Microcomputer program ACRE helps answer . . .

When water is limited, how many acres do you plant?

Richard L. Snyder

Drought-stressed corn showing curled leaf response.

A microcomputer program, ACRE, calculates the number of acres of field and row crops to plant, given a limited water supply. Inputs include crop water balance parameters and the anticipated supply of irrigation water. This program is useful for determining how many acres to plant when the goal is to avoid the kind of water stress that impairs marketable production of a crop.

Insufficient water supplies can decimate an irrigated crop. As water becomes scarce, the first management step is to evaluate and improve the irrigation system to attain maximum application efficiency and avoid deficit irrigating. Application efficiency (AE) is the ratio of applied water (AW) stored in the crop root zone to the total water applied. Reducing surface runoff and distributing water more evenly improves AE and decreases the total depth of AW per acre needed to refill the soil. Water can then be distributed over more acres.

Irrigation regimes

Full irrigation. The terms *full irrigation* and *deficit irrigation* refer to irrigation applications where the goals, respectively, are to refill and not to refill the crop root zone to field capacity. The ACRE program assumes full irrigation when determining acres to plant. When full irrigation is employed, applied water (AW) is predetermined, using soil water depletion (D_W) before irrigation and application efficiency (AE) from previous system evaluations as:

$$AW = D_W \div AE \qquad (1)$$

where AW and D_W are in inches and AE is expressed as a fraction. Calculating AW with Eq. 1 ensures that (a) the mean depth of water infiltrating the low quarter equals D_W and (b) soil water content returns to near field capacity in 87.5% of the field. The low quarter is that quarter (25%) of the field infiltrating the least water. When applications are properly timed and full irrigation is employed, crop water stress is minimized and the crop normally accumulates the maximum (potential) seasonal evapotranspiration (P_{ET}).

Good irrigation scheduling is important to acreage planning; its goal is to determine when and how much water to apply for optimal production. For most crops, marketable production is optimized by supplying sufficient water to avoid plant water stress. Exceptions include cotton, sugar beets and processing tomatoes. Recent work by D. W. Grimes, water scientist at UC's Kearney Agricultural Center, shows optimal cotton production occurs when moderate water stress reduces seasonal crop evapotranspiration (ET_S) less than P_{ET}. Similarly, there is evidence that moderate water stress during late season increases the sugar content of sugar beets and increases soluble solids in processing tomatoes. In these three crops — cotton, sugar beets and tomatoes — moderate water stress improves product quality and growers often get higher prices.

Planning the number of acres to plant involves careful assessment of irrigation scheduling using a water balance procedure. Irrigations are timed to avoid stress or to achieve a specific level of plant water stress. Soil water is depleted by evapotranspiration and is replaced mainly by irrigation. However, sources of water, in addition to irrigation, include contributions from (1) stored soil water, (2) effective rainfall, (3) shallow water tables and (4) plant interception of fog. In many cases, ignoring these other sources of water leads to inaccurate scheduling and overirrigation.

Water stored in the soil from the previous season or from off-season rainfall can contribute to crop water use. The amount supplied equals the difference between the preseason and end-of-season soil water contents. The difference is referred to as preseason usable water in the ACRE program. For efficient irrigation planning, preseason soil water content should be measured and a desired end-of-season soil water content identified to calculate preseason usable water.

Rainfall contributions (effective rainfall) can be a significant source of water for evapotranspiration of winter crops in California. Discussing methods to estimate effective rainfall is beyond the scope of this article. Simply stated, effective rainfall is the portion of rainfall that is stored in the crop root zone or coats the plants during the cropping season.

Contributions from shallow water tables are site-specific, depending on water table depth, crop rooting, soil characteristics and water quality. Water table contributions to crop water needs can be large, and ignoring them can lead to significant errors in irrigation scheduling.

Plant interception of fog by crops grown in coastal areas and interception by winter cereals can be appreciable. Water gained by plant interception of fog has been observed to contribute more water to a crop than is lost on some days. Evaporation of intercepted fog reduces the energy available for transpiration and, therefore, soil water extraction. D_W is overestimated in foggy areas when interception is not considered.

Deficit irrigation. In deficit irrigation, the depth of water infiltrated into the low quarter is less than D_W. This leads to a decline in mean soil water content and an increase in spatial variability of soil water content throughout the field. Declining soil water content can cause water stress, reduced ET_S and lower yield. However, spatial variability of water stress makes it difficult to estimate the effects of deficit irrigation on crop yield.

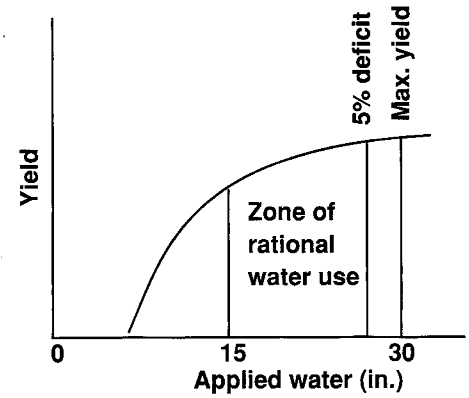

Fig. 1. Relationship between absolute yield of cotton and applied water, showing a zone of rational water use.

Yield predictions are often based on correlations between yield and ET_s rather than on deterministic relationships between yield and quantifiable plant water stress. This in itself presents a problem when employing deficit irrigation to stretch limited water supplies over more acreage. Furthermore, uneven application of irrigation water complicates the use of production functions for planning acres to plant. In full irrigation, applied water is determined using Eq. 1 to ensure that 87.5% of the field receives a depth of water exceeding D_W. When a crop is deficit irrigated, less water is applied and the percentage declines. Portions of the field receiving a depth equal to or greater than D_W are expected to attain maximum production, and the deficit irrigated parts may exhibit yield reductions. Because of this spatial variability, deficit irrigating results in a curvilinear relationship between yield and applied water (AW).

The previously mentioned Grimes research identified the relationship in figure 1 to show that a rational range of AW exhibits little loss in cotton productivity. This relationship results from uneven deficit irrigation application that leads to spatial variability of water stress. Water stress can reduce absolute yield and ET_s, but many interacting physical and biological factors determine the level of water stress. Some of these factors include: (1) crop ability to avoid water stress, (2) crop ability to tolerate water stress, (3) spatial variability in soil water content, (4) soil fertility, (5) crop root distribution, (6) water tables, (7) evaporative demand, (8) irrigation frequency, (9) irrigation distribution uniformity, (10) irrigation water quality and (11) pests. Clearly, predicting yield is complex.

During extreme drought conditions, deficit irrigation may be employed to further stretch water supplies. The influence on yield may be small for deep-rooted, drought-tolerant crops grown on soils with high water-holding capacity; however, deficit irrigation is not recommended for most high-value, fresh market fruit and vegetable crops.

ACRE - drought acreage planning program

Sources	inches
Preseason usable water	4.0
Water table	0.0
Fog	0.0
Effective rainfall	1.0
Applied water	27.5
Total sources	32.5
Losses	**inches**
Crop-water requirement (ET_s)	27.0
Application losses (assuming 80% seasonal efficiency)	5.5
Total losses	32.5
Irrigation water available	**acre-feet**
Water for irrigation	1,000
Acres to plant	437
Esc - exit program	P - print on paper

Fig. 2. Simulated computer screen display from the ACRE program.

ACRE program's purpose

The ACRE program simplifies and organizes procedures to estimate the number of acres to plant, based on irrigation water supply. Necessary input variables include seasonal crop evapotranspiration (ET_s), application efficiency (AE) and water supply. Possible additional input variables include usable preseason stored soil water, effective rainfall, water table contributions and/or fog interception. In some cases, these additional input variables can be overlooked; however, in other cases, ignoring them leads to serious miscalculations of irrigation water needs. Assuming the mean depth of water applied to the low quarter is equal to D_W, the ACRE program accounts for all possible water sources to more accurately assess irrigation water needs.

Water balance calculations

The amount of acreage to plant depends on a balance between the quantity of water supplied from all sources and expected water losses from the irrigated field. Sources of water include:

Preseason usable water	(U_c)
Water table contribution	(T_c)
Fog contribution	(F_c)
Rainfall contribution	(R_c)
Applied water	(AW)

Losses of water from an irrigated field include:

Crop water requirement	(ET_s)
Application losses	(A_l)

where crop water requirement is the seasonal cumulative crop evapotranspiration that results in the highest marketable yield. Application losses are calculated from D_W and AE from a previous irrigation system evaluation as:

$$A_l = AW - D_W = (D_W \div AE) - D_W \quad (2)$$

The total of all water sources must equal the total of all losses. Rearranging terms, the AW requirement is calculated as:

$$AW = (ET_s + A_l) - (U_c + T_c + F_c + R_c) \quad (3)$$

where all the variables are entered in inches. For example, given the following data:

Variable		Inches
ET_s	=	27.0
U_c	=	4.0
T_c	=	0.0
F_c	=	0.0
R_c	=	1.0

depletion of soil water to be replaced by irrigation is:

$$D_W = 27.0 - (4.0 + 0 + 0 + 1.0) = 22.0$$

application losses, assuming an AE of 0.8, are:

$$A_I = (22.0 \div 0.8) - 22.0 = 5.5$$

and AW needed for the season is:

$$AW = (27.0 + 5.5) - (4.0 + 0 + 0 + 1.0) = 27.5 \text{ inches}$$

Sources of information on how to estimate water supplied by preseason usable water, water tables, fog interception and rainfall are included in the user's guide for the ACRE program.

Acres to plant

Deciding on how many acres to plant depends on the AW needed for production and the quantity of irrigation water supplied during a season. Water quantities are typically expressed in acre-feet, so the depth of applied water in inches is first divided by 12 to convert to acre-feet per acre. For example, 27.5 inches of water equals 27.5 ÷ 12 = 2.29 acre-feet per acre. Acreage to plant is calculated as the acre-feet of water supplied divided by the acre-feet per acre of AW needed to produce the crop. In our example, if 1,000 acre-feet of water are supplied by a water district and/or pumping ground water, acres to plant are calculated as:

$$\text{Acres to plant} = 1{,}000 \div 2.29 = 437$$

Acreage planning with ACRE

ACRE, a user-friendly program, displays a single screen for data entry and output. Sources of water, the crop water requirement, AE and water supplied for irrigation can be entered and/or edited on the computer screen. A value of zero can be entered for sources of water that are insignificant or unknown. However, ignoring significant sources of water can lead to overestimating water needs and underestimating acres to plant. AE is used to calculate application losses from the water balance. An example of the output using the sample data presented earlier is shown in figure 2. Using these data, 437 acres should be planted.

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The ACRE program is written in compiled QuickBasic by Microsoft, Inc. for IBM compatible MS DOS computers. For further information about the ACRE program, write: R. L. Snyder, Biometeorologist, University of California, Department of Land, Air and Water Resources, Davis, California 95616.

Dry polymer crystals on the left contrasted with same crystals after 130 ml of water have been added.

A greenhouse experiment finds . . .

Water-sorbing polymers do not conserve water

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To assess claims that water-sorbing polymers promote water conservation, a greenhouse experiment with container-grown marigolds was conducted to determine the effect of adding the polymers to soil mix. Plant growth and water retention in 1- and 3-quart containers were not particularly affected, but in the 6-quart size, maximum water retention was significantly higher for the 4 lb/yd³ polymer treatment than for the other treatments, and the time from watering to wilt progressively increased from 6.1 to 7.4 days for the 0, 1, 2 and 4-lb/yd³ treatments. However, no water conservation occurred because evapotranspiration was not significantly affected by the polymer treatment.

As a result of the drought in California, various products have been suggested to promote water conservation, including commercially produced water-sorbing polymers that can absorb hundreds of times their weight in water. The claim is that incorporating these polyacrylamide polymer granules in the soil results in increased retention of large quantities of water that become available for plant growth.

The difference between amounts of water retained by treated and untreated soils depends on soil texture, soil structure and the salinity of both soil and water. Untreated soil media itself is capable of retaining large quantities of water; the greatest increase in water retention by polymer treatment can be expected in media containing large pores.

Promotion of polymers as water conserving received a major boost by one large California water district noted for effectively educating the public and promoting water conservation. The district distributed packets containing a sample of polyacrylamide polymer granules. The packet's label carried the following message:

> How to save water without even trying. This package of 'polyacrylamides' can help you save water, and make caring for your plants easier at the same time. The little beads inside attract and hold water up to 10 times longer than soil alone. Simply mix into the soil of a 6-inch potted plant, and water once. You shouldn't have to water again for 2 to 3 weeks. Using polyacrylamides in all your pots and garden areas can reduce your watering needs by 60% or more! They are available in larger quantities at your nursery.

Greenhouse experiment

An experiment was conducted in the greenhouse on potted plants in three container sizes to check the validity of the claims. The containers were 5 inches in diameter by 5 inches high, 6 inches in diameter by 7 inches high, and 8 inches in diameter by 9 inches high. Approximate volumes of these containers were 1, 3 and 6 quarts. The potting mix consisted of 50%