

Conservation irrigation of field crops: a drought-year strategy

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Through careful preplant planning, the grower can make maximum use of a limited supply of water.

To make the most efficient use of limited water supplies in the production of field crops, a sequence of key decisions must be made before planting. These decisions are particularly important in a drought year such as 1977 in California.

The decisions are:

1. Selection of crop types and varieties.
2. Priority ranking of fields for planting, based on soil characteristics and irrigation methods.
3. Calculation of initial soil refill and growing-season irrigation requirements.
4. Determination of crop acreages to be planted.
5. Irrigation scheduling.

These preplant planning decisions are the basis for "conservation irrigation"—defined as the highly efficient use of limited water supplies in a system designed to achieve approximately 85 percent of the maximum possible yield. Conservation irrigation is made possible by University of California research findings on crop water use throughout the past decade. This article outlines procedures that may be used

to make the key preplanting decisions with a reasonable degree of confidence.

Crop and variety selection

The grower, taking into consideration his producing, handling, and marketing capabilities, should select crops and varieties with short growing seasons (i.e., reduced seasonal water requirements), high yield capability in the area, and recognized drought resistance.

Table 1 gives water-requirement and yield information on six major Central Valley crops and specifies yield goals that are 85 percent of maximum. Although the yield goals are still high by most standards, they are attainable with the irrigation guidelines presented here. This means that, if yields, under normal irrigation conditions, are lower than the goals shown in table 1, some factor other than water is limiting, and little or no further drop in yield would be expected from the procedures described for cutting back on water normally applied.

Values in this and the following tables result directly or

are derived from research on crop water use throughout the years 1969-1976 by the author and colleagues. Figures given here are conservative averages and/or approximations reflecting results of field trials on each of the crops listed. They are, of course, subject to some variation under specific circumstances.

Ranking fields for planting

Conservation irrigation aimed at 85 percent yields means there will be some crop water stress. The more water the soil can store in the root zone, the less intense the stress and the less the yield loss. In ranking fields for order of planting, consider soil depth, texture, salinity level, and irrigation method. A further important soil factor is good internal drainage. A well-drained soil means improved soil aeration and more rapid crop growth, so fields otherwise equal may be selected on this basis.

Assuming good drainage, the best soils for conservation irrigation are of low salinity, have a heavy loam or clayey texture, and are deep. Table 2 shows estimates of "crop extractable water" (CEW) that can be stored in soils of different depths and textures. Every crop in table 1 can extract the quantities of water listed in table 2—and some even more.

In designating fields for planting, efficiency of the method of irrigation also must be considered. The important factors are: (1) how evenly the irrigation system can spread water over the field without runoff, and (2) how small the quantity or depth of water it can spread evenly. The more even the spread and the smaller the depth the system can apply, the higher the potential for effective conservation irrigation. Most surface irrigation systems, however, can readily be made more effective by shortening runs of furrows or borders or by reducing basin sizes. Also, slopes can often be reduced by redirecting furrows, borders, or basins.

To achieve the potential of the irrigation system, the grower must understand the water needs of his crop and the ever-changing water status of his soil, and irrigate accordingly.

Calculating irrigation requirements (Initial soil refill)

Irrigation requirements for initial soil refill are based on different considerations than are growing-season requirements, which are crop specific. For initial soil refill, four factors are important—the crop extractable water the soil can hold (table 2); the degree to which the last crop in the field was irrigated; the effectively stored off-season rainfall; and the irrigation storage efficiency. A simple formula for computing the water needed to refill the profile follows:

$$\text{Irrigation requirement for initial soil refill (inches, or acre-inches/acre)} = \frac{(\text{CEW} \times \text{ILC}) - \left(\frac{\text{ROS}}{2} - 1\right)}{\text{IRR STOR EFF}}$$

Where:

CEW = crop extractable water (table 2).

ILC = irrigation of the last crop. This is a factor that reduces CEW if there is residual soil water. Use these figures:

- If the previous crop was fully irrigated: 0.6
- If it was moderately irrigated: 0.8
- If it was very little irrigated: 1.0

ROS = inches of rainfall effectively stored in the soil since harvest of the previous crop. (It is assumed that weeds have not been allowed to flourish.)

IRR STOR EFF = irrigation storage efficiency, or the fraction of applied water remaining in the root zone after refilling. Use these figures:

- If irrigating by drip or sprinklers: 0.8
- If by short furrows or borders or small basins: 0.7
- If by long furrows or borders or large basins: 0.6

Calculating irrigation requirements (growing season)

Growing-season irrigation requirements are based on: crop type; the yield fraction established as a goal; rainfall expected during the growing season; and the irrigation use efficiency. The formula for computing these requirements is as follows:

$$\text{Irrigation requirement during the growing season (inches, or acre-inches/acre)} = \frac{\text{ET } 0.85\text{Y} - \text{CEW} - \text{R } 0.90}{\text{IRR USE EFF}}$$

Where:

ET 0.85Y = the actual crop water (evapotranspiration, or ET) requirement to attain a yield level 85 percent of maximum. Expressed as depth of water in inches, and shown in table 1 for Central Valley conditions.

CEW = crop-extractable water.

R 0.90 = rainfall expected during the growing season with a 90 percent certainty, i.e., the minimum inches of rainfall expected in 9 out of 10 years. This is usually zero for summer crops in the Central Valley.

TABLE 1. WATER REQUIREMENTS, MAXIMUM YIELDS, AND YIELD REDUCTION RATIOS OF MAJOR FIELD CROPS IN THE CENTRAL VALLEY

Crop	Under normal field conditions			Conservation irrigation—85% of maximum		
	Crop water requirement (ET) inches	Maturity (emergence to maturation) days	Maximum yield per acre	Yield goal per acre	Yield reduction ratio*	Actual crop water requirement to attain yield goal inches
Alfalfa	47	210	9.4 tn	8.0 tn	1.0	40.0
Cotton	30	160	3 bales	2.5 bl	1.25	26.4
Corn	25	113	10,000 lb	8,500 lb	1.25	22.0 [†]
Grain sorghum	22	113	8,000 lb	6,800 lb	1.0	18.7
Pinto beans	20	97	3,600 lb	3,000 lb	2.35	18.7
Pink beans	16	96	3,600 lb	3,000 lb	2.1	14.9

* Yield reduction ratio, or index of relative drought resistance, is defined as the percentage of yield loss expected as a result of a 1 percent crop water (evapotranspiration, or ET) deficit. For example, corn, with a 10 percent crop water deficit, is expected to produce a yield 12.5 percent below maximum. However, relative drought resistance is not the only factor to consider when selecting among crops, even in a water-short year. For example, grain sorghum is significantly more drought resistant than corn, but, at the 85 percent yield level, corn uses water more efficiently—provided the extra water required per acre and recommended irrigation sequences for corn can be followed. Otherwise, grain sorghum might well be the better choice.

[†] Figure used in text in an example based on planning a conservation-irrigation program for corn production.

TABLE 2. CROP EXTRACTABLE WATER (CEW) THAT CAN BE STORED IN SOILS OF DIFFERENT TEXTURES AND DEPTHS

Soil depth feet	Soil texture		
	Clay, clay loam, silty clay loam, or silt loam	Loam or sandy loam	Loamy sand or sand
1	Not feasible to farm such shallow soils using conservation irrigation principles; plant stress would be too intense.		
2			
3	5.50	4.50	
4	7.25	5.75	
5	9.00	7.00*	4.00
6	10.50	8.00	4.50
7	12.00	9.00	5.00

* Figure used in corn production example.

IRR USE EFF = irrigation use efficiency, or the fraction of water applied in the growing season that the crop actually uses in evapotranspiration. It takes into account crop rooting characteristics, crop responses to salt levels in the irrigation water, irrigation method, and the fact that the crop is being somewhat under-irrigated. Table 3 shows suggested efficiencies for the different crops and irrigation methods (for waters with total salts up to 1,000 ppm).

Calculating irrigation requirements (hypothetical example)

Corn is to be produced at a yield level of 8,500 pounds per acre in the Central Valley on a loam soil with a hardpan at the 5-foot depth. Irrigation will be by short furrows, and the last crop was moderately but not fully irrigated. Rainfall since the last harvest has been 6 inches. No rainfall is expected in the corn growing season.

$$\begin{aligned} \text{Total irrigation requirement (inches)} &= \frac{(\text{CEW} \times \text{ILC}) - \left(\frac{\text{ROS}}{2} \cdot 1\right)}{\text{IRR STOR EFF}} + \frac{\text{ET } 0.85 \text{ Y} - \text{CEW} \cdot \text{R } 0.90}{\text{IRR USE EFF}} \\ &= \frac{(7.0 \times 0.8) - \left(\frac{6}{2} \cdot 1\right)}{0.7} + \frac{22.0 \cdot 7.0 \cdot 0}{0.75} \\ &= 5.1 + 20.0 = \underline{25.1 \text{ inches}}, \text{ or acre-inches per acre } \end{aligned}$$

Crop acreages to be planted

Having determined that the conservation irrigation requirement to grow an 85 percent corn crop is 25.1 acre-

inches per acre (or 2.1 acre-feet per acre) divide this figure into your total water supply to determine the acreage to plant. For example, suppose you have 400 acres of land and a water allocation of 1 acre-foot per acre, or a total allocation of 400 acre-feet. Divide 400 by 2.1 acre-feet per acre: your water supply is sufficient to irrigate 190 acres. Note that, if your present corn yield level does not exceed 8,500 pounds per acre a program of conservation irrigation may not reduce your normal yield per planted acre.

Irrigation scheduling (initial soil refill)

Conservation irrigation requires unhindered root growth, with attendant maximum ability to extract stored soil water. For such root growth, the soil profile must be refilled to field capacity early in the season before roots would normally penetrate. In the upper soil, this means before germination; in the subsoil, either then or not long thereafter. Refill may be accomplished by off-season rainfall alone, or in combination with preirrigation.

Scheduling the initial soil refill depends on the method of irrigation and on whether or not a germination irrigation will be required. For each irrigation system there is a minimum depth of water that can be effectively distributed over the field. With drip or sprinkler systems the minimum may be 1 inch or less, but with long furrows or borders it may be 4 inches or more.

If your system's minimum application depth is large, the first irrigation in the regular growing season may be quite wasteful, because crop water use up to that time is not rapid. Therefore, you may choose to limit the depth of the preirrigation to the minimum your irrigation system allows, and finish the initial soil refill with the excess water your system requires you to apply in the first growing season irrigation. The same principle applies if a germination irrigation is required. As a

TABLE 3. IRRIGATION USE EFFICIENCIES FOR GROWING SEASON IRRIGATION OF FIELD CROPS USING DIFFERENT IRRIGATION METHODS, WITH A YIELD GOAL 85 PERCENT OF MAXIMUM

Crop	Irrigation method		
	Drip or sprinkler	Short furrows or borders, or small basins	Long furrows or borders, or large basins
Alfalfa	0.90	0.85	0.80
Cotton	.95	.90	.85
Corn	.80	.75*	.70
Grain sorghum	.90	.85	.80
Pinto beans	.75	.70	.65
Pink beans	.75	.70	.65

* Figure used in corn production example.

TABLE 4. INFORMATION NEEDED FOR CONSERVATION IRRIGATION SCHEDULING DURING THE GROWING SEASONS OF SELECTED CENTRAL VALLEY FIELD CROPS GROWN ON SOILS OF DIFFERING DEPTHS AND TEXTURES

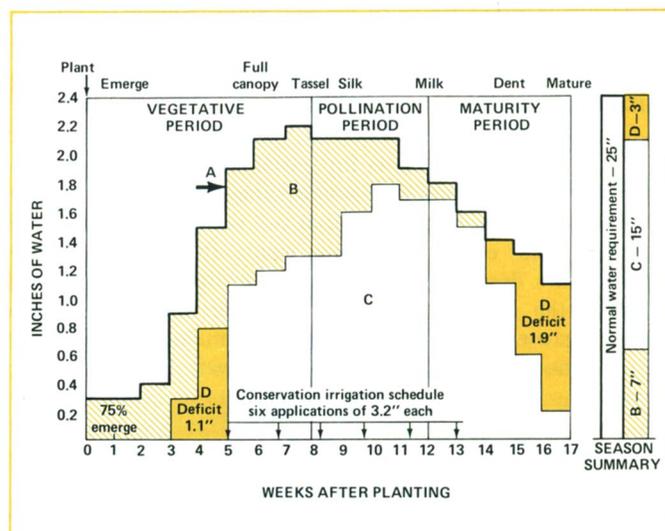
Crop type*	Soil depth feet	Soil texture											
		Clay, clay loam, silty clay loam, or silt loam				Loam or sandy loam				Loamy sand or sand			
		First irr. [†]		Season [‡]		First irr. [†]		Season [‡]		First irr. [†]		Season [‡]	
		weeks	inches	weeks	inches	weeks	inches	weeks	inches	weeks	inches	weeks	inches
Cotton	7	7	3	9	5	2	11	4	1.5	14			
	5	7	3	11	5	2	13	4	1.5	15			
	3	7	3	13	5	2	15						
Corn	7	5	6	6	4	4	7	3	2.5	9			
	5	5	6	7	4**	4**	8**	3	2.5	10			
	3	5	6	8	4	4	9						
Grain sorghum	7	3	2	6	3	2	7	3	2	9			
	5	3	2	7	3	2	8	3	2	10			
	3	3	2	8	3	2	9						
Pinto beans	7	4	5	6	3	3.5	7	2	2	9			
	5	4	5	7	3	3.5	8	2	2	10			
	3	4	5	8	3	3.5	9						
Pink beans	7	3	3	7	2	2	8	2	2	9			
	5	3	3	8	2	2	9	2	2	10			
	3	3	3	9	2	2	10						

* Maturities as shown in table 1.

[†] Timing and depth of the first irrigation. Suggested timing is in weeks after 75 percent emergence. Depth (inches) is the maximum usefully applied unless also finishing initial soil refill.

[‡] Irrigation season length.

** Figure used in example in text.



Expected water use by hypothetical corn crop used as an example in the text to illustrate a conservation-irrigation program aimed at 85 percent of maximum possible yield. (A) 25 inches: normal water requirement (evapotranspiration) of medium-maturity corn in the Central Valley. (B) 7 inches: water extractable by corn from a preirrigated loam soil 5 feet deep. (C) 15 inches: water that will be supplied by conservation irrigation during the growing season. (D) 3 inches: crop water deficit expected in conservation irrigation aimed at 85 percent of maximum possible yield.

rule of thumb in the latter case, you may figure that the actual water needed to rewet the seedbed for germination will seldom exceed 1.5 inches, and more likely will be around 1 inch.

Returning to the example in which the initial soil refill irrigation requirement was 5.1 inches, suppose your short furrow system can evenly distribute a minimum application of 3 inches, and a germination irrigation will be required. It would be wasteful to preirrigate with 5.1 inches and then follow up with a 3-inch germination irrigation. It would be a better choice to preirrigate with 3 inches, and finish filling the profile with the germination irrigation.

Irrigation scheduling (growing season)

The procedure recommended is to set the dates of the first and last irrigations, then to distribute the water evenly in time between these dates. The number of irrigations, and therefore the frequency of irrigation, will depend on the minimum depth your system can evenly distribute and on the total depth to be applied during the irrigation season. In our corn production example this total depth is 20 inches.

The first growing season irrigation date depends on crop type and soil texture, i.e., soil water-holding capacity. Timing of the final irrigation depends on the same factors plus soil depth. The more shallow the soil, the later the final irrigation. Together, these dates determine the length of the irrigation season. Table 4 suggests reasonable timings of first irrigations and lengths of irrigation seasons for crops grown on soils of differing depths and textures.

Alfalfa is not included in table 4, because it is harvested repeatedly through the growing season and responds differently to water in different parts of the season. Briefly, the water-use efficiency of alfalfa is high in spring, medium in summer, and low in fall. Therefore, when water is short, alfalfa should be irrigated normally from the beginning of growth in the spring until your water supply is exhausted. At that time the crop will go dormant, but it should rejuvenate itself almost fully when water is again available.

Grain sorghum and corn need to establish a secondary root system for high production. These roots begin fairly close to the soil surface about 3 weeks after emergence, when the upper soil may have dried considerably by evaporation. For these crops, it is important to make sure that the dried layer does not prohibit the new roots from reaching the moist soil a few inches below. This is more often a problem with grain sorghum than with corn; hence table 4 calls for the first growing season irrigation of sorghum only 3 weeks after emergence.

The problem can also be serious in corn, however, and is most likely to occur in clay-type soils with a cloddy seedbed. In such an instance, the first irrigation of corn should be applied at 3 weeks after emergence, rather than the 5 weeks shown in table 4.

Determining number and frequency of growing-season irrigations

The conservation-irrigation schedule determines exactly when the plant stresses will occur. Research shows that the least damage to yield will result when the stress is distributed throughout the season—or at least not concentrated in one period. In table 4, both the timing of the first irrigation and the length of the irrigation season have been planned to allow

some plant stress at the beginning and some at the end of the growing season.

On many soils, some stress will also occur during the irrigation season. To minimize its effect, irrigate frequently with small amounts of water and at evenly spaced time intervals. (An example of how to calculate your frequency and application depth follows.) When scheduling irrigations, keep in mind that: (1) the crop water needs are nearly the same in each week of the irrigation season as given in table 4, although they tend downward in the latter weeks; and (2) leaf cover is essentially full throughout the irrigation season, so there is no need to worry about evaporation losses due to frequent irrigation. Research shows such losses from a crop fully leafed out are not influenced by frequency of soil wetting.

Returning to our corn production example, scheduling would be done as follows. The total water allocation was 25.1 acre-inches per acre, and we will assume 6 inches have been applied in the preirrigation and germination irrigation as previously suggested, leaving 19.1 inches for the growing season. Table 4 shows that on our 5-foot-deep loam soil the first irrigation should be applied 4 weeks after emergence, it should be no greater than 4 inches of water, and the final irrigation is to be applied 8 weeks later.

The number of irrigations is calculated as follows:

$$\text{Number of irrigations (N)} = \frac{\text{Irrigation season water supply (inches)}}{\text{Minimum depth system can effectively apply (inches)}}$$

For the corn production example:

$$N = \frac{19.1 \text{ inches}}{3.0 \text{ inches}} = 6 \text{ irrigations @ 3.2 inches each}$$

Note that the final irrigation of the season has its influence after the end of the irrigation season as defined in table 4. Therefore N-1 irrigations are used to calculate irrigation frequency as follows:

$$\text{Irrigation frequency (days)} = \frac{\text{Weeks in irrigation season} \times 7}{N - 1}$$

For the corn production example:

$$\text{Irrigation frequency} = \frac{8 \times 7}{6 - 1} = \frac{56}{5} = \text{approximately 11 days}$$

The graph shows seasonal water use by the hypothetical corn crop, using this irrigation schedule.

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