Estimating

WATER REQUIREMENTS

of Hard Red Spring Wheat for Final Irrigations

University of Idaho Cooperative Extension System

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Introduction

Producers of hard red spring wheat know that inadequate water reduces yield and quality. However, excessive water can also cause reductions in yield and quality. This type of loss may be difficult to identify and quantify because the problem may be attributed to a cause other than poor irrigation techniques. For example, diseases such as take-all, foot rot, Rhizoctonia root rot, black chaff, bacterial leaf blight, black point, and scab all infect cereals, and their rates of infection and their severities increase with poorly timed and excessive irrigation.

Often growers ask, How much water will my crop need before I can turn the water off? Are there any easy methods for determining when the water can be turned off? When will the crop mature?
Some irrigation managers use head color or stem node color as an indicator of when to irrigate, how much water to apply, and when to turn water off. But plant diseases and water and nitrogen stresses can affect plant color and therefore the reliability of these methods for irrigation scheduling. Other managers rely entirely on the number of irrigations applied. This method does not recognize that plant water use varies with temperature or that rainfall affects the need for irrigation water.

Some producers base their entire irrigation scheduling program on soil moisture content, regardless of crop. In limited moisture years, however, water they could have applied to a crop that would gain more benefit they use instead on a crop that could have easily matured with the water already available in the soil.

Irrigation scheduling using water-use tables (See University of Idaho CIS 1039, *Irrigation Scheduling Using Water-use Tables*) closely matches available water with the crop's demand. This method accounts for water stored in the soil as well as the stage of crop development. This method works well when water-use tables are readily available and the irrigator is diligent in tracking crop water use. However, many irrigators need a quick method to determine if sufficient water exists to finish the crop without a loss of yield or quality.

By estimating a crop's future water requirements based on visual examination of plant development and by using soil texture and the "feel and appearance" method to estimate available stored soil water, you can determine if adequate water exists to complete crop development or if additional irrigation is required. Even irrigators who primarily rely on other methods may use this method to help "fine tune" current irrigation practices.

Wheat growth and water use

Three principles are basic to effectively managing irrigated wheat crops for optimal yield and quality. These principles are: (1) cereal plants develop in a genetically predetermined pattern; (2) the rate of development is driven by temperature through maturity, although some varieties may be strongly affected by day length; and (3) over the growing season, solar radiation and the resulting air temperature is the dominant factor in determining evaporative demand and the rate of water use by wheat. Wind and relative humidity have less impact.

Hard red spring wheat development as a function of temperature

Cereal grain plants undergo specific growth stages that can be easily recognized. Weather conditions during the growing season affect the rate of development. The minimum temperature, or base temperature *(BaseT)*, for spring wheat development is 32°F. The maximum temperature from emergence through the two-leaf stage, Haun stage 2.0, is 70°F, and the maximum temperature for plant development thereafter is 95°F. Plant growth slows and then ceases when the temperature falls below 32°F or exceeds the maximum.

Further reading

Irrigation Scheduling Using Water-use Tables, CIS 1039, Order #481, $1.50

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EXAMPLE 1:
Calculating growing-degree days

Suppose the low temperature for the day was 56°F, the high temperature was 98°F, and wheat was in the early dough development stage, Haun stage 14.0. Then *MinT* equals 56°F and *MaxT* would be set to 95°F. The number of growing-degree days for this particular day is then:

$$DGDD = \left(\frac{56°F + 95°F}{2}\right) - 32°F$$

or

$$DGDD = 43.5°$$

Adding each day's value to the previous days' values provides the accumulated growing-degree days (GDD).

Daily growing-degree days (*DGDD*) are calculated by averaging the minimum (*MinT*) and the maximum (*MaxT*) temperatures for a 24-hour period and then subtracting the base temperature (*BaseT*):

$$DGDD = \left(\frac{MinT + MaxT}{2}\right) - BaseT.$$

When the minimum temperature for the 24-hour period falls below 32°F, *MinT* is set to 32°F. When wheat plants have two or fewer leaves and the maximum temperature exceeds 70°F, the *MaxT* is set at 70°F. When wheat plants have progressed beyond the two-leaf stage and the maximum temperature exceeds 95°F, *MaxT* is set to 95°F (example 1).

Although hard red spring wheat development depends primarily on temperature, some highly day-length sensitive varieties will require a minimum day length to trigger flower initiation. After floral initiation, however, day-length sensitive variety development becomes more dependent on temperature.

Eight-leaf early maturing varieties require 130 GDD per leaf. Eight-leaf standard varieties require about 143 GDD per leaf. Early maturing varieties from emergence through heading, Haun stage 11.0, accumulate 1,365 GDD, while standard varieties require 1,500 GDD (table 1). After the completion of heading through to maturity, early

Table 1. Approximate cumulative growing-degree days for eight-leaf hard red spring wheat cultivars from emergence through ripening.

Stage of development		Cumulative GDD[1]	
Description	Haun scale	Standard maturity	Early maturity
First awns visible	10.1	—	—
Inflorescence emergence (heading)	—	—	—
First spikelet of inflorescence visible	10.2	1390	1260
1/4 of inflorescence emerged	—	—	—
1/2 of inflorescence emerged	10.5	—	—
3/4 of inflorescence emerged	10.7	—	—
Emergence of inflorescence completed (fully headed)	11.0	1500	1365
Anthesis (flowering)			
Beginning of anthesis (flowering begins about the middle of the head and progresses toward the top and bottom of the head at the same time)	11.4	—	—
Anthesis half-way	11.5	—	—
Anthesis complete	11.6	1590	1445
Milk			
Kernel watery ripe	12.1	1645	1495
Early milk	13.0	1835	1685
Medium milk	—	—	—
Late milk	—	—	—
Dough			
Early dough	14.0	2000	1820
Soft dough	14.5	2040	1890
Hard dough	15.0	2245	2095
Ripening			
Kernel hard (difficult to divide by thumbnail; physiological maturity)	15.5	2320	2170
Kernel hard (can no longer be dented by thumbnail)	16.0	2400	2250
Harvest ripe (direct combining)	—	—	—

Note: Seven-leaf standard maturing varieties require 143 GDD fewer than eight-leaf varieties, and nine-leaf varieties require 143 GDD more.

[1] Cumulative growing-degree days (GDD) is the sum of daily growing degree-days (DGDD) from emergence to specific growth stage.

Source: Baur A., C. Fanning, J.W. Enz and C.V. Eberlein. 1984. Use of Growing-Degree Days to Determine Spring Wheat Growth Stages. EB 37. North Dakota State University Cooperative Extension Service, Fargo, ND.

EXAMPLE 2:
Calculating days to maturity

Suppose a standard maturing wheat crop is in the early dough stage, Haun stage 14.0. It will require an additional 400 GDD (2,400 GDD - 2,000 GDD) (table 1) to reach maturity.

If the low temperatures are expected to be about 55°F and the high temperatures about 95°F for the remainder of the growing period, then about 43 GDD [(55°+95°)/2 - 32°] will accumulate each day. The days required for the crop to develop from the early dough stage to kernel hard is therefore

400 GDD ÷ 43 GDD/day = 9.3 days, or about 10 days

and standard maturing varieties require about the same number of GDD to complete development. Standard maturing eight-leaf hard red spring wheat varieties develop eight leaves prior to heading and require about 2,400 GDD to mature. Early maturing eight-leaf varieties require about 200 GDD less.

Seven-leaf standard maturing varieties require 143 GDD fewer than eight-leaf varieties, and nine-leaf varieties require 143 GDD more.

The pattern does not vary signficantly from year to year. A growing season may be exceptionally warm or cold, and it may take fewer or more calendar days for wheat to ripen, but the amount of heat units required remains the same.

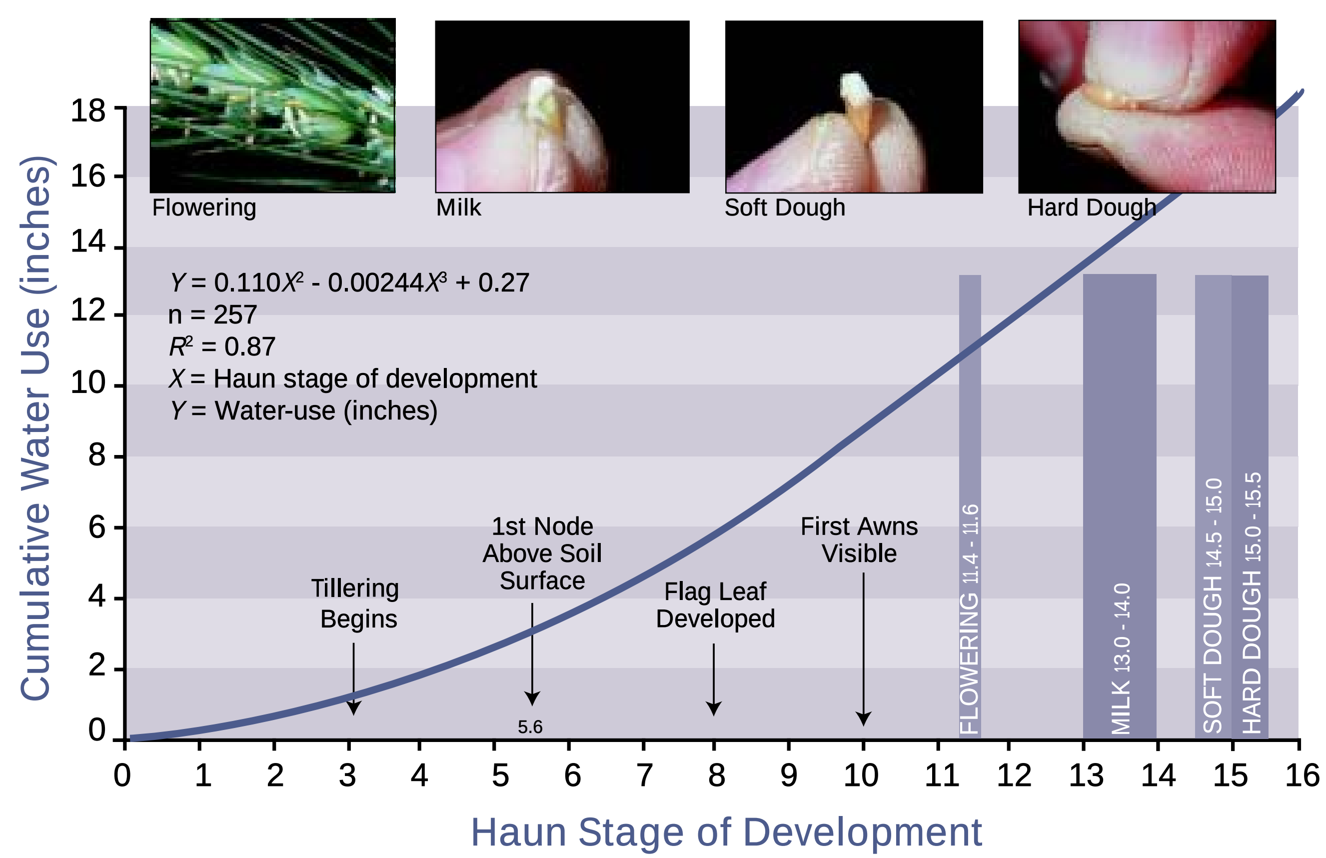
The growing-degree day concept along with accurately staging crop development can be used to calculate the number of days to maturity (example 2).

Water use in relation to plant development stage

The daily rate of water use by wheat is dependent upon climatic conditions and the density of crop vegetation. Temperature has a major effect on crop water use; wind and relative humidity have less impact.

The relationship between water use and the Haun stage of development also has been found to be significant (figure 1). In general, water use by irrigated hard red spring wheat from emergence to heading, Haun stages 0 to 10, is about 8 to 9 inches. Average water use

FIGURE 1: Cumulative water-use by evapotranspiration for irrigated hard red spring wheat in relation to plant development stage[1].



Modified from Bauer, A., A.L. Black, and A.B. Frank. 1989. Soil Water Use by Plant Development Stage of Spring and Winter Wheat. Exp. Sta. Bull. 519. North Dakota State University, Fargo. Photos by Jack Kelly Clark, courtesy University of California Statewide IPM Project

[1] Flowering–pollen shed; milk–kernel liquid appears milky; soft dough–kernel is mealy or doughy; hard dough–kernel starch is firm and can be divided with a thumbnail while holding its shape.

EXAMPLE 3:
Calculating total available soil water

Total available soil water = total water holding capacity - total water deficit

Suppose wheat is at the milk stage with an effective root depth at milk stage of 3.5 feet and that soil depths and textures are as follows:

Soil depth (inches)	Soil texture	Water-holding capacity[1] (inches/inch)
0-12	Silt loam	0.20
12-18	Loam	0.17
18-42	Sandy loam	0.14

[1]Water-holding capacity is from table 2.

Calculate water-holding capacities and estimated deficits for 6-inch increments and for the entire profile:

Soil depth (inches)	Water-holding[1] capacity (inches)	Estimated water deficit[2] (inches)
0-6	6 x 0.20 = 1.20	1.20 x 10% = 0.12
6-12	6 x 0.20 = 1.20	1.20 x 20% = 0.24
12-18	6 x 0.17 = 1.02	1.02 x 30% = 0.31
18-24	6 x 0.14 = 0.84	0.84 x 40% = 0.34
24-30	6 x 0.14 = 0.84	0.84 x 40% = 0.34
30-36	6 x 0.14 = 0.84	0.84 x 25% = 0.21
36-42	6 x 0.14 = 0.84	0.84 x 25% = 0.21
Total	6.78	1.77

[1] *Soil depth* (inches) x *water-holding capacity* (inches/inch)
[2] *Water-holding capacity* (inches) x *soil-moisture deficiency* (%) (from table 3)

Then,

Total available soil water =
6.78 inches - 1.77 inches = 5.01 inches

Table 2. Water-holding capacity for various textural classes of soils. (To be used when soil series is unknown.)

Soil textural class	Water-holding capacity (inches/inch)	Water-holding capacity (inches/foot)
Sand	0.04	0.43
Loamy sand	0.08	0.94
Sandy loam	0.14	1.67
Sandy clay loam	0.14	1.67
Loam	0.17	2.10
Silt loam	0.20	2.44
Silt	0.18	2.12
Clay loam	0.16-0.18	2.0-2.16
Silty clay loam	0.18	2.16
Silty clay	0.17	2.04
Clay	0.16	1.94

Source: McDole, R.E., G.M. McMaster, and D.C. Larson. 1974. Available Water-Holding Capacities of Soils in Southern Idaho. CIS 236. University of Idaho Cooperative Extension System and Agricultural Experiment Station, Moscow, ID.

per Haun development stage is essentially constant from the eight-leaf unfolding through kernel hard stages, stages 7 to 15. That is, on average, from stage 7 through stage 15, hard red spring wheat will use about 1.5 inches of water per Haun stage of development.

Water management for irrigated spring wheat

Determining effective crop-rooting depth

You will need to examine soil moisture content carefully to the effective crop-rooting depth. The unrestricted effective root zone of hard red spring wheat at Haun stages 8 to 11.6, flag leaf through flowering, is about 2 to 3 feet. At milk development, the effective rooting depth has reached its maximum, about 3 to 3.5 feet. Effective root zones may be shallower due to soil compaction, impervious layers (rock), or water-saturated soil conditions. See CIS 1039, *Irrigation Scheduling Using Water-use Tables*, for additional information on effective rooting depth.

Determining soil water-holding capacity

Soil water-holding capacity varies with soil texture, from 0.43 inches per foot of soil for sand-textured soils to 2.44 inches per foot of soil for some silt loam soils (table 2). A uniform silt loam soil at field capacity at the maximum effective rooting depth of a crop at the milk stage of development will hold about

2.44 inches/foot x 3 feet = 7.3 inches

Water-holding capacities for specific soil texture classifications and soil series can be obtained from county soil surveys available from the Natural Resources Conservation Service and soil conservation districts or from county extension offices. Once soil textures and the depths of each are known, water-holding capacities can be estimated from table 2. Total water-holding capacity to the effective rooting depth can be calculated by summing the water-holding capacities of each soil layer in the profile.

Determining available soil water

Available water can be determined with the "feel and appearance" method (table 3). This method estimates the water deficit in the soil based on how a soil sample ribbons, forms a ball, or rolls between the fingers. Since water use occurs more rapidly from soil depths closer to the surface than from greater depths, and irrigation practices vary from producer to producer, an auger or soil sampling probe will be required to adequately assess soil moisture conditions.

Take soil samples in 6-inch increments to the maximum effective root depth, usually 3.5 feet for unrestricted root zones of hard red spring wheat. If time for sampling is limited, one sample, taken at one-third the effective root zone depth, will give a representative soil-moisture level if soil texture does not vary with depth (example 3).

Allowable soil moisture depletion

The percentage of available soil water at field capacity that the crop can use without causing yield or quality loss is called the management allowable depletion (MAD). The MAD in cereal grains will vary with stage of development.

Wheat at all stages of development except boot through flowering and ripening may use up to 55 percent of the available water in the soil at field capacity without injury to yield or quality. From boot to flowering, allow the crop to use up to to 45 percent of the available water in the soil at field capacity. Once hard red spring wheat has matured to the hard dough stage, Haun stage 15, up to 90 percent of the water in the soil may be used.

Determining water requirements and final irrigation

The water requirement to complete development of hard red spring wheat can be calculated at any stage of development, but recognizing the correct stage of crop development is essential (figure 1). To do so, examine kernel development carefully, selecting heads from various parts of the field.

Table 3. Feel and appearance method for estimating soil moisture deficiency. (The numbers in parentheses indicate inches of water deficit per foot of soil.)

Soil-moisture deficiency	Coarse texture	Moderately coarse texture	Medium texture	Fine and very fine texture
0% (Field capacity)	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. (0.0)	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. (0.0)	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. (0.0)	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. (0.0)
0-25%	Soil tends to stick together slightly, sometimes forms a very weak ball under pressure. (0.0 to 0.2)	Soil forms weak ball, breaks easily, will not slick. (0.0 to 0.4)	Soil forms a ball, is very pliable, slicks readily if relatively high in clay. (0.0 to 0.5)	Soil easily ribbons out between fingers, has slick feeling. (0.0 to 0.6)
25-50%	Soil appears to be dry, will not form a ball with pressure. (0.2 to 0.5)	Soil tends to ball under pressure but seldom holds together (0.4 to 0.8)	Soil forms a somewhat plastic ball, will sometimes slick slightly with pressure. (0.5 to 1.0)	Soil forms a ball, ribbons out between thumb and forefinger. (0.6 to 1.2)
50-75%	Soil appears to be dry, will not form a ball with pressure. (0.5 to 0.8)	Soil appears to be dry, will not form a ball. (0.8 to 1.2)	Soil is somewhat crumbly but holds together with pressure. (1.0 to 1.5)	Soil is somewhat pliable, will form a ball under pressure. (1.2 to 1.9)
75-100% (100% is permanent wilt point)	Soil is dry, loose, single-grained, flows through fingers.(0.8 to 1.0)	Soil is dry, loose, flows through fingers. (1.2 to 1.5)	Soil is powdery, dry, sometimes slightly crusted but easily broken down into a powder. (1.5 to 2.0)	Soil is hard, baked, cracked, sometimes has loose crumbs on surface. (1.9 to 2.5)

Note: A ball is formed by squeezing a handful of soil very firmly.
Source: Israelsen, O.W., and V.E. Hansen. 1962. Irrigation Principles and Practices. Third Edition. New York: John Wiley and Sons, Inc.

Definitions of terms

Allowable soil moisture depletion—Depth of water that a crop can remove without loss to yield or quality: total water holding capacity x MAD

Available water—Water held in the soil between the existing soil-moisture content and the wilting point.

Field capacity—the maximum amount of water that can be held by soil against gravity. Field capacity varies with soil texture.

Management allowable depletion (MAD)—The percentage of available water at field capacity that can be used by the crop at a particular stage of development without loss of yield or quality due to moisture stress.

Minimum available water—Minimum depth of water, in inches, that should remain in soil to avoid loss to yield or quality. If plants are allowed to utilize this minimum available water, a reduction in yield and quality will result because more energy is required to extract the water from the soil.

Soil moisture deficiency—The difference between field capacity and the current moisture level in the soil. The value is expressed as a percentage of total water holding capacity.

Total water-holding capacity—The depth of water a soil at field capacity can hold in the root zone against gravity and be available to the crop: the difference between field capacity and wilting point.

Table 4 gives estimated water use from heading completion to hard dough. If the total available water equals or exceeds the estimated water use plus the minimum available water level then additional irrigation is not required. However, if estimated water use plus the minimum available water level is less than the total available water, irrigation is advised. Because only a portion of the irrigation water applied to the soil is stored in the crop-root zone, calculate the full amount of water to apply by dividing the net irrigation requirement by the application efficiency (as a decimal). Typical irrigation system application efficiencies are provided in table 5 (example 4).

Table 4. Estimated water use from flowering to hard dough for hard red spring wheat.

Haun scale	Description	GDD[1]	Water-use[2] during this stage (inches)	Water-use to hard dough (inches)
11.0-12.0	Heading complete to watery ripe (includes flowering)	145	1.5	6.4
12.0-13.0	Watery ripe to early milk (watery ripe)	190	1.6	4.8
13.0-14.5	Early milk to soft dough (milk)	205	1.6	3.2
14.5-15.0	Soft dough to hard dough (soft dough)	205	1.6	1.6

[1] GDD, from table 1, is the growing-degree days required to complete this Haun stage.
[2] Water-use during this stage is an estimated value derived from the difference between cumulative water values as calculated by the equation $Y = 0.110X^2 - 0.00244X^3 + 0.27$ where X = Haun stage and Y = cumulative water use in inches.
Source: Bauer, A., A.L. Black, and A.B. Frank. 1989. Soil Water Use by Plant Development Stage of Spring and Winter Wheat. Exp. Sta. Bull. 519. North Dakota State University, Fargo.

Table 5. Typical irrigation system application efficiencies.

	Application efficiency (%)	Water required to put 1 inch of water in crop-root zone (inches)
Surface systems		
Furrow	35-65	1.5-2.8
Corrugate	30-55	1.8-3.3
Border, level	60-75	1.3-1.7
Border, graded	55-75	1.3-1.8
Flood, wild	15-35	2.8-6.7
Surge	50-55	1.8-2.0
Cablegation	50-55	1.8-2.0
Sprinkler systems[1]		
Stationary lateral (wheel or hand move)	60-75	1.3-1.7
Solid set lateral	60-85	1.2-1.7
Traveling big gun	55-67	1.5-1.8
Stationary big gun	50-60	1.7-2.0
High-pressure center pivot	65-80	1.3-1.5
Low-pressure center pivot	75-85	1.2-1.3
Moving lateral (linear)	80-87	1.1-1.2
Micro irrigation systems		
Surface/subsurface drip	90-95	1.05-1.1
Micro spray or mist	85-90	1.1-1.2

[1]For sprinkler systems, use the lower values for wide nozzle spacing and windy conditions.
Source: Sterling R. and W.H. Neibling. 1994. Final Report of the Water Conservation Task Force. IDWR Report. Idaho Department of Water Resources, Boise, ID.

EXAMPLE 4:
Calculating the final irrigation

Suppose you want to determine if adequate water exists to complete the development of a hard red spring wheat crop that is in the milk stage. Assume the estimated total water-holding capacity, estimated total water deficit, and total available water given in example 3:

Line		Example value	Your value
1	Total water holding capacity of soil in the effective root zone (inches)	6.78	_____
2	Management allowable depletion (MAD) (boot through flowering = 0.45; watery ripe to hard dough = 0.55; and hard dough to harvest ripe = 0.90)	0.55	_____
3	Allowable soil moisture depletion (inches) (= Line 1 x Line 2)	3.73	_____
4	Minimum available water (inches) (= Line 1 - Line 3)	3.05	_____
5	Available water (inches) (Determine using feel and appearance method or appropriate field instrumentation)	5.01	_____
6	Water available to crop without loss to yield or quality (inches) (= Line 5 - Line 4)	1.96	_____
7	Estimated water-use from current stage to hard dough (inches) (see table 4)	3.20	_____
8	If Line 6 is greater than Line 7, adequate water is available to complete development. If Line 6 is less than Line 7, an irrigation application is advisable. Proceed to Line 9.		
9	Net irrigation requirement (inches) (= Line 7 - Line 6)	1.24	_____
10	Application efficiency (as a decimal from table 5)	0.70	_____
11	Actual amount of water to apply (inches) (= Line 9 ÷ Line 10)	1.77	_____

Example 4 discussion

The estimated total water-holding capacity of the soil is 6.78 inches (Line 1). At the milk to hard dough stage, the MAD level is 55 percent of the estimated total water-holding capacity (Line 2). That is, the crop could use as much as 3.73 inches (6.78 inches x 0.55) if the soil profile was filled to field capacity (Line 3). But in this case the soil profile is not filled to field capacity but contains an available water content of 5.01 inches (Line 5).

To calculate water available to the crop without loss to yield or quality (Line 6), subtract the minimum available water (Line 4) from the available water (Line 5):

5.01 inches - 3.05 inches = 1.96 inches.

Compare the water available to the crop without loss to yield or quality (Line 6) to the estimated water use from the current stage of development, milk, to hard dough (Line 7). Because the estimated water use required to complete crop development is greater than the water available to the crop, irrigation is advised.

To calculate the net irrigation requirement (Line 9), subtract the water available to the crop without loss to yield or quality (Line 6) from the estimated water use for the crop from the current stage of crop development to hard dough (Line 7):

3.20 inches - 1.96 inches = 1.24 inches.

Because only a portion of the irrigation water is delivered to the crop root zone, adjust the irrigation requirement for the application efficiency (Line 10) of your particular irrigation system (table 5). For a high-pressure center pivot system, you would apply

1.24 inches ÷ 0.70 = 1.77 inches.

In this example, if the available water in the effective root zone was equal to or greater than 6.34 inches, then additional water would not be needed. Though the crop is not mature at Haun stage 15, hard dough, there should be adequate water in the soil to carry the crop to maturity.

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