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Drought Tip

Field Irrigation Water Management in a Nutshell

DANIELE ZACCARIA, UC Cooperative Extension Specialist in Agricultural Water Management, University of California, Davis

Introduction

Effective irrigation management at field level requires farmers and irrigators to know the relationships between the flow rate being delivered onto the field, the acreage being irrigated, the duration of irrigation (set time), and the total amount of irrigation water needed relative to that applied. All these parameters should be combined in a way so each irrigation can replenish the water used by the crop since the previous irrigation or rain event, while avoiding water deficit to plants and/or excessive water applications relative to the soil intake rate and total water-holding capacity in the root zone. These criteria are generally valid except when farmers follow deficit irrigation strategies during certain stages of the crop cycle, or when salt leaching is needed through irrigation to maintain the root zone salinity at acceptable levels for optimal crop growth, health, and production. With over-applications, water moves off the field by runoff or downward into the soil profile below the root zone where plant roots cannot eventually reach it. Detailed information about leaching practices is available in UC ANR Drought Tip *Managing Root Zone Salinity in a Drought Year* (UC ANR Publication 8550).

Relationships between Irrigation Parameters

The relationships between the above-indicated irrigation parameters are generally valid for all irrigation methods, and they are particularly relevant during periods of limited water supply to achieve high irrigation efficiency and minimize water losses from irrigated fields.

This publication illustrates how to use a few helpful equations to answer practical questions related to field irrigation management decisions. Examples and key points are presented in the sections below to show their application to, and illustrate how they can give insights about, the sufficiency and efficiency of an irrigation event.

Question A) What is the maximum water depth that should be applied during an irrigation?

The maximum gross irrigation depth ($D_{G\,MAX}$) in inches that should be applied for an efficient irrigation event can be calculated using equation 1:

$$D_{G\,MAX} = [(MAD \div 100) \times W_a \times Z] \div Eff_A \qquad (1)$$

where:

MAD = management allowable depletion (%), which is the maximum percentage of water available to plants that the irrigation manager allows to be extracted (depleted) from the soil root zone before irrigation should occur. MAD is a recommended threshold of soil water depletion that should not be exceeded in order to prevent occurrence of water deficit to plants. Usually, the recommended values of MAD range between 30 and 50 percent of total soil available water, with the lower value for shallow-rooted crops and the higher value for deep-rooted crops.

W_a = available water-holding capacity (inches of water per foot of soil depth) of the soil being irrigated

Z = root depth (feet), that is, the soil depth where the water-uptake roots are located

Eff_A = application efficiency (percent) of the irrigation method and system used

Average values of W_a, MAD, and Z for the different soil types and crops can be found in table 1 and table 2. Average range values of Eff_A for various irrigation methods and systems in the western United States are presented in box 1.

Equation 1 allows calculating the maximum gross water depth that should be applied per irrigation, which corresponds to the maximum allowable depletion of soil between irrigations plus an extra amount of water to compensate for inefficiencies occurring with the irrigation method used. This calculated irrigation depth sets the upper limit that irrigators should not exceed to achieve efficient irrigation.

Table 1. **Average available water-holding capacity (W_a) for various soil textures**

Soil		W_a (inches of water per foot of soil)
General description	**Texture class**	
light, sandy	coarse sand	0.5
	fine sand	0.9
	sandy loam	1.2
medium, loamy	fine, sandy loam	1.5
	loam	1.8
	silt loam	2.0
heavy, clay	clay loam	2.2
	clay	2.4
	peat/muck	6.0

Source: Modified from U.S. Bureau of Reclamation, Agrimet Irrigation Guide website, (https://www.usbr.gov/pn/agrimet/irrigation.html).

Table 2. **Average root depth (Z) and management allowable depletion (MAD) for different crops**

Crop	Average root depth (ft)	MAD (%)
alfalfa	8.0	55
pasture	2.5	50
turf	1.5	50
small grains	4.5	55
beans	3.0	40
corn	5.5	50
potatoes	3.5	40
sugar beets	4.0	50
cotton	5.0	55
orchards	8.0	50–65
grapes	6.0	65

Source: Modified from U.S. Bureau of Reclamation, Agrimet Irrigation Guide website, (https://www.usbr.gov/pn/agrimet/irrigation.html).

For sprinkler- and microirrigated fields, irrigations aimed at filling the entire root zone depth with water are often conducted before or at the crop season start. If farm conditions allow (i.e., if there are no water supply restrictions and timing of water availability from the source is not an issue), all the other irrigation events during the crop season could be conducted with light and frequent water applications that aim at filling a smaller root zone depth where the majority of water-uptake roots are located, which is referred to as effective root depth, Z_E. This practice could slightly increase the soil evaporation when the crop is not at full canopy development, but at the same time it allows spoon-feeding water to the plant roots, avoiding long wetting-drying cycles, and also preventing the risk of over-irrigation and consequent water losses by deep percolation and surface runoff.

Under these circumstances, the water depth to apply during in-season irrigation events can be calculated by considering only the effective root depth instead of the entire root depth and thus by replacing in equation 1 the term Z with Z_E, as shown in equation 2.

$$D_{G\,EFF} = [(MAD \div 100) \times W_a \times Z_E] \div Eff_A \qquad (2)$$

where:

$D_{G\,max\,e}$ = the maximum gross irrigation depth in inches that should be applied during in-season irrigation events

Z_E = effective root depth, that is, the soil depth (feet) where the majority of water-uptake roots are located, usually corresponding to 70 to 80 percent of the actual root depth

Example 1. Determine the maximum amount of water in inches that should be applied on a sprinkler-irrigated potato field with sandy loam soil, where the application efficiency of the irrigation system is 85 percent.

From table 1 and table 2 it can be seen that the average water-holding capacity of a sandy loam soil is around 1.2 inches per foot of soil, the maximum crop root depth is 3.5 feet, and the recommended MAD value for potato is 40 percent of total available water.

MAD = 40%

W_a = 1.2 in/ft

Z = 3.5 ft

Eff_A = 0.85

Box 1 – Application Efficiency

Some extra water must be added to the soil in addition to the amount needed to adequately replenish water used by the crop since the last irrigation or rainfall. Such extra water is required to compensate for losses from the irrigation systems that occur through deep percolation, surface runoff, evaporation, wind-drift, and nonuniform water application. Because of losses occuring during irrigation application, application efficiency is always less than 100 percent.

Application efficiency is defined as the ratio of ***water beneficially used by the crop to the total water applied***, where "beneficial use" includes water used for crop evapotranspiration, frost protection, salt leaching, canopy cooling, etc. Application efficiency provides an indication of how well an irrigation system performs its objective of applying water in adequate amounts and uniformly throughout the field, and allowing it to be stored in the crop root zone to meet the crop water requirements. No irrigation system can achieve 100% application efficiency, but adequate system design, regular maintenance, and careful irrigation management can minimize water losses, thus increasing the relative portion of applied water that is beneficially used by plants. Some irrigation methods perform relatively better than others in terms of the water application rate matching the soil intake rate and for the evenness with which water is distributed throughout the field (distribution uniformity). Table 3 shows potential values of application efficiency for properly-designed and well-managed irrigation systems.

Table 3. **Ranges of potential application efficiency (Eff_A) of well-designed and well-managed irrigation systems**

Irrigation method/system	Potential Eff_A (%)
Sprinkler	
LEPA	80–90
linear move	75–85
center pivot	75–90
traveling gun	65–75
side-roll	65–85
hand-move	65–85
solid-set	70–85
Surface	
furrow (conventional)	45–65
furrow (surge)	55–75
furrow (with tailwater reuse)	60–80
basin	60–75
precision level basin	65–80
Microirrigation	
bubbler (low head)	80–90
microspray	85–90
micropoint source	85–90
microline source	85–90
surface drip	85–95
subsurface drip	90–95

Source: Adapted from Howell 2003.

$$D_{G\,MAX} = [(40 \div 100) \times 1.2 \text{ in/ft} \times 3.5 \text{ ft}] \div 0.85 = 2.0 \text{ inches}$$

However, field research studies have shown that the majority of uptake roots of potato plants are usually concentrated in the first 20 to 24 inches of soil. In order to optimize irrigation and minimize the risk of overwatering, light and frequent in-season irrigations can be conducted to refill only the effective root depth (Z_E) of 24 inches (2 feet). In this case, the gross water depth to apply during in-season irrigation events is calculated as shown below.

$$D_{G\,EFF} = [(40 \div 100) \times 1.2 \text{ in/ft} \times 2.0 \text{ ft}] \div 0.85 = 1.1 \text{ inches}$$

Key Point of Example 1: A relatively low total depth of applied water (2.0 or 1.1 inches) is needed for this field setting to refill the crop root zone (either to 3.5 feet or 2.0 feet deep) and minimize deep percolation losses. For this reason, sprinkler irrigation is used to achieve a higher application efficiency.

Question B) How many inches of water are applied during an irrigation?

Equation 3 can be used to calculate the water depth (inches) applied during an irrigation:

$$Q \times T = 449 \times A \times D_G \qquad (3)$$

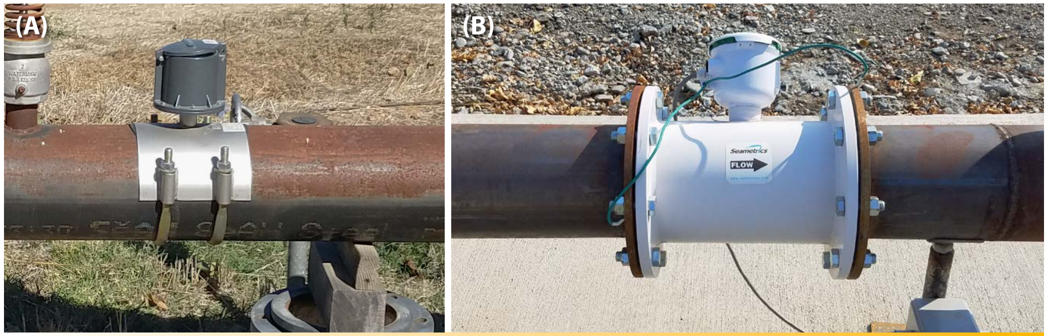

Figure 1. Examples of paddle-wheel (A) and magnetic (B) flowmeters installed in the main supply lines of irrigation system. The paddle-wheel flowmeter has a freely rotating impeller that generates a frequency and voltage signal that is proportional to the flow rate. The magnetic flowmeter uses a magnetic field applied to the metering tube, which results in a potential difference that is proportional to the flow rate and is sensed by electrodes aligned perpendicular to the flux. *Photos:* A. Fulton.

where:

Q = flow rate (gallons per minute) of water being applied onto the field

T = irrigation set time (hours) used to irrigate the field

449 = conversion factor needed when flow rate is measured in gallons per minute (gpm). It is not used in this equation when flow rate is measured in cubic feet per second (cfs). Note that 1.0 cfs = 449 gpm.

A = irrigated area (acres)

D_G = gross irrigation depth (inches) applied, which includes the amount necessary to refill the depleted soil moisture plus extra water to offset inefficiencies (mainly losses due to deep percolation and surface runoff) and eventual salt leaching

Example 2: How many inches of water per week are applied to an 80-acre field where the measured average pump flow rate is 350 gpm and the irrigation set time is 16 hours per day for 6 days?

Q = 350 gpm

T = 16 hours per day for 6 days = 96 hours

A = 80 acres

$$D_G = [(Q \times T) \div (449 \times A) = (350 \text{ gpm} \times 96 \text{ hr}) \div (449 \times 80 \text{ ac}) = 0.93 \text{ inches}$$

To convert the water depth (inches) into volume (gallons), note that 1 acre-inch = 27,154 gallons.

It should be noted that for accurate irrigation management, the flow rate should be properly measured with flow meters (fig. 1) and not be assumed on the basis of the nominal or maximum pump capacity, or from uncertain information provided by field personnel. Additional information about measuring flow rate in irrigation systems is available from the UC ANR Publication 21644, *Measuring Irrigation Water Flow Rates* (Hanson and Schwankl 2009).

Key Point of Example 2: Under this irrigation situation, an average of 0.93 inches of water has been applied over the course of this 6-day irrigation event. This is a relatively low depth of applied water, indicating that the irrigation system provides good control of the water. Depending on the crop and growth stage, the water manager should verify that the crop water requirements are being adequately met with the amount of applied water.

Irrigating Efficiently

Question C) What flow rate is needed to apply a certain depth of water to a field and achieve a target application efficiency?

The flow rate necessary to apply a certain net water depth (inches) to a field with a target application efficiency can be computed using equation 4.

$$Q = 449 \times A \times D_N \div T \times Eff_A \quad (4)$$

where:

D_N = net depth of water to be applied to refill the depleted soil moisture. D_N is a net depth and does not include the extra water necessary to offset the irrigation losses (surface runoff, deep percolation, wind drift, etc.) due to inefficiencies, but only the amount of water necessary to match the crop evapotranspiration since the last irrigation or rainfall event.

Example 3: What flow rate is necessary to apply the net water depth of 2 inches over an 80-acre field with a total irrigation set time of 160 hours, while reaching an application efficiency of 85 percent?

A = 80 acres

D_N = 2 inches

T = 160 hours

Eff_A = 0.85

$$Q = (449 \times 80 \text{ ac} \times 2 \text{ in}) \div (160 \text{ hr} \times 0.85) = 528 \text{ gpm}$$

Key Point of Example 3: If a substantially higher flow rate than the above-calculated value is actually being delivered, this could be related to lower application efficiency. The above calculation can help growers and irrigators to assess if they are being efficient with their water supply and thus achieve reasonable water management goals.

Question D) How many acres can I irrigate with a certain available water supply?

Equation 5 can be used to answer this question.

$$A = (Q \times T) \div (449 \times D_G) \quad (5)$$

Example 4: How many acres can be irrigated with a flow rate of 250 gallons per minute, if the desired depth to be applied is 3 inches per set, each set is 16 hours long, and the total number of sets is eight?

T = 16 hours per set × 8 sets = 128 hours

D_G = 3 inches

Q = 250 gpm

$$A = (250 \text{ gpm} \times 128 \text{ hr}) \div 449 \text{ hr} \times 3 \text{ in} = 23.7 \text{ acres}$$

Key Point of Example 4: This calculation can be particularly useful when making decisions about how many acres of a crop could be planted and adequately irrigated with a 250 gpm supply of water and with an irrigation system able to apply water at an average depth of 3 inches. At least 23.7 acres could be irrigated in this situation, and probably more, because most crops have a maximum water demand (ET rate) of about 2.0 inches per week in California during the summer growing season.

Question E) How long should I irrigate in order to apply a certain amount of water over my field?

The total irrigation duration necessary to apply a certain water depth (inches) over a field can be computed using equation 6.

$$T = (449 \times A \times D_G) \div Q \quad (6)$$

Example 5: How long should I operate the irrigation system to apply the gross depth of 3 inches of water over my 80-acre field, if the measured flow rate available is 400 gpm?

D = 3 inches

A = 80 acres

Q = 400 gpm

$$T = (449 \times 80 \text{ ac} \times 3 \text{ in}) \div 400 \text{ gpm} = 269 \text{ hours}$$

Key Point of Example 5: The above calculation suggests that it will require 269 hours, or almost 11 days of operation, to apply an average of 3.0 inches of water across this 80-acre field. Depending on the crop, its growth stage, and the weather conditions, this could indicate that the water flow rate may or may not be sufficient to meet the maximum crop water requirement (ET), particularly if the crop is grown in the Central Valley of California during the hot summer months.

Example 6: How many hours should I operate the irrigation system to apply the volume (Iv) of 125 gallons per plant (gal/plant) to a 40-acre field, where the plant density (PL_D) is 150 plants per acre (plant/ac), if the measured available flow rate when the system operates is 750 gpm?

Iv = 125 gal/plant

PL_D = 150 plant/ac

A = 40 acres

Q = 750 gpm

The total irrigation time (hours) can be calculated by dividing the total volume to apply over the 40 acres by the system flow rate and then converting the minutes into hours, as shown below.

$$T = (I_V \times PL_D \times A) \div (Q \times 60) = (125 \text{ gal/plant} \times 150 \text{ plant/ac} \times 40 \text{ ac}) \div (750 \text{ gpm} \times 60 \text{ min/hr}) = 17 \text{ hours}$$

Key Point of Example 6: The above calculation suggests that it will require 17 hours to meet the estimated water requirement of 125 gallons per plant over a 40-acre field. This calculation can be useful when the crop water requirements are expressed in volume of water per plant and when determining irrigation set time of fields (orchards and vineyards) with different plant densities.

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University of California
Agriculture and Natural Resources
Communication Services
2801 Second Street
Davis, CA 95618

Telephone 1-800-994-8849
E-mail: anrcatalog@ucanr.edu

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