# ESTABLISHING

AN

# IRRIGATION PROGRAMME


INDIAN COUNCIL OF AGRICULTURAL RESEARCH
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# IRRIGATION PROGRAMME

*By*
C. R. K. PRASHAR
F. A. O. Irrigation Expert
Institute of Agricultural Research
Addis Ababa, Ethiopia
*And*
R. M. HAGAN
Professor of Water Science and Engineering
University of California, Davis
California, U. S. A.


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## ESTABLISHING AN IRRIGATION PROGRAMME

To establish an irrigation programme one must have adequate information on water supply, climate, plant, soil and economic factors. An adequate and dependable water supply facilitates irrigation application in accordance with the biological needs of plants. Then, the problem is to determine the suitability of the crop to the environment and the marketability of the produce. Soils may be altered by grading to change slope, operations to modify profile characteristics, addition of amendments and leaching to correct pH and salinity, organic and inorganic manuring to improve fertility, and pesticides for control of soil-borne diseases, nematodes, etc. However, factors such as climate can be modified little, if at all, and thus determine the cropping and the irrigation programme.

Irrigation programme can facilitate crop production in several ways, viz. providing moisture control; efficient use of fertilizers; better adjustment of cultural practices, such as sowing and harvesting schedules; permit double cropping and intercropping; the introduction of high value crop-potatoes, hybrid maize, sugarcane, long-staple cotton, fruits, vegetables, etc. The extent to which these objectives can be achieved depends on the total water supply.

**Total water require nents.** To determine whether sufficient water is available for irrigation, estimates must be made of the total farm water requirements. Aspects which need to be considered are evapotranspiration losses and application losses including surface run-off and deep percolation. In addition, allowances may be made for conveyance losses and necessary leaching. It is not adequate to know only the total water requirements, since they change with the advance of season, being low in the early stages, rising to a peak at the time of maximum growth, and declining thereafter. Thus, each crop will have periods of maximum rate of water-use depending on the stage of growth and weather conditions. Irrigation interval has to be shortened during the peak demands to prevent damage to crops. These peak rates must be taken into consideration in any irrigation programme and water supply must be assured to meet the demands at such peak periods.

Application losses determine irrigation application efficiency ($E_a$) which is calculated as follows :

$$E_a = 100 \frac{W_s}{W_f}$$

since $$W_f = W_s + R_f + D_f \rightarrow W_s = W_f - (R_f + D_f)$$

$$E_a = 100 \left( 1 - \frac{R_f + D_f}{W_f} \right)$$

where $W_f$=Irrigation water delivered on the farm

$W_s$=Irrigation water stored in the root-zone of soil on the farm

$R_f$=Surface run-off from farm including losses in distribution

$D_f$=Deep percolation losses

Irrigation application efficiency ranges from nearly 100 per cent to 30 per cent and sometimes lower. Low efficiencies arise from irregular land surface, irrigation system poorly suited to prevailing conditions and inefficient operational procedures including too high a rate of water application, excessively long irrigation runs on highly permeable soils, and inadequate control of water distribution. In any irrigation system some water is lost during application. Even under sprinkler irrigation system these losses can be appreciable, particularly under windy conditions.

Over and above the estimates of total water requirements as described above, certain allowance has to be made for leaching the salts from the root-zone. In a surface irrigation method, deep percolation losses may provide the required leaching. However, with a sprinkler irrigation system, additional water will be needed for leaching. Leaching of salts may occur naturally through heavy rains.

**Factors determining suitable irrigation schedules.** Irrigation scheduling is a means of supplying water in accordance with the crop needs. Factors, such as water retention characteristics of soil and rooting depth of crop, which determine the supply of water available to crops, and any factors, such as climate and the extent of plant cover on soil surface, which affect water-use rate, must be considered in determining irrigation schedules. Accordingly, before an irrigation programme is planned, the local situation should be analyzed in terms of soil, plant, climatic and management factors.

(1) *Soil factors.* Among the soil factors involved are soil structure, texture and depth, mechanical impedance, infiltration rate, internal drainge rate, aeration, moisture retention characteristics, hydraulic conductivity, ground water-table conditions, soil-salinity, toxic substances, plant diseases and nematodes, temperature and soil-fertility.

(2) *Climatic factors.* Climatic factors for consideration are temperature, solar radiation, wind, humidity, day-length, length of growing season and diurnal fluctuations.

(3) *Plant factors.* Plant factors include crop varieties, rooting characteristics, drought resistance behaviour, growth stages critically affected by water stress, organs or plant constituents to be harvested, effect of water stress on quality of harvested produce and the length of growing season.

(4) *Management factors.* The principal management factors include dates of planting, resultant plant population, irrigation scheduling in relation to critical growth periods, fertilizer application, crop protection measures, and dates of harvesting.

Irrigation affords opportunities for double or even triple cropping. Selection and planting of crops can be so arranged that the peak rates of water-use by different crops do not clash. Studies at Arizona in the south-western United States reveal that a water flow of 2.5 cusecs would be sufficient for 180 acres of cotton, 257 acres of alfalfa or 340 acres of a rotation consisting of 120 acres of alfalfa, 120 acres of cotton, 80 acres of small grains and 20 acres of sorghum. Such programme is dependent on climate, particularly the total and seasonal distribution of rain, characteristics of crops, especially root depth and density and soil-water-retention characteristics. Intercropping raises irrigation requirements, but the increased production obtained justifies the greater water use.

TABLE I. OPTIMAL IRRIGATION LEVELS AND NET PROFITS FOR WHEAT CROP IN RELATION TO PRICE OF WATER UNDER DIFFERENT SOURCES OF WATER SUPPLY

| Sources of water supply | Cost per acre inch of water (Rs) | Optimum level of irrigation (inches) | Net profit with the optimum irrigation (Rs) |
|---|---|---|---|
| Persian wheel | 18 | 7.6 | 28.8 |
| Tube-well (working on oil) | 8 | 9.3 | 71.4 |
| Tube-well (working on electricity) | 4 | 11.0 | 118.4 |
| Canal | 0.50 | 13.6 | 163.0 |

(5) *Economic factors.* Operational policies including pricing of water and the scheduling of water deliveries to farms can have a major effect on crop patterns and on water-use efficiency. It is the

universal experience that water will be misused and wasted where it is abundant and free or relatively cheap. This may ultimately cause drainage problems and increased salinity, loss of plant nutrients through leaching, and a subsequent reduction in crop yields. Where cost of water is high, efficiency in its use is higher. The optimal level of irrigation and corresponding net profits are inversely related to the cost per unit of water, as shown from experimental data given (Prashar and Singh, 1963) in Table I.

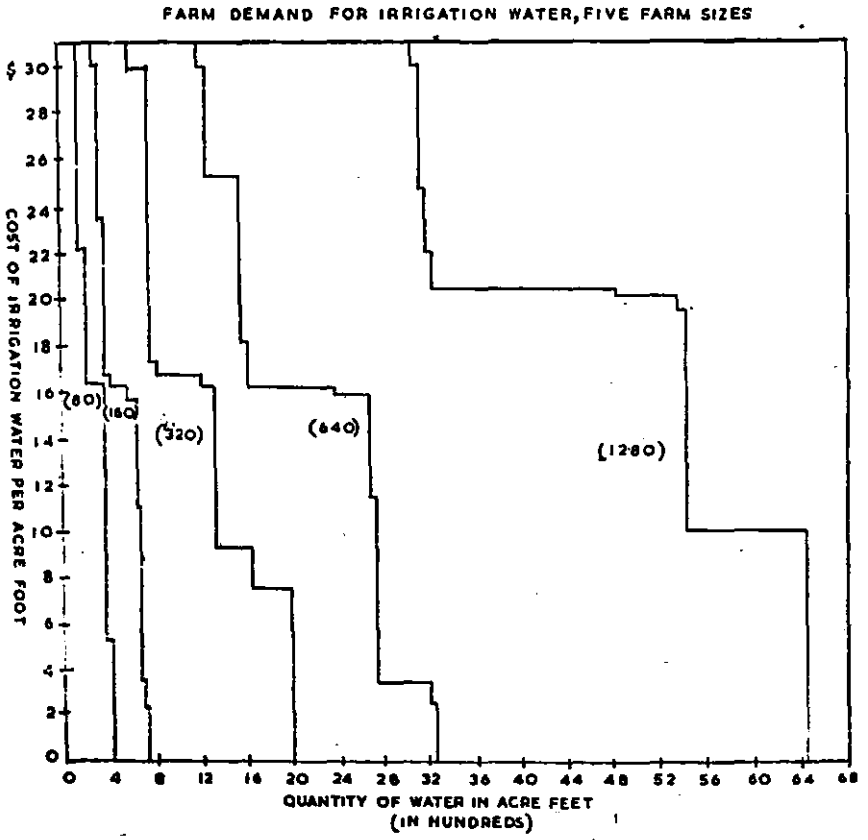


Fig. 1. Optimum water quantity in relation to water cost for different farm sizes.

Net returns per acre for individual crops become critical in the choice of cropping patterns. The relative ranking of different crops and therefore the optimum choices and resource allocations will change considerably with variable water costs, or quantities of water available. The quantities of water need be so regulated that its purchase at a particular price sufficiently ensures, that each successive application is consistent with the profit maximization goal. However, when the objective is to attain maximum production, an increase in water-use may be justified. Studies in California—USA (Moore and Hedges, 1963),

using linear programming techniques, also revealed that the optimum water quantity for different farm sizes (80, 160, 20, 640 and 280 acres) varied as the cost for water ranged from zero to $30.00 per acre foot. 'Stepped' demand schedule for different farm size sare given in figure 1. These steps, each representing a combination of a quantity of water and a particular price, are not necessarily parallel among the five farm sizes The study showed that the amount of water used at a certain price depends upon a specific combination of crops and the acreage of each, that give the maximum total net farm returns under the particular water cost conditions. These water prices are extremely influential in determining cropping patterns, optimum water-use, and efficiency in water-use. In areas where water is plentiful and cheap in comparison to other production costs and crop values, there may be little incentive for a farmer to conserve water by improving the efficiency of his irrigation operations. When low water price is fixed for some reasons, special regulatory measures will have to be imposed to ensure efficient water-use, otherwise the inefficient use of water will create drainage problems and a consequent reduction in crop yield.

(6) *Water supply.* The water supplying organization can also affect irrigation efficiency by its choice of water delivery schedules and of the size of stream made available to individual farmers. In some irrigation projects, the water delivery schedule may make it impossible for the farmer to schedule his irrigations at the precise time when water is needed by the crop.

The rotation system, for example, allows little choice. For the farmer who elects to pass his turn may indeed need water before the time of the next delivery, generally a week or two later. If he accepts water on schedule, consideration must be given to the crop that should be irrigated. In other projects, the farmer may receive a small stream of water under a continuous delivery system. Here, he must apply water on some part of his farm at all times when evaporative demand is high in order to cover the irrigated acreage in time for the next irrigation. Continuous flow systems are often inefficient, but they may be quite efficient under one or more of the following situations :

(1) the flow rate can be properly adjusted to evapo-transpiration rate and water can be shut off wherever it is no longer needed ; or (2) flow-rate is too small for efficient surface irrigation and sprinklers are available. Maximum flexibility and the greatest opportunity to irrigate on a more scientific basis occurs where irrigation water is available on demand. Water is usaully ordered a day or two in advance where project distribution systems have capacities to satisfy crop needs during periods of peak demand. Where groundwater is

plentiful and of good quality, the farmer needs only to turn on a pump to irrigate. In spite of the advantages, many farmers misuse the demand delivery system by irrigating a crop much more frequently than needed.

Irrigation schedules and application must consider other farming operations. For example, a farmer might elect to irrigate alfalfa sooner than necessary because he anticipates harvesting a crop of hay the following week.

**Determination of irrigation schedules.** As discussed above, crop irrigation requirements vary with soils, type of plants, stage of growth, and weather conditions. It is impossible to recommend a universally applicable irrigation schedule. The optimum irrigation programme, from a farmer's point of view, is the one which is most profitable.

Crops differ in their tolerance to the depletion of soil water before irrigation. A crop such as paddy responds favourably to frequent irrigations and even to continuous submergence. Some crops, such as berseem, potatoes, and most winter vegetables, require moist conditions and suffer if more than 40 to 50 per cent of available water in soil 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 programme for specific crops should vary according to the prevailing conditions.

Criteria for scheduling irrigation thus vary from one situation to another. Where water is scarce or expensive, irrigation should be scheduled to maximize crop production per unit of applied water. Where arable land is more scarce than water, irrigation should be scheduled to maximize crop production per unit of planted area. However, in certain situations, irrigation schedules may be modified to minimize irrigation costs, facilitate farm operations, viz. to overcome problems of poor germination, slow penetration of irrigation water, to control atmospheric temperatures, or the groundwater level, to accomplish leaching of salts, and accommodate schedule of water delivery to farms.

The following approaches may be used to schedule irrigation :

1. Measurements or observations of water deficit in plants

   Requires knowledge of relations between measured or observed deficit and crop yields.

2. Calculated schedules

   Based on (a) estimated soil water depletion allowable without loss of crop yield and (b) an estimate of water-use rates.

3. Evapo-transpiration rates

   Computed from evaporation or meteorological data. Also requires information on allowable depletion of available soil water.

4. Soil water measurements

   Also requires information on allowable depletion of available water or allowable suctions.

**Irrigation schedules based on measurements or observations of plant water deficits.** The most direct approach to the scheduling of irrigations would be the measurements or observations of plant water dificits which can be tolerated without adversely affecting crop yields and/or quality.

Plants respond to water stress in a number of ways and although responses vary in magnitude and type between species, they may be useful in some cases as criteria for irrigation need.

Measurements of plant water deficits, which have been proposed and used to some extent, include relative water content or turgidity, stomatal opening, transpiration rate, osmotic concentration of cell sap, and total water potentials (For a detailed review, refer Hagan and Laborde, '966). Unfortunately, the values obtained by all these measurements depend on *(i)* the plant part selected and its age, *(ii)* time of day, and *(iii)* exposure of the plant part selected. These measurements may also be affected by climatic conditions, soil fertility, disease and other factors influencing plant growth. Many of these measurements are time consuming and require highly refined equipment. Equipment needed for making the more fundamental measurements is not as yet suitable for field use. Even when measurements are made under carefully standardized conditions, considerable research is needed to establish critical values as to the basis for scheduling irrigations.

The present difficulties in making plant water measurements suggest that more attention should be given to finding practical ways to use easily detected visual symptoms of water-stress to guide irrigations.

The most obvious and frequently observed symptom of water-stress is wilting of a part or entire plant. Increasing water-stress in many plants causes a darkening of colour and loss of sheen. Water-stress

in some crops leads to the appearance of carotenoid (yellow and orange colours) and anthocyanin (purple colours) pigments; shortening of internodes (as in sugarcane and cotton); retardation of shoot elongation (as in grapes); change in leaf angle and apparent colour (as in bean); leaf rolling (as in maize, clover and some pasture grasses); and leaf abscission (as in almond). Unfortunately, by the time water stress symptoms can be observed in most crops the plant has already been under stress for some time and yields may be affected. However, in some cases with cotten, grapes, bean and perhaps other crops, visible symptoms are adequate indices for scheduling irrigation. More detailed studies may possibly lead to recognition of useful visual indicators for other crops.

Visual symptoms of water stress can be effectively used to schedule irrigation where plants growing on certain areas of a field dry out more quickly because of sandy soil, shallow depth, restricted infiltration, smaller irrigation applications or other reasons. As the dryness of these areas relative to the rest of the field is learned through experience, then the appearance of visual stress in these areas can be useful in scheduling irrigation for the whole field.

Another possibility deserving further attention is the use of selected plants or specially treated plants grown with the main crop to indicate irrigation needs. If indicator plants can be selected or treated so that they visually show water stress at a desirable interval before the crop is affected, they could be a useful guide to irrigation scheduling. This approach is potentially useful, especially so, in the rapidly developing countries, but requires considerable experimentation.

With the exceptions indicated above, delaying irrigation until visual water stress symptoms appear will generally lead to reduced yields.

**Calculated irrigation schedules (Irrigation Guides).** Approximate irrigation schedules, sometimes called Irrigation Guides, can be calculated from the following relation :

$$\text{Irrigation interval (days)} = \frac{\text{Supply of soil water usable without affecting crop yield}}{\text{Rate of water-use per day}}$$

The amount of water which can be stored within the root zone, and which can be used by the crop without being adversely affected, will be termed as the total available water and can be calculated from the equation as follows :

$$\text{Total available water} = \frac{(FC\text{-}WP)}{100} \cdot S_b \cdot D_r$$

where $FC$ is the average field capicity, $WP$ is the wilting point (or permanent wilting percentage), $S_b$ the bulk specific gravity, and $D_r$ the effective depth of rooting.

To avoid any possible crop damages due to drought, the generally accepted irrigation practices recommend to irrigate the crop before arriving at the wilting moisture content, i.e., before complete depletion of the total available water. The depth of water which can be depleted before the crop is adversely affected is termed the usable available water, or the allowable depletion of soil water.

The allowable depletion is the equivalent depth of water which can be depleted from the root zone before the occurrence of unacceptable adverse effects on the crop. It can be calculated as follows :

$$\text{Allowable depletion} = \sum_{i=1}^{n} \left( \frac{FC_i - WP_i}{100} \right) S_{b_i} \cdot d_i \cdot f_i$$

where $n$ is the number of soil layers or increments sampled within the effective rooting depth and $FC_i$, $WP_i$ $Sb_i$, $d_i$ and $f_i$, are the field capacity, wilting point, bulk specific gravity, depth of soil layer and the ratio of allowable depletion to the total available water, all in the i-th layer. The fraction f reflects the root activity and completeness of water extraction from each depth. Accordingly, it will diminish with soil depth, but it will increase as roots grow during the crop season. Since information for each soil depth within the root zone is often lacking, the following simplified expression may be used :

$$\text{Allowable depletion} = \left( \frac{FC - WP}{100} \right) \cdot S_b \cdot D_r \cdot F$$

where $FC$, $WP$, $S_b$, $D_r$ and $F$ are the field capacity, wilting point, bulk specific gravity, depth of soil and the ratio of allowable depletion to the total available water, all for the entire root zone.

The allowable depletion is dependent upon :

(1) The fraction of the available water which is contacted by roots as they grow through the soil.

(2) The potential rate at which soil water can be supplied per unit area of absorbing roots in relation to rate of water loss from leaves. The rate of supply of soil water to roots is limited by the hydraulic conductivity of the soil which declines with increasing soil water suction (or tension).

(3) The soil water suction corresponding to different degrees of soil water depletion.

The soil water suction influences plant water deficits and thus affects water absorption and plant growth processes. The magnitude of plant water deficit which can be tolerated without adverse effects is dependent primarily upon the crop and stage of growth. Some crops appear to have critical periods during which they are greatly affected by water deficits and thus are particularly responsive to irrigations.

Thus the allowable depletion (usable available water) will depend upon the crop, the soil, the climate, and even the management conditions and will tend to increase during the growing season as the roots extend deeper and more completely through the soil.

The allowable depletion and the usable water fractions f and F as described above should not be confused with extraction information as published for some crops. These extraction patterns usually express the water taken from each depth as a fraction or percentage of the total water extracted from the entire root zone.

Therefore irrigation planning and scheduling is greatly complicated by the fact that the allowable depletion is determined by many soil, plant, climatic and management factors. Listed in Table II are those factors which tend to reduce the allowable depletion and thus raise the probability that crops will respond to relatively frequent irrigations. Also listed in Table II, are those factors which tend to increase the allowable depletion water and thus decrease the probability that crops will be benefited by relatively frequent irrigations.

TABLE II. CONDITIONS AFFECTING THE ALLOWABLE DEPLETION OF SOIL WATER AND THE FREQUENCY OF IRRIGATION

| *Conditions tending to require relatively frequent irrigations* |
|---|
| **Plant** |
| Shallow, sparse, slow-growing roots. |
| Major growth occurs during non-rainy season and/or periods of high evaporative demand. |
| Fresh weight yields of reproductive organ desired. |
| **Soil** |
| Shallow soil; poor structure impeding root growth. |
| Slow infiltration and internal drainage; poor aeration. |
| Root disease, nematodes present. |

Small fraction of available water held at low suctions.

Saline soils and/or saline irrigation water.

Fertility level high ; nutrients concentrated in top-soil.

Very high soil temperature, with shallow-rooted crops.

**Weather**

High evaporative rates.

No rainfall during growing season.

**Management**

Planted at beginning of hot dry weather.

Maximum yield desired even though maturation may be retarded.

Market value dependent on total fresh weight yield or size of harvested organ.

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*Conditions permitting relatively infrequent irrigations*

**Plant**

Deep, dense, fast-growing roots.

Xerophytic characteristics.

Major growth occurs during rainy season and/or periods of low evaporative demand.

Dry weight yields of reproductive organ desired.

**Soil**

Deep soil ; good structure.

Good infiltration, internal drainage, aeration.

Large fraction of available water held at low suctions.

Non-saline.

Fertility level low ; nutrients distributed in profile.

Constant water-table in reach of roots.

**Weather**

Low evaporative rates.

Rain during growing season.

**Management**

Planted and grown during rainy season and/or period of low evaporative demand.

Planted and well established before hot dry weather.

Early maturation required to achieve harvest or favourable marketing even though yield may be somewhat depressed.

Market value determined by total dry weight, percentage dry weight, or content of specific constituent.

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It must also be recognized that other factors such as adequacy of supply and cost of water, availability and cost of labour, water delivery schedule, and type of irrigation system used may also affect the irrigation schedule selected.

The potential rate of water-use from a cropped field (the potential evapo-transpiration rate) is a function of meteorological conditions. The actual rate of evapo-transpiration is usually smaller and is determined by :

(1) Extent to which crop covers the soil surface

This is affected by planting density, stage of growth, soil fertility, crop protection measures, cultural operations, and other management decisions.

(2) Stage of crop growth

This affects not only the extent of soil surface coverage by the crop but also the transference of water vapour to the atmosphere by altering leaf geometry and crop surface roughness. Also the rate of water loss per unit leaf area often declines because of senescence as the crop matures.

(3) Soil water supply

Plants will transpire at the potential rate and evaporation from the soil surface can proceed at the potential rate only when the soil is wet and water is freely available.

Thus the actual evapo-transpiration depends not only on climatic factors, but also on crop, soil and even management factors.

To calculate a suitable irrigation interval, one must have information on:

(1) Allowable depletion of soil water under the prevailing soil, plant, climatic and management conditions.

As pointed out above, the allowable depletion for a given crop will vary over the growing season. It must also be realized that this allowable depletion may need to be adjusted in accordance with such considerations as water cost, changes in actual supply of irrigation water, changes in the relative market value of the crop, etc.

(2) Actual evapo-transpiration rate under the prevailing climatic conditions as modified by soil, plant and management conditions.

> The relation between actual and potential evapo-transpiration will change over the growing season. Thus, as the irrigation season progresses, adjustments must be made in the numerical factor used to correlate actual evapo-transpiration with evaporation as computed from meteorological data or as measured by pans or evaporimeters.

With the above information, the irrigation interval can be calculated as follows :

$$\text{Irrigation interval} = \frac{\text{Allowable depletion}}{\text{Rate of actual evapo-transpiration}}$$

Allowable depletion can be expressed in any convenient units (mm, cm, inches) giving total depth of water. Evapo-transpiration rates should be expressed in the same units per day. This gives irrigation interval in days.

The Irrigation Guides prepared by the Soil Conservation Service of the United States Department of Agriculture, for some irrigated areas of the western United States contain in a convenient tabular form some suggested irrigation intervals computed from typical values for field capacity, wilting point, crop rooting depth, allowable depletion and evapo-transpiration rates. Field capacity and wilting point data are obtained from soil surveys. Approximate rooting depths for major crops of the area on typical soils are assumed from local experience or data obtained under similar conditions in other locations.

These Guides recognize, as discussed above, that only a fraction of the total available water which can be stored within the root zone can be used before crop growth and yield are affected. The Soil Conservation Service in preparing these Guides approximates the allowable depletion by determining the total available water in the top one-quarter of the root zone and multiplying by two. Thus the allowable depletion is one-half of the total available water in the root zone for soils which have uniform water-holding capacities for all increments of depth. However, the allowable depletion will be less than one-half of the total capacity in the root zone in soil underlain with subsoils having higher water-holding capacities than the upper portion of the root zone. The SCS procedure (U.S. Soil Conservation Service, 1957) is illustrated by the following example :

Assume a soil having an available water capacity of 1.75 inches in the top foot and 2 inches in the second foot. The depth of root zone is 5 ft. Thus, one-quarter of the root zone depth will be 1.25 feet. The total available water capacity of the top one-quarter will be

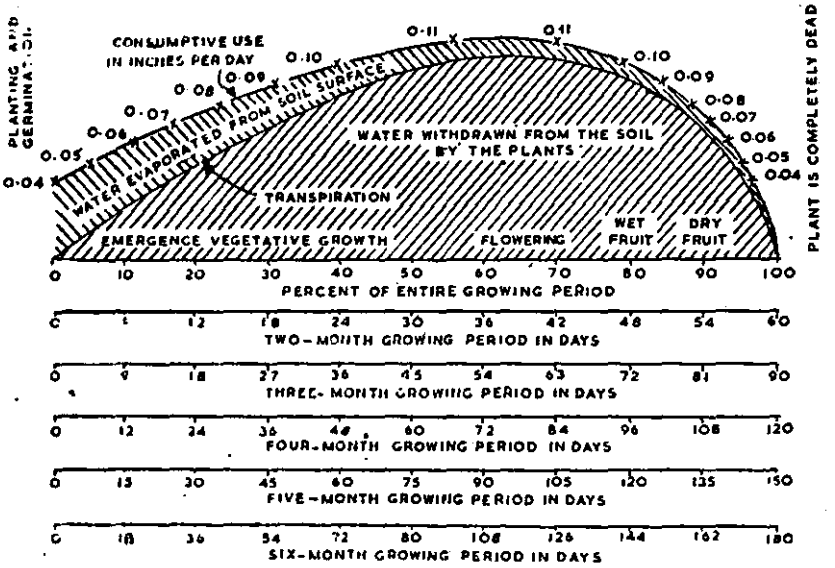


Fig. 2. Consumptive use of water for various periods of growth (Israelsen and Hansen, 1962).

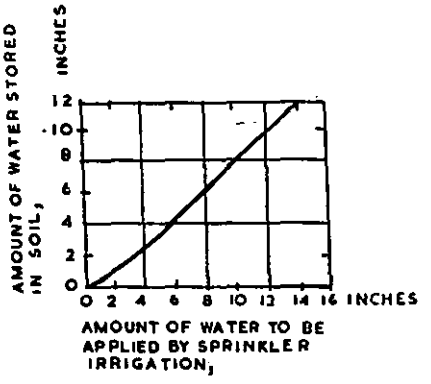


Fig. 3. Depth of water that must be applied by typical sprinkler system to store given depth of water in soil (Israelsen and Hansen, 1962).

1.75 + $\frac{2.0}{4}$ or 2.25 inches, and the allowable depletion will equal 2.25 × 2 or 4.5 inches.

These Guides contain, for indicated soils and given climatic regions, the adapted crops, assumed rooting depth, the allowable depletion, and the resultant irrigation frequency in days, on the basis of the above calculations and estimated values for actual evapo-transpiration. The Guides also warn the user that certain crops may require irrigation at even more frequent intervals to maintain favourable yields and/or crop quality. These include crops with relatively shallow or sparse roots and those harvested for fresh weight yield of vegetative organs.

The Irrigation Guides also provide useful information on water application. The net water to be added in irrigation equals the allowable depletion plus the allowances for application losses and for leaching when necessary. Appropriate irrigation methods are also indicated in these Guides including suggested application rates, stream size, length and width of borders, furrow spacing, estimated field application efficiency using suggested irrigation methods, and gross irrigation application. A typical Irrigation Guide, prepared by the Soil Conservation Service of the U.S. Department of Agriculture for an area in Southern California, is reproduced in Table VI at the end.

Generalized or unique consumptive-use curves may be used in scheduling irrigation programmes (Fig. 2) (Israelsen and Hansen, 1962). These curves can be used to estimate the consumptive use for a specific crop over its growing season from planting to maturity. It may be convenient to prepare this information in a tabular form. If the total usable available water in the root zone is known at sowing; the remaining quantity (consumptive use minus usable available water at sowing) has to be given during the crop growing season.

The depth of water to be stored in the soil during an irrigation affects the efficiency with which it can be applied. This is particularly true with most surface irrigation systems. It should also be considered when using sprinkler systems.

Figure 3 represents the amount of water that must be applied by a typical sprinkler irrigation system in order to store the required amount of water. The application efficiency is normally less when smaller amounts of water are to be applied.

On the basis of the growing season of crop its consumptive use is estimated from the generalized curve or tables. This information, together with depth of rooting, allowable depletion of water per unit depth of soil within root zone, and irrigation efficiency permit the setting up of irrigation schedules. It also gives the corresponding depths of

TABLE III. IRRIGATION FREQUENCY AND DEPTH OF WATER TO BE APPLIED BY SPRINKLING IRRIGATION WHEN VARYING AMOUNTS OF AVAILABLE WATER REMAIN IN THE SOIL

Length of growing period = 3 months — Soil texture = Coarse

| Time since planting (days) | Consumptive use of water (inches per day) | Average depth of rooting (inches) | Maximum depth of available water in root zone (inches) | Interval in days between irrigations and depth in inches to be applied when different amounts of available water remain in the soil | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 75% | | 50% | | 25% | | 0% | |
| | | | | Days | Depth (inches) | Days | Depth (inches) | Days | Depth (inches) | Days | Depth (inches) |
| 0-9 | 0.05 | 2 | 0.2 | 1 | 0.3 | 2 | 0.4 | 3 | 0.5 | 4 | 0.6 |
| 9-18 | 0.07 | 6 | 0.6 | 2 | 0.5 | 5 | 0.7 | 8 | 1.0 | 10 | 1.3 |
| 18-27 | 0.08 | 11 | 1.1 | 3 | 0.6 | 7 | 1.1 | 10 | 1.5 | 13 | 1.9 |
| 27-36 | 0.09 | 16 | 1.6 | 4 | 0.8 | 8 | 1.4 | 13 | 2.0 | 17 | 2.5 |
| 36-45 | 0.10 | 21 | 2.1 | 5 | 1.0 | 10 | 1.7 | 15 | 2.5 | 20 | 3.1 |
| 45-54 | 0.11 | 26 | 2.6 | 6 | 1.1 | 12 | 2.1 | 17 | 2.9 | 24 | 3.7 |
| 54-63 | 0.11 | 31 | 3.1 | 7 | 1.3 | 14 | 2.4 | 21 | 3.3 | 28 | 4.2 |
| 63-72 | 0.10 | 35 | 3.5 | 8 | 1.5 | 17 | 2.7 | 25 | 3.7 | 34 | 4.7 |
| 72-81 | 0.09 | 38 | 3.8 | 11 | 1.6 | 21 | 2.9 | 33 | 4.0 | 44 | 5.1 |
| 81-90 | 0.05 | 41 | 4.2 | 20 | 1.7 | 41 | 3.1 | 61 | 4.2 | 82 | 5.5 |

water to be applied using a given irrigation system when varying amounts of available water remain in the soil. These tables for given crops need to be prepared for soils of typical textural classes. One such table for a coarse soil is given in Table III.

The usefulness of computed irrigation schedules improves as more accurate information on allowable depletion for given crops under given conditions is obtained through local experience and experimentation and as more exact data are developed on actual evapo-transpiration rates.

**Irrigation schedules based on evapo-transpiration rates.** Much attention is now being given to the estimation of evapo-transpiration rates from evaporation data or meteorological measurements. To be useful for irrigation scheduling, the method used must provide accurate values of evapo-transpiration over short time intervals.

Evaporative devices or the energy balance approaches offer possible way to determine short-term evapo-transpiration rates at a central location for daily reporting to farmers in an irrigation project. Even a single meteorological measurement such as solar or net radiation may offer an adequate basis for scheduling irrigation (Jensen and Haise, 1965). The U.S. Bureau of Reclamation has modified this procedure using a single crop curve to express the ratio of actual evapo-transpiration to potential evapo-transpiration for various stages of crop growth.

A great variety of evaporation pans, tanks, atmometers or other types of evaporimeters have been developed. The major problem has been the establishment of reliable correlations between the measured evaporation and evapo-transpiration. Although a high correlation may exist between measured evaporation and evapo-transpiration, devices must be calibrated under specific conditions. Evaporation pans are now being used to schedule irrigations in Hawaii and other western United States. These pans can record rainfall and irrigation water as it is being applied with sprinkler irrigation systems. Irrigation is started when the water surface in the pan drops to a level which reflects depletion of the usable available water. Irrigation is then stopped just before the pan overflows from the water added by the sprinklers. This method can be adopted to various crops by adjusting the characteristics of the pan and its location with respect to the crop canopy so that its evaporation rate approximates the evapo-transpiration rate for the crop.

As pointed out earlier, information on the allowable depletion of soil water for given crops in given situations must also be known to develop efficient irrigation schedules from computed

TABLE IV. TYPICAL BUDGET SHEET FOR SCHEDULING IRRIGATIONS

Crop : Irrigated pasture (Root zone, 3 feet deep)

Soil : Fine sandy loam, 4 feet deep

Usable available water (allowable depletion) = 2.5 inches

Crop Constant : k = 0.8

| Date | Rainfall (inches) | Irrigation (inches) | Measured evaporation[1] $E_w$ (inches) | Computed evapo-transpiration $E_w$ k (inches) | Usable available water remaining in root zone (inches) |
|---|---|---|---|---|---|
| July 1 | | | | | 2.50[2] |
| „ 2 | | | 0 38 | 0.30 | 2.20 |
| „ 3 | | | 0.24 | 0.19 | 2.01 |
| „ 4 | | | 0.28 | 0.22 | 1.79 |
| „ 5 | | | 0.35 | 0.28 | 1.51 |
| „ 6 | | | 0.31 | 0.25 | 1.26 |
| „ 7 | | | 0.33 | 0.26 | 1.00 |
| „ 8 | | | 0.35 | 0.28 | 0.72 |
| „ 9 | | | 0 40 | 0.32 | 0.40 |
| „ 10 | | | 0.45 | 0 36 | 0.04 |
| „ 11 | | 2.50 | 0.50 | 0.40 | 2.14 |
| „ 12 | | | 0·28 | 0.22 | 1.92 |
| „ 13 | 0.42 | | 0·14 | 0.11 | 2.23 |
| „ 14 | 0.25 | | 0·19 | 0.15 | 2.33 |
| „ 15 | | | 0.31 | 0.25 | 2.08 |

[1] $E_w$ may be measured with an evaporation pan or computed from meteorological data. An appropriate crop constant k must be used to convert to evapo-transpiration.

[2] Budget record starts from July 1 assuming soil profile as wet throughout root zone by irrigation or rain on June 30. Budget could start with usable available water at any level as determined by soil moisture sampling.

evapo-transpiration rates. Suitable irrigation intervals can then be calculated as in the preceding section using the evapo-transpiration data obtained.

Some irrigators find it convenient to use a budget sheet to record the measured evaporation data, the computed evapo-transpiration, rainfall, irrigations, and the usable available soil water in the crop root zone. A typical budget sheet is given in Table IV.

Where irrigations are to be scheduled for a number of crops and fields, an irrigation scheduling board (as developed by Pruitt, 1958 and Jensen and Middleton, 1965, for use in the Columbia Basin Project of the western United States) is convenient. This device maintains a visual record of accumulated or net evaporation and of usable water depletion for each field.

The board as shown in Figure 4 consists of a metal base with magnetic crop slides and evaporation indicator. Along the left edge of the board there is an evaporation scale marked in inches and tenths of inches. The position of the main indicator shows accumulated $E_w$. When each new $E_w$ value is obtained, the indicator is slid up the scale accordingly. A crop slide for each field on the farm may be seen on the board. The scale for each crop is proportioned to the main evaporation scale in accordance with the crop factor for that crop. Thus one inch on the main scale might show as 0.8 inch (equivalent to one inch of soil water) on the crop slide. The crop slide is movable and its length shows the amount of usable available water which can be held within the root zone for the crop at this stage of growth. When the reservoir is completely filled by irrigation, the crop slide is moved up the board so the bottom of the crop slide is at the top edge or hairline of the evaporation indicator. This shows the soil water reservoir to be full. As evaporation occurs, the indicator is raised and moves over the crop slide. Thus, it indicates on the crop slide the amount of water used from the soil and the amount which still remains. Each crop is due for irrigation when the top edge or hairline of the indicator reaches the top mark of the crop slide. In case of water addition by precipitation, each crop slide may be moved up an equivalent amount or the evaporation indicator moved down. In the latter case the left-hand scale records net accumulated rather than gross accumulated evaporation.

Instead of this special board, use can be made of a simple cardboard chart with an evaporation scale at the left and columns to be filled in for each cropped field in accordance with the usable available water and water-use rate for each. A rubber band can be moved up the chart to record accumulated evaporation and to indicate depletion

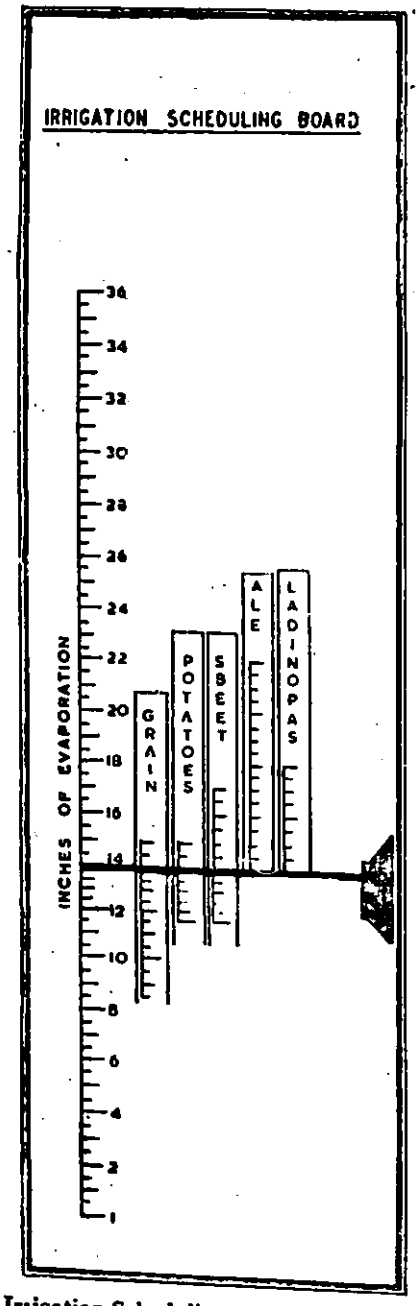


Fig. 4. Irrigation Scheduling Board (Taken from Jensen *et al*., 1961).

TABLE V. SOIL WATER SUCTION (FOR SOIL DEPTH WITH MAXIMUM ROOT ACTIVITY) AT WHICH WATER SHOULD BE APPLIED FOR MAXIMUM YIELDS OF VARIOUS CROPS GROWN IN DEEP, WELL-DRAINED SOIL FERTILIZED AND MANAGED FOR MAXIMUM PRODUCTION (ADOPTED FROM TAYLOR, 1965)[1]

| Crop | Soil suction (bars) | Crop | Soil suction (bars) |
|---|---|---|---|
| **Vegetative crops** | | **Seed crops** | |
| Alfalfa | 1.50 | Alfalfa | 2.00 |
| Beans (snap, lima) | 0.75 - 2.00 | Alfalfa - bloom | 4.00 - 8.00 |
| Cabbage | 0.50 - 0.70 | Alfalfa - ripening | 8.00 - 15.00 |
| Canning peas | 0.30 - 0.50 | Seed carrots (60-cm depth) | 4.00 - 6.00 |
| Celery | 0.20 - 0.30 | Onions (7-cm depth) | 4.00 - 6.00 |
| Grass | 0.30 - 1.00 | Seed onions (15-cm depth) | 1.50 |
| Lettuce | 0.40 - 0.60 | Lettuce - productive | 3.00 |
| Sugarcane | 0.25 - 0.30 | Coffee | required short periods of low potential to break bud dormancy, followed by high water potential |
| Sweet corn | 0.50 - 1.00 | | |
| Tobacco | 0.30 - 0.80 | | |
| **Root crops** | | | |
| Broccoli - early | 0.45 - 0.55 | | |
| Broccoli-post-bud | 0.60 - 0.70 | | |
| Carrots | 0.55 - 0.65 | | |
| Cauliflower | 0.60 - 0.70 | | |
| Onions - bulbing | 0.55 - 0.65 | | |
| Onions - early | 0.45 - 0.55 | | |
| Potatoes | 0.30 - 0.50 | | |
| Sugar beets | 0.40 - 0.60 | | |
| **Grain crops** | | **Fruit crops** | |
| Corn - vegetative | 0.50 | Avocadoes | 0.50 |
| Corn - ripening | 8.00 - 12.00 | Bananas | 0.30 - 1.50 |
| Small grains - vegetative | 0.40 - 0.50 | Cantaloupe | 0.35 - 0.40 |
| Small grains - ripening | 8.00 - 12.00 | Deciduous fruit | 0.50 - 0.80 |
| | | Grapes - early | 0.40 - 0.50 |
| | | Grapes - mature | 1.00 |
| | | Lemons | 0.40 |
| | | Oranges | 0.20 - 1.00 |
| | | Strawberries | 0.20 - 0.30 |
| | | Tomatoes | 0.80 - 1.50 |

[1] Where two values for soil water suction are given, the lower suction value is used when evaporative demand is high and the higher value when it is low; intermediate values are used when the atmospheric demand for evapo-transpiration is intermediate. These values are subject to revision as additional experimental data become available.

of usable available water. This system is used widely in the Columbia Basin Project U.S.A. where evaporation data are printed in the local newspapers or could be broadcasted by local radio stations. The scheduling of irrigations by this approach is simple, but the farmer usually requires assistance from the Agricultural Extension Worker to initiate the programme.

**Irrigation schedules based on soil moisture measurements.** Instead of determining when the usable available soil water is consumed by knowing the total usable available water and the rate of its use by evapo-transpiration, the level of the supply of soil water is measured directly by soil samplings or by using tensiometers or electrical resistance blocks. As in the other approaches to scheduling irrigations, the usable available water (or allowable depletion) must be known for each cropping situation. When the usable available water has been consumed (or allowable depletion has been reached) as indicated by soil water samples or computed from measurements with calibrated tensiometers or resistance blocks, irrigation should be applied.

When soil water relations are measured and expressed in weight or volume units, the total available water and the usable available water (or allowable depletion) are greatly dependent upon soil texture. Thus, the limits of usable available water in any cropping situation must take into consideration the soil texture effect.

The usable available water in soils can be expressed in terms of the corresponding range of soil water potential or soil water suction which can be measured by tensiometers or calibrated electrical resistance blocks. Usable soil water suction ranges are slightly affected by soil texture. Accordingly, irrigation schedules for a given crop which are based on soil water suction are approximately applicable to any soil in which root growth is normal. Table V, adopted from Taylor (1965), gives soil water suction values at which irrigation should be applied to a number of crops grown on deep, well-drained soil which is fertilized and managed for maximum production. This table summarizes research by investigators from many countries. Where a range of suction values is given, the lower suction values should be used when the evaporative demand is high and the higher suction value when it is low. Intermediate values are used when the evaporative demand is intermediate. The ranges reported here reflect the influences of the many soil, plant, climatic, and management factors discussed previously, and they also reflect inadequacies in experimental data. As an example, for alfalfa a suction from 4 to 8 bars is given. When evaporative demand is high, it should be at a suction level of 4 bars; whereas when evaporative demand is low, irrigation can be delayed until a suction value of 8 bars is approached.

When using soil water suction as the criterion for irrigation, the depth of water to be applied can be determined by (*i*) the cumulative evapo-transpiration since the last irrigation where this is known ; or (*ii*) converting the soil water suction to the corresponding depletion of soil water content by use of the soil water content versus soil water suction relations for the soil where this information is available.

Tensiometers, resistance blocks, or other instruments for determining irrigation need are most useful in water deficient areas where cost of water is usually high and where high value crops are grown. Crops with established root systems like orchard trees are easier to instrument than annual crops with an expanding root system. In the case of tree crops, installations of tensiometers or resistance blocks can be semi-permanent. However, instruments placed in annual crops are normally destroyed or removed and reinstalled each crop season. Where qualified technical personnel are available, as on large or co-operative farms, soil water gauging devices can be more easily managed and the data can be better interpreted in terms of scheduling irrigations.

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TYPICAL IRRIGATION GUIDE FOR AREA IN SOUTHERN CALIFORNIA, U.S.A.

| | | | CROPS | | | | IRRIGATION SPECIFICATIONS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | ROOT ZONE DEPTH (feet) | NET MOISTURE TO BE REPLACED EACH IRRIGATION (inches) | PEAK PERIOD CONSUMPTIVE USE RATE (in./day) | IRRIGATION FREQUENCY DURING PERIOD OF MAXIMUM CONSUMPITVE USE (days) | ADAPTED CONSERVATION IRRIGATION METHODS | BASIC INTAKE RATE Border Flooding or Sprinkler in./hr. Furrow or Corrugation | STREAM SIZE Borders or Flooding Unit Stream of a/100 Furrow of Corrugation Max. Stream g.p.m. | MAX. BORDER WIDTH feet Furrow or Corrugation spacing inches | MAX. LENGTH OF RUN (feet) | EST. FIELD EFF. | CROSS IRRIGATION APPLICATION (inches) | ESTIMATED TIME REQUIRED (Hours) |
| 3 | 4 | | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| | | | | | | | | | SLOPE GROUP 0.25 - 1%, (AV. - 0.6%) | | | | | |
| | 1.00 | CITRUS | 4 | 2.4 | .19 | 13 | FURROW | 3.0 gpm | 16 | 36 | 160 | 70 | 3.4 | 3.5 |
| | | " | 4 | 2.4 | .19 | 13 | SPRINKLER | 1"/hr | - | - | - | 70 | 3.4 | 3.5 |
| | | WALNUTS | 6 | 3.6 | .19 | 19 | FURROW | 3.0 gpm | 16 | 36 | 220 | 70 | 5.1 | 4.0 |
| | | DECIDUOUS | 6 | 3.6 | .19 | 19 | SPRINKLER | 1"/hr | - | - | - | 75 | 4.8 | 5.0 |
| ARE | | ALFALFA | 5 | 3.0 | .28 | 11 | BORDER | 3.5"/hr | 0.024 | 30 | 220 | 70 | 4.3 | .5 |
| ANDS | | " | 5 | 3.0 | .28 | 11 | SPRINKLER | 1"/hr | - | - | - | 70 | 4.3 | 4.5 |
| NY | | POTATOES | 2 | .74 | .28 | 3 | FURROW | 3.0 gpm | 16 | 16 | 100 | 70 | 1.0 | .5 |
| | | " | 2 | .74 | .28 | 3 | SPRINKLER | 1"/hr | - | - | - | 65 | 1.1 | 1.0 |
| | | | | | | | | | SLOPE GROUP 1 - 2%, (AV. - 1.5%) | | | | | |
| | | CITRUS | 4 | 2.4 | .19 | 13 | FURROW | 2.5 gpm | 6.5 | 36 | 160 | 65 | 3.7 | 3.0 |
| | | " | 4 | 2.4 | .19 | 13 | SPRINKLER | 1"/hr | - | - | - | 70 | 3.4 | 3.5 |
| | | WALNUTS | 6 | 3.6 | .19 | 19 | FURROW | 2.5 gpm | 6.5 | 36 | 160 | 65 | 5.5 | 4.5 |
| | | DECIDUOUS | 6 | 3.6 | .19 | 19 | SPRINKLER | 1"/hr | - | - | - | 75 | 4.8 | 5.0 |
| | | ALFALFA | 5 | 3.0 | .28 | 11 | BORDER | 3.5"/hr | 0.017 | 20 | 160 | 65 | 4.6 | .7 |
| | | " | 5 | 3.0 | .28 | 11 | SPRINKLER | 1"/hr | - | - | - | 70 | 4.3 | 4.5 |
| | | POTATOES | 2 | .74 | .28 | 3 | FURROW | 2.5 gpm | 6.5 | 16 | 100 | 65 | 1.1 | 0.5 |
| | | " | 2 | .74 | .28 | 3 | SPRINKLER | 1"/hr | - | - | - | 65 | 1.1 | 1.0 |
| | | | | | | | | | SLOPE GROUP 2 - 4%, (AV. - 3%) | | | | | |
| IIIsl | | CITRUS | 4 | 2.4 | .19 | 13 | FURROW | 2.0 gpm | 3.3 | 36 | 110 | 60 | 4.0 | 4.0 |
| | | " | 4 | 2.4 | .19 | 13 | SPRINKLER | 1"/hr | | - | - | 70 | 3.4 | 3.5 |
| | | WALNUTS | 6 | 3.6 | .19 | 19 | FURROW | 2.0 gpm | 3.3 | 36 | 110 | 60 | 6.0 | 5.5 |
| | | DECIDUOUS | 6 | 3.6 | .19 | 19 | SPRINKLER | 1"/hr | - | - | - | 75 | 4.8 | 5.0 |
| | | ALFALFA | 5 | 3.0 | .28 | 11 | BORDER | 3.5"/hr | 0.013 | 20 | 110 | 60 | 5.0 | 0.8 |
| | | " | 5 | 3.0 | .28 | 11 | SPRINKLER | 1"/hr | - | - | - | 70 | 4.3 | 4.5 |
| | | POTATOES | 2 | .74 | .28 | 3 | FURROW | 2.0 gpm | 3.3 | 16 | 100 | 60 | 1.2 | 0.5 |
| | | " | 2 | .74 | .28 | 3 | SPRINKLER | 1"/hr | - | - | - | 65 | 1.1 | 1.0 |
| | | | | | | | | | SLOPE GROUP 0.25 - 1%. | | | | | |
| I | IL 56 VERY DEEP | 1.4 | CITRUS | 4 | 3.4 | .18 | 19 | FURROW | 2.0 gpm | 16 | 36 | 330 | 70 | 4.9 | 5.5 |
| | SOILS THAT ARE | | " | 4 | 3.4 | .18 | 19 | SPRINKLER | .5"/hr | - | - | - | 75 | 4.5 | 9.0 |
| | LIGHT TEXTURED | 1.2 | WALNUTS | 6 | 4.4 | .19 | 23 | FURROW | 2.0 gpm | 16 | 36 | 330 | 70 | 6.3 | 7.0 |
| | WITH MODERATELY | | DECIDUOUS | 6 | 4.4 | .19 | 23 | SPRINKLER | 0.5"/hr | - | - | - | 75 | 5.9 | 12.0 |
| | RAPID PERMEABILITY | 1.3 | ALFALFA | 5 | 3.9 | .26 | 15 | BORDER | 1.5"/hr | 0.0069 | 30 | 660 | 70 | 5.6 | 2.0 |
| | TO 20 OR 30 INCHES | | " | 5 | 3.9 | .26 | 15 | SPRINKLER | .5"/hr | - | - | - | 70 | 5.6 | 11.0 |
| | AND COARSE TEX- | 1.5 | IRRIG. PAST | 3 | 2.7 | .26 | 10 | BORDER | 1.5"/hr | 0.012 | 30 | 660 | 70 | 3.9 | 0.8 |
| | TURED WITH RAPID | | " | 3 | 2.7 | .26 | 10 | SPRINKLER | .5"/hr | - | - | - | 65 | 4.2 | 8.5 |
| | PERMEABILITY IN | 1.7 | POTATOES | 2 | 1.25 | .27 | 5 | FURROW | 2.0 gpm | 16 | 16 | 220 | 70 | 1.8 | 1.5 |
| | THE LOWER PART. | | " | 2 | 1.25 | .27 | 5 | SPRINKLER | .5"/hr | - | - | - | 65 | 1.9 | 4.0 |
| | SOME HANFORD AND | | | | | | | | | | | | | |
| | MORENO SANDY | | | | | | | | | | | | | |
| | LOAMS ARE LIKE THIS. | | | | | | | | | | | | | |
| | | | | | | | | | SLOPE GROUP 1 - 2%, | | | | | |
| IIel | | 1.4 | CITRUS | 4 | 3.4 | .18 | 19 | FURROW | 1.5 gpm | 6.5 | 36 | 220 | 65 | 5.2 | 6.5 |
| | | | " | 4 | 3.4 | .18 | 19 | SPRINKLER | .5"/hr | - | - | - | 75 | 4.5 | 9.0 |
| | | 1.2 | WALNUTS | 6 | 4.4 | .19 | 23 | FURROW | 1.5 gpm | 6.5 | 36 | 220 | 65 | 6.8 | 8.5 |
| | | | DECIDUOUS | 6 | 4.4 | .19 | 23 | SPRINKLER | 0.5"/hr | - | - | - | 75 | 5.9 | 12.0 |
| | | 1.3 | ALFALFA | 5 | 3.9 | .26 | 15 | BORDER | 1.5"/hr | 0.0054 | 20 | 660 | 70 | 5.6 | 2.5 |
| | | | " | 5 | 3.9 | .26 | 15 | SPRINKLER | .5"/hr | - | - | - | 70 | 5.6 | 11.0 |
| | | 1.5 | IRRIG. PAST | 3 | 2.7 | .26 | 10 | BORDER | 1.5"/hr | 0.0094 | 20 | 440 | 70 | 3.9 | 1.0 |
| | | | " | 3 | 2.7 | .26 | 10 | SPRINKLER | 0.5"/hr | - | - | - | 65 | 4.2 | 8.0 |
| | | 1.7 | POTATOES | 2 | 1.25 | .27 | 5 | FURROW | 1.5 gpm | 6.5 | 16 | 160 | 65 | 1.9 | 1.0 |
| | | | " | 2 | 1.25 | .27 | 5 | SPRINKLER | .5"/hr | - | - | - | 65 | 1.9 | 4.0 |
| | | | | | | | | | SLOPE GROUP 2 - 4%. | | | | | |
| IIel | | 1.4 | CITRUS | 4 | 3.4 | .18 | 19 | FURROW | 1.0 gpm | 3.3 | 36 | 160 | 60 | 5.7 | 11.0 |
| | | | " | 4 | 3.4 | .18 | 19 | SPRINKLER | .5"/hr | - | - | - | 75 | 4.5 | 9.0 |
| | | 1.2 | WALNUTS | 6 | 4.4 | .19 | 23 | FURROW | 1.0 gpm | 3.3 | 36 | 160 | 60 | 7.3 | 14.0 |
| | | | DECIDUOUS | 6 | 4.4 | .19 | 23 | SPRINKLER | .5"/hr | - | - | - | 75 | 5.9 | 12.0 |
| | | 1.3 | ALFALFA | 5 | 3.9 | .26 | 15 | BORDER | 1.5"/hr | 0.004 | 20 | 440 | 65 | 6.0 | 3.5 |
| | | | " | 5 | 3.9 | .26 | 15 | SPRINKLER | .5"/hr | - | - | - | 70 | 5.6 | 11.0 |
| | | 1.5 | IRRIG. PAST | 3 | 2.7 | .26 | 10 | BORDER | 1.5"/hr | 0.0074 | 20 | 330 | 65 | 4.2 | 1.5 |
| | | | " | 3 | 2.7 | .26 | 10 | SPRINKLER | .5"/hr | - | - | - | 65 | 4.2 | 8.0 |
| | | 1.7 | POTATOES | 2 | 1.25 | .27 | 5 | FURROW | 1.0 gpm | 3.3 | 16 | 100 | 60 | 2.1 | 1.5 |
| | | | | 2 | 1.25 | .27 | 5 | SPRINKLER | .5"/hr | - | - | - | 65 | 1.9 | 4.0 |
| | | | | | | | | | SLOPE GROUP 0.25 - 1%. | | | | | |
| I | IL 5 VERY DEEP | 1.7 | CITRUS | 4 | 4 | .17 | 23 | FURROW | 2.0 gpm | 16 | 36 | 330 | 70 | 5.7 | 6.5 |
| | SANDY LOAM SOILS | | " | 4 | 4 | .17 | 23 | SPRINKLER | .5"/hr | - | - | - | 75 | 5.3 | 10 |
| | WITH GRANULAR TO | | WALNUTS | 6 | 6 | .18 | 33 | FURROW | 2.0 gpm | 16 | 36 | 660 | 70 | 8.6 | 9.5 |
| | MASSIVE STRUCTURE | | DECIDUOUS | 6 | 6 | .18 | 33 | SPRINKLER | .5"/hr | - | - | - | 75 | 8.0 | 16 |
| | AND A UNIFORM | | ALFALFA | 5 | 5 | .25 | 20 | BORDER | 1.5"/hr | 0.0043 | 30 | 660 | 70 | 7.1 | 3.5 |
| | MODERATELY RAPID | | " | 5 | 5 | .25 | 20 | SPRINKLER | .5"/hr | - | - | - | 70 | 7.1 | 14.0 |
| | PERMEABILITY. | | IRRIG. PAST | 3 | 3 | .25 | 12 | BORDER | 1.5"/hr | 0.0092 | 30 | 660 | 70 | 4.3 | 1 |
| | HANFORD, MORENO, | | " | 3 | 3 | .25 | 12 | SPRINKLER | .5"/hr | - | - | - | 70 | 4.3 | 9.0 |
| | OR YOLO SANDY | | POTATOES | 2 | 1.25 | .27 | 5 | FURROW | 2.0 gpm | 16 | 16 | 220 | 70 | 1.8 | .9 |
| | LOAM | | " | 2 | 1.25 | .27 | 5 | SPRINKLER | .5"/hr | - | - | - | 65 | 1.9 | 4.0 |

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