water is not available, expensive filtration units may be necessary.
2. Considerable time is required to check for clogged and damaged emitters. Roots are highly dependent upon emitter water, clogged emitters can result in rapid plant stress.
3. Coyotes and rodents may chew on surface polyethylene plastic laterals and emitters.
4. Above ground distribution systems may interfere with cultivation practices.
5. Design assistance often is difficult to obtain. The system must be of adequate design to ensure that each emitter is applying the same amount of water and that the system is capable of meeting peak demand.

Drip irrigation is a relatively new irrigation method and has not been completely evaluated. More experience and familiarity with its use, may bring greater adoption of this method.

Information on drip irrigation design and techniques is available at Cooperative Extension Service offices.

Furrow Irrigation

In the past, furrow irrigation was widely practiced in foothill orchards, however its current use is limited. In furrow irrigation one to four furrows or channels are used to transport water down orchard rows. These channels are filled with irrigation water which is allowed to percolate into the soil reservoir.

Advantages of furrow systems include:

1. Low initial cost is the major advantage of furrow irrigation systems.
2. Operation with minumum water pressure.

Limitations and disadvantages of furrows are:

1. Furrows must be reestablished each season or even within a season.

2. Construction is critical. They must be of adequate length, width, and spacing to achieve uniform soil wetting.

3. Sloped ground prevents water from standing in channels to achieve uniform soil penetration.

4. Furrows may restrict the use of farm equipment within the orchard.

5. Labor requirements are very high to achieve efficient water penetration and to repair damaged furrows on sloping ground.

These limitations make furrow irrigation a poor choice for commercial irrigation in the foothills, particularly when compared to much higher irrigation efficiency obtained with sprinkler systems. Furrow irrigation has application in small farm operations or in home orchards.

Irrigation systems are designed to efficiently provide water during periods of peak demand (June, July, August). When using peak demand systems in non-peak months, irrigation scheduling and amounts must be accurate if water wastage is to be avoided. Systems that are not capable of meeting peak demand should be improved to meet maximum ET demand. However, on some farms system improvement is not economically possible and/or water supply is limited. In such situations farmers need to do the best they can with their systems. The following suggestions may help:

1. Start irrigation early in the season to avoid getting behind.

2. Minimize the time that systems are not operating.

3. Maintain systems in the best possible state of repair.

4. Reduce the irrigation water requirement through cover crop control practices.

If fields are allowed to dry during low ET demand periods, they will get even drier at higher use periods later in the season.

IRRIGATION SYSTEM EFFICIENCY AND ANALYSIS OF 1979-80 SYSTEM TESTS CONDUCTED IN EL DORADO COUNTY

The application of water through an irrigation system is never a totally efficient process. All the water that enters a system that is not eventually used by the crop in effect lowers the efficiency of the irrigation. Efficiency is reduced by runoff, evaporation and deep percolation.

Runoff generally occurs when the system applies water too fast. It can also occur from system leaks. Excessive application rates may result from original design error or occur as a result of system wear. Runoff problems are readily visible and can be corrected by redesigning or repairing the system.

Evaporation loss is not as easily dealt with. Losses occur during irrigation and then from the ground surface thereafter. Sprinkler irrigation evaporative losses are fairly comparable at about 2 to 8 percent during the irrigation irrespective of system type. Losses appear to be less from continuous water application as opposed to repetative, night only irrigations, however definative data is not available. Individual plants, especially young trees, may be mulched with organic material or the ground covered with plastic sheets; these practices are not economically feasible for most situations. Otherwise, little can be done to reduce water loss by evaporation from the soil surface where sprinklers are used. Cover crops reduce surface evaporation, but transpire far more water than they save.

The least obvious but most common reduction in irrigation efficiency occurs through water being lost to deep percolation. When more water is applied than can be stored in the root zone, the excess drains past the root zone, eventually entering springs, creeks, or ground water supplies. This excess water is not used by the crop and is lost just as evaporation and runoff are lost, resulting in decreased irrigation efficiency.

Irrigation systems should be evaluated periodically to determine whether they are operating at maximum efficiency. System evaluation can help to determine:

1. If the system is properly designed.
2. If system wear has reduced performance.
3. If the system is being properly managed to meet plant needs and soil conditions.

Farmer Evaluation of Systems

Simple system evaluations can be performed by the farmer. By observing sprinkler stream, droplet size and coverage pattern, the farmer can estimate the probable uniformity of water application. He can also spot sprinkler discharge problems associated with high or low line pressures or worn nozzles. By measuring line pressure and sprinkler discharge at several locations and observing the depth of wetted soil, he can estimate application rate and the effectiveness and uniformity of the irrigation. Equipment and procedure for simple evaluations are as follows:

1. A pressure gauge (1-100 psi) with a pitot tube attachment. This is used to measure pressure at the sprinkler orfice and along a lateral. A pressure gauge may also be fitted with a pipe connection which can be placed on a sprinkler riser to monitor line pressure. NOTE: To provide good uniformity, the pressure variation along a lateral should not exceed 20 percent of the pressure at the beginning of the lateral.

2. A watch with a second hand, a container of known volume (preferably 1 gallon) and a length of hose. These are used to measure the volume of water discharged at the sprinkler in gallons per minute.

3. A new nozzle of specified size. This may be placed in various locations along a lateral to determine nozzle wear and the need for replacement.

4. A soil tube or shovel. These are used to estimate soil moisture depletion before the irrigation. They are also used to determine the depth and uniformity of water application over an area during and after an irrigation.

In addition to the previous measurements, determining the distance between sprinklers on a lateral and the distance between the laterals themselves allows a farmer to accurately determine the average application rate with the following formula:

$$I = \frac{96.3\ Q}{S_s \times S_L}$$

Where:

I = application rate (inches/hour)
Q = individual sprinkler discharge (gpm)
S_s= distance between sprinklers (feet)
S_L= distance between laterals (feet)

As a final step, a farmer can gather useful information by placing several catch cans around a sprinkler or along a lateral. By comparing volumes caught at various locations, a more accurate estimate of application efficiency and uniformity may be formed. Performing the simple evaluation procedures mentioned should quickly give the farmer a better understanding of his irrigation systems capabilities and his management practices.

Consultant Evaluation of Systems

When more detailed information is desired, a technical system evaluation can be conducted by a trained irrigation consultant using a variety of measurements taken before, during and after an irrigation. Full system analysis will provide precise information on a system's capabilities and will serve as a basis for making corrections if needed. The procedure is described in detail with field data examples in Farm Irrigation System Evaluation: A Guide For Management, Chapter II by John Merriam and Jack Keller (1978). Drip irrigation systems evaluation procedures are also described in this publication.

1979-80 Efficiency Tests

During 1978 orchard irrigation trials and 1979 IMS monitoring program, questions were raised about the efficiency of sprinkler irrigation in El Dorado County orchards and vineyards, especially those blocks having overtree and overvine systems. To answer these questions technical system evaluations were performed on 16 farms during the 1979 and 1980 irrigation seasons. The procedure was similar to that described by Merriam. Catch cans were placed on the ground in patterns which measured actual water reaching the ground during an irrigation. After determining sprinkler application rate, length of irrigation run and soil moisture depletion before and after the run, catch can data were analyzed to determine several values used to rate the efficiency of water application of a sprinkler system. Briefly, the names given these values, their significance and their methods of calculation are as follows:

1. Approximation of losses between application and infiltration (E_a) - this is the difference between water applied and water caught during an irrigation. Losses are due primarily to evaporation. Values usually range between 80 and 95 percent.

$$E_a = \frac{\text{average depth caught}}{\text{average depth applied}} \times 100$$

2. Coefficient of Uniformity (UC) - this is a common way to evaluate sprinkler application uniformity through statistical representation of the catch pattern. UC of less than 80 percent is usually considered to be inadequate uniformity.

$$UC = (1- \frac{\text{average deviation from average can catch)}}{\text{average can catch}} \times 100$$

3. Distribution uniformity (DU) - this is an indication of the uniformity of water infiltration throughout a field. DU values of less than 67 percent are generally considered unacceptable; however, this can be dependent upon crop characteristics and site factors.

$$DU = \frac{\text{average catch rate in lowest quarter } (\tfrac{1}{4}) \text{ of test cans}}{\text{average catch rate}} \times 100$$

4. Potential Application Efficiency of Low Quarter (PELQ)- this value is an indication of how effectively a system uses the water supply and what total system losses may be; under good management, to satisfy a given soil moisture depletion. Low PELQ is usually associated with poorly designed systems.

$$PELQ = \frac{\text{average catch rate in lowest quarter } (\tfrac{1}{4}) \text{ of test cans}}{\text{average application rate}} \times 100$$

5. Application Efficiency of the Low Quarter (AELQ) - this value indicates how well a system is being used from the amount of applied water stored in the root zone. Ideally AELQ = PELQ. Lower values for AELQ indicate problems in management or use of a system resulting in water loss to deep percolation.

$$AELQ = \frac{\text{average depth of the low quarter } (\tfrac{1}{4}) \text{ can catches stored in the root zone}}{\text{average depth applied}} \times 100$$

Results of the 1979-80 system evaluations are presented in Table 11. Several catch can patterns were used which may have influenced some evaluation figures. Several evaluations were conducted over a complete irrigation run. Selected test descriptions and details are available in the Appendix.

From data analysis of system efficiency tests, several conclusions may be drawn:

1. Application losses (E_a) did not appear to be excessive for the tested systems as they ranged between 5 to 20 percent of applied water.

2. Overhead systems usually have relatively low application rates (.15 in/hour or less) when compared to portable sprinkler systems (usually greater than .20 in/hour and many times much greater). Therefore overheads must be run for longer periods of time to adequately satisfy similar soil moisture depletions.

3. The majority of tests indicated adequate system design as PELQ values exceeded 70 percent. Those systems with much lower values could possibly benefit from pressure adjustments and/or nozzle changes after further evaluation.

4. Overhead systems appear to perform well on a variety of spacing patterns. It appears that there may be economic justification in going to a wider spaced system if design criteria are met. Substantial savings in capital investment and maintenance cost may be realized when fewer risers and sprinkler heads are required.

In addition to system evaluations presented in Table 11, IMS personnel measured sprinkler discharge rates on many portable irrigation lines in El Dorado orchards. Estimation of moveable system capabilities were then made using the following steps to estimate application rate:

1. Sprinkler discharge rates (Q) are measured with a watch, hose, and known volume container at various points on a lateral line. For example: 1 gallon is caught in 15 seconds, that equals 4 gallons/minute discharge rate.

2. Given a standard sprinkler spacing along a moveable lateral line (S_s) of 20 feet.

3. Given a standard grower practice of alternate row irrigation, making the distance between laterals (S_L) twice the distance between tree rows, usually 20 to 25 feet (in this example 24 feet).

4. Values are then placed into the application rate formula, where I equals application rate:

$$I = \frac{96.3\ Q}{S_s \times S_L} \quad \text{or} \quad I = \frac{96.3 \quad 4.0}{20 \times (2)24} = 0.50$$

TABLE 11. 1979-1980 System in Effeciency Evaluation Results

System Type	Sprinkler Spacing (feet)	Operating Pressure	Sprinkler Discharge	Application Rate (in./hr)	E_a	UC	DU	PELQ	AELQ
PLU Overhead	50x60	23 psi	2.61 gpm	.084	89.7	86.4	80.8	72.1	72.1
MAR * Overhead	54x60	38 psi	3.25 gpm	.097	85.0	81.6	71.0	60.8	--
SCH Overhead	45x50	NR	2.80 gpm	.12	93.2	83.9	75.9	70.8	57.7
DEL Overhead	32x48	NR	1.62 gpm	.102	97.5	87.9	80.8	73.4	--
IRV Overhead	42x42	NR	2.16 gpm	.118	96.4	77.1	64.1	61.9	61.9
ENC * Overhead	54x60	68 psi	6.0 gpm	.178	83.9	90.0	83.3	77.9	48.2
BUL Overhead	46x52	50 psi	3.75 gpm	.15	79.0	72.0	51.3	40.7	40.6
NCN Overhead	30x53	20 psi	1.50 gpm	.089	66.9	66.2	45.7	30.3	30.3
BOE * Overvine	35x48	45 psi	2.00 gpm	.115	90.2	80.6	73.7	66.0	--
BVS Overvine	32x48	40 psi	3.22 gpm	.14	95.0	85.0	82.8	72.1	72.0
MIR Overvine	40x48	45 psi	3.00 gpm	.15	98.2	83.4	71.6	70.9	37.0
HUS * Undertree	32x34	NR	2.72 gpm	.196	88.0	65.4	54.0	48.5	48.6
WAS Portable	20x40	48 psi	5.0 gpm	.60	91.0	80.6	74.0	67.4	40.1
B-GH Overvine	36x40	NR	2.0 gpm	.130	86.0	86.0	82.0	70.0	--
GOL ** Overvine	32x40	NR	1.63 gpm	.10	108.0	82.0	73.0	80.0	--
PEK Overvine	40x48	NR	3.0 gpm	.15	83.0	91.0	85.0	73.0	--

* Complete test data shown in the Appendix

** Length of run not documented

NR = data not recorded

Application rate (I) is calculated to be .50 in./hr. If a 70 percent potential system efficiency is assumed, .35 in./hr. would be infiltrated to satisfy any soil moisture depletion (.50 in./hr. x 70% = .35 in./hr.)

From the measured discharge rates and resulting application rates, the length of irrigation run necessary to most effeciently supply water to the root zone can be calculated. For instance, from measured discharge rates infiltration rate along a lateral is calculated to be .35 in./hr. If soil moisture depletion is measured with the neutron probe as 3.0 inches, then to just refill the depletion would require the system to run 8.57 hours (obtained by dividing 3.0 inches depletion by .35 in./hr. infiltration rate).

It is standard farmer practice in the El Dorado area to run moveable lines for 12 hours. In this example then, 4.2 inches of water would be infiltrated during the irrigation (.35 in./hr x 12 hours), resulting in a deep percolation loss of 1.2 inches (the difference between soil moisture depletion and total water infiltrated). In many cases this standard practice of irrigating 12 hours results in excessive application. However, twelve hour runs sometimes result in under-irrigation in those cases where application rates are low and allowable depletions are large. Table 12 shows how twelve moveable systems in El Dorado orchards vary in respect to discharge rate, application rate and ability to satisfy allowable depletion.

Observations made while conducting measurements on moveable irrigation systems indicated the following problems occur frequently on El Dorado farms.

Farm System Number	Sprinkler Discharge Rate (gpm)	Sprinkler Spacing (feet)	Calculated Application Rate (in/hr)	Infiltration Rate at 70% Efficiency (in./hr.)	Usual Length of Run (hours)	Total Amount Infiltrated During Run (inches)	Allowable Depletion To Be Satisfied (inches)
100-6	2.0	20x40	.24	.17	12	2.04	3.0
110-4	5.0	20x38	.63	.44	12	5.28	3.5
110-5	6.0	20x38	.76	.53	12	6.36	3.4
110-8	5.0	20x40	.60	.42	12	5.04	3.8
120-3	4.0	20x40	.48	.34	12	4.08	2.5
150-1	1.7	20x40	.20	.14	12	1.68	3.0
160-2	1.5	20x40	.18	.13	24	3.12	3.5
205-2	3.5	20x40	.42	.29	12	3.48	3.5
205-4	2.0	20x36	.27	.19	12	2.28	2.5
220-3	2.1	20x40	.25	.18	12	2.16	3.5
225-1	3.0	20x44	.33	.23	12	2.76	2.8
355-4	3.0	20x36	.36	.25	12	3.00	3.3

Table 12. Results of simple analysis of moveable sprinkler systems.

1. Many systems are in a poor state of repair, containing worn nozzles, leaking gaskets and malfunctioning sprinklers resulting in runoff losses and or deep percolation.
2. Discharge rates are often extremely variable along a lateral line resulting in poor distribution uniformity.
3. Standard farmer practice of 12 hour sets with moveable systems show only 1/3 of the systems performing efficiently. A third of the systems apply too much water and another third not enough to refill the soil profile.

WATER SOURCES

Irrigation water is a necessity for economic production of most crops grown in the foothills. In planning any agricultural endeavor high priority must be given to developing a water source. This source will have a direct influence on many vital decisions such as: the type of crop or the variety to be planted, acreage to be planted, plant spacing, time needed to achieve economic production levels, potential yield and quality, type and design of irrigation systems and the amount and timing of applied irrigations. In short, water source will influence practically every facet of the sequence of total farm crop development.

A variety of water sources are available for foothill farming including: irrigation district watershed storage supplies distributed through pipelines and ditches, streams, wells, springs, ponds and rainfall stored in the soil. Water from stored soil moisture will always be available, although having only this source may be insufficient and prove severely limiting to farming. The amount of stored water depends upon soil texture, depth and the amount and occurrence of rainfall. When other sources are available, they should be used to supplement stored soil moisture from rainfall.

Pressurized pipeline water is probably the best overall water source although its availability is limited in many foothill areas. This water is usually of high quality, clean (maybe filtered), is under pressure, and normally is available at all times. All irrigation systems may be used with this water supply source. However, where urban users share this water, water treatment costs may prohibit its use for agriculture. Pressure problems may occur in some areas during peak demand periods as a result of overtaxing a portion of the distribution system. The ever-increasing demand for high quality water by businesses and homeowners may result in this type of water becoming less available to agriculture.

Ditch water is an alternative source within district service areas. This water may be less expensive than piped water. This source is almost as reliable as piped water although breaks do occur in the system. Availability is usually limited to the growing season and then on a continuous flow basis. This water is not generally treated chemically or filtered, and pressure must be derived from the elevation differential between the ditch and the field. Irrigation systems used with this source may require pumps to provide pressure and/or screens or filters to remove debris. Storage reservoirs can conserve any unused portion of water from continuous flow delivery, saving water for later use.

The development and use of wells as an irrigation source in the foothills is often very risky, but may be a successful alternative if no water district services are available. The highly variable nature of foothill geologic formations makes ground water location, depth and flow rates extremely variable. Water quality can vary from very good to poor as a result of presence of dissolved minerals or sand. Drilling a well and providing and maintaining pumping and storage facilities is expensive. However, if a well with significant water volume of good quality is developed, it can be a fairly reliable irrigation water source. In several foothill areas drip systems are very effectively used with wells, especially on vineyards. Usually a lack of well water volume limits other types of irrigation systems, although sprinklers are occasionally used to irrigate limited acreage.

Springs are sometimes used to irrigate small areas, but most springs do not supply enough water to be significant water sources.

Farm ponds represent another water source available for some foothill farms. They are refilled annually from winter rainfall runoff. Provided construction requirements and costs are not excessive, ponds can be excellent sources of inexpensive irrigation water. Ponds also provide attractive additions to agricultural developments and in many cases have recreational value. To truly be an effective water source, ponds must be properly located and maintained to have adequate depth to prevent evaporative losses. Dam structure and size and underlying mass (soil structure) must be analyzed to assure the desired amount of water can be safely stored. Pond water usually needs to be pumped to the field to be irrigated. Pond water can be used with any type of irrigation system, although filtering will be required before use with drip systems.

Impounding any stream flow involves securing water rights from the State of California. This can prove to be a time-consuming process which must be completed before building any dam.

THE DEVELOPMENT AND EVOLUTION OF THE IRRIGATION MANAGEMENT SERVICE IN EL DORADO COUNTY

INTRODUCTION

Rainfall during the winter of 1976 failed to refill El Dorado Irrigation District reservoirs. If a similar water short season would follow in 1977, it was apparent that normal water usage would totally deplete all stored reserves before winter rainfall could alleviate the drought.

The El Dorado Irrigation District (EID) requested users to practice voluntary conservation. In cooperation with the Water and Power Resources Service, the District also initiated an Irrigation Management Service (IMS). The program was designed to provide irrigation scheduling information so that farmers could apply water more efficiently. Water and Power Resources Service provided part of the manpower, the monitoring equipment and technical expertise. Water and Power Resources Service financial aid was scheduled to be gradually reduced over a period of three years, at which time farmers would recognize the benefits of IMS scheduling and individually pay for the service. The Irrigation District was expected to provide program management, the balance of the labor and transportation.

Three neutron moisture probes were used to measure soil moisture at nearly 300 separate irrigation monitoring stations in 1976. The major crops under the IMS were pears and apples and irrigated pasture. The program started late and access tubes were installed after some moisture depletion had occurred. This made it more difficult to pinpoint field capacity -- a vital figure in calculating moisture depletion for water budget evaluation of soil moisture.

Neutron probe sites were read 25 to 30 times during the first season. This required a staff of 3½ people, 2½ doing probe reading and one devoting time to program management and bookkeeping. The 1/2 time person was a work-study student working with the Farm Advisor's Office and was the only person with a strong technical background in soil-water management directly involved in operating the IMS program.

At the onset of the program definitive data was not available; therefore, irrigation refill points and amounts were developed from the best available estimates. Recognizing the need for definitive irrigation criteria, approximately 25 tensiometers were obtained to be installed for determination of more accurate allowable depletions or refill points. This effort was soon terminated, apparently because other activities were more pressing and personnel lacked confidence in tensiometer reliability. This decision resulted in errors being incorporated for the next two years of irrigation scheduling.

Problems occurred in delivering the IMS information to growers in graph form. As probe readers were pressed for time in maintaining their schedule, they did not provide adequate verbal communication or interpretation of information collected. As a consequence, most growers continued with their own scheduling methods either because they didn't understand the graphs or didn't trust the information presented.

The 1976 program made one major contribution. It did show that grower irrigation practice varied widely from farm to farm and that there were potentials for much greater irrigation efficiency along with some water conservation.

1977 IRRIGATION MANAGEMENT SERVICE SEASON

Precipitation in 1977 was about the same as 1976 and even less water was recovered for reservoir storage. Water rationing was necessary, but how to determine the set amounts for agricultural use was not as obvious. In view of the lack of reliable information in the area the EID Board of Directors finally adopted a uniform coundy-wide water allocation for orchards and pastures of 2.3 acre-feet per acre. In order to resolve the questions raised and to have a basis for further allocations should they again be needed, the Irrigation District manager asked the University of California Cooperative Extension to initiate a research study of orchard water requirements.

Crop water use studies were undertaken in 1977 and 1978 and have been published ("California Agriculture," September, 1979). The studies showed that crop water use rates were highly variable in the Sierra foothills and range from 20 to over 40 inches, with the high rates found at low elevations on south facing slopes in orchards with heavy cover crops.

Research data collection fully absorbed the available time of two persons working in the Farm Advisor's Office, and they were not able to directly participate in operation of the 1977 IMS program. However, they were able to conduct calibration of the neutron moisture probes for all major soils.

The 1977 IMS program was staffed by three people. Most of the neutron probe reading in 1977 was done by new inexperienced personnel, again without formal eduction in soil-water-plant relationships. They received little training other than how to use the neutron moisture probe and where the monitoring stations were.

Seasonal readings dropped to about once a week and when sickness or transportation problems developed, an occasional week was missed. Graphing of readings for growers was dropped as being too time consuming. Instead, notes were left when irrigations were due.

Growers responded more favorably to the irrigation notes than they did to the graphs. Drought limitations on water supply made them more concerned and interested in IMS. Some growers became uneasy when reading frequencies were interrupted. Growers also received reports every two weeks on the amount of water they had used from their allocations. Fearing that they would run out of water before harvest, growers tended to irrigate more conservatively than suggested by neutron moisture probe recommendations. Because their crop water requirements were lower, many growers east of Placerville ended the season without using all their allocated water. As a consequence, the EID Board was able to allocate additional water to growers mostly west of Placerville who had depleted their supplies while following neutron probe recommendations.

As a summary of the 1977 season, the drought made growers appreciative of the need for an IMS. A survey showed that growers wanted IMS to continue, but were not ready to finance it.

1978 IRRIGATION MANAGEMENT SERVICE SEASON

Heavy rainfall during the winter and spring of 1978 terminated the drought. IMS had one more season to operate with partial financial support from the Water and Power Resources Service. To have growers willing to finance a program thereafter would require a more efficiently operated and accurate IMS. At the request of the Cooperative Extension horticultural farm advisor, the Irrigation District agreed to assign a UC graduate to establish accurate refill points for IMS farms. These farms then were entered into the Water and Power Resources Service computer for irrigation scheduling.

By the season's end, about 30% of the probe sites had accurate refill points and were operating under the computer prediction system. Farmers received weekly computer printouts showing field depletions and expected dates of the next irrigations. Farmers responded quite favorably to this new IMS procedure. Though fewer probe readings were required, they were still necessary for accuracy until the computer predictive capability could be fine-tuned and tested.

The pear and apple orchard water requirement studies conducted by the University of California Cooperative Extension Service were completed in the fall of 1978. This information was now available to help improve IMS accuracy. One more season was obviously needed to refine the IMS program. University of California Cooperative Extension offered to undertake this task in cooperation with the Water and Power Resources Service if EID could provide funds to hire two experienced and trained people to conduct IMS under the direction of Cooperative Extension for the 1979 season. A fourth season for IMS was eventually negotiated.

The 1978 season demonstrated that computer irrigation scheduling could be used in El Dorado County and that growers were receptive to weekly computer information.

1979 IRRIGATION MANAGEMENT SERVICE SEASON

The fourth season of IMS started early in the year with all test stations being monitored after a thorough rainfall for accurate field capacity determinations. More farms were added to the program and poor monitoring stations were moved to more accurate locations within the same orchards. In addition, nearly every site that had not been calibrated based on tensiometer data in 1978 had an 18" deep tensiometer installed. In a very short period of time virtually all sites had accurate refill points based on 60 centibar tensiometer readings at the 18-inch depth. With accurate measurements of field capacity and refill points, allowable depletions could then be calculated. Values were then entered into the Water and Power Resources Service computer and for the first time all IMS farms were being computer scheduled.

1979 irrigation service operation depended upon measuring field moisture status each week with the neutron probe. On the same day, as a moisture reading was made, a computer printout was mailed to growers for each field checked. This procedure resulted in up-to-date weekly information for grower use. Together with irrigation recommendations, codling moth trap counts were monitored by irrigation managers and included on the printouts sent to growers. The intention was to coordinate pest management with irrigation management. By coordinating the two programs, insect sprays and irrigations could be applied for optimal insect control and optimal crop performance.

Because computer printouts were new to foothill irrigation management, newsletters and meetings were offered to acquaint growers on how to read and interpret the furnished information. These meetings combined with frequent field contacts removed the mystery of irrigation scheduling, got farmers personally involved in IMS and developed confidence in irrigation recommendations.

During the 1979 season, it was recognized that there was more to irrigation management than just telling farmers when to irrigate. By beginning to look at irrigation system efficiency, system problems and inadequacies were identified and corrected resulting in substantial water savings. Also by determining system application rates, irrigation managers were able to recommend not only when to irrigate, but how long to run the system to exactly refill the soil profile, which was a significant improvement in the information delivered to farmers.

Irrigation scheduling in 1979 was well received by participants. Serious farmers were highly interested in field soil moisture status, system efficiency and limitations, and cultural practices used to reduce field water use. Several farmers indicated that they would pay to retain the services of irrigation management.

Review of the 1979 season indicated that the following observations are important in establishing a viable irrigation management service.

1. The computer scheduling method if properly operated with accurate data can be an accurate economical scheduling technique. Site specific crop coefficients were developed for the variety of microclimates existing in the Sierra foothills based on the research data collected in 1977 and 1978.
2. Establishing field capacities, refill points and allowable depletions with tensiometers is very important to

irrigation scheduling accuracy.

3. Irrigation monitoring stations must be placed in a representative location in the field, not where convenience dictates.
4. Considerable time must be spent on farmer communication and education to develop confidence in recommendations.
5. Irrigation is only part of a complex farm management process. Recommendations must be compatible with other farm practices.
6. Irrigation programs can do much more for farmers than simply telling them when to irrigate. Recommendations can be made on how systems perform and how to efficiently use systems to apply just the right amount of water to refill the soil profile.
7. Efficient irrigation management can not afford to miss measurements or recommendations. Farmers begin to depend on recommendations and misses can be critical to program confidence.

The 1979 irrigation management season outlined the major goals and work areas for moving toward efficient economical IMS in 1980.

1980 IRRIGATION MANAGEMENT SERVICE SEASON

The primary objective of the 1980 IMS was to refine and verify computer capability to predict irrigation needs from climate data. Site specific crop curves based on 1979 data greatly enhanced computer operation for IMS. Verification efforts demonstrated that computer predictions for most sites were sufficiently accurate to allow elimination of neutron probe checks for two or more irrigations (see Computer Irrigation Scheduling). This reduction in probe checking can cut program labor requirements in half.

The 1980 program continued to expand. Twenty new farms were added. Crop water requirements for other important foothill crops were studied. These included plums, cherries, Christmas trees, wine grapes and irrigated pasture. These results are reported in the Water Requirements section. A more comprehensive study of wine grape water requirements is needed. Farmer irrigation strategies usually encompass deficit irrigation and controversy persists as to the degree of dryness required for optimum wine quality. System analysis work was continued, but much more needs to be completed before the El Dorado Irrigation Management Program is actually fully practicing water budget irrigation.

Farmer involvement and confidence improved during the 1980 season. This was the second and for some farmers the third season where they used computer recommendations. Confidence was increased because the same personnel operated the computer program from its inception. Farmers knew them personally and could rely on their irrigation knowledge.

Farmers became more involved in the program when they responded favorably to being asked to maintain accurate records of irrigation and tillage practices. The irrigation consultants had previously monitored these events needed for computer calculations. With farmers keeping records, less field checking was required. As a result, program operation became much more efficient.

The 1980 IMP was conducted by the El Dorado County Farm Advisors Office under contract with the United States Water and Power Resources Service and included development of:

1. Site specific crop curves based on terrain, elevation and crop type.
2. Water requirement guidelines for major foothill crops for use in setting irrigation district water allocations in drought years.
3. Evaluation of system efficiency tests conducted in 1979-80.
4. Production of Foothill Irrigation Water Management Manual to serve as a guide for irrigation management practice in all Sierra Nevada foothill farms.

1981 IRRIGATION MANAGEMENT PROGRAM

Even though nearly all El Dorado farmers have accepted computer scheduling, system analysis needs to be completed and water budget irrigation demonstrated before farmers will have optimum motivation to finance the service. The 1981 El Dorado Irrigation Management Program remains in doubt due to financing uncertainties. If asked to pay for IMS in 1981, some farmers would choose to do their own scheduling, using techniques they observed during IMS operation.

However, once growers see that water budget irrigations would save them more money than it would cost, they would probably prefer to have a computer do their calculations for them and a consultant to confirm that all systems are functioning properly.

Despite the fact that the El Dorado IMS has not completed the final important step of system analysis, this irrigation management program is probably among the most sophisticated in existence.

Five years in building, this model must be taken to completion to provide a positive image of IMP success for those starting new programs.

The El Dorado IMP logically should be integrated into the New California Irrigation Management Information Service (CIMIS) to stimulate CIMIS capacity to bring an IMP to the point of commercial adoption. This could be accomplished in the 1981 season by the CIMIS staff and 1 technician assigned to El Dorado, provided a team could be assembled to handle system analysis. A joint effort of the Soil Conservation Service, Cooperative Extension and farmers, with farmers paying for the additional personnel required could develop the needed systems data.

After farmers have practiced and experienced computer programmed water budget irrigation, they then should be asked to finance the costs of an irrigation management consultant to operate the 1982 program. CIMIS computer and weather collection could be made available until computer programs become available for commercial computers.

APPENDIX

NEUTRON MOISTURE PROBE CALIBRATION

In order to use the neutron moisture probe it is necessary to calibrate the neutron count or index to water content in inches of water per foot of soil. A number of techniques for calibration are available but the best results are obtained by calibrating neutron probes on soil specific basis. By becoming familiar with the soil composition within the irrigation area a calibration can be developed for each significantly different soil type.

The soil specific calibration procedure requires a neutron probe site (access tube) or, for added accuracy several sites, equipment to take undisturbed soil cores at the desired depths, a soils drying oven, sample cans and a scale to weigh each sample before and after drying.

Undisturbed soil cores of known volume are taken approximately 15 inches from a neutron access tube at the desired depths (usually first, second, and third foot). These cores are placed in soil cans, marked for depth of sample and weighed. Immediately before coring a neutron count is taken at the same depth that the soil cores will be taken. These data will then allow a direct comparison between the neutron count and actual water content. With this procedure care must be exercised to get exact volumes of undisturbed soil and to weigh samples immediately to reduce errors. Weighed soil samples can then be transported to the lab for drying. After 24 hours of drying time samples can be cooled and reweighed. The following table shows data collected from an El Dorado County Aiken loan:

1	2	3	4	5	6	7	8	9	10	11
Hole #	Depth	Gr. Weight Grams		CAN Weight Grams	Net Weight Grams		% Moisture	Bulk Density	In.H_2O Ft.Soil	Probe Count
		Wet	Dry		Water	Soil				
1	6"	291.5	236.5	82.0	55.0	154.5	36%	1.12	4.84	16288
1	18"	297.8	244.0	80.5	48.8	163.5	30%	1.19	4.28	15778
1	30"	311.2	256.0	80.5	55.2	175.5	31%	1.28	4.76	19170

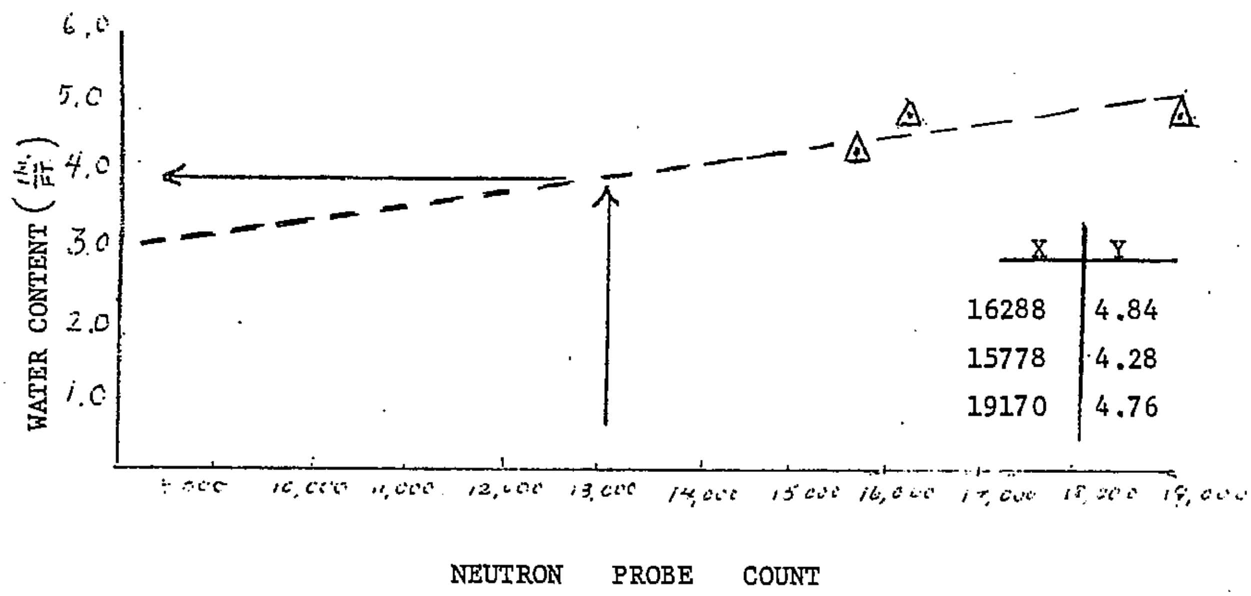
The calculations are as follows: Colum #3, the gross weight was determined in the field and column # 4 was weighed after thorough drying. Column # 6, the net weight of water may be caluclated by subtracting the weight after drying from the weight before drying (#4 - #3). Column #7, the weight of dry soil my be calculated by subtracting the gross dry weight from the weight of the container (#4 - #5). Column #8, the percent moisture is calculated by dividing the water weight by the weight of the dry soil (#6 ÷ #7). Column #9 the bulk density is equal to the weight of the dry soil divided by the volume of the core sample (137.4 cm^3) or #7 ÷ 137.4). Column #10, the inches of water per foot of soil is calculated by this equation:

$$\text{in/ft} = \frac{\text{bulk density x percent moisture x 12 inches}}{\text{density of water x 100}}$$

For example, a soil sample with a bulk density of 1.12 g/cm^3 and percent moisture of 36%, inches of water/Foot soil would be calculated as follows:

$$\text{in/ft} = \frac{1.12\ g/cm^3 \text{ x } 36\% \text{ x } 12''}{1.0 g/ml \text{ x } 100} = 4.84 \text{ inches}$$

With this information column #10 may be graphically plotted against column #11 to show the calibration curve.



X	Y
16288	4.84
15778	4.28
19170	4.76

Once the line is drawn to best fit the data, the line can be used to find soil moisture for any neutron count. When calibrating probes it is necessary to select enough points to accurately project the path of the line. Poor data points from compacted samples should be discarded. In this example the per foot value at the 6 inch depth is high which is possibly due to organic material usually abundant near the soil surface. In this instance, or in cases where the first foot is highly cultivated, the first foot value may not be accurate for calibration use. Also, if the sample is taken too close to the surface, neutron particles may be lost to the atmosphere resulting in a low neutron count.

Once all the calibration data has been analyzed it is often convenient to represent the data in a linear (however the calibration line is not necessarily linear) mathematical form, Y=mX+b, where m is equal to the value of the slope and b is the value of the y intercept. This is achieved through a statistical regression analysis or by simply choosing two points on the hand drawn line and calculating the slope and y intercept. By this method the slope is equal to the change in the y value divided by the change in the x value (slope = $\frac{\Delta Y}{\Delta X}$. For example, if the two points are (15778, 4.28) and (19160, 4.76) the slope would equal:

$$\text{Slope} = \frac{4.76 - 4.28}{19160 - 15778} = \frac{.48}{3392} = .0001415$$

We can then substitute this value and one of the (X,Y) points into the equation and calculate the intercept. For example:

Slope = .0001415, X = 15778, Y = 4.28

By substitution into Y = mX+b and solving for b we see:

$$\begin{aligned} 4.28 &= (.0001415) \times (15778) + b \\ 4.28 &= 2.23 + b \\ 4.28 &- 2.23 = b \\ 2.05 &= b \end{aligned}$$

We now have calculated the two critical calibration values, the slope and the y intercept. The calibration for the given data follows:

Y in/ft = (.0001415) x (neutron count) + 2.05

With this equation we can convert each neutron count to inches of water. For handy field use each of these neutron count-inches per foot pairs can be calculated and typed in tabular form. The following chart shows these neutron count inches/feet water pairs between 2.95 inches and 3.50 inches. These values were used for neutron hydroprobe #1 during the 1979 irrigation season in El Dorado County.

With the use of more than one probe it is necessary to calibrate each probe and possible to recalculate previous calibrations which may have changed due to repairs. Ideally, each probe should be calibrated to the soil. However, in most instances this is not practical. A suitable solution is to statistically calibrate the new probe to a previous accurate calibration.

The technique uses the soil calibrated probe to obtain a reading in a standard reproduceable environment and to assign that environment an inches per foot reading. An excellent standard in calibrations is simply a bucket of water with a sealed access tube held in the center. By placing a three inch spacer in the tube the probe can be rested on the spacer and readings can be taken in a virtually identical environment.

in/ft H_2O	Neutron Count
2.95	11236
3.00	11356
3.05	11477
3.10	11597
3.15	11717
3.20	11838
3.25	11958
3.30	12078
3.35	12199
3.40	12319
3.45	12439
3.50	12560

The first step is to use the newly soil calibrated probe and take 20 or more readings in the water bucket. By taking the average of these 20 readings and substituting the average bucket count into the calibration an inches per foot value can be assigned to the water bucket. For example, 20 counts in the bucket has given us an average neutron value of $\overline{X} = 20740$ by using the calibration equation: Y in/ft = (.0001415) x (neutron count) + 2.05

and substituting in our 20 count average we see:

$$Y = (.0001415) \times (20740) + 2.05$$

$$Y \text{ in/ft} = \underline{\underline{4.98 \text{ inches}}}$$

To develop the new calibration for another probe, 20 or more counts are taken in the bucket environment to generate another average bucket count. This value is then used in the equation to adjust the slope resulting in the new probe reading exactly like the soil calibrated probe. For example, 20 counts in the bucket have yielded the average value 23500 by using the neutron count:

$$X = 23500 \text{ the intercept } B = 2.05 \text{ and } Y \text{ in/ft} = 4.98$$

we can substitute and find the new slope:

$$Y \text{ in/ft} = (\text{new slope}) \times (\text{neutron count}) + 2.05$$
$$4.98 = (\text{new slope}) \times (23500) + 2.05$$

solving for slope. we find:

$$\frac{4.98 - 2.05}{23500} = \text{new slope} = \underline{\underline{.0001246}}$$

Substituting the new slope gives us the calibration for the new probe:

$$Y \text{ in/ft} = (.0001246) \times (\text{neutron count}) + 2.05$$

This procedure can be carried out for any number of probes and if correctly done each will read the same value at the same site at the same time. For example:

PROBE #	CALIBRATION EQUATION	FIELD NEUTRON COUNT	CALCULATED INCHES OF WATER/FT. OF SOIL
One	Y = (0001415) (neutron count) + 2.05	8480	3.25
Two	Y = (.0001246) (neutron count) + 2.05	9630	3.25

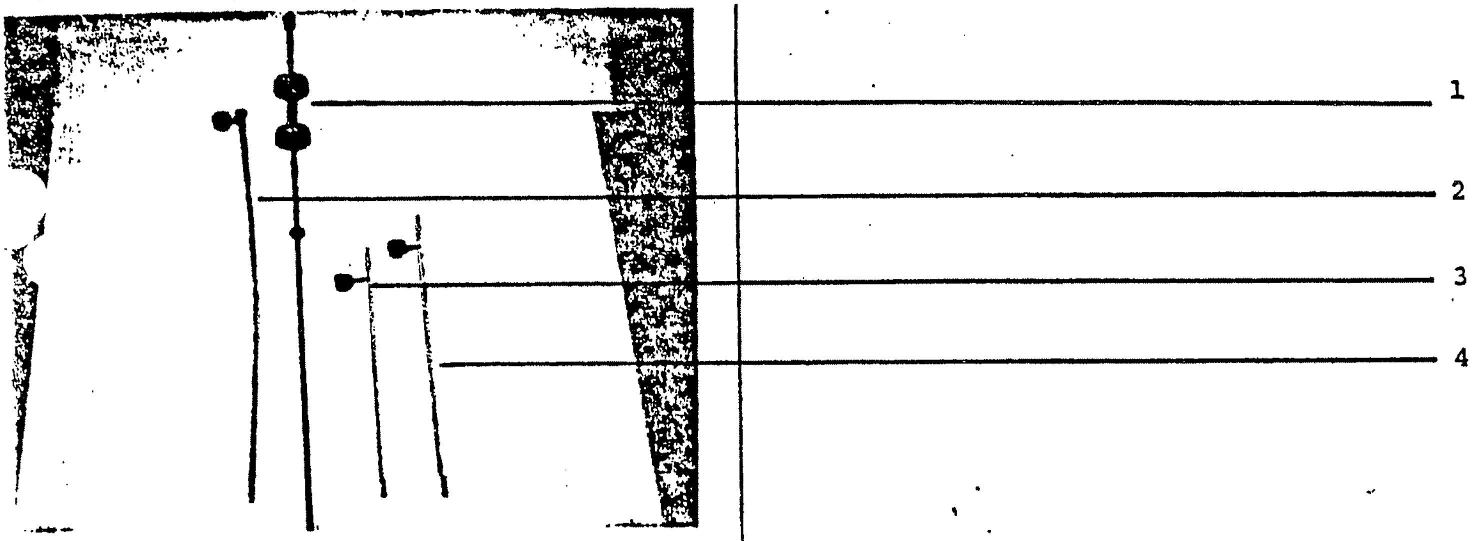
Even though each probe has a different field neutron count, they both read 3.25 inches of water, therefore the calibrations are working properly.

Normally, each neutron probe will read consistantly throughout the season, however, at the time of calibration, 20 counts are taken within the probe shield and the average and the standard deviation are calculated. If the standard deviation is not within the manufacturers specifications, the probe may require servicing.

Throughout the irrigation season, average standard counts should be taken and compared to the standard counts taken during calibration. If the two averages are considerably different, the probe will require recalibration.

SPECIAL TOOLS FOR SITE INSTALLATION

Key No.	
1	Slide hammer used to prepare access holes for tensiometers. Shaft is marked in 6-inch increments.
2	48 inch tensiometer
3	24 inch tensiometer
4	30 inch tensiometer
5	Slide Hammer used to install neutron access tubes
6	3 foot neutron access tube
7	Power head for soil auger used to drill holes for neutron access tubes
8	3 foot neutron access tube
9	3 foot soil auger. Two inch diameter
10	5 foot soil auger. Two inch diameter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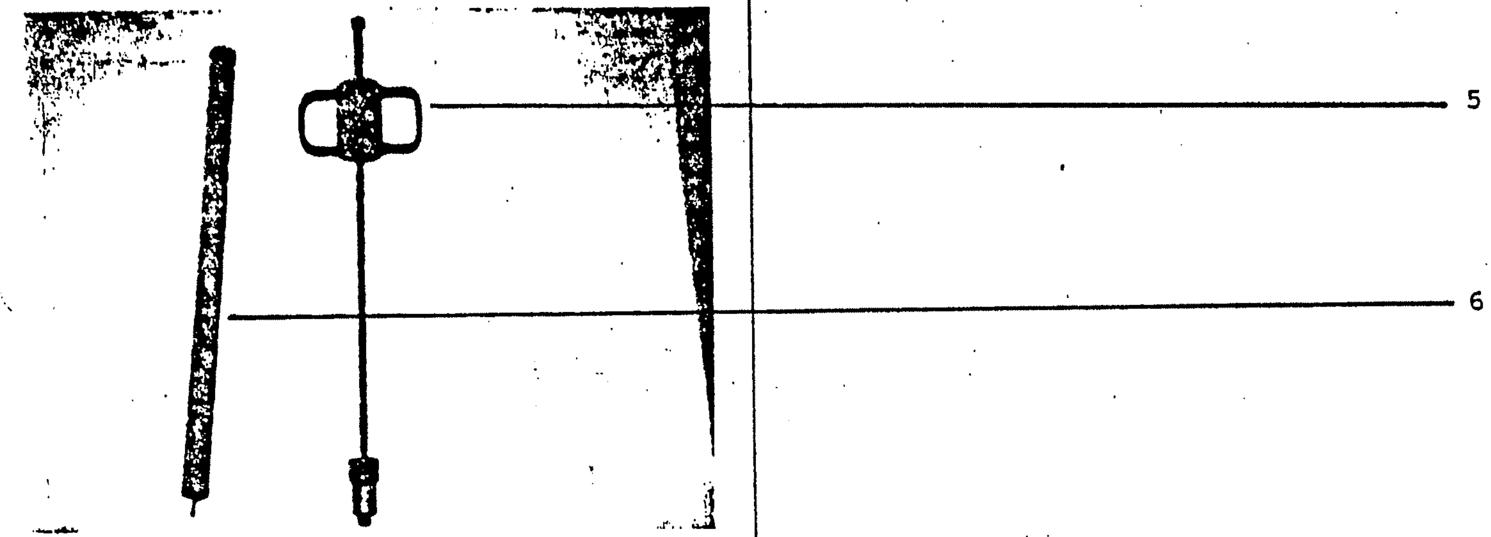
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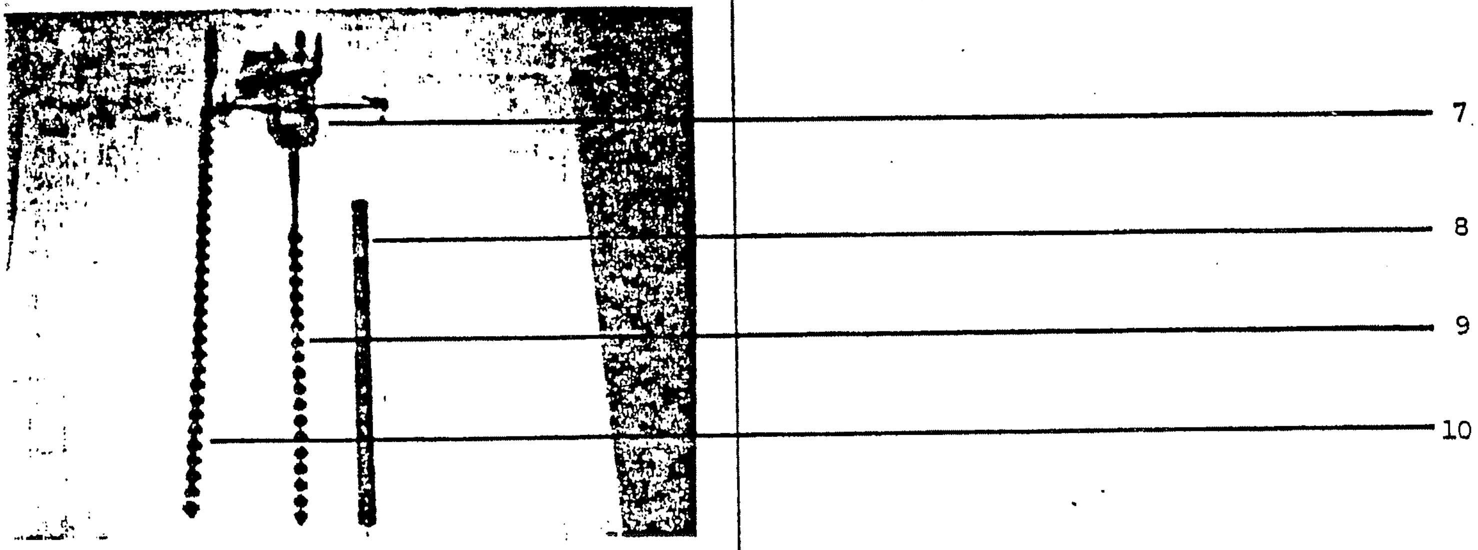
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CONSTRUCTION DETAILS FOR PLASTIC VACUUM GAUGE TENSIOMETERS

Constructing tensiometers is a learning experience. As more instruments are built the technique evolves toward more durable and superior designs. The construction method outlined here is a modification of the initial design by D.W. Henderson. This modified design has been used successfully for El Dorado irrigation management. Certainly other alternatives in materials and methodology exist. For some materials sources are listed for convenience; however, this does not constitute an endorsement.

MATERIALS

1. Size #3 rubber stopper, available from Scientific supply houses. Stoppers that are resistant to breakdown from solar radiation are more desirable.

2. Clear rigid plastic tubing, 7/8" OD - 3/4" ID. A 4 inch length is used for each tensiometer.

3. PVC Tee - Schedule 40 1/2 x 1/2 x 1/2 Slip, available from pipe supply houses.

4. PVC plastic pipe, Schedule 80, 1/2 inch ID. cut to length as desired.

5. Ceramic tensiometer cup. One bar standard round bottom neck top cup. 7/8" dia. 2 3/4" length neck measures 17/32" x 1/2". Available from Soil Moisture Equipment Corp.
   P.O. Box 30025
   Santa Barbara, Calif. 93105

6. 1/4" NPT schedule 80 threaded insert.

7. Vacuum gauge, 2-inch dial, full vacuum range, preferably with dial calibrated in centibars - 0-100, 1/4" NPT male thread. Available from:

   (a) Rubber covered (for protection against weather and flooding) Irrometer gauge. Irrometer Co., Inc., P.O. Box 2424, Riverside, California 92506

(b) Perma Rain tensiometer gauge. Perma-Rain Irrigation Systems, P.O. Box 880, Lindsay, California.

(c) Soil Moisture Equipment Corp., P.O. Box 30025, Santa Barbara, Ca 95105.

8. PVC cement for making solvent, slip-joint connections for plastic tubing and Tee.

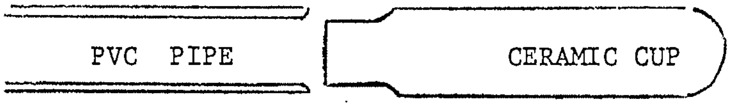
9. Epoxy resin cement for connecting ceramic cup to plastic tubing.

10. Teflon tape for sealing threaded connections.

CONSTRUCTION

1. Cut PVC plastic pipe to the desired lengths (24", 36", 48") to permit placing ceramic tip into the soil at the desired depth. Pipe cuts must be smooth and square for proper installation of the ceramic cup.

2. Ream or machine the inside of one end of the PVC pipe. This is done to accomodate the curved shoulder on the ceramic cup.

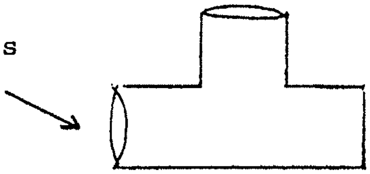


3. Pre check the fit between the PVC pipe and the ceramic cup because inside diameters of PVC pipe and outside diameter of the cup necks can vary somewhat. In construction of a group of tensiometers it is a good idea to selectively fit pipe and cup. If the pipe opening is too small the pipe can be reamed with tapered reamer, but the taper must be very small. If such a reamer is not available, grind the outside of the neck lightly on grinder or sandpaper.

4. If all parts fit properly, cement with epoxy, glue the tip (part 5) to the PVC plastic pipe. If the pipe opening is slightly too large, use liberal amounts of epoxy cement. Occasionally pipe pieces must be rejected because they are too large. Be sure to follow the mixing instructions on the epoxy tube.

Immediately after gluing, place the pipe in a vertical position with the tip up until the cement begins to harden. This will prevent excess glue from closing off the ceramic tip opening. After the glue hardens, the pipe can be turned to an upright position with the tip down until the epoxy glue has completely hardened (24 hours). The ceramic cup must be glued on straight or it will not enter the soil properly.

5. Take the slip tee (part 3) and ream or machine one of the straight through ends to 7/8" ID. This is done so that the clear plastic tubing can be glued into the slip tee.



6. Using PVC cement attach a four inch section of the clear tubing (part 2) and the 1/4 NPT , insert to the tee as shown in the diagram. In making connections with PVC cement, the following instructions should be followed.

   (a) With a clean rag, wipe off all dirt, dust and moisture, from the pipe and inside of the fitting before solvent is applied.

   (b) Apply a uniform coat of the solvent to the inside of the fitting.

   (c) Apply a liberal coat of solvent to the outside of the pipe making sure the coated area is equal in length to the depth of the fitting socket.

   (d) Insert the pipe quickly into the fitting and turn the pipe approximately 1/4 turn to distribute the solvent and remove air bubbles. Hold the joint for about 15 seconds so the fitting does not move on the pipe.

   (e) Use a clean rag and wipe off all excess solvent from the outside of the pipe and fitting.

7. After 24 hours the epoxy glue joint should be thoroughly dry and the tee assembly can be attached to the PVC pipe using the PVC glue.

8. Screw the vacuum gauge (part 7) into the finished tensiometer using teflon tape or non-hardening pipe thread compound to obtain a tight seal. Allow all joints to dry before filling with water and testing.

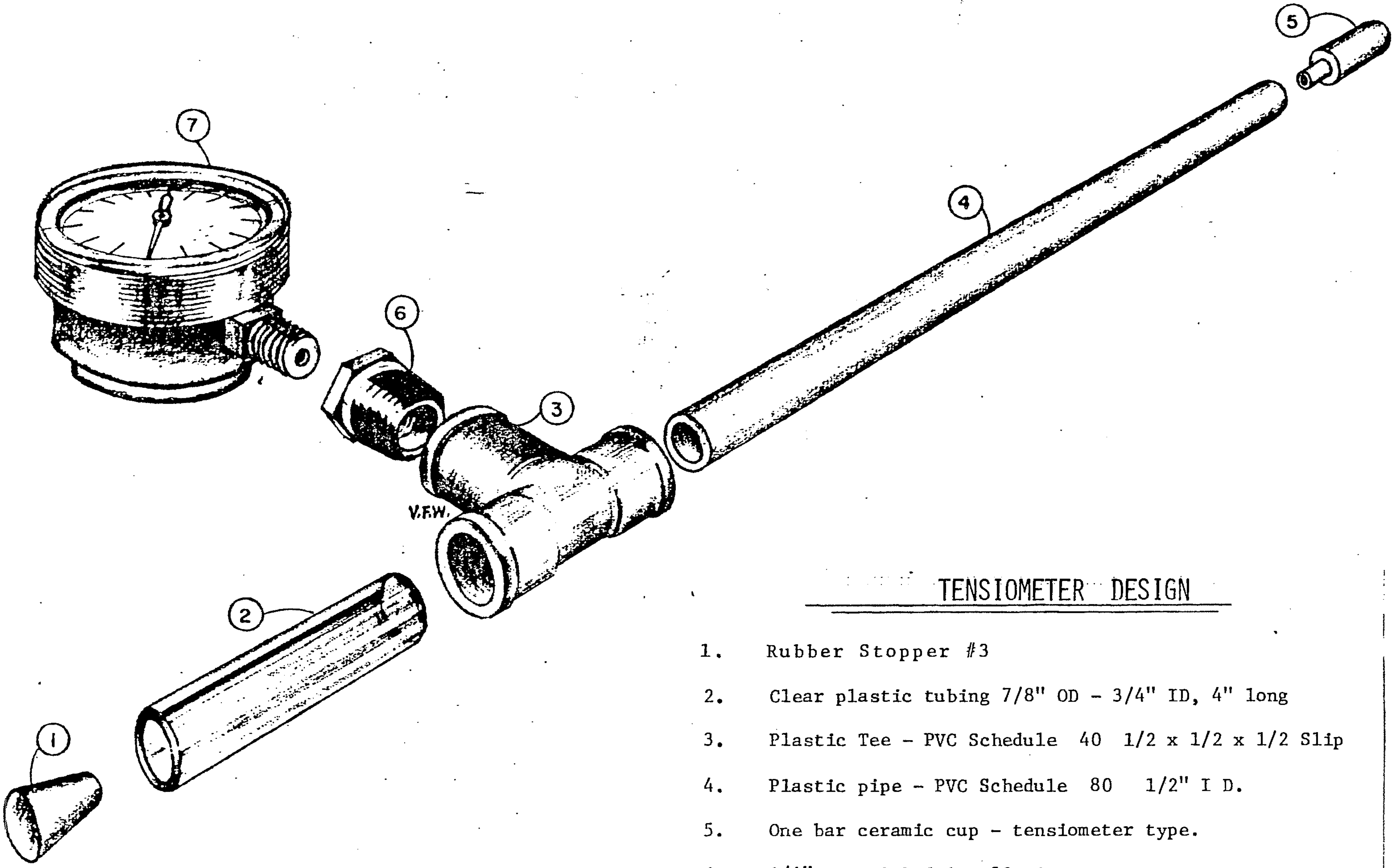
9. Fill the tensiometer with water and seal with the rubber stopper (part 1). Be sure not to apply excess pressure when inserting the stopper into the top. It is best to push the stopper in gently. If the stopper is not pushed in far enough, there is a possibility for an air leak, and the instrument will not test properly.

TESTING

The tensiometer must be free of leaks to function properly, and each instrument must be tested before use. This can be done very simply. Testing is easier if the ceramic cups are soaked in water for a day or two before starting. Fill the instrument completely with freshly boiled and cooled water. (Avoid use of hard water.) Tap the instrument and gauge lightly to help remove air, and if air accumulates at the top, refill with water. Close the top, wipe excess moisture off the outside of the cup, and expose the cup to open air. Water will evaporate from the cup and the vacuum gauge should register 50 or more without collecting much air at the top of the sight tube after five to eight hours in still air or one to two hours if a fan is used to blow air past the cup. If the instrument does not pass this test, open the top, remove the air, refill and retest as before. If the tensiometer does not perform properly, look for a leak.

The most common points where leaks have developed are (1) where the vacuum gage is threaded in, (2) at the neoprene stopper, and (3) rarely where the ceramic cup is cemented to the PVC pipe.

If the tensiometer passes this test, it is probably satisfactory for field use. However, an additional testing step is desirable and may be a continuation of the first step. When the dial is reading in the range from 40 to 70, place the cup in a small plastic bag and close around the tubing above the cup with a rubber band to prevent further evaporation, and record the dial reading. If the dial reading the next day is within five units of the reading when the plastic bag was put on, the instrument has passed a stiff test, and should function well in the field. If it passes the first step but not the second, a slow leak is indicated.



TENSIOMETER DESIGN

1. Rubber Stopper #3
2. Clear plastic tubing 7/8" OD - 3/4" ID, 4" long
3. Plastic Tee - PVC Schedule 40 1/2 x 1/2 x 1/2 Slip
4. Plastic pipe - PVC Schedule 80 1/2" I D.
5. One bar ceramic cup - tensiometer type.
6. 1/4" pipe Schedule 80 insert.
7. 1/4" pipe thread vacuum gauge 0-100 cb.

SITE SPECIFIC CROP CURVES

For accurate predictions of ET using weather data, crop curves that reflect individual farm water requirements are essential. During the 1979 season, crop curves were calculated for each unique group of El Dorado County orchards. These site specific crop curves for pears and apples were used in conjunction with Water and Power Resources Service computer programs to provide field irrigation scheduling for the 1980 irrigation management program in El Dorado County.

Site specific crop curves for El Dorado County orchards are presented as monthly KC values in the following table.

1979 CROP CURVES

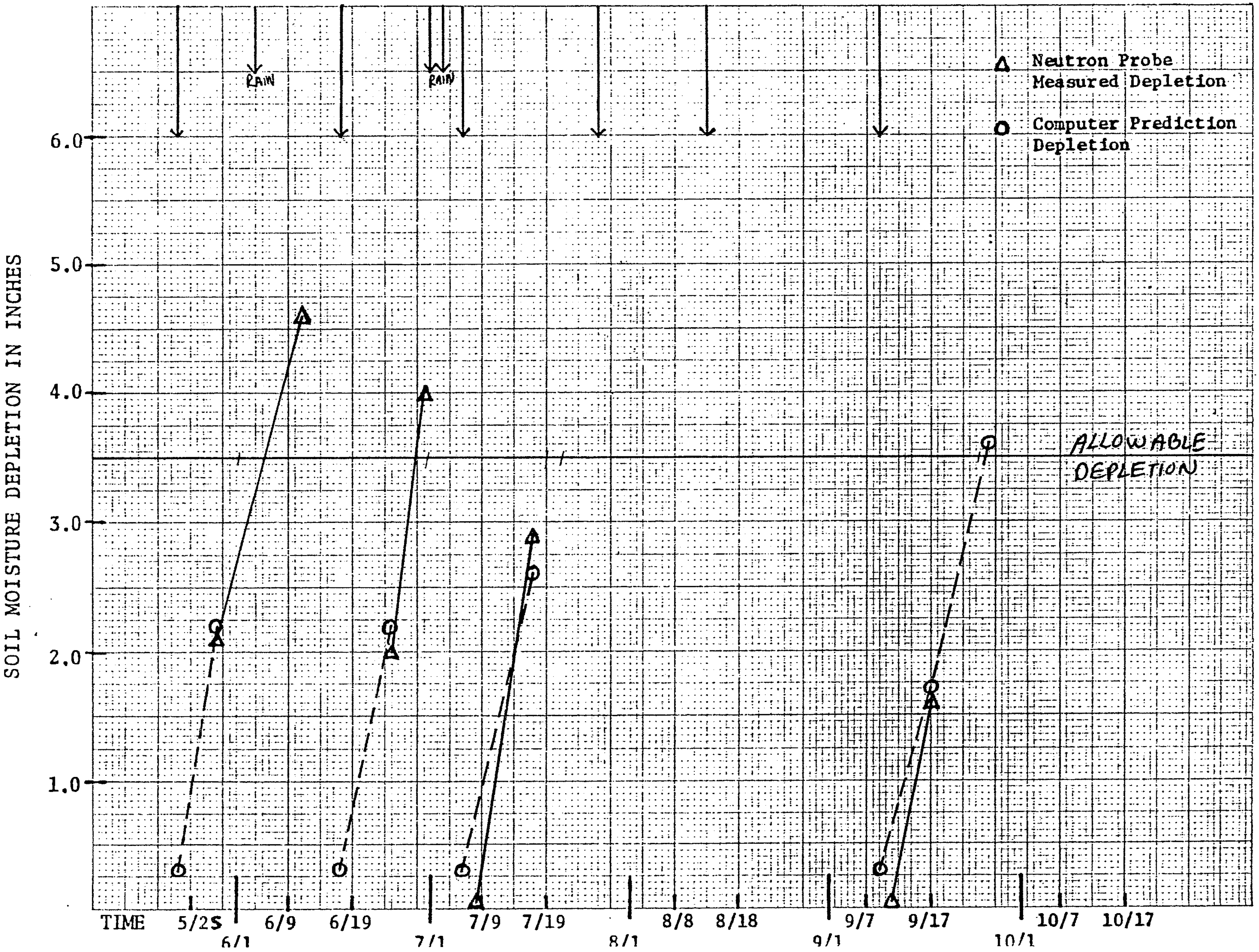
	ELEVATION	MAY				JUNE				JULY				AUGUST				SEPTEMBER			
		SOUTH SLOPE		NORTH SLOPE		SOUTH SLOPE		NORTH SLOPE		SOUTH SLOPE		NORTH SLOPE		SOUTH SLOPE		NORTH SLOPE		SOUTH SLOPE		NORTH SLOPE	
		COVER	NO COVER	COVER	NO COVER	COVER	NO COVER	COVER	NO COVER	COVER	NO COVER	COVER	NO COVER	COVER	NO COVER	COVER	NO COVER	COVER	NO COVER	COVER	NO COVER
PEARS	1000 1500	No Data Collected at this Elevation																			
	1500 2000	.83	.53	.66	*	1.12	.71	.79	*	1.24	.68	.78	*	1.12	.86	.67	*	1.12	.85	.79	*
	2000 2500	.75	*	.58	*	.93	*	.68	*	.90	*	.83	*	.95	*	.74	*	N/A	*	.68	*
	2500 3000	.64	*	.46	*	.89	*	.59	*	.86	*	.65	*	.76	*	.68	*	.89	*	.70	*
	3000 3500	*	*	.40	*	*	*	.58	*	*	*	.60	*	*	*	.62	*	*	*	.65	*
APPLES	1000 1500	No Data Collected at this Elevation																			
	1500 2000	.86	*	*	*	1.12	*	*	*	1.17	*	*	*	1.12	*	*	*	1.10	*	*	*
	2000 2500	.75	*	.58	*	.93	*	.68	*	.90	*	.83	*	.95	*	.74	*	.99	*	.68	*
	2500 3000	.58	.52	.50	.45	.75	.56	.62	.50	.80	.71	.70	.68	.83	.76	.72	.65	.79	.72	.70	.65
	3000 3500	.52	*	.51	.44	.73	*	.58	.48	.79	*	.67	.58	.80	*	.70	.62	.74	*	.70	.65

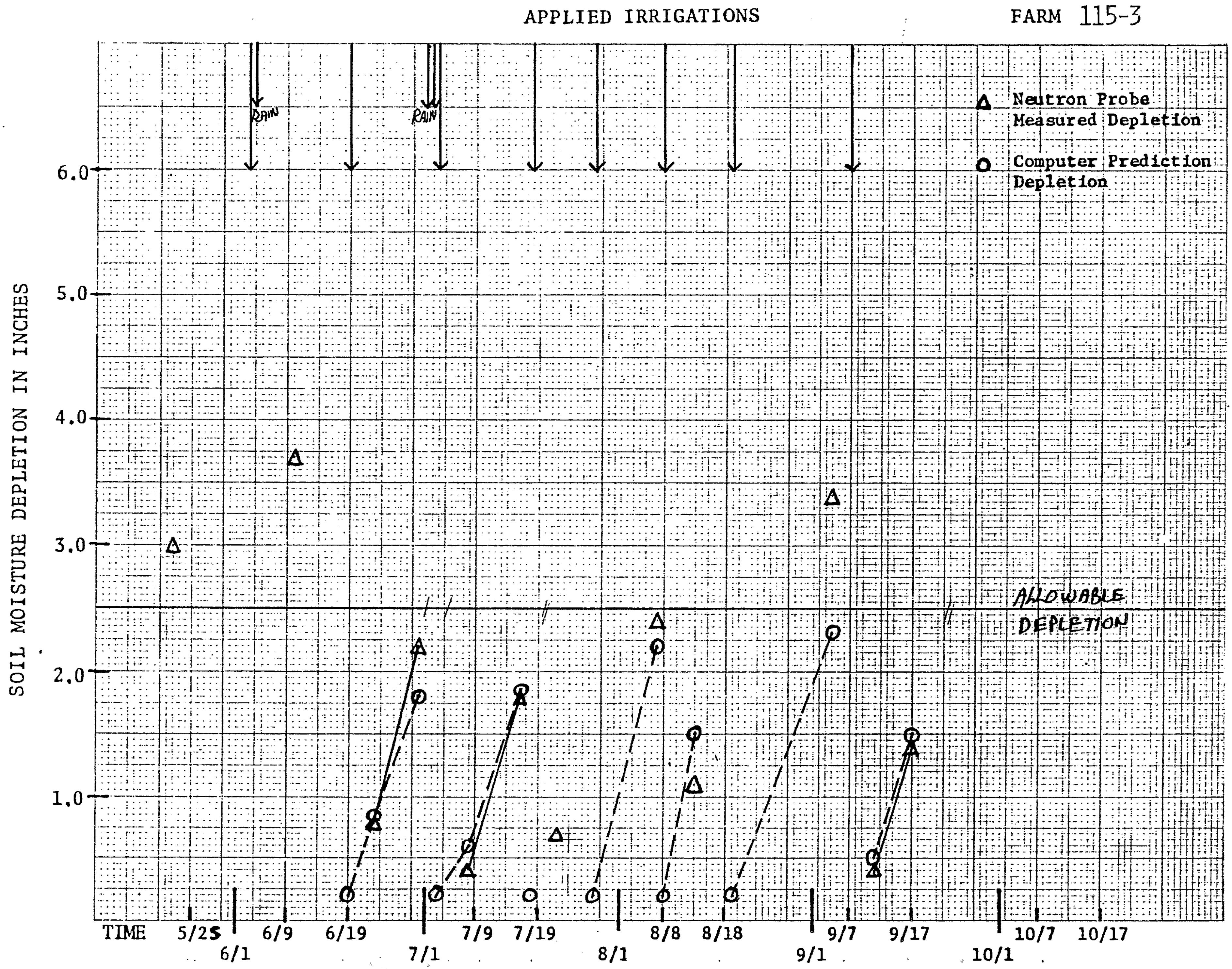
*These conditions were not actually encountered in orchard monitoring. Crop curves for these conditions are synthesized from documented site effects demonstrated by monitored orchards.

COMPUTER VERIFICATION GRAPHS

The following 14 graphs show computer predicted soil moisture depletions based on weather data compared with actual measured soil moisture depletions. Graphs for farms 110-4, 115-3, 303-1, 405-1, 410-2, and 600-1 represent a high degree of predictive accuracy. Graphs for farms 205-4, 225-1, 350-3, 355-4 represent acceptable accuracy. Serious predictive errors are represented in graphs for farms 405-4,410-5, 410-6 and 425-1.

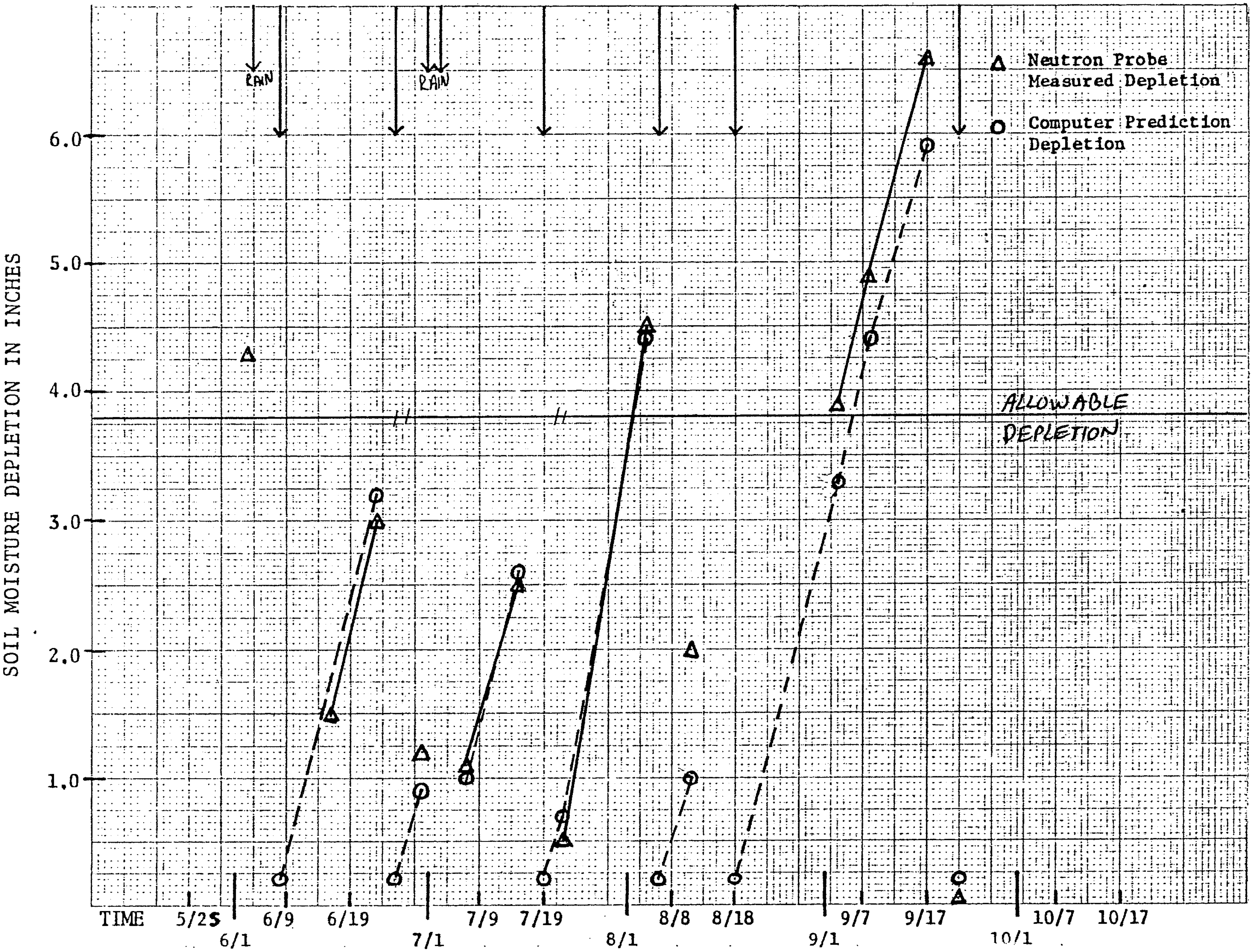
APPLIED IRRIGATIONS FARM 110-4




APPLIED IRRIGATIONS
FARM 115-3
RAIN
RAIN
Δ Neutron Probe Measured Depletion
O Computer Prediction Depletion
ALLOWABLE DEPLETION
SOIL MOISTURE DEPLETION IN INCHES
6.0
5.0
4.0
3.0
2.0
1.0
TIME
5/25
6/1
6/9
6/19
7/1
7/9
7/19
8/1
8/8
8/18
9/1
9/7
9/17
10/1
10/7
10/17

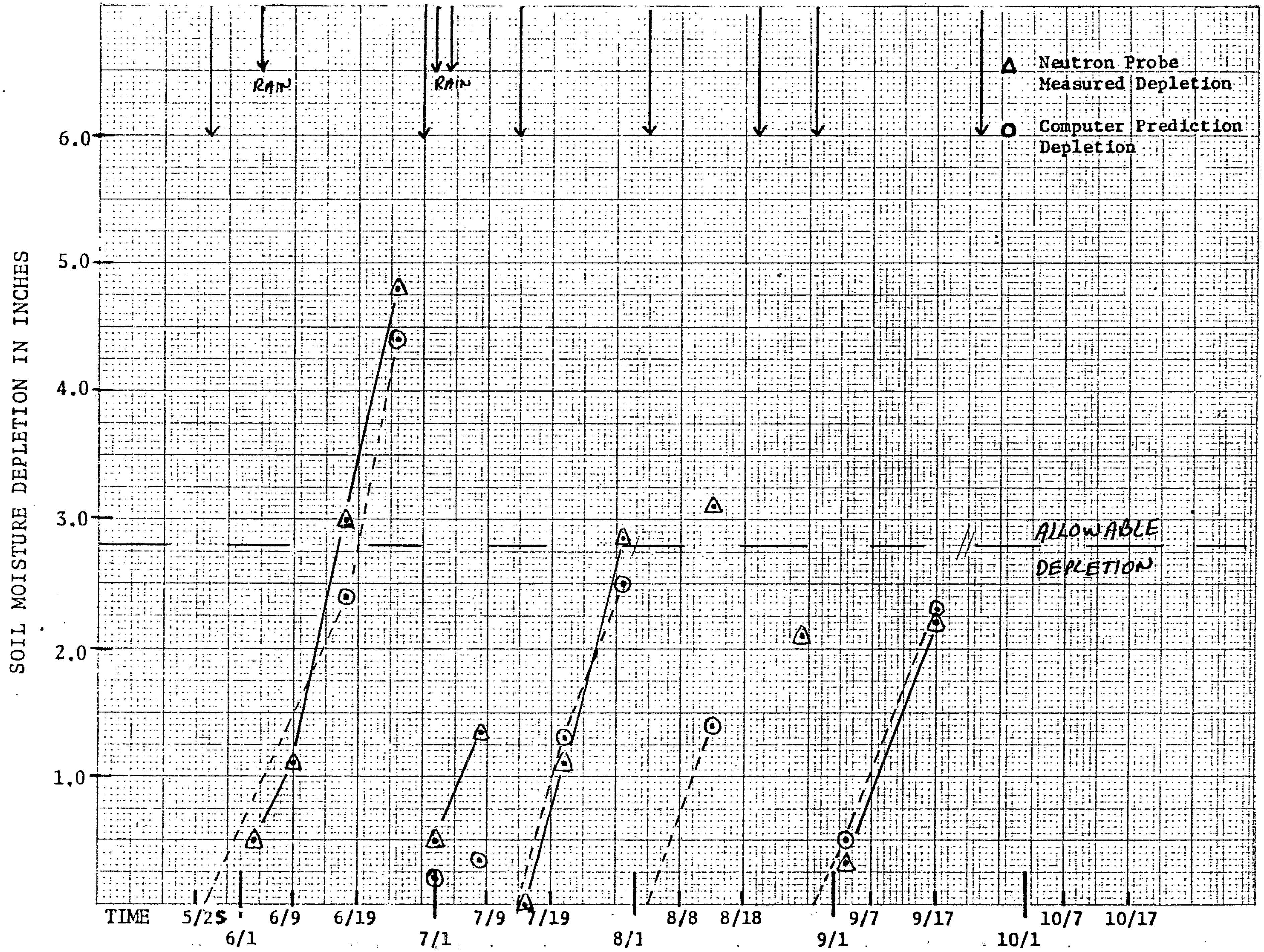
APPLIED IRRIGATIONS

FARM 303-1



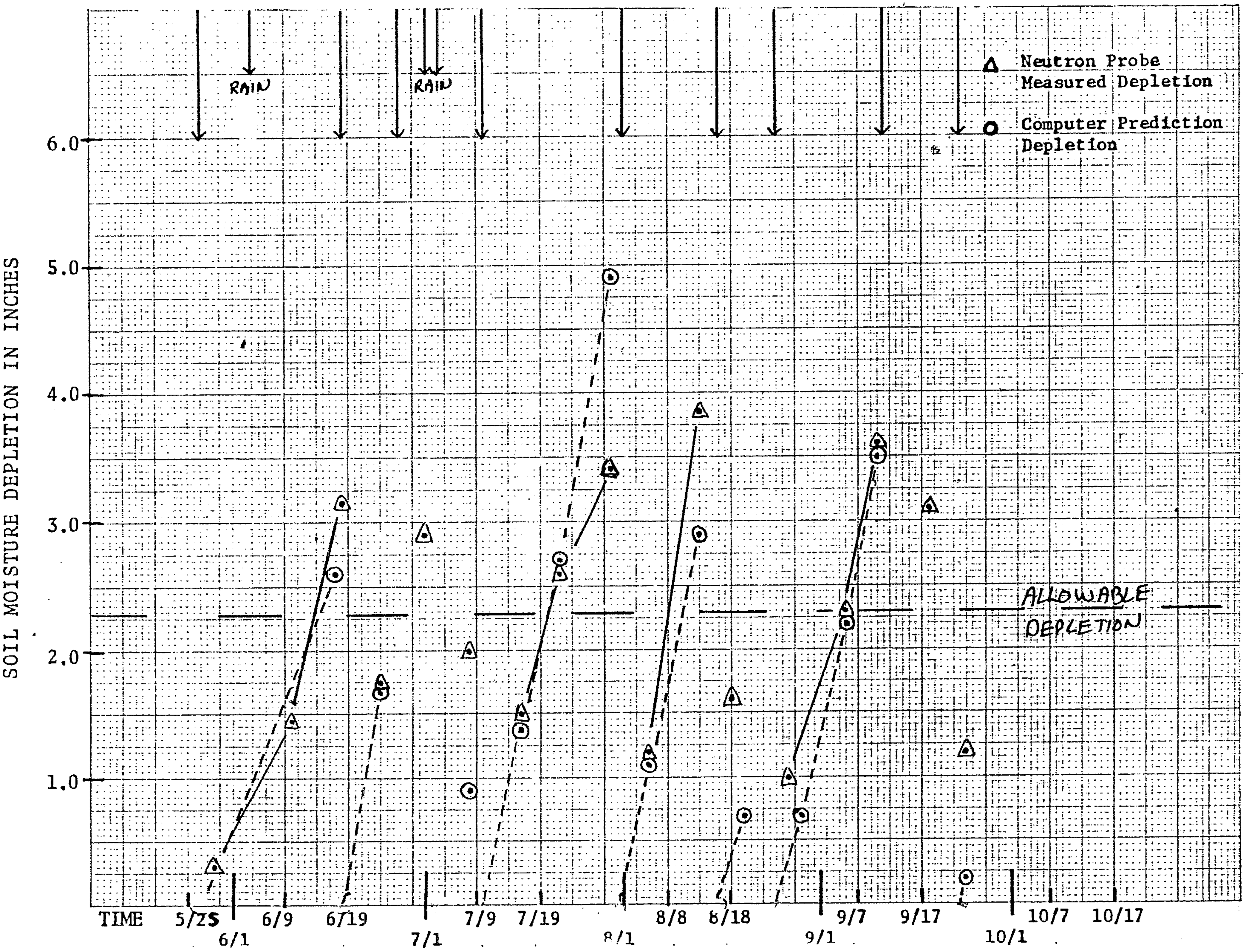
APPLIED IRRIGATIONS

FARM 405-1

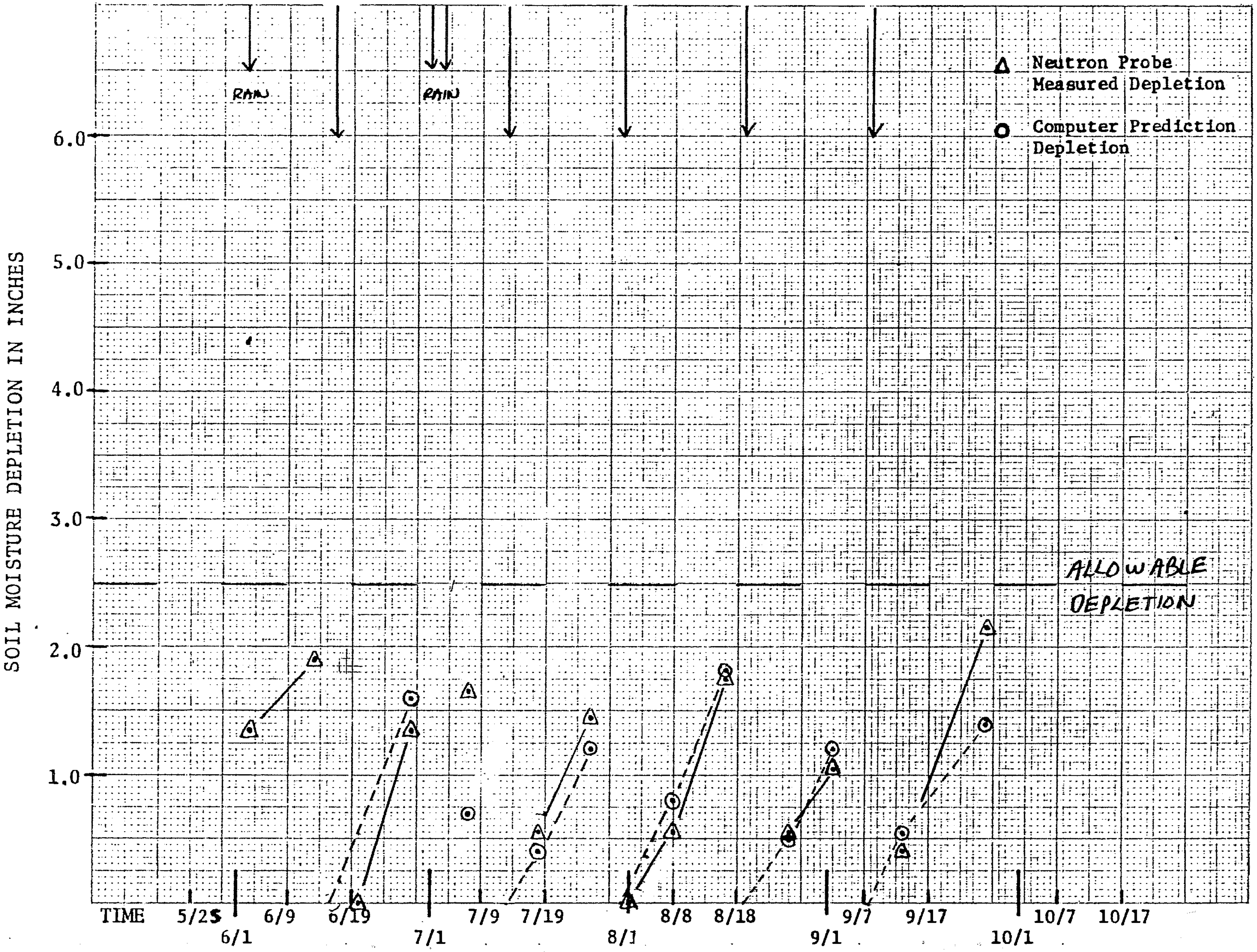


APPLIED IRRIGATIONS

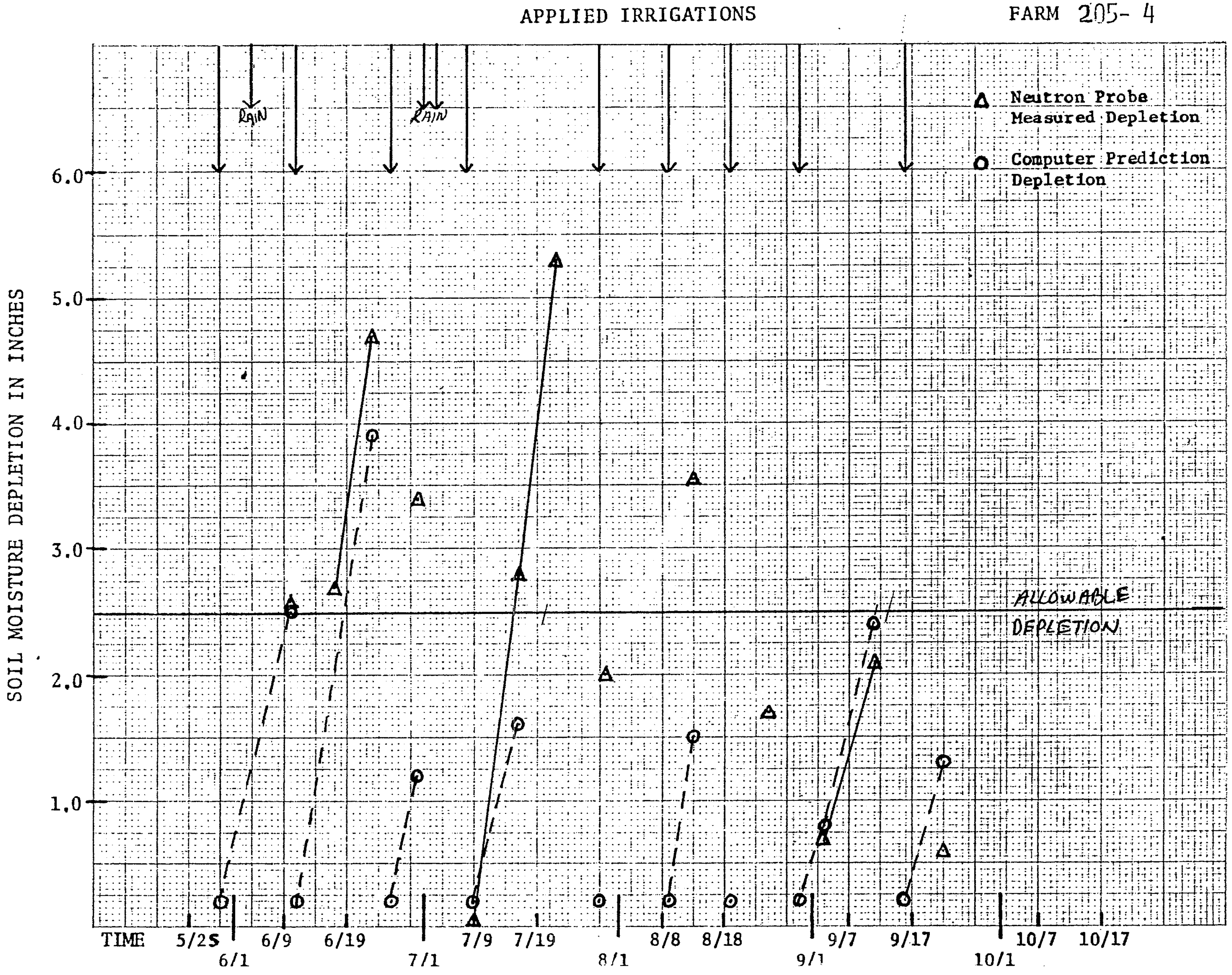
FARM 410-2



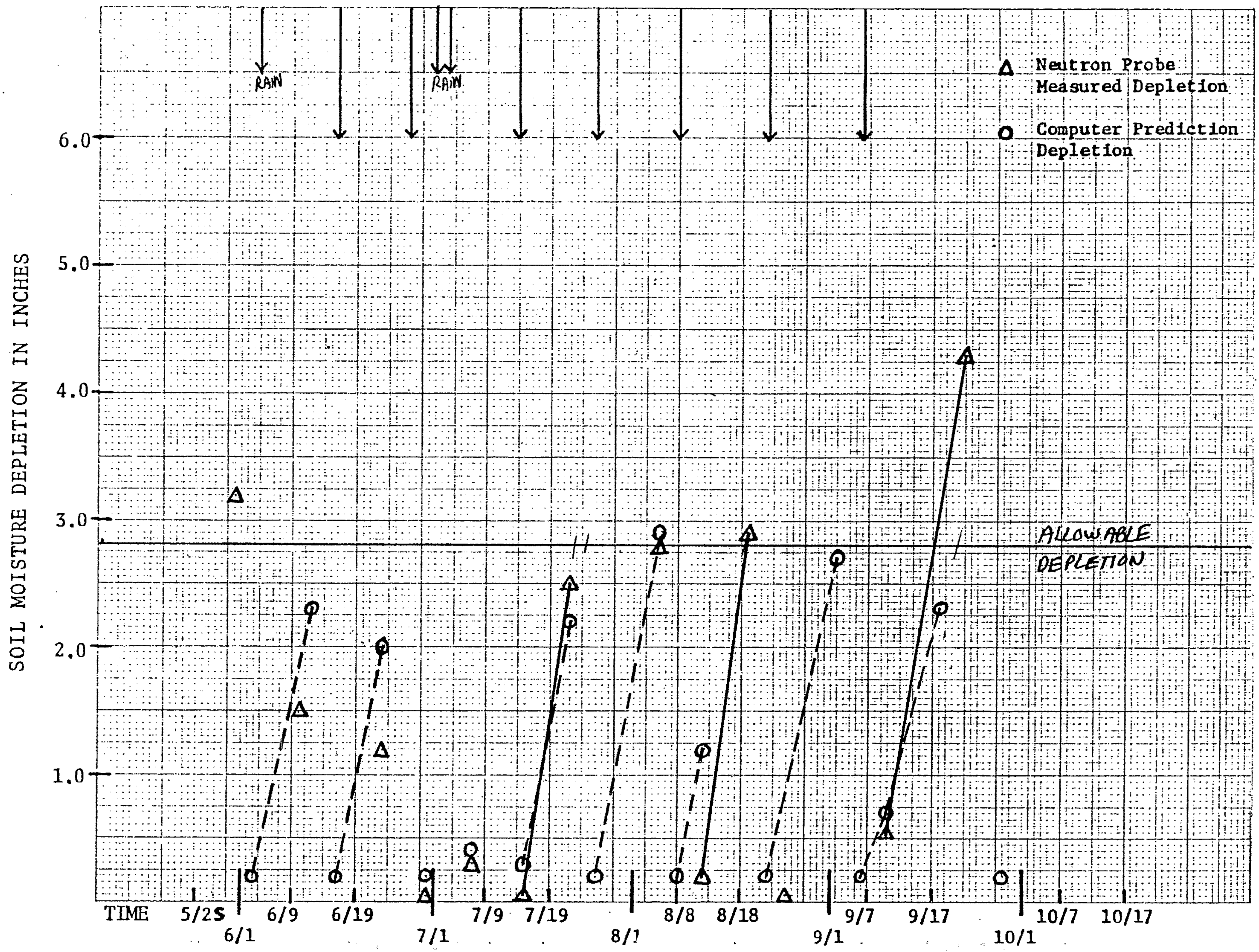
APPLIED IRRIGATIONS FARM 600-1



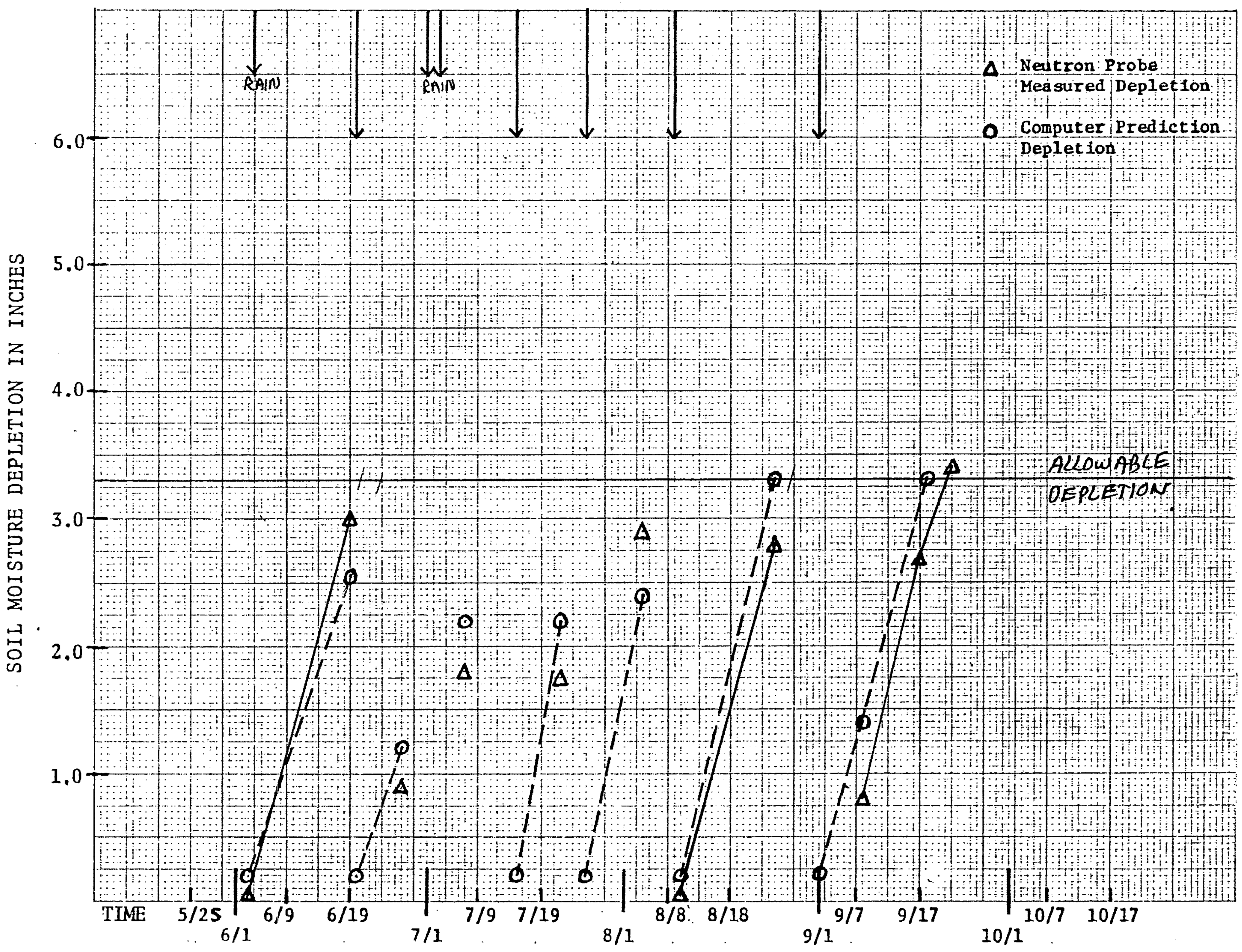
FARM 205- 4


APPLIED IRRIGATIONS
RAIN
RAIN
Neutron Probe Measured Depletion
Computer Prediction Depletion
ALLOWABLE DEPLETION
SOIL MOISTURE DEPLETION IN INCHES
6.0
5.0
4.0
3.0
2.0
1.0
TIME
5/25
6/1
6/9
6/19
7/1
7/9
7/19
8/1
8/8
8/18
9/1
9/7
9/17
10/1
10/7
10/17

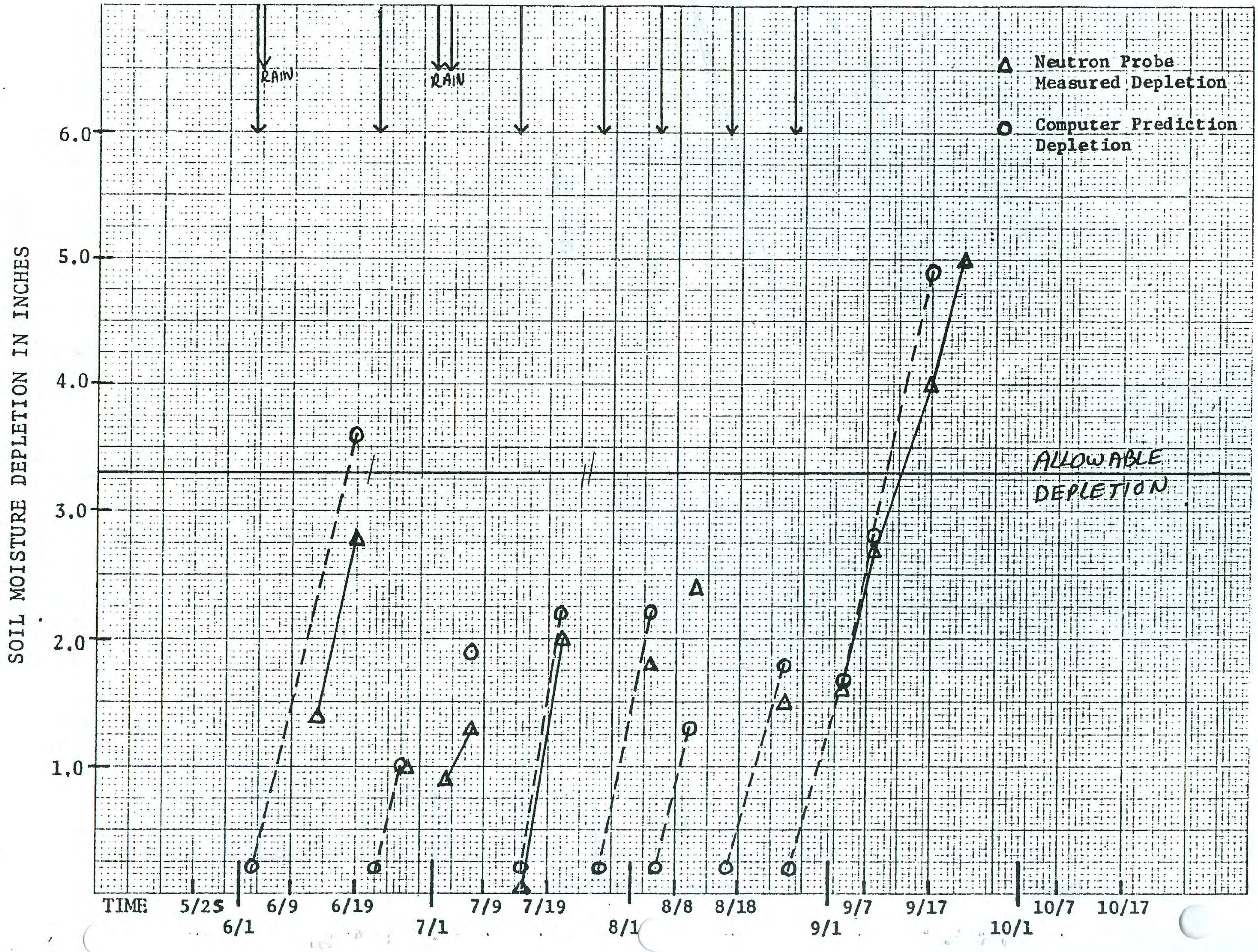
APPLIED IRRIGATIONS FARM 225 -1



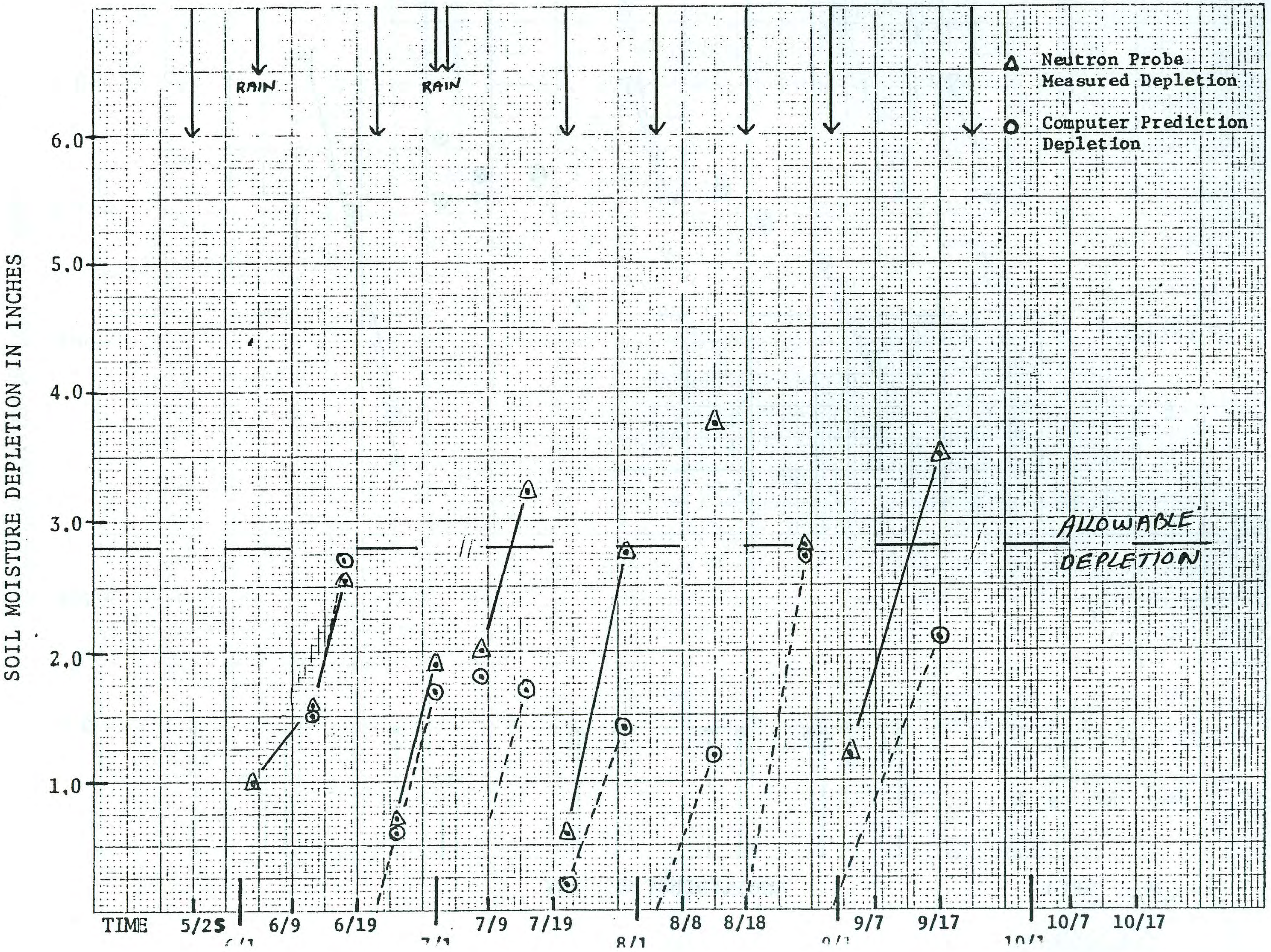
APPLIED IRRIGATIONS FARM 350-3



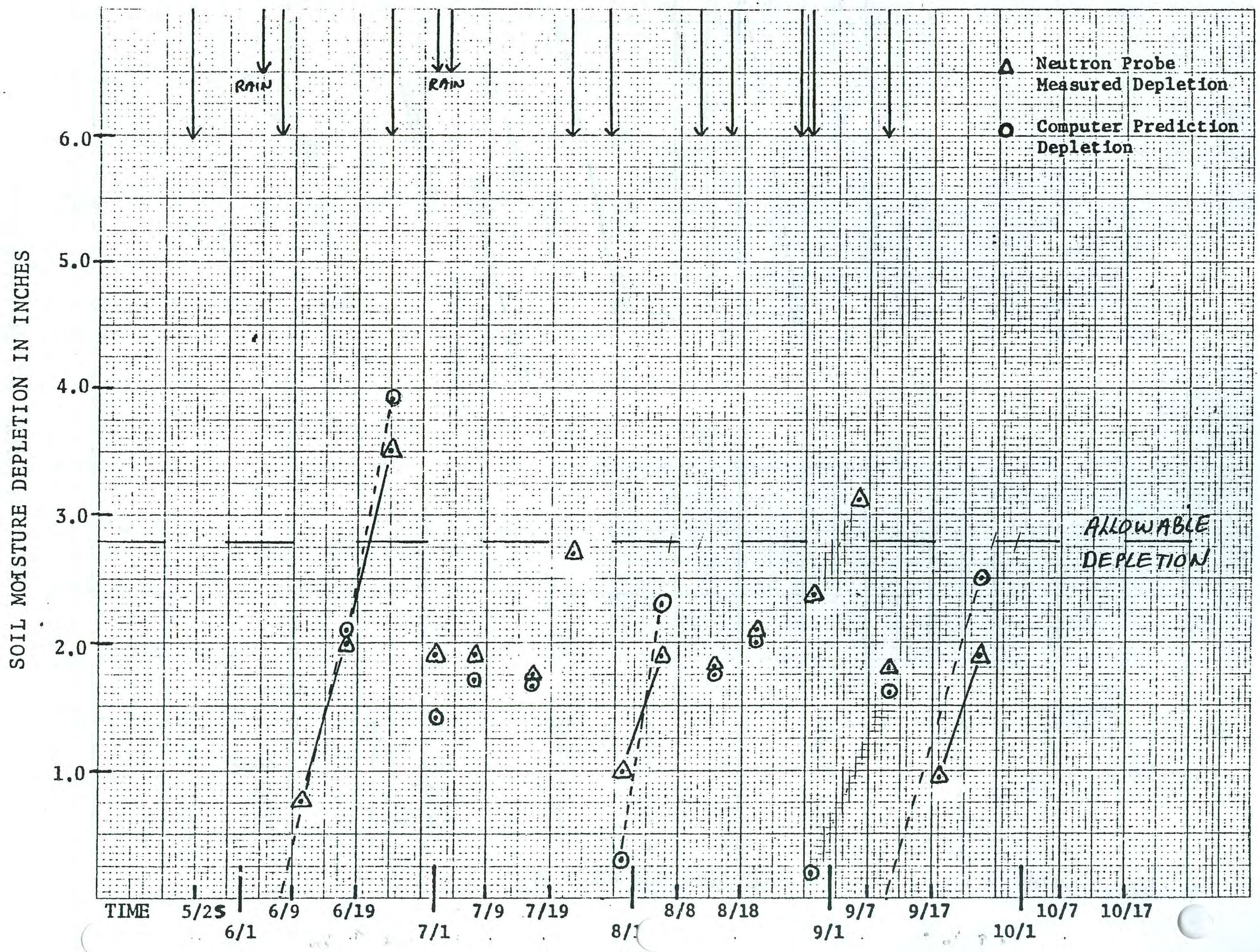
APPLIED IRRIGATIONS FARM 355-4



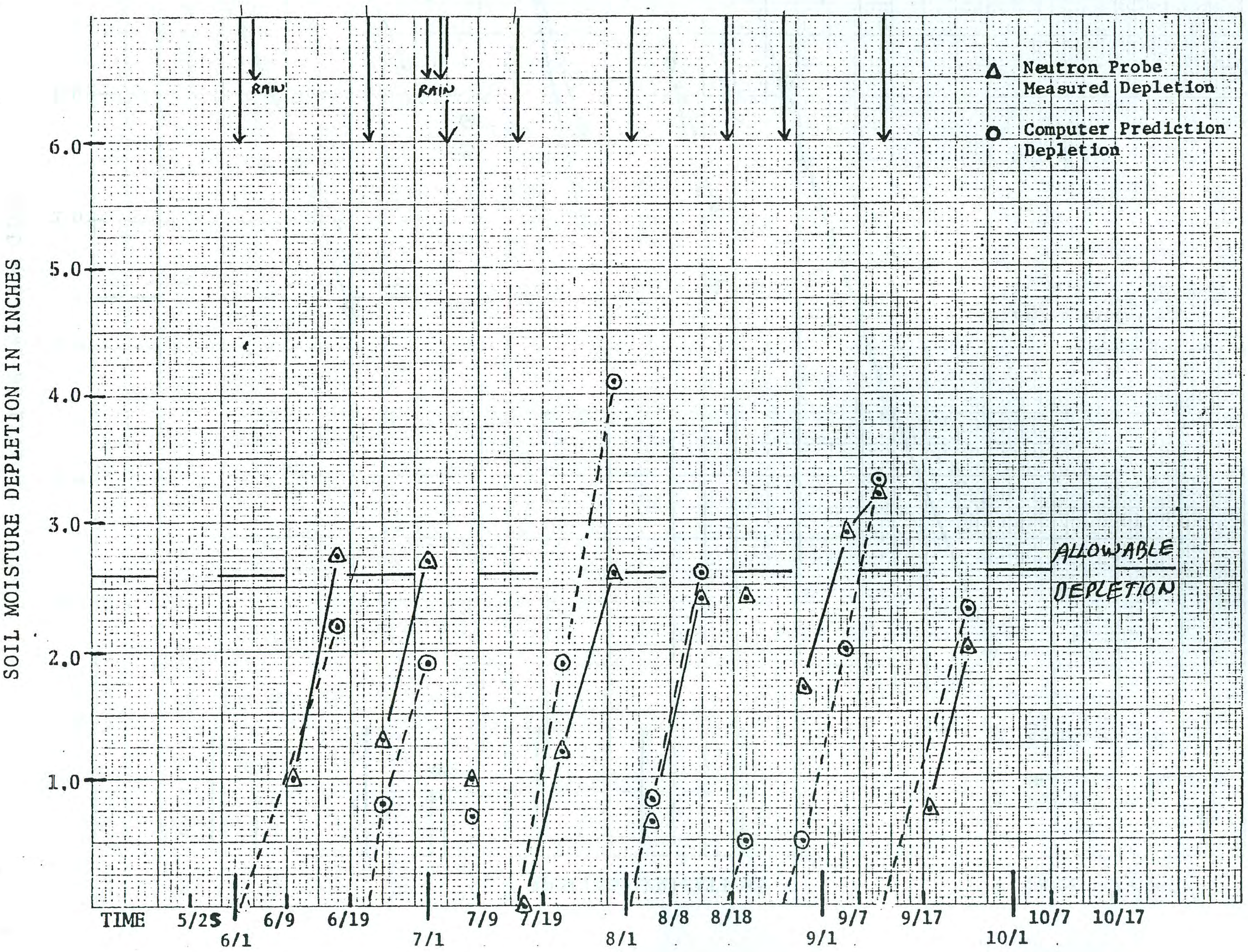
APPLIED IRRIGATIONS FARM 405-4

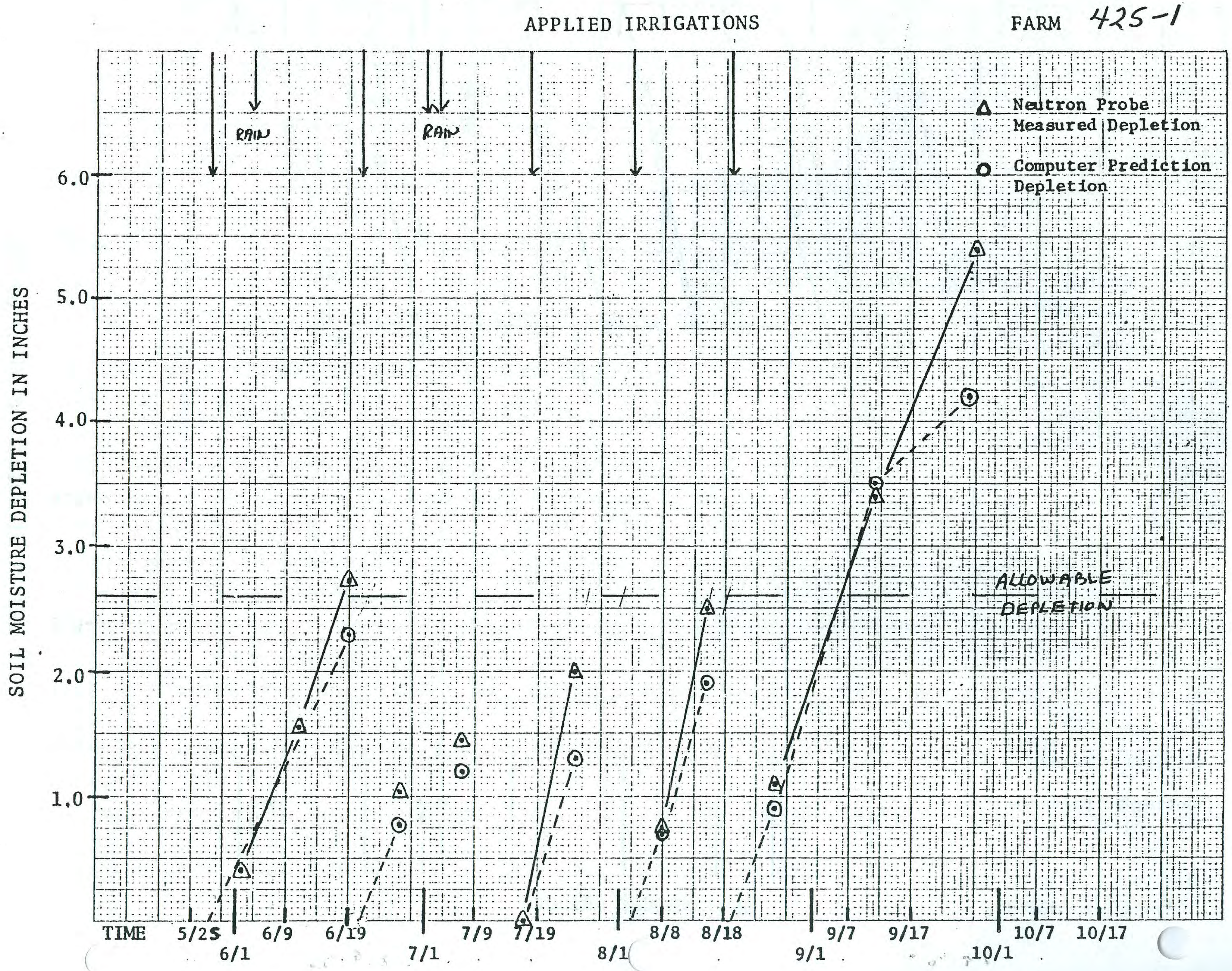


APPLIED IRRIGATIONS FARM 410-5



APPLIED IRRIGATIONS FARM 410-6




APPLIED IRRIGATIONS
FARM 425-1
RAIN
RAIN
Neutron Probe Measured Depletion
Computer Prediction Depletion
ALLOWABLE DEPLETION
SOIL MOISTURE DEPLETION IN INCHES
6.0
5.0
4.0
3.0
2.0
1.0
TIME
5/25
6/1
6/9
6/19
7/1
7/9
7/19
8/1
8/8
8/18
9/1
9/7
9/17
10/1
10/7
10/17

SELECTED SPRINKLER IRRIGATION TESTS

The following four irrigation system evaluations show the procedure used to collect data and the calculations made to evaluate system performance. Tests are shown for two overtree, an overvine and an under tree system.

OVERTREE SPRINKLER TEST - PEAR ORCHARD - ENC

Riser height = 18 feet
Flow rate = 6 gpm, operating pressure 68 psi
Sprinkler make = Rainbird 30 ws
Sprinkler size = 11/64 nozzle
Test done between 4 sprinklers
Distance between sprinklers - 54'
Distance between laterals - 60'

Application rate $\frac{6.0 \times 96.3}{54 \times 60} = \boxed{0.178 \text{ in./hr.}}$

System on - 6:00 P.M. 8-16-79
System off - 9:45 A.M. 8-17-79

Soil moisture depletion = 1.35 inches
Soil moisture depletion = field capacity

Irrigation run = 15.75 hours

Catchment can arrangement:
Four rows of cans were placed in the center aisles between tree rows between 4 sprinklers. Each row had 14 cans. Drawing shows can arrangement. Depth caught was measured in milliliters and converted to inches with a multiplier of .005.

60'

S					S
*	300	470	310	410	*
	440	440	400	365	
	510	495	410	385	
	470	505	405	480	
	530	460	470	515	
	460	490	510	490	
	485	515	490	470	54'
	510	480	530	520	
	480	515	480	505	
	440	510	625	480	
	430	525	510	460	
	410	510	480	455	
	495	585	425	410	
	500	520	450	420	
*					*
S					S

Water applied = .178 in. x 15.75 hr. = 2.80 inches

Average depth caught - 470 ml. x .005 = 2.35 inches

$$E_a = \frac{\text{average depth caught}}{\text{average depth applied}} \times 100$$

$$E_a = \frac{2.35}{2.80} \times 100 = /\overline{\underline{83.9\%}}/$$

$$UC = \left(1 - \frac{\text{av. deviation from av. catch}}{\text{average catch}}\right) \times 100$$

$$UC = \left(1 - \frac{.0135}{0.15}\right) \times 100 = /\overline{\underline{90\%}}/$$

Average of low quarter of catch cans, from 56 use 14 cans =

394 ml. x .005 = 1.97 inches or .125 in./hr.

$$DU = \frac{\text{average catch rate in low quarter}}{\text{average catch rate}} \times 100$$

$$DU = \frac{0.125}{0.15} \times 100 = /\overline{\underline{83.3\%}}/$$

$$PELQ = \frac{\text{average catch rate in low quarter}}{\text{average application rate}} \times 100$$

$$PELQ = \frac{0.125}{0.178} \times 100 = /\overline{\underline{70.2\%}}/$$

$$AELQ = \frac{\text{average depth of low quarter stored in root zone}}{\text{average depth applied}} \times 100$$

$$AELQ = \frac{1.35}{2.80} \times 100 = /\overline{\underline{48.2\%}}/$$

OVERTREE SPRINKLER TEST - PEAR ORCHARD - MAR

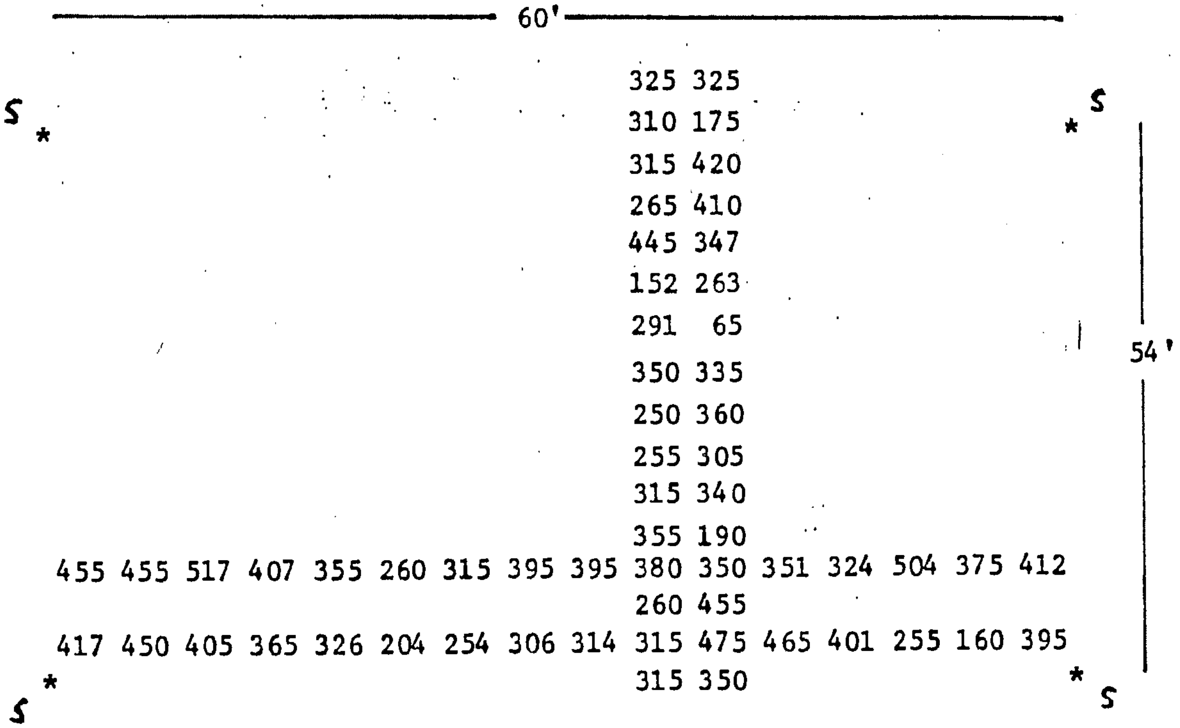
Riser height = 6 meters
Flow rate = 3.25 gpm, operating pressure, 38 psi
Sprinkler make = Rainbird 29B
Sprinkler size = not recorded
    Test done between 4 sprinklers
    Distance between sprinklers - 54'
    Distance between laterals - 60'
Application rate $\frac{3.25 \times 96.3}{54 \times 60}$ = /0.097 in./hr./

System on - 10:50 A.M. 7-16-79
System off - 11:10 A.M. 7-17-79
Test run - 24 hours and 20 minutes

No soil moisture measurements taken for this test.

Catchment can arrangement:

Two rows of cans were arranged in an east-west direction between 2 sprinklers. Distance between cans was 4 feet; distance between rows was 4 feet. Two rows of cans were placed in a north-south orientation with distance between the cans being 4 feet; distance between the rows 6 feet. Drawing shows can pattern. Depth caught was measured in milliliters and converted to inches with a multiplier of .005.



Water applied = .115 in./hr. x 18.75 hr. = 2.15 inches

Average depth caught = 388 ml. x .005 = 1.94 inches

$$E_a = \frac{\text{average depth caught}}{\text{average depth applied}} \times 100$$

$$E_a = \frac{1.94}{2.15} \times 100 = \boxed{90.2\%}$$

$$UC = \left(1 - \frac{\text{average deviation from average catch}}{\text{average catch}} \right) \times 100$$

$$UC = \left(1 - \frac{0.020}{0.103} \right) \times 100 = \boxed{80.6\%}$$

Average of low quarter of catch cans, from 32 use 8 cans =

286 ml. x .005 = 1.43 inches or 0.076 in./hr.

$$DU = \frac{\text{average catch rate in low quarter}}{\text{average catch rate}} \times 100$$

$$DU = \frac{0.076}{0.103} \times 100 = \boxed{73.7\%}$$

$$PELQ = \frac{\text{average catch rate in low quarter}}{\text{average application rate}} \times 100$$

$$PELQ = \frac{0.076}{0.115} \times 100 = \boxed{66\%}$$

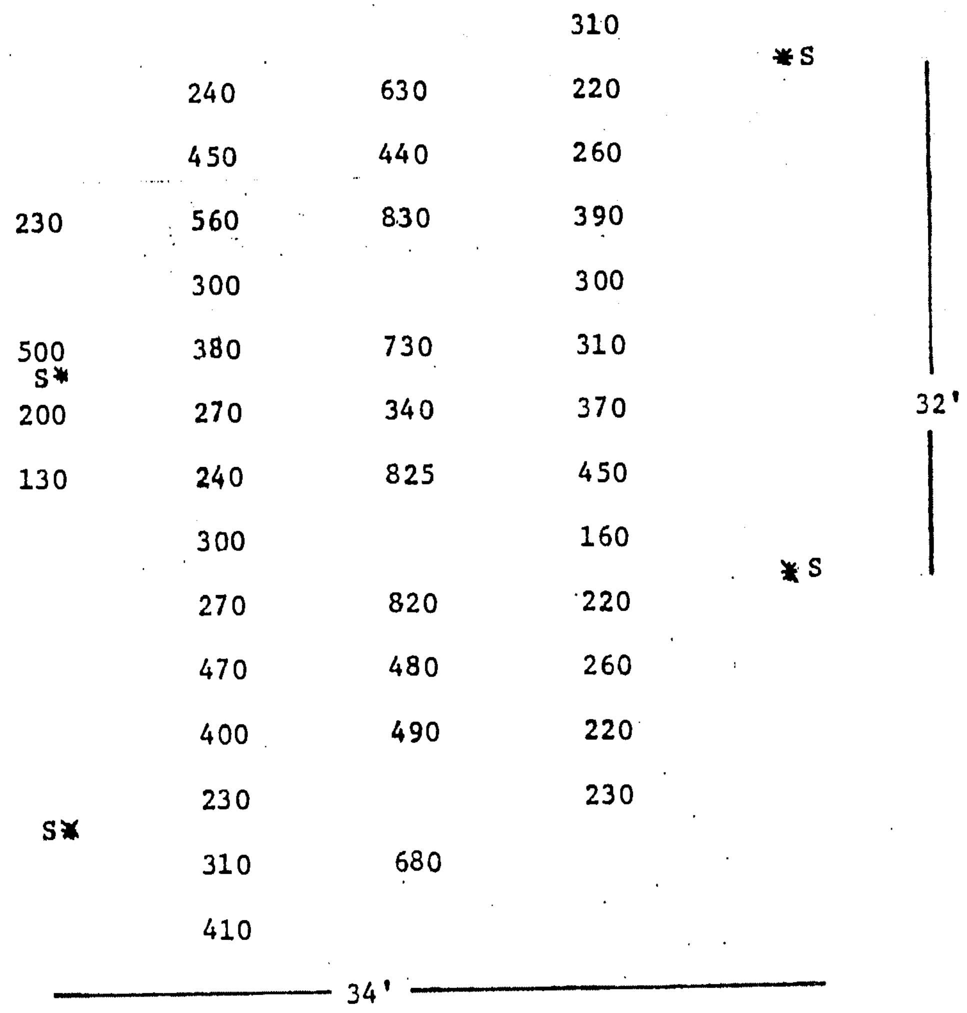
UNDER TREE SPRINKLER TEST - PEAR ORCHARD - HUS

Riser height = 12 inches
Flow rate = 2.2 gpm; pressure not recorded
Sprinkler make = Rainbird 14H
Sprinkler size = 7/64 nozzle, 11° angle
Test done between 4 sprinklers
Distance between sprinklers - 32'
Distance between laterals - 34'
Application rate $\frac{2.22 \times 96.3}{32 \times 34}$ = /0.196 in./hr./

System on - 7:15 A.M. 9-4-80
System off - 6:15 P.M. 9-4-80
Irrigation run = 11 hours

Soil moisture depletion 1.05 inches
Soil moisture depletion - field capacity

Catchment can arrangement:
Four rows of cans were placed within a square area between 4 sprinklers. Distance between rows was 8.5 feet; distance between cans in rows was 4 feet. Drawing shows can arrangement. Depth caught was measured in milliliters and converted to inches with a multiplier of .005.



			310
	240	630	220
	450	440	260
230	560	830	390
	300		300
500	380	730	310
200	270	340	370
130	240	825	450
	300		160
	270	820	220
	470	480	260
	400	490	220
	230		230
	310	680	
	410		

Water applied = .196 inches x 11 hours = 2.16 inches

Average depth caught = 1.90 inches

$$E_a = \frac{\text{average depth caught}}{\text{average depth applied}} \times 100$$

$$E_a = \frac{1.90}{2.16} \times 100 = \boxed{88\%}$$

$$UC = \left(1 - \frac{\text{average deviation from average catch}}{\text{average catch}} \right) \times 100$$

$$UC = \left(1 - \frac{0.060}{0.173} \right) \times 100 = \boxed{65.4\%}$$

Average of Low Quarter of catch cans, from 41 use 10 cans =

210 ml. x .005 = 1.05 inches or .095 in./hr.

$$DU = \frac{\text{average catch rate in low quarter}}{\text{average catch rate}} \times 100$$

$$DU = \frac{0.095}{0.173} \times 100 = \boxed{54.9\%}$$

$$PELQ = \frac{\text{average catch rate in low quarter}}{\text{average application rate}} \times 100$$

$$PELQ = \frac{0.095}{0.196} \times 100 = \boxed{48.5\%}$$

$$AELQ = \frac{\text{average depth of low quarter stored in root zone}}{\text{average depth applied}} \times 100$$

$$AELQ = \frac{1.05}{2.16} \times 100 = \boxed{48.6\%}$$

IRRIGATING SIERRA NEVADA FOOTHILL CROPS EFFICIENTLY TO CONSERVE WATER

*SECOND DRAFT

By
Dick Bethell
County Director
University of California Cooperative Extension
El Dorado County

Irrigating Foothill Crops Efficiently To Conserve Water

Introduction

The costs and difficulties of developing new water supplies to meet the needs of a growing population makes conservation of existing supplies especially attractive. Through careless and uniformed irrigation, much water is lost to runoff, excessively deep percolation and evaporation that could otherwise be saved for later use.

The farmers participating in the El Dorado Irrigation District's Irrigation Management Service (IMS) not only save 2000 acre feet of water annually, but are achieving better crop performance at lower costs. The many foothill growers who are unable to participate in an organized IMS program can still employ IMS knowledge awnd concepts to achieve similar results.

This phamplet presents an overview of that information and dicusses how to plan and carry out an irrigation management program for an individual farm.

WATER REQUIREMENTS

Cropped fields loose water in two ways: 1.) direct evaporation of water from the soil surface and 2.) transpiration, which is water vapor lost through pores (stomates) in plant leaves. This combination evaporation from the soil and transpiration from the plant is called evapotranspiration (ET). It is normally considered the "crop water requirement"; that is, the amount of water actually used by the crop.

Orchard

Orchard and vineyard water requirement and irrigation management studies conducted by The University of California Cooperative Extension in El Dorado County from 1977 through 1982 showed that most El Dorado County crops could be successfully produced with water quantities ranging from slightly to substantially below the crop water requirement. For example, orchards subjected to some stress between irrigations produced fruit with better flavor and suffered only a slight yield loss. Vegetative growth was reduced in tree tops and centers. Sunlight penetrated into trees better, increasing photosynthesis and fruit quality.

Further reductions in orchard water supply progressively decrease fruit size. Crop yield is not only lowered, but crop marketability is drastically diminished. Consumers demand large size fruit.

Vineyard

Greater water stress can be tolerated by wine grapes. Vine water requirements should be met early in the season to establish the foliage canopy needed for maturing the crop. Thereafter, water stress can be increased to stop further foliage development. Grape berry size and yields are reduced, but the concentration of sugars and flavor constituents makes for a better wine.

Conifers

Native fir species are natural conservers of water and perform quite well with low water supplies in Christmas tree plantations. They make their annual growth during the spring when the water supply is ample. Monterey pine, which grows as long as temperatures are favorable, needs it's water requirement fully met for sustained growth.

Irrigated Pasture

Irrigated pasture performs best under a full water requirement regime.

There are other major influences on water requirements besides the crop type. They are the amount of ground covered by the crop, elevation of the farm, slope direction of the planted field, crop load, overall site exposure, the presence and management of other vegetation, and crop adaptation to dryness.

Ground Covered by Crop

Many crops do not totally shade the ground, especially during early stages of growth. Evaporation of water from dry soil surfaces between plants is very low. In such cases, the water requirement or ET rate is determined by the area of leaf surface intercepting sunlight; or, to put it another way, the percent of soil surface shaded by the crop. For this reason the water requirement for mature orchards and vineyards leafing out in the Spring and for newly planted orchards or vineyards is considerably less than maximum ET. As growth increases, ET reaches it's maximum when foliage nearly covers the ground.

Elevation

As elevation increases, water requirement decreases. Table 1 shows this influence on the water requirements of certain foothill crops as determined by the University of California studies.

	Inches of Water Required Per Season				
	Pear-Apples	Stone Fruits*	Wine Grapes	Pasture	Christmas Trees
500-1000	**	**	**	50	**
1000-1500	**	**	22	46	**
1500-2000	44	44	18	43	**
2000-2500	39	39	15	**	9
2500-3000	36	36	13	**	7
3000-3500	33	33	10	**	6
3500-4000	31	31	**	**	6

Table 1. Water used by various crops during a normal season at different elevations. These figures reflect average slope and crop conditions.

* Early maturing stone fruit will not require as much water as post-harvest water requirements are less.

** No data collected.

Slope Direction

South and southwest slopes increase the water requirements of the crop by as much as 25% over north slopes. Many foothill farms are located on mountain ridges that slope from east to west with north and south facing slopes tapering towards river canyons. Irrigation systems should be designed to irrigate plantings on different slopes as separate blocks.

Crop Load

Orchards with heavy crops can use up to 50% more water than orchards that failed to set crops.

Site Exposure

Besides solar radiation, other climatic factors help determine the ET rate. These include temperature, wind and humidity. Hot dry winds on highly exposed sites may cause up to 25 percent more water loss.

Other Vegetation

Weeds or a covercrop consume water from the same soil in which the crop is growing. This use needs to be included in the crop's water requirement. Unmanaged, this vegetation can use more than a third of a mature orchard's water requirement, and can deplete rain or irrigation water stored in vineyard and Christmas tree plantation soils. Carefully managed, this vegetation can be used to minimize soil erosion with only a modest increase in the crop water requirement.

Crop Adaptation To Dryness

Most tree and vine crops have mechanisims for adapting to dryness. They also can become water dependant with excessive irrigation. If irrigation amounts or frequencies are gradually decreased, trees and vines make internal osmotic adjustments to maintain a favorable cell water status. They also increawse water extraction from deeper parts of the soil profile. Foliage will alter shape and alignment to reduce exposure to solar radiation. Stomate closesure increases to conserve water. These adaptive mechanisms allow trees and vines at best, to suffer only modest decreases in productivity, and, at worst, to survive during droughts.

IRRIGATION REQUIREMENT

Water requirement should not be confused with the irrigation requirement. The water requirement is the water actually used in growing the crop. The irrigation requirement is the water that must be applied to replace the water used by the crop. Delivering and applying water to the land involves some losses by evaporation, surface runoff and percolation below the root zone. These loses can be minimized by good irrigation practices, but are difficult to eliminate. They are much more likely to occur with furrow and flood irrigation than with sprinkler or drip irrigation. Even the best application systems (drip, micro sprinklers and permanent set sprinklers) lose 10 to 15% of the water applied. Portable sprinkler systems lose about 25%.

In general:

Irrigation requirement = ET - Effective Rainfall + Irrigation System Losses

Effective rainfall is winter rain water stored in the soil available to plants plus any subsequent rainfall used by the growing crop. The irrigation requirement is less for deep rooted crops on deep soils, as more of their water requirement comes from stored rainfall, provided winter rains fill the soil profile.

The irrigation requirement can vary tremendously from one farm to another. For example, pears grown on a four foot deep soil on a north slope at 3200 feet elevation may require less than 20 inches of irrigtion per season compared to up to 55 inches required for pears grown on a south slope at 1500 feet on a two foot deep soil.

The higher elevation orchard stores about 8 inches of rainfall, twice as much as the lower orchard. It uses six inches less water than an orchard on a south slope at the same elevation. Less water needs to be applied at the higher elevation, which lowers irrigation system water losses.

WHEN TO IRRIGATE

"How often should I irrigate?" is a commonly asked question. The question itself implies that there is a fixed interval between irrigations.

In the previous discussion on water requirements, it should have become apparent that water is not used uniformly throughout the season. Use in the spring is low because weather is cool and plants are developing their new foliage. High summer solar radiation increases water use. Harvesting of crops and cooler fall days again lower the use rate. Table 2 shows this seasonal variation in water demand in two foothill pear orchards.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	TOTAL
Orchard A			1.0	3.5	5.4	8.3	9.5	8.8	5.9	2.4			44.8
Orchard B			0.7	1.7	3.6	5.5	6.3	5.8	3.9	1.6			29.1

Table 2. Monthly water use in acre inches of water in two environmentally different foothill pear orchards.

Four methods for scheduling irrigtions are practical for foothill agriculture. They are:

1. Use established irrigation management services offered by irrigation districts or private consultants. Few irrigation districts currently offer these services, but as districts are confronted with developing expensive new water supplies, they may find it cheaper to offer irrigation management services to extend their existing water supplies. Private consultants are available. They frequently use neutron probes to measure soil water. These devices monitor water depleted from the soil, making it easy to calculate the irrigation requirement. Neutron probe costs and technical requirements deter individual growers from acquiring and using them. More information on IMS programs and neutron probes is available in "Irrigation Management For the Sierra Nevada Foothills of California". *

2. Tensiometers are excellent for scheduling irrigations for orchards, vegetables, berries, pasture and drip irrigation in vineyards. Tensiometers measure the tension by which soil holds water. As a soil drys, the tension increases. Guidelines for irrigating different crops have been established based on the amount of tension that affects plant performance. Tensiometers do not function after tensions of 80 to 90 centibars are reached. About 50% of the available soil water normally has been used at this point. Crops which are not irrigated until soils are dryer (fir Christmas trees, sprinkler irrigated wine grapes after canapies are developed) must use other soil moisturing measuring instruments such as gypsum blocks or neutron probes for accurate scheduling.

   Growers must learn how to use and maintain tensiometers properly to develop confidence in them for scheduling. "Questions and Answers About Tensiometers" University of California Leaflet 2264 is useful for doing this and can be obtained at most UC Cooperative Extension county offices.

   * "Irrigation Management For The Sierra Nevada Foothills of California" was prepared by the University of California Cooperative Extension and published by the United States Bureau of Reclamation, 2800 Cottage Way, Sacramento California 95825.

Tensiometers cost about 30 dollars per instrument. They can be used for a number of years after they are installed. Care must be taken to remove guages in winter or to cover them to protect them from freezing.

3. Water budget scheduling using ET data published in newspapers or broadcast on radio can be an economical way of scheduling irrigations. To do this effectively, the amount of water that can be removed from the soil between irrigations needs to be determined. Soil survey reports available at U.S. Soil Conservation Offices are useful in calculating this amount. After an irrigation, daily ET's are added together until water used equals the allowable amount of water that can be safely removed between irrigations. For improved accuracy, adjustments should be made for elevation and slope direction as they differ from the base site from which the ET information was generated. More information on ET amd water budget scheduling is available in "Basic Irrigation Scheduling", University of California leaflet 21199.

4. Maintaining your own evaporation pan gives a good visual estimate of the water requirement right at your own farm. Pans can be made from wash tubs, 55 gallon barrels or any other comparable container that provides an exposed water surface. Care should be taken to keep animals from drinking from them or swimming in them. As with scheduling option 3, the quantity of water that can be depleted from the soil between irrigations must be determined. When this amount is depleted, start irrigation. If using sprinklers, irrigate long enough to refill the evaporation pan.

Some farmers through experience can visually assess the crop need for irrigation. Such experts are the exception. Experience with the El Dorado Irrigation District IMS program showed that most farmers made serious errors in scheduling irrigations, and that even the most astute schedulers occasionally exercised poor judgment in timing irrigations. Some farmers like to irrigate frequently to avoid the possibility of plant stress. This increases evaporation losses from a more wet ground surface and may stimulate plants to use more water.

HOW MUCH TO IRRIGATE

To irrigate efficiently, the amount of water applied at each irrigation must be accurately estimated. To do this one needs to know:

1. The depth of the root zone. A shovel or backhoe can be used to expose the root zone for examination. The root zone of

mature orchards and vineyards usually occupies the full depth of most foothill soils.

2. The soil type to determine how much water the root zone contains. Soil survey reports produced by the U.S. Soil Conservation Service contain this information. Foothill soils usually hold about 1.5 to 2.0 inches of available water per foot of soil depth.

3. The amount of available water that can be depleted from the soil profile before irrigation is needed. This ranges from 30 to 95 percent for various crops.

4. The percent of ground covered by the crop. When 70 to 80 percent of the ground is shaded by the crop, full ground cover and full ET can be assumed. Use this formula when less than full cover occurs:

   Crop ET = ET x % canopy

   For example.

   Crop ET = .2 inch per day x 50%
   = .1 inch per day

5. The irrigation system efficiency (See section on How Long To Irrigate).

When 50% of the stored soil water has been used, irrigate:
- fruit and nut orchards before harvest
- most vegetables
- Montery pine Christmas trees
- irrigated pasture
- wine grapes while foliage to mature crop is forming

When 85 - 95% has been used, irrigate:
- fir Christmas tree species
- wine grapes with developed canopies
- orchards and vineyards after harvest

Watch field for signs of permanent wilt to avoid crop damage.

As discussed earlier, normal irrigation practices result in some losses during application. These normally range from 10 to 25%. If they exceed 25%, then repair or redesign the system to improve efficiency of the application. The amount of irrigation water to apply is determined by dividing the amount of available water depleted from the soil by the application efficiency. (See section on How Long To Irrigate to evaluate application efficiency).

Example of Amount of Water to Apply

A mature orchard fully covers the ground. Rooting depth is 3 feet of loam soil that contains 6 inches of available water. The orchard is irrigated by permanent-set sprinklers after 3 inches of the available water is depleted from the soil. 3.53 inches of irrigation are applied because this sprinkler system has been found to be 85% efficient in replacing water used by the crop (3 inches divided by 0.85 = 3.53 inches).

Whether scheduling irrigations with tensiometers, using water budget calculations or observing an evaporation pan, errors may be made in estimating the amount of water to apply. Applications should be checked for their accuracy. This can be done with a shovel or soil probe* to determine the depth of wetting. When checking orchards or vineyards, do this the third day after irrigation to allow the soil to fully drain.

Tensiometers may be placed at different depths at the same site to evaluate wetting. The first tensiometer is usually placed 18 inches deep and a second at 30 inches to 36 inches when the root zone is 3 to 4 feet. A third tensiometer may be needed to assess the depth of wetting in deeper soils. When there is no change in reading on the deepest instrument after an irrigation, water may not be reaching it. If the deepest instrument reads 0 to 10 for most of the interval between irrigations, too much water may have been applied, resulting in water losses to percolation past the root zone. A zero reading on tensiometers may occur when dryness has sucked water out of the instrument. Make sure the tensiometer is full of water before reading.

Amount to Apply With Drip Irrigation

Drip irrigation is viewed as the best way to conserve water. Actually, drip irrigation is only slightly more efficient than well designed sprinkler irrigation, and the amounts of water to apply can be more difficult to estimate, as only a small percentage of the ground area is wetted. This can lead to over irrigation with drip systems and loss of water to deep percolation. The formula shown below, and the checks for irrigation accuracy just discussed, can be used to insure efficient drip or microsprinkler irrigation.

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* Soil probes suitable for foothill use should be made of 3/8 inch steel rods, 4 or 5 feet in length, with a handle welded onto one end. Soil probes that remove a core of soil so wetness can be examined are available from agricultural supply stores and mail order catalogues.

Canopy Area Formula

Gallons per plant per day = ET (inches/day) x plant spacing (ft^2) x .622 (gal/in ft^2)

Example: Gallons/plant/day = .2 x (7 x 8) x .622
= 7 gallons per plant per day

HOW LONG TO IRRIGATE

The following steps need to be taken in determining how long to irrigate:

1. Determine the rate water is applied by your irrigation system. This is expressed as inches of water applied to the ground surface per hour for sprinklers and gallons per hour per emitter for drip irrigation. Microsprinkler application rate may be expressed in either gallons per hour or inches applied.

2. Assesss soil ability for filtration and penetration of water. Infiltration refers to the ability of water to move into the soil surface. If runoff occurs soon after the system is turned on, the application rate is too high for the water to infiltrate readily into the soil. Penetration refers to how the water moves through the soil. If a layer of soil resists penetration, the upper soil will fill and runoff will occur some number of hours after irrigation was started. The system should be shut off for awhile, or the application rate lowered to avoid runoff.

3. Check system application uniformity. There are many opportunities for lack of uniformity in applications. Changes in elevation causes pressure changes at sprinkler and drip orifices and different flow rates. Differences in nozzle size, nozzle wear, sprinkler types and system design can lead to lack of uniformity of water applied, and cause water losses to runoff and deep percolation. Pressure compensating emitters and sprinkler flow control devices are available to adjust for elevation changes. Proper system maintenance is very important for good application uniformity. Sometimes systems are poorly designed or water pressure is not adequate for efficient operation. If systems design assistance is needed, consult local U.S. Soil Conservation Service personnel for assistance in answering design questions.

Test the application uniformity of your irrigation system. For a sprinkler system, place cans at various points in the field to catch water while the system is running. Use a measuring cup to catch water from a drip emitter for a given length of time. The degree of variability represents the inefficiency of the application.

When a desirable application rate and system uniformity have been achieved, calculate how long it will take to complete irrigation. To do this, divide the amount of water to be applied by the rate of application.

An example for sprinklers:

The irrigation requirement is 4 inches applied to the field surface. The application rate is 0.16 inches per hour applied by a permanent set sprinkler system.

$$\frac{\text{4 inches}}{\text{0.16 inches per hour}} = \text{25 hours of irrigation time}$$

An example for drip:

The irrigation requirement is 32 gallons per plant per week. Emitters apply 1 gallon per hour and each plant has 2 emitters.

$$\frac{\text{32 gallons}}{\text{1 gal/hr} \times 2} = \text{16 hours of drip irrigation/week}$$

FINE TUNING CONSERVATION EFFORTS

A number of things can be done to enhance your conservation efforts:

* Check for and repair all leaks in the system.
* Check and replace worn sprinkler nozzles. Repair or replace malfunctioning sprinklers.
* Shut the system off exactly at the designated time for the completion of irrigation.
* Check your application amount by using catch cans, checking with a shovel or soil probe and by reading your meter at the beginning and the end of irrigation. Meter readings, if available, show cubic feet used. Divide this reading by the area of the irrigated field to obtain the amount of water applied in inches.

  For example:
  The meter shows 6000 cubic feet at the start of irrigation and 8000 at the end. 8000 - 6000 is 2000 cubic feet of water applied. The field is 100 feet wide and 120 feet long or 12,000 square feet.

  $$\frac{\text{2000 cubic feet}}{\text{12,000 sq. feet}} = \text{0.16 ft. or 1.9 inches water applied to the ground}$$

  Compare this amount with the amount planned for irrigation.

* Suppress competing vegetation. Winter vegetation often robs orchards and vineyards of stored winter rainfall before the crop even starts to use water. Summer weeds may use more than a third of the water in cropped fields. They should be cultivated, mowed, of sprayed to control them. Applying preemergent chemicals to control weeds in the row and planting a low water using dwarf grass between rows, can strike a good compromise between preventing soil erosion and conserving water. A mixture of dwarf rye and dwarf fescue called Companion grass is performing well in orchards. Chemical weed control saves more moisture than cultivation. Cultivating exposes moist soil which increases evaporation.

DB/dl

Summary Of Steps To Develop An Individual Irrigation Management Program

Efficient irrigation depends on knowing when to irrigate, how much water to apply, how long to run your system and having an efficient irrigation application system.

When to Irrigate

* Don't irrigate at fixed intervals.

* Minimize the frequncy of irrigations to reduce ground surface evaporation.

* Refill the soil to reduce the frequency of irrigations.

* Select a method or combination of methods for scheduling irrigations accurately.

> Tensiometers - accurately measure need for water up to about fifty percent depletion of soil moisture. Not good for scheduling in dryer soils.
>
> Water Budget - requires a daily record of ET and establishing the point of depletion where irrigation should be started. Requires adjustments for your site. A Tensiometer can be used to set irrigation point.
>
> Evaporation Pan - When on site, no site adjustments are needed. Depletion point at which irrigation is needed must be established the same as for the water budget method. Other methods - gypsum blocks, neutron probes and other devices are good, but more difficult to acquire. Visual assessment of crop condition often lacks accuracy.

How Much To Irrigate

* Identify depth of root zone with a shovel, backhoe or from crop guidelines.

* Identify soil type and amount of available water the root zone holds.

* Identify the allowable depletion of soil water for various points throughout the season. (See main text)

* Estimate the percent ground covered by the crop. Make adjustments in the amount of water required when not at full cover.

* Divide water used since last irrigation by the irrigation system efficiency to get amount of irrigation to apply.

How Long To Irrigate

* Determine how much water your irrigation system applies per hour.

* Observe whether the water infiltrates and penetrates without runoff at this rate.

* Check the application uniformity at various points along your irrigation system. Upgrade system if needed to improve application efficiency.

* Divide the amount of water to be applied by the rate of application to determine hours to run your irrigation system.

Fine Tune

* Repair leaks, replace worn and defective parts, clean plugged orifices and take other actions to keep system operating efficiently.

* Shut system off at designated time.

* Test adequacy of applications with shovel, soil probe or tensiometers.

* Minimize water removed by non-crop vegetation. Mow, disc, apply herbicides or use of low water using ground covers as appropriate for the crop and site.

DB/dl

Tensiometer Guidelines

for Foothill Orchards and Vineyards

Orchard - Sprinkler Irrigation

Mature Trees - install instruments at 18 inches and 36 inches under the tree canopy. Before harvest irrigate at 60 centibars on 18 inch instrument. After harvest irrigate at 80 centibars after water column has broken. (Refill instrument before next reading.)

Non-bearing - place instrument into center of root zone. Irrigate at 30 to 40 centibars.

Vineyard - Sprinkler Irrigation

Mature Vines - install instruments at 18 inches and at the lower part of the root zone between vines in the vine row. Irrigate at 60 centibars on 18 inch instrument while vine canopy is developing. After canopy is developed, irrigate when deep instrument reads 70 to 80 centibars or after vine shoot extension has ceased, but before interior leaves dry from stress.

Non-bearing - install a tensiometer into center of root zone. Irrigate at 30 centibars.

Orchard - Drip Irrigation

Mature trees - install tensiometers at 18 inches and at 3 to 4 feet at emitter site. Irrigate when either instrument reads 30 centibars.

Non-bearing - install a tensiometer in the center of the root zone with emitter close by. Irrigate when the tensiometer reads 30 centibars.

Vineyard - Drip Irrigation

Mature vines - install tensiometers at 18 inches and at the lower part of the root zone between vines in the vine row at emitter site. Irrigate at 50 centibars on 18 inch instrument while the canopy is developing. After canopy has develpped, irrigate when 18 inch tensiometer reads 80 centibars or just after water column has broken in the instrument. (Refill instrument before next reading.)

Non-bearing - install tensiometer into center of root zone with emitter close by. Irrigate at 30 centibars.

Tensiometers may be purchased locally from:
Jim Kosta - 626-8474
Ron Mansfield - 626-6521

For further information on the use of tensiometers "Question and Answers About Tensiometers" leaflet 2264 at the University of California Cooperative Extension Office, 311 Fair Lane, is available.

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