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Cooperative Extension

Irrigation of Small Grains in Arizona

Water use and irrigation requirement

Wheat and barley use about 2 ft of water in Arizona, but 3 to 3.5 ft of applied water is often required with surface flood irrigation due inefficiencies in the irrigation system. Less irrigation water is required with more efficient irrigation systems such as sprinkler or drip. If 6 inches of water is applied per irrigation, then six or seven irrigations are required during the season. The first post-emergence irrigation is generally needed by the 5 leaf stage and the last irrigation by soft dough. An example irrigation schedule is presented in Table 1. For an explanation of small grain growth stages and heat units to attain these stages see Ottman (2004).

Season water use by small grains

Water use in small grains is negligible during early development, increases rapidly during jointing, peaks during grain fill, and falls steeply during senescence as the crop turns color (Table 2). Water use is most affected by developmental stage before the crop fully covers the soil surface and after the crop turns color. Otherwise, water use increases as the season progresses due to increased solar radiation and temperature. Water use can be greater than the longer term average on windy days especially.

Table 1. Example irrigation schedule for durum planted on December 10 at Maricopa on a sandy loam soil.

Stage	Irrigation date
Planting	Dec 10
5-leaf	Feb 04
2 nodes	Feb 27
Pre-boot	Mar 16
Heading to flowering	Mar 30
Milk	Apr 11
Soft dough	Apr 22

Irrigation systems

Small grains can be produced successfully with a variety of irrigation systems. Drip and sprinkler irrigation systems can apply smaller amounts of water than surface flood systems, and therefore, less applied water moves past the root zone. Surface flood systems are more efficient at leaching salts, which is a consideration if salts are a problem. Small grains can be grown equally well on beds or flat ground. Beds have an advantage if infiltration is a problem, the field has substantial sidefall, or a sufficient head of water can not be delivered. Growing small grain plants in furrows in a bed system can slow the advance of surface irrigation water, increase water infiltration, but result in less efficient irrigation.

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Table 2. Average daily water use of durum planted at Maricopa on December 10.

Month	Days	Average daily water use
		inches/day
Dec	8-14	0.02
	15-21	0.02
	22-31	0.02
Jan	1-7	0.02
	8-14	0.03
	15-21	0.04
	22-31	0.05
Feb	1-7	0.06
	8-14	0.07
	15-21	0.09
	22-28	0.10
Mar	1-7	0.12
	8-14	0.15
	15-21	0.18
	22-31	0.22
Apr	1-7	0.26
	8-14	0.32
	15-21	0.33
	22-30	0.36
May	1-7	0.34
	8-14	0.26
	15-21	0.09
	22-31	0.01

Stress by stage

Water stress at any stage can reduce yields of small grains. However, small grains are most susceptible to water stress during jointing, least susceptible during grain fill, and intermediate in susceptibility during tillering (Day and Intalap, 1970). Yield is reduced by water stress during tillering by reduced tiller number. Water stress during jointing reduces plant height and susceptibility to lodging (Ottman et al., 2001), but also reduces kernels per head and yield potential. Water stress during grain fill can reduce kernel weight and result in unacceptable grain test weight.

First Irrigation

The first post-emergence irrigation for wheat and barley is usually needed by about the 5-leaf stage. Applying the first irrigation earlier may temporarily increase crop growth but not increase grain yield, or may actually reduce crop growth through waterlogging or cooling of the soil. Rainfall often allows the first irrigation to be delayed. The first irrigation may be applied early to help in the germination of the seed if the soil crusts or to prevent seedling desiccation in cracking soils. The first irrigation may also be applied early if the crop has a critical need for nitrogen fertilizer. The price or availability of water is a factor that may warrant applying the first irrigation early. Applying the first irrigation too early can result in loss of soil nitrogen by leaching or denitrification (loss as a gas). Waterlogged conditions also hinder nitrogen uptake from the soil since plant roots need oxygen to take up nitrogen. The symptoms of waterlogged soil conditions are yellowing and lack of growth of the plants. Delaying the first irrigation as long as possible with the intention of promoting root development and improving the ability of the crop to extract deep soil moisture is a questionable practice

(Ottman et al., 1987). Plant wilting is usually a sign that the first irrigation is needed or should have been applied sometime earlier.

Last Irrigation

The timing of the last irrigation for wheat and barley is usually a difficult decision. Applying an unnecessary irrigation at the end of the season wastes water and can cause lodging. Conversely, water stress at the end of the season may reduce kernel weight, test weight, and yield. On a sandy loam soil, the last irrigation is needed at soft dough (Husman and Ottman, 1998). About 3 to 4 inches of water is needed to carry the crop from soft dough to maturity. The average sandy loam soil holds about this amount of plant available water in the active rooting zone. On sandier soils, the last irrigation may be needed between soft dough and hard dough, and on heavier soils, the last irrigation may be applied before soft dough. Obviously, the timing of last irrigation depends on soil type, the irrigation system, the growth stage of the crop, expected weather conditions, and other factors. Nevertheless, no irrigation water is needed once the heads have completely turned color from green to tan since the crop is mature at this point and the kernels cease to accumulate dry weight. Do not confuse the gradual color change of the crop between flowering and hard dough with the tan color of the head that occurs at maturity. It usually is not economical to apply a final irrigation to benefit a few green tillers in a mature crop. A final irrigation is sometimes applied at maturity not for crop water requirements but to soften the soil for tillage after harvest.

Critical soil moisture depletion

Small grains should generally be irrigated when 50% of the available water is depleted. However, grain yield was increased by 786 lbs/acre for barley and 837 lbs/acre for durum if irrigations were applied at 35% rather than 50% depletion in a study conducted at the Maricopa Agricultural Center (Table 3). The cost of producing this additional grain yield includes one or two additional surface flood irrigations, an additional 34 lbs N/acre, and increased harvesting and hauling costs. Therefore, whether or not irrigating at 35% depletion is economical depends on the difference between the increased costs and increased revenue. Another consideration is the irrigation system utilized, since irrigating at 35% depletion rather than 50% depletion can be achieved without applying more water with drip or sprinkler irrigation, but not with surface flood irrigation.

Irrigation scheduling methods

Irrigations can be scheduled using set calendar dates or days between irrigations based on grower experience, methods that directly measure soil moisture or crop stress, or the soil water balance method. Grower experience is useful in scheduling irrigations under average conditions, but it is difficult to adjust for unusual weather or variations in irrigation water supply. Soil moisture and crop water stress can be measured in a variety of ways (Martin, 2001) and calibrated at certain critical levels to trigger irrigation. However, these techniques are more often used in higher value crops than small grains. The soil water balance method can estimate soil moisture and impending crop stress without the investment in sensors and collection of the data they provide, but some accuracy may be lost.

Soil water balance method

The soil water balance method of irrigation scheduling treats soil water as a "bank" from which water is "withdrawn" by the crop and water is "deposited" by irrigation when withdrawals reach a critical level. The critical level

Table 3. Grain yield of barley and wheat as affected by soil moisture depletion fraction at irrigation. This research was conducted at Maricopa and the data is an average of two varieties and two years (Husman et al., 1999; Husman et al., 2000a; Husman et al., 2000b; Ottman and Husman, 2002).

	Grain yield	
Soil moisture depletion fraction	Barley	Wheat
% of available water holding capacity	lbs/acre	
35	8578	6633
50	7792	5796
65	6773	4872
80	3982	3606

Table 4. Rooting depth of small grains at various growth stages.

Rooting Depth	Growth stage
0.5	Emergence
1.0	2 leaf
1.5	4 leaf
2.0	6 leaf
2.5	2 node
3.0	Flag leaf collar visible
3.5	Heading
4.0	Kernel watery (wheat) or kernel milky (barley)

Table 5. Average available water holding capacity for various soil textures in Arizona. For a listing of available water holding capacities for specific soils types in Arizona see http://ag.arizona.edu/crops/irrigation/soilcapacities.html .

Soil texture	Available water holding capacity inches/foot
Sand	0.85
Sandy loam	1.38
Sandy clay loam	1.73
Loam	1.94
Silty clay loam	2.30

is referred to as a maximum allowable depletion, and is the product of the acceptable depletion fraction (Table 3), rooting depth (Table 4), and the available water holding capacity of the soil (Table 5):

Maximum allowable depletion (inches) =
Depletion fraction x Rooting depth (ft) x
Available water (inches / ft)

As an example, if we assume a depletion fraction of 50%, a rooting depth of 3 ft., and available water of 1.73 inches / ft, then an irrigation is triggered when 2.6 inches of water are used (0.5 x 3 x 1.73). If daily crop water use is 0.20 inches per day, then 2.6 inches of water is used in 13 days (2.6 inches / 0.2 inches per day), and the irrigation interval is 16 days since water use calculation begins 3 days after the previous irrigation to allow for drainage or use of excess water.

Arizona Meteorological Network, AZMET

Daily crop water use can be estimated by multiplying evapotranspiration for a grass reference crop (ETo) provided by the Arizona Meteorological Network, AZMET (http: / / ag.arizona.edu / azmet) by a crop coefficient (Kc):

Water use = ETo x Kc

An example of reference evapotranspiration (ETo) provided by AZMET is shown in Table 6. The crop coefficient (Kc) converts evapotranspiration of the grass reference crop (ETo) to evapotranspiration (ET) or water use of the crop of interest. Crop coefficients (Kc) at various growth stages are provided for wheat and barley in Table 7.

Table 6. An example of a weekly standard report from AZMET listing reference evapotranspiration, ETo, along with other weather data.

DATE	AIR TEMP			REL HUM			SOIL TEMP		WIND SPEED		SOLAR RAD	RAIN	**ETo**	HEAT UNITS		
	MX	MN	AV	MX	MN	AV	4" AV	20" AV	MX	AV				55	50	45
MAR 21	96	51	75	76	18	39	71	66	25	9.4	453	0.00	**0.30**	17	21	26
MAR 22	90	66	78	53	24	38	74	67	26	9.4	542	0.00	**0.30**	22	27	32
MAR 23	91	58	75	77	17	43	71	68	18	3.8	408	0.00	**0.18**	19	24	29
MAR 24	91	58	76	63	13	32	67	67	15	4.5	523	0.00	**0.25**	19	24	29
MAR 25	89	59	73	59	15	35	69	67	13	3.6	547	0.00	**0.23**	19	24	29
MAR 26	83	54	69	66	12	36	69	67	22	7.2	561	0.00	**0.28**	14	19	24
MAR 27	84	53	69	64	14	35	70	67	15	4.5	566	0.00	**0.24**	14	19	24
AVERAGE	89	57	74	65	16	37	70	67		6.1	514					
TOTALS												0.00	**1.78**	124	157	192

Table 7. Crop coefficients (Kc) and growing degree days, GDD (86/45 °F) at various growth stages for full season barley and durum.

		Barley		Durum	
Growth stage	Description	GDD	Kc	GDD	Kc
1 leaf	1 leaf expanded	95	0.37	137	0.30
2 leaf	2 leaves expanded	130	0.41	212	0.35
3 leaf	3 leaves expanded	201	0.44	286	0.40
4 leaf	4 leaves expanded	271	0.48	360	0.46
5 leaf	5 leaves expanded	342	0.51	434	0.53
6 leaf	6 leaves expanded	412	0.55	509	0.60
1 node	1 node above ground	483	0.62	564	0.66
2 node	2 nodes above ground	602	0.69	675	0.79
Flag leaf visible	Flag leaf visible	707	0.84	813	0.88
Flag leaf collar	Flag leaf collar visible	780	0.90	873	0.96
Boot	Swelling of flag leaf sheath	836	0.93	933	0.99
Heading	Head emerges	893	0.95	971	1.02
Flowering	Pollen shed	930	0.98	1142	1.10
Water	Kernel watery	952	1.04	1306	1.14
Milk	Kernel milky	1117	1.11	1470	1.16
Soft dough	Kernel mealy	1282	1.15	1716	1.15
Hard dough	Kernel hardening, losing color	1529	1.13	1814	1.13
Maturity	Kernel mature, heads tan	1628	0.96	1962	1.07
Harvest	Kernel dry, brittle, hard	1777	0.32	2306	0.22

Arizona Irrigation Scheduling System, AZSCHED

The computer software program, Arizona Irrigation Scheduling System, AZSCHED (http://cals.arizona.edu/crops/irrigation/azsched/azsched.html), uses the soil water balance approach to schedule irrigations and automatically calculates water use from data provided by the automated weather stations, AZMET.

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