University of Idaho Extension

BUL 912

Scheduling the Final Irrigation for Wheat and Barley

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Introduction

CROP PRODUCTION IN IRRIGATED AREAS is becoming more water constrained. In many areas, municipal water use is increasing with urban expansion where periodic drought episodes occur. Water rights adjustments will potentially reduce the amount of available irrigation water, particularly where sourced from ground water. At the same time, increased irrigation (i.e., water, energy and labor) costs as well as other production inputs have reduced the economic return for grain crops. As a result, it is now more necessary than ever to achieve the best grain yield and quality per unit of water applied.

Management of crop water stress at different grain formation stages offers an opportunity to conserve water during late-season crop development without adversely affecting yield and quality. In many irrigated areas, irrigation of spring grains continues after the kernel is mature with the belief that continued water applications increase grain weight and yield during all crop growth stages. Field experience of long-time University of Idaho Extension faculty indicates that when the final irrigation is applied to refill the soil profile of sandy-loam or silt-loam soils to field capacity at the soft dough stage, sufficient water can be stored in the soil profile to meet the crop water requirement until harvest. Water applied after these stages will either remain in the soil profile or percolate below the crop root-zone, without improving returns.

Optimum irrigation management during grain formation sustains agronomic and economic productivity while reducing the water applied and the risk of water related diseases. The purpose of this bulletin is to help growers determine the optimum timing and amount of the final irrigation application needed to sustain agronomic and economic returns for wheat and barley production.

In addition to yield, grain quality (e.g., protein, plumps, test weight) of wheat and barley is a crucial consideration for end-use quality. For example, water management during grain formation stages affects the grain quality where water applied by a sprinkler system close to grain harvest can result in water related diseases that reduce grain test weight and quality.

Water Use Pattern for Wheat and Barley

An average crop water use pattern for early spring to harvest periods of spring and winter grains is shown in Figure 1. The timing difference is due to winter grain evapotranspiration (ET) beginning in the spring as soon as sufficient heat units have been received to break dormancy (i.e., greenup), while spring grain ET is delayed until the crop can be planted

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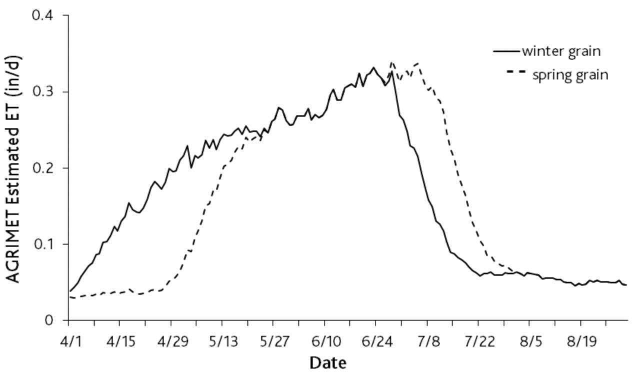

Figure 1. Estimated ET for winter and spring grain at Kimberly, ID, 30-year average.

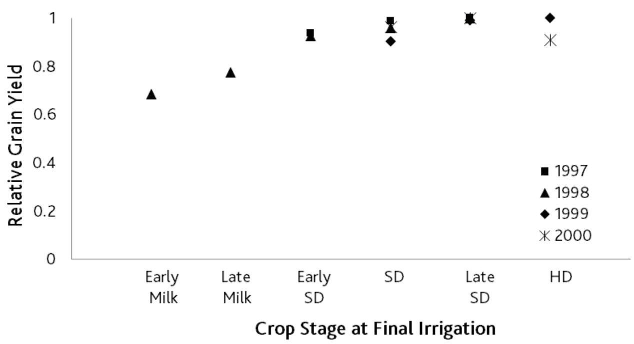

Figure 2. Relative grain yield response to crop stage at final irrigation [milk, soft dough (SD) and hard dough (HD)] for hard red winter wheat (1997-1998), hard red spring wheat (1999, 2000). Water supply by surface drip irrigation.

and emerge. Following spring grain emergence, the water use patterns are similar, with winter grain reaching maturity a few weeks sooner. An important characteristic of the water use curve for both winter and spring grains is the rapid decrease in ET at the end of the season. The decrease is more abrupt than for most other major crops in Idaho. This characteristic is important to keep in mind since it is easy to continue irrigating to meet peak ET even after the ET has dropped. Over irrigation at this point increases irrigation costs, does not increase yield or quality, may increase the chance for fungal diseases such as black point and may decrease protein and test weight.

The early water use pattern and rapid end-of-season ET decline make grains an effective rotation crop in water-short conditions, since water can be shut off on the grains early with limited yield or quality penalty and transferred to other crops such as potatoes, corn or alfalfa where timely application of irrigation water will provide a greater economic benefit.

Yield and Quality Response to Final Irrigation Timing and Nitrogen Application Rates

Potential grain yield is determined during tillering. The maximum number of grain heads is determined at this stage, where the crop is only 4 to 6 inches tall. Yield losses due to excessive stress during this stage typically cannot be recovered; the remaining yield potential can only be maintained by best management for the remainder of the season. The next critical stage is flowering when the number of kernels per head is determined. Following flowering, excessive water stress can reduce the number of seeds per head and the weight and plumpness of the kernels. This is reflected in Figure 2, which shows lowest yield with earliest cutoff (greatest and earliest water stress).

In five plot years (two locations) for wheat and three plot years (one location) for malting barley, there was never a significant yield increase due to irrigation after the root zone was filled at soft dough. In most years the yield was statistically equal or reduced for irrigation past soft dough. Black point was more of a problem in later irrigation cutoffs in years such as 2000, with weather conditions favoring its development (Table 1). Therefore, under full-water conditions, the best return for water applied was to stop irrigation with the root zone filled to hold 2.0 to 2.5 inches of usable water at soft dough. In water-short conditions, Figure 2 indicates the yield penalty that would be incurred by an earlier irrigation cutoff. The value of lost grain production could then be compared to the potential gain from adequately irrigating another crop. For example, irrigation cutoff with a full profile at early milk would give an expected yield of only 70 percent of full season irrigation.

In a trial conducted in 2015 on malting barley at Kimberly, Idaho, final irrigation at soft dough resulted in similar returns as compared to an additional irrigation. When the final irrigation was at late boot, severe yield losses and elevated proteins for malting purposes were measured. Maximum measured yield was achieved at the same nitrogen rate (135 lbs. applied N + soil inorganic N) at both the soft dough and soft dough + 7d cutoff where additional nitrogen applications did not increase yield, and proteins numerically increased at N application levels above those needed to achieve maximum measured yield

(Figure 3). Nitrogen applications rates to maximize yield at the soft dough and soft dough + 7d irrigation cutoffs were within the range of current University of Idaho recommendations for irrigated spring malt barley. Thus, proper fertilizer nitrogen and irrigation management will ensure optimal agronomic and economic goals are met.

Water Use During Late-Season Crop Stages

Water use during a given crop stage will vary somewhat from year to year, depending on weather conditions. Values given in Table 2 are three year averages for 2-row malting barley at Burley, Idaho. Values for hard red spring wheat are estimated using an equation relating cumulative water use to Haun crop stage. Thus, irrigation cutoff at soft dough is applicable if at least 2 inches of usable water is stored in the crop root zone for wheat and 2.5 inches for barley.

Usable Water Stored in the Crop Root Zone

Measured root water extraction patterns indicate that barley and wheat can remove water from soil to a depth of at least three feet if no restrictive soil layers are present. Depth of the crop root zone and the soil texture establishes the water holding capacity (WHC) of the root zone. Only about half of the WHC can be used between irrigations without reduction in crop yield or quality. Root zone depth may be limited by rock, dense soil layers, seasonal high water table or irrigation system operation. Water that can be used by the crop for various soil textures and depths is shown in Table 3. Although many other soil textures are present in southern Idaho, these textures cover the majority of the cropped area. Heavier-textured silt loams are generally found in the Treasure Valley, the south side of the Snake River in the Magic Valley and in some areas of eastern Idaho. Light-textured silt loams are generally found in the Upper Snake Valley (Rexburg Bench, etc.), while sandier soils generally occur on the north side of the river in the Magic Valley and the Fort Hall area.

Soil texture for a particular field may be determined from the USDA-NRCS soil survey or by other field or laboratory tests. Fields may contain multiple soil textures, so the dominant one is usually chosen for water management purposes. Table 4 combines water required past soft dough and usable root zone water

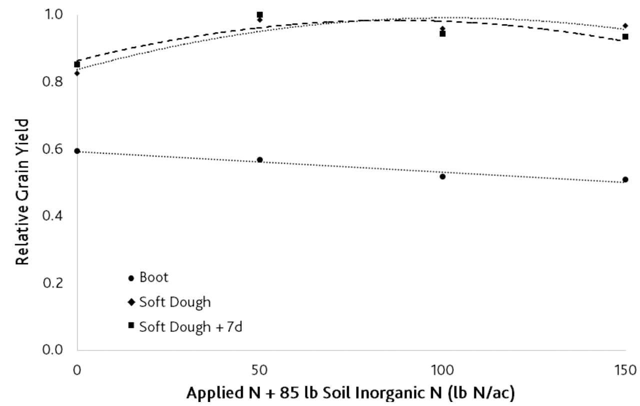

Figure 3. Malting barley relative grain yield at specified irrigation cutoffs and applied N rates at Kimberly, Idaho.

Table 1. Percent of two row malting barley kernels infected with black point at Burley and spring wheat at Rupert in 2000.

Crop	Crop Stage at Irrigation Cutoff		
	Late milk	Soft dough	Hard dough
	———(%)———		
2-row malting barley	3	4	9
Spring wheat	3	6	9

Table 2. Crop water use for selected malting barley and hard red spring wheat crop stages and total seasonal water use.

Crop stage	2-row malting barley	Hard red spring wheat
	———(in)———	
Emergence to milk	11.6*	14.3**
Milk to soft dough	3.4	2.1
Soft dough to hard dough	1.9	0.8
Hard dough to harvest	0.8	1.2
Seasonal total	17.7	18.4

*2000-2002 average for two row malting barley at Burley, Idaho.

**Estimated from Y=0.110X^2-0.00244X^3+0.27 where Y=cumulative water use (inches) and X=Haun crop stage of development (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).

Table 3. Water usable by crop without water stress when initially at field capacity (e.g. MAD=0.5).

Root zone depth	Sandy loam	Light-textured silt loam	Heavier-textured silt loam
(in)	———(in)———		
12	0.8	1.0	1.2
24	1.6	2.0	2.4
36	2.4	3.0	3.6

Table 4. Irrigation water needed past soft dough for no yield or quality reduction.

Root zone depth	Sandy loam	Light-textured silt loam	Root zone depth
(in)		(in)	
12	1.2	1.0	0.8
24	0.4	0	0
36	0	0	0

storage to identify the depth of water that must be applied past soft dough on shallow or low water-holding soils. For example, a sandy-loam soil 12 inches deep will need an irrigation of about 1.2 inches after soft dough to supply additional water to bring the crop to harvest with no yield or quality penalty. Note that for light or heavier-textured silt-loam soils at least 24 inches deep, no additional water is needed after soft dough if at least the top 2 feet of soil is wetted to field capacity at that time.

It is important to note that roots will not extend into dry soil in search of deeper water; moist soil is required for root extension. For example, in heavier textured silt-loam soils, runoff potential limits application per pivot revolution to no more than 0.75 inch. If the soil starts at field capacity, 0.75 inch of water use will dry the soil to about 70 percent available soil water. Adding 0.75 inch of net irrigation will rewet the top 18 inches to field capacity. In this scenario, the effective root zone depth is about 18 inches due to system operation, even if deeper soil is present.

Table 5 is presented as one tool to help estimate water required to refill the root zone. Percent available soil water may be determined by the feel and appearance method. A description may be found in UI Bulletin 833 "Estimating Water Requirements of Hard Red Spring Wheat for Final Irrigations." USDA-NRCS has an excellent visual tool "Estimating Soil Moisture by Feel and Appearance." Table 5 also relates readings from watermark granular matrix sensors or tensiometers to percent available water. In addition, the Washington State University Irrigation Scheduler can be used to estimate available soil water. The depth of water required to refill 1 foot of soil at the indicated moisture content to field capacity is also given for the three soil textures. For example, if a tensiometer reads 30 cbars on a sandy-loam soil, percent available water is 50 percent, and 1.04 inches of water is required to refill one foot of soil to field capacity with a center pivot or 1.19 inches is required using a hand or wheel line. The same tensiometer reading on a heavy-textured silt loam indicates that the soil is at 100 percent available water (field capacity) and no refill is needed.

Table 5. Relationship between soil moisture expressed as either percent available water or watermark readings and in to refill 1 foot of soil to field capacity with pivot, hand line, wheel line or solid set systems.

Available soil water	Sandy loam WHC=1.67 in/ft			Light-textured silt loam WHC=1.97 in/ft			Heavier-textured silt loam WHC=2.25 in/ft		
	Water-mark reading	Pivot or linear	Hand or wheel line	Water-mark reading	Pivot or linear	Hand or wheel line	Water-mark reading	Pivot or linear	Hand or wheel line
(%)	(cbars)	(inch of water to refill 1 ft of soil)		(cbars)	(inch of water to refill 1 ft of soil)		(cbars)	(inch of water to refill 1 ft of soil)	
100	10	0	0	10	0	0	30	0	0
85	12	0.32	0.36	15	0.37	0.42	38	0.42	0.48
80	14	0.42	0.48	17	0.49	0.56	42	0.56	0.64
75	16	0.52	0.60	20	0.62	0.70	45	0.70	0.80
70	18	0.63	0.72	22	0.74	0.84	50	0.84	0.96
65	20	0.73	0.84	25	0.86	0.98	55	0.98	1.12
60	24	0.84	0.95	30	0.98	1.13	62	1.12	1.29
55	27	0.94	1.07	35	1.11	1.27	68	1.26	1.45
50	30	1.04	1.19	40	1.23	1.41	75	1.41	1.61
40	43	1.25	1.43	62	1.48	1.69	100	1.69	1.93
30	71	1.46	1.67	119	1.72	1.97	200	1.97	2.25

What is Soft Dough?

It is somewhat difficult to develop a description of soft dough that produces consistency among a number of irrigators. Many have developed their own distinct approach which is successful for them but may not transfer well to others. Useful definitions for a number of crop stages have been developed:

- Flowering: pollen shed
- Milk: kernel liquid appears milky
- Soft dough: kernel is mealy or doughy (Figure 4 and 5)
- A rule of about 24 days after flag leaf emergence can be helpful in identifying the general time period.
- Hard dough: kernel starch is firm and can be divided with a thumbnail while holding its shape.

Economic Implications of Early Irrigation Cutoff

Table 6 summarizes the relative yield and quality of malting barley when irrigation is stopped at specified crop stages with a 2 foot root zone near field capacity. The yield relative to that at soft dough is the same as that shown in Figure 2. The relative price based on quality reflects less plump kernels when irrigation cutoff is at milk, and the tendency toward black point with irrigation after soft dough on adequate water-holding soil. Combining these factors gives the calculated crop value per acre for irrigation cutoff at the indicated crop stages. This table may be used to estimate increase in crop value as final irrigation is scheduled at later crop stages. For example, scheduling the final irrigation at soft dough rather than milk, increased crop value from $634 to $813 or $179/acre. However, scheduling the final irrigation post-soft dough (nearly hard dough) decreased crop value by $106/acre. Table 7 summarizes crop value for final irrigation at specified crop stages for hard red wheat. As was the case for malting barley, irrigation past soft dough with a 2 foot root zone on a silt-loam soil at field capacity decreases crop value relative to soft dough and incurs additional irrigation costs.

Table 8 indicates that two pivot irrigations or one set-move irrigation could be saved by irrigation cutoff at soft dough rather than hard dough on adequate water-holding soils. An alternative method of assessing

Figure 4. Barley at soft dough grain stage presenting mealy characteristics of kernel. Photo by C.W. Rogers.

Figure 5. Kernel at soft dough from left to right: whole kernel with awn, kernel with chaff removed, mealy kernel, kernel after kneading in fingers. Photo by C.W. Rogers.

Table 6. Relative value and three year average value of malting barley production per acre for each irrigation cutoff treatment.

Irrigation stopped with root zone filled to field capacity	Relative yield SD base (decimal)	Relative price based on quality (decimal)	Relative crop value (decimal)	Crop value ($/ac)*
Milk	0.87	0.9	0.78	634
Pre-SD	0.94	1.0	0.94	764
Soft Dough (SD)	1.0	1.0	1.0	813
Post-SD	0.97	0.9	0.87	707

*Based on average contract prices of $6.50/bu or $13.50/cwt and expected non-stressed yield of 125 bu/acre.

Table 7. Relative crop yield and four year average value of hard red wheat production per acre for each irrigation cutoff treatment.

Irrigation stopped with root zone filled to field capacity	Relative yield SD base (decimal)	Crop value ($/ac)*
Early Milk	0.69	304
Late Milk	0.78	343
Early Soft Dough	0.93	409
Soft Dough	0.95	418
Late Soft Dough	1	440
Hard Dough	0.96	422

*Based on average price of $4.00/bu and average yield of 110 bu/ac.

irrigation cost is shown in Table 9, which shows the effect of system type and pumping lift. For example, the typical cost of applying 1 acre-inch of water by center pivot from a canal source is about $0.69, while it would be about $2.74 for a 400 foot lift. In contrast, the cost of applying 1 acre-inch with a set-move system from a canal source is about $4.35 or $6.87 for a 400 foot lift. The difference in cost is primarily due to labor and to the extra pressure and water required to deliver 1 acre-inch net with a set-move system.

An alternative approach to evaluating the need for additional irrigation at various crop stages is shown in Figures 6 and 7. The crop value and irrigation costs are summarized in Figure 6. The curve for total value of the product in Figure 6 can be obtained by methods shown in Tables 6 and 7. Irrigation cost is for a center pivot with 200 foot lift. As shown earlier, Figure 2, the maximum crop value occurs when irrigation is stopped with a relatively full root zone at soft dough.

Figure 7 evaluates this same information in terms of the marginal cost of irrigation and the marginal crop value resulting from the final irrigation occurring at various crop stages. It shows that for all crop stages before soft dough, the crop value added by each irrigation exceeds the cost of that irrigation. Profit is maximum at the stage where the marginal cost of the irrigation equals the marginal value produced by that irrigation. This analysis also shows maximum profit occurring with irrigation stopped at soft dough with a full root zone (i.e., 2.0-2.5 inches of usable water in the crop root zone).

Additional Resources

University of Idaho Bulletin 833 "Estimating Water Requirements of Hard Red Spring Wheat for Final Irrigations"

University of Idaho CIS 236 "Irrigation Scheduling Using Water Use Tables"

University of Idaho CIS 1217 " Southern Idaho, 2015: Spring Barley Quick Facts"

USDA-NRCS "Estimating Soil Moisture by Feel and Appearance"

University of Idaho Bulletin 742 "Idaho Spring Barley Production Guide"

Washington State University "Irrigation Scheduler-Mobile" available at: http://weather.wsu.edu/is

Table 8. Total irrigation and number of events for the season, two row malting barley, three year average.

Treatment	Irrigation depth (in)	Estimated number of pivot irrigations*	Estimated number of solid-set or set-move irrigations**
Emergence to Milk	11.6	14	6
pre-Soft Dough	13.6	17	8
Soft Dough	14.9	19	8.5
post-Soft Dough	16.0	20	9
Hard Dough	16.8	21	9.5
Harvest	17.6	22	10

*Net irrigation of about 0.8 inches per revolution.

**Net irrigation of about 1.8 inches per set.

Table 9. Typical cost ($) per acre-inch applied (considering system application efficiency) for surface/canal systems.

System type	Canal water	Groundwater lift (ft)			
		100	200	300	400
Center pivot	0.69	1.23	1.69	2.21	2.74
Set/move	4.35	5.09	5.58	5.92	6.87

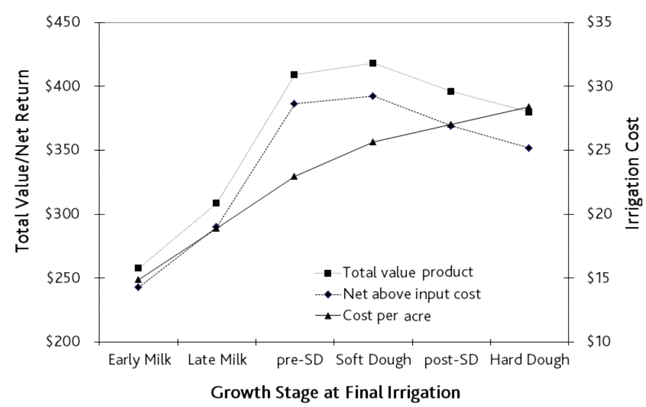

***Figure 6**. Cost return data for hard red spring wheat when irrigations are applied at specified times.

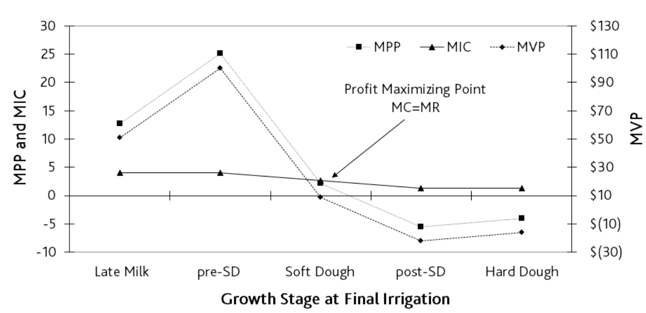

***Figure 7**. Marginal physical product (MPP), marginal irrigation cost (MIC) and marginal value of product (MVP) for hard red spring wheat when irrigations are applied at specified times.

*Figures by Wilson Gray, Extension agricultural economics specialist, retired (Twin Falls).

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