Scheduling the Last Irrigation on Wheat and Barley

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Agricultural production in irrigated areas is becoming more water-constrained. For example, domestic and municipal water use is increasing with urban expansion and drought periodically reduces surface water supplies. The potential reduction in irrigation water supply due to water rights adjustments may also reduce ground water supplies. At the same time, increased costs of irrigation (water, energy, and labor) and other production inputs have reduced the economic return for a grain crop. 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. Standard practice in many irrigated areas is to continue irrigation of spring grains beyond physiological maturity, with the belief that high water applications increase grain weight and yield during all crop growth stages. Field experience of long-time University of Idaho County Extension Faculty indicates that when the last irrigation is applied to refill the soil profile of sandy loam or silt loam soil to field capacity at Soft Dough stage, sufficient water can be stored in the soil to meet the crop water requirement until harvest. Robertson (1999) also has suggested that the last irrigation at Soft Dough would result in optimum grain production. Water applied after these stages either remains in the soil profile or percolates below the crop root-zone, reducing water use efficiency and wasting water.

The objective of optimum irrigation management during grain formation is to sustain economic productivity while reducing the water applied and the risk of water related diseases. The purpose of this paper is to help growers determine the optimum time and amount of the last irrigation application needed to sustain economic return for wheat or barley.

The quality of barley grain is an important consideration for malting. Water management during grain formation stages affects the grain quality. Water applied by a sprinkler system close to the barley harvest can cause water related diseases that reduce grain test weight and quality required for malting

Crop Water Use Pattern for Small Grains

An average crop water use pattern for winter and spring grain is shown in **Figure 1**. The patterns are similar, with the spring grain curve lagging by about 1-2 weeks. The timing difference is due to winter grain ET beginning in the spring as soon as sufficient heat units have been received to break dormancy, while spring grain ET is delayed until the crop can be planted and emerge. Following emergence, the patterns are similar, with winter grain reaching maturity about 1-2 weeks sooner. An important characteristic of the water use curve for both is the rapid decrease in ET at the end of the season. The decrease is more abrupt than for most other crops. 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.

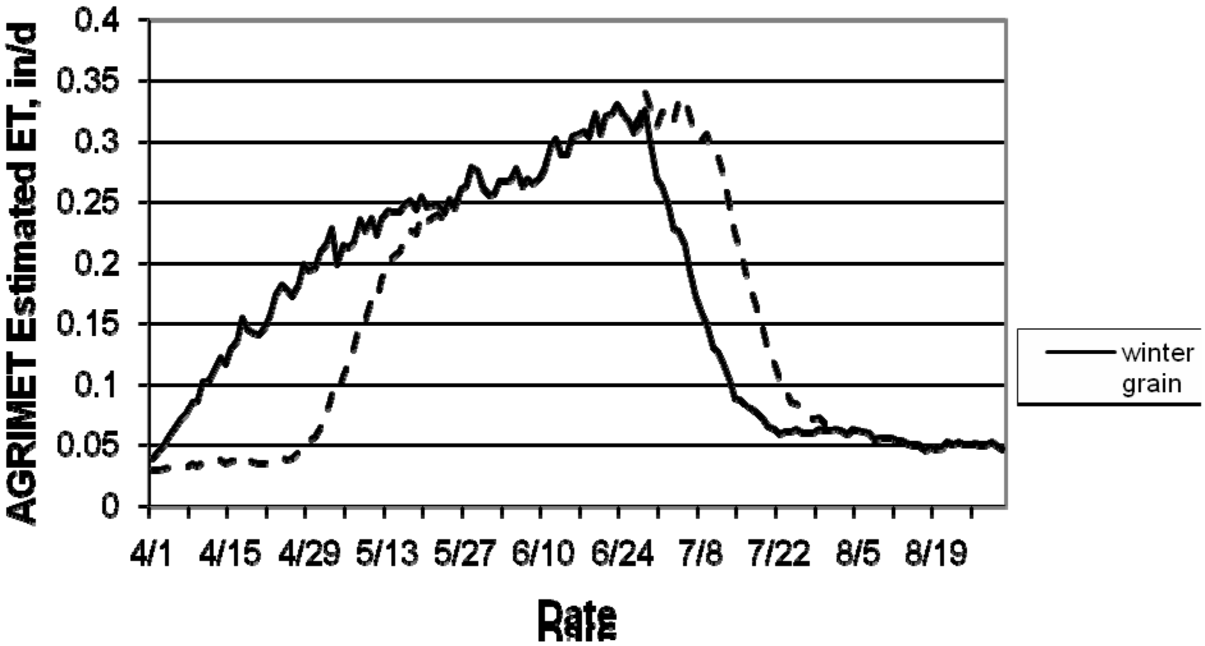

Figure 1. AGRIMET estimated ET for winter and spring grain at Kimberly, ID, 30-year average.

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

Yield and Quality Response to Irrigation Cutoff

Potential crop yield is determined during tillering. The maximum number of grain heads is determined in this stage, where the crop is only 4-6 inches tall. Yield loss 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, where 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 **Figures 2 and 3**, which show lowest yield with earliest cutoff (greatest and earliest water stress).

In 5 plot years (2 locations) for wheat and 3 plot years (1 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 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 inches of usable water at Soft Dough.

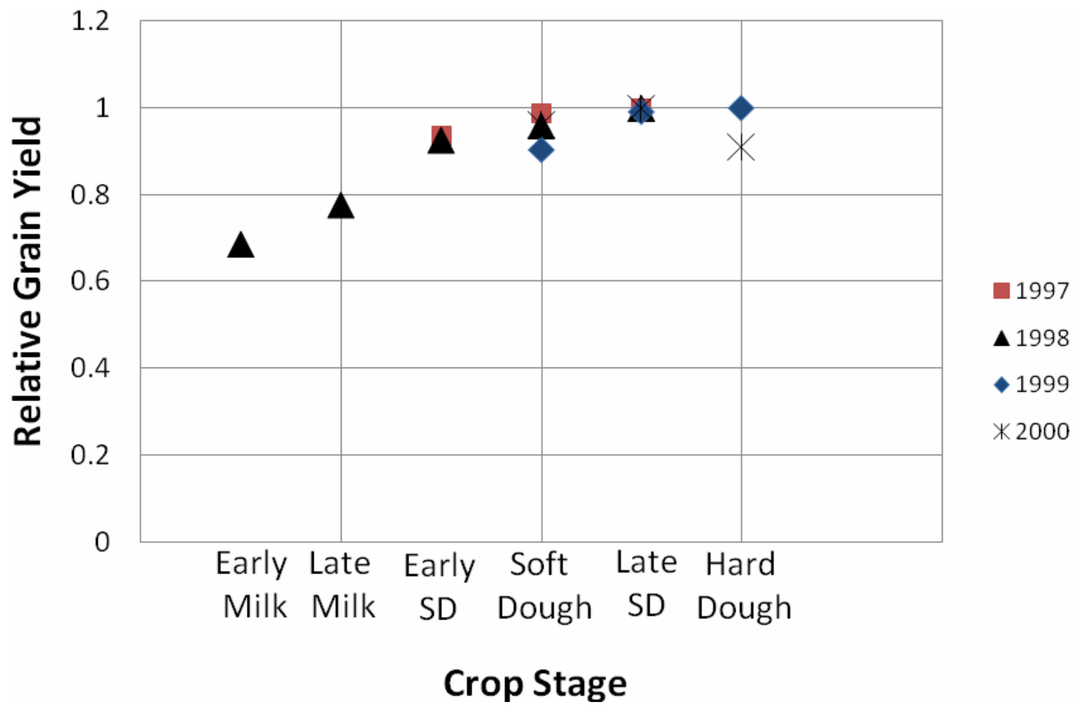

Figure 2. Yield response to crop stage at last irrigation for hard red winter wheat 1997-1998), hard red spring wheat (1999, 2000). Water supply by surface drip irrigation.

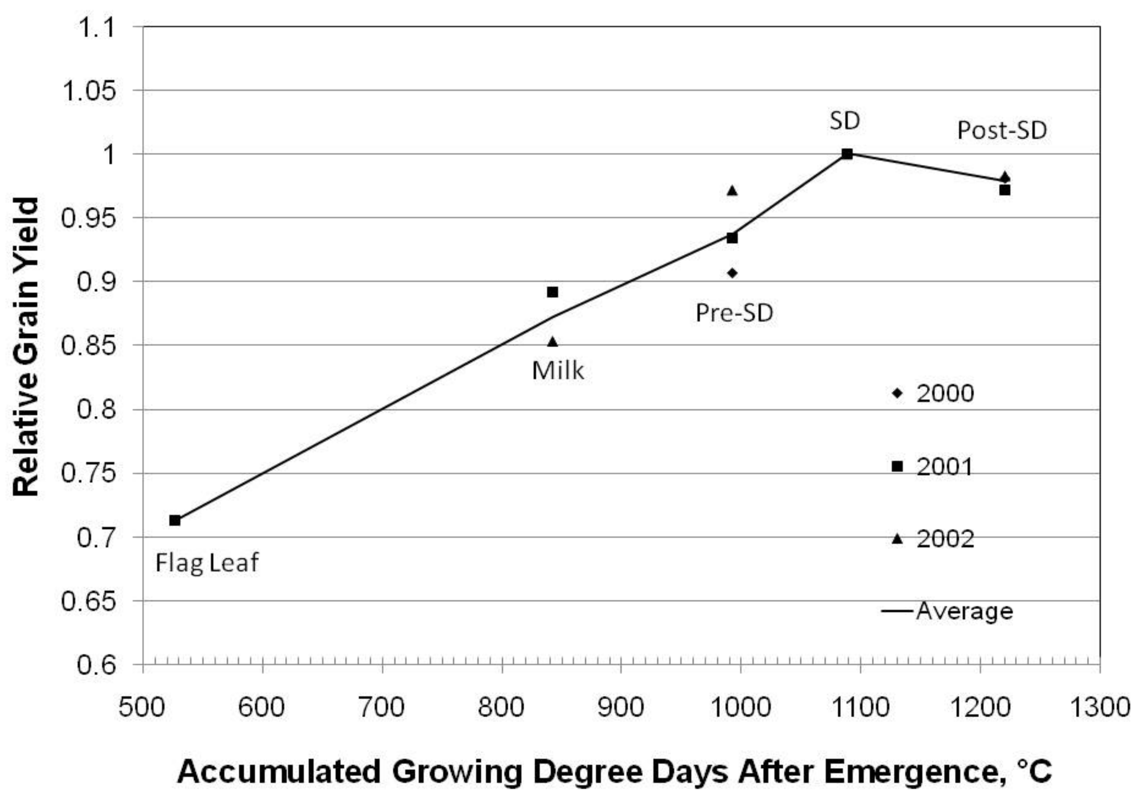

Figure 3. Malting barley yield at specified irrigation cutoff relative to yield with full-season irrigation.

Table 1. Percent of kernels infected with black point, 2-row malting barley at Burley, ID 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

Barley production contracts allow for product rejection at disease and damage levels > 5%

In water-short conditions, **Figures 2 and 3** indicate 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 on malting barley with a full profile at early milk would give an expected yield of only 70% that of full season irrigation (**Figure 2**).

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 3-year averages for 2-row malting barley at Burley, ID. Values for hard red spring wheat are estimated using an equation relating cumulative water use to Haun crop stage. Note that seasonal water use for the two crops agrees well and water use from Soft Dough to harvest is 2.7 inches for malting barley and 2 inches for spring wheat. This is consistent with current recommendations to cut off irrigation at Soft Dough if at least two inches of usable water is stored in the crop root zone.

Table 2. crop water used (inches) for selected malting barley and hard red spring wheat crop stages and total seasonal use.

Crop stage	2-row malting barley	Hard red spring wheat
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, ID

** 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.)

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 3 feet if no impeding 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 soil conditions. 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 Ft. Hall area.

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

Root zone depth, inches	Sandy loam	Light-textured silt loam	Heavier-textured silt loam
12	0.8	1.0	1.2
24	1.6	2.0	2.4
36	2.4	3.0	3.6

Soil texture for a particular field may be determined from the USDA-NRCS soil survey or by other field or laboratory tests. Many fields 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 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.

Table 4. Irrigation (inches) needed past Soft Dough for no yield or quality reduction.

Root zone depth, inches	Sandy loam	Light-textured silt loam	Heavier-textured silt loam
12	1.2	1.0	0.8
24	0.4	0	0
36	0	0	0

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. This is an important consideration since it may define the depth of root zone although soil is deeper than wetting due to irrigation. For example, in heavier textured silt loam soils, runoff potential limits application per pivot revolution to no more than ¾ inch. If the soil starts at field capacity, ¾ inch of water use will dry the soil to about 70% available soil water. Adding ¾ inch of net irrigation will re-wet 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 evaluate water required to re-fill 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. The depth of water required to re-fill one 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%, and 1.04 inches of water is required to re-fill 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% available water (field capacity) and no re-fill is needed.

Table 5. Relationship between soil moisture expressed as either percent available water or watermark readings and inches to re-fill one foot of soil to field capacity with pivot, hand line, wheel line or solid set systems.

Percent 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 cbars	Inches to refill 1 ft of soil **pivot or linear**	Inches to refill 1 ft of soil **hand or wheel line**	Water-mark Reading cbars	Inches to refill 1 ft of soil **pivot or linear**	Inches to refill 1 ft of soil **hand or wheel line**	Water-mark Reading cbars	Inches to refill 1 ft of soil **pivot or linear**	Inches to refill 1 ft of soil **hand or wheel line**
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	0.6	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[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

As shown in **Figure 4**, calendar date is not very useful since onset of Soft Dough at Aberdeen ranged from June 9 in 1992 to June 28 in 1993. Visual appearance of the crop is not a good indicator since noticeable color change does not usually occur until Hard Dough (**Figure 5**). Therefore, the description listed above is still probably the most generally applicable, although a general rule of about 24 days after flag leaf emergence will be helpful in identifying the general time period.

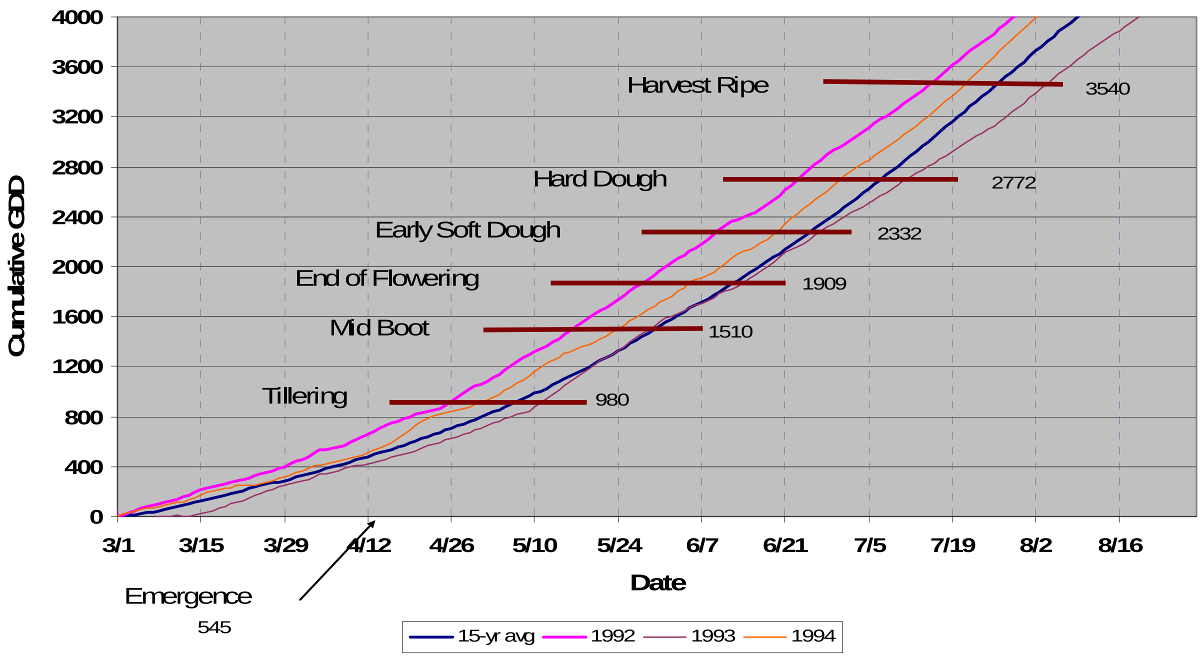

Figure 4. Variation in timing of crop stages at Aberdeen. Crop stages achieved earliest in 1992, latest in 1993 and slightly earlier than average in 1994.

[1] From: University of Idaho Bulletin 833 “Estimating water requirements of hard red spring wheat for final irrigations

Figure 5. Visual differences in 2-row malting barley at early milk, Soft Dough and Hard Dough crop stages (from Robertson).

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 last irrigation is scheduled at later crop stages. For example, scheduling the final irrigation at Soft Dough rather than Milk, increased crop value by $813-$634 or $179/acre. However, scheduling the last irrigation at post-Soft Dough (nearly Hard Dough) decreased crop value by $106/acre. **Table 7** summarizes crop value for last 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 6. Relative value and 3-year average value of **malting barley** production per acre for each irrigation cutoff treatment.

Irrigation stopped with root zone filled to field capacity at:	Relative yield (SD base)	Relative price based on quality	Relative crop value	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 4-year average value of **hard red wheat** production per acre for each irrigation cutoff treatment.

Irrigation stopped with root zone filled to field capacity at:	Relative yield (SD base)	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

Table 8 indicates that 2 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 irrigation cost is shown in **Table 9**, which shows the effect of system type and pumping lift. For example, the typical cost of applying one 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 one 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 one acre-inch net with a set-move system.

Table 8. Total irrigation and number of events for the season , two-row malting barley, 3-year average.

Treatment	Total Irrigation Season		
	Irrigation Depth, inches	Estimated # of Pivot Irrigations *	Estimated # 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).

System type	Water source				
	Surface	Groundwater lift in feet			
	canal	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

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 (**Figures 2 and 3**), the maximum crop value occurs when irrigation is stopped with a relatively full root zone at Soft Dough.

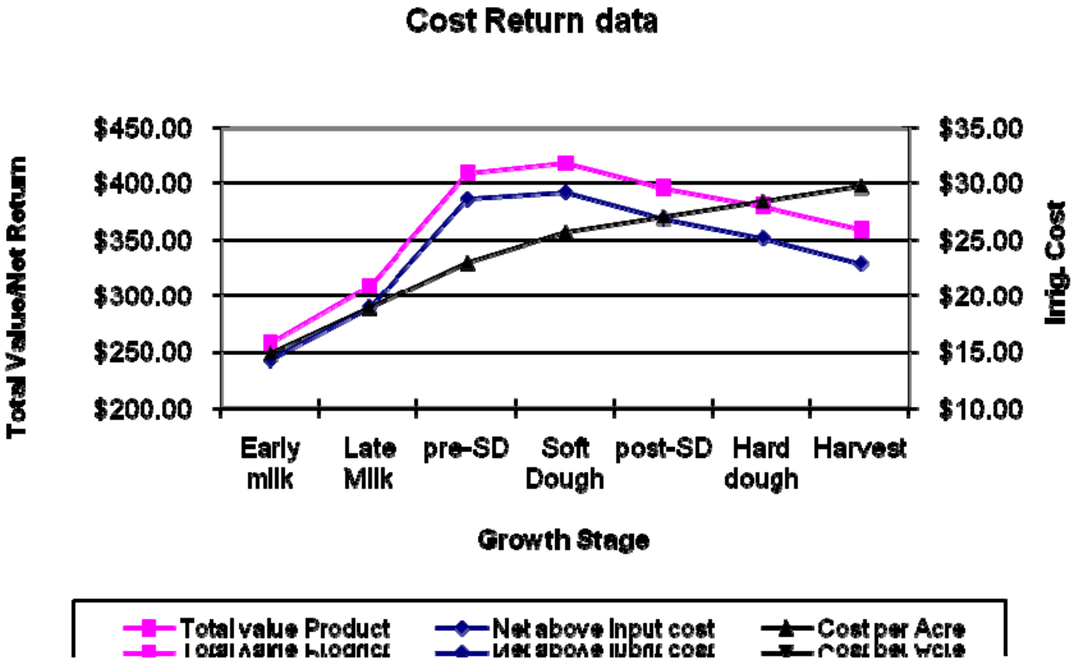

Figure 6. Cost return data for hard red spring wheat.

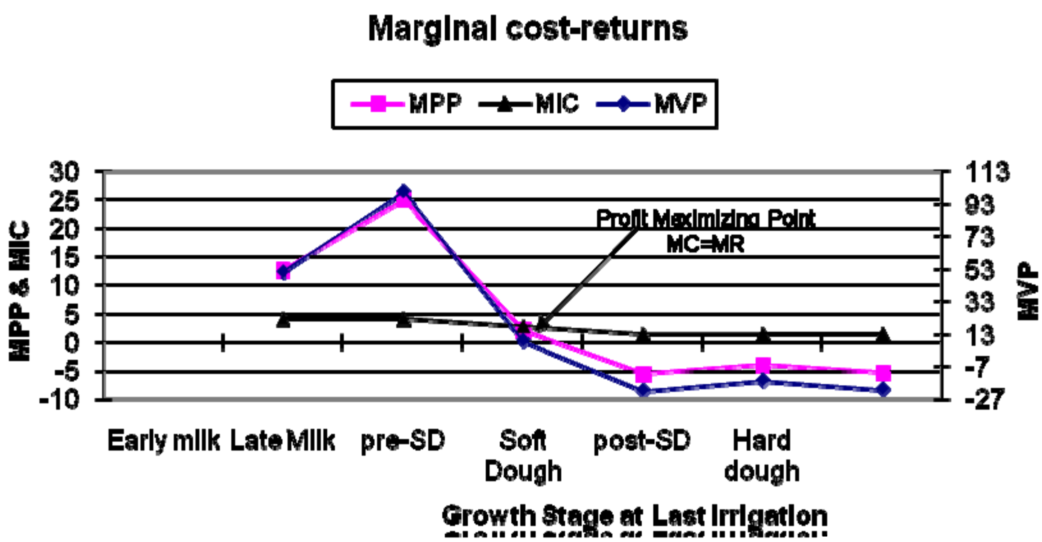

Figure 7. Marginal physical product (MPP), Marginal irrigation cost (MIC) and Marginal value of product(MVP) for hard red spring wheat.

Figure 7 evaluates this same information in terms of the marginal cost of irrigation and the marginal crop value resulting from the last 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 (e.g. 2-2.5 inches of usable water in the crop root zone).

Putting it all Together

A farmer irrigates 125 acres of malting barley with a center pivot on a sandy loam soil 18 inches deep. Lift is 300 feet. Expected yield (no water stress) is about 120 bu/acre. Available moisture at a crop stage between Milk and Soft Dough (e.g. pre-Soft Dough) is 60%. What is a likely scenario if : (1) irrigates to 100% available at Hard Dough, (2) irrigates to 100% available at Soft Dough and then adds one more irrigation of 0.8 inches or (3) stops irrigation immediately?

Case 1: Irrigation to a full root zone at Hard Dough would be similar to the post-Soft Dough crop stage in **Table 6,** which indicates a relative crop value of 0.87. Projected crop value would be 0.87*120 bu/acre*$6.50/bu or **$679.**

Irrigation cost from current conditions (60% available soil moisture at pre-Soft Dough) to a full root zone at Hard Dough would be 1.26 inches to fill at pre-Soft Dough+ (16.8 inches at Hard Dough-13.6 inches at pre-Soft Dough). Water needed = 1.26+3.2 = 4.46 inches. From **Table 9**, the cost to apply 1 inch of water through a center pivot with 300 foot lift is $2.21. The cost for 4.46 inches would be $2.21/acre-inch*4.46 inch= **$9.86/acre**

Case 2: Irrigation to Soft Dough with a full root zone would be (1.2+0.4)/2 or 0.8 inches short of ideal moisture with an 18-inch soil depth. With a 0.8 inch irrigation after Soft Dough, this requirement would be fully met so an un-stressed yield of 100% of maximum would be expected. Crop value would be 1.0*120 bu/acre*6.50/bu or **$780/acre**.

Irrigation cost from case 3 to full root zone at Soft Dough would be 1.26 inches to fill at pre-Soft Dough+ (14.9 inches at Soft Dough-13.6 inches at pre-Soft Dough)+0.8 inches.. Water needed = 1.26+1.3+0.8 = 3.36 inches. From Table 9, the cost to apply 1 inch of water through a center pivot with 300 foot lift is $2.21. The cost for 3.36 inches would be $2.21/acre-inch*3.36 inch= **$7.42/acre**

Case 3: From **Table 5**, it would take 0.84 inches of irrigation to fill 12 inches of soil depth to 100% available. It would take (18/12)*0.84 or 1.26 inches to fill 18 inches to field capacity. This means that currently he is 1.26 inches short of a full 18-inch root zone. This condition is like working with a full root zone somewhere between milk and pre-Soft Dough. To better evaluate, **Table 8** shows that it takes 2 inches of water use between milk and pre-Soft Dough. Therefore, this is like being 1.26/2 or 63% of the way back from pre-Soft Dough to milk. **Figure 3** shows that estimated relative yield at this condition is about 0.9. That is, yield resulting from stopping irrigation at this point would be about 90% of un-stressed yield. Expected yield would be 0.9*120bu/acre or 108 bu/acre. Crop value would be 108 bu/acre* $6.50/bu or **$702/acre.**

Additional irrigation cost for this option is $0.

Summarizing:

Stop with part-full root zone at pre-Soft Dough: crop value=$702/acre
Irrigation cost =$0/acre

Stop at Soft Dough with full root zone: crop value=$780/acre
Irrigation cost=$7.42/acre

Stop at Hard Dough with full root zone: crop value=$679/acre
Irrigation cost=$9.86/acre

Incremental costs:

Stop immediately vs. Soft Dough with full root zone: crop value=$780-702=$78/acre benefit
Irrigation cost =$7.42-0 = $7.42/acre

Incremental benefit-incremental cost = $70.58

Stop immediately vs. Hard Dough with full root zone: crop value=$679-702=-$23/acre benefit
Irrigation cost=$9.86-0= $9.86/acre/acre

Incremental benefit-incremental cost =-$23-9.86=-32.86/acre

Stop at Soft Dough with full root zone vs. Hard Dough with full root zone:
crop value=$679-780= -101/acre
Irrigation cost=$9.86-7.42 = $2.44/acre

Incremental benefit-incremental cost = -$101-$2.44= -$103.44

It can be seen that the alternative of stopping at Soft Dough and adding another 0.8 inch irrigation is the most economically beneficial. Also, the incremental value of crop production for these alternatives is much larger than the incremental irrigation cost, although even $2.44/acre applied to several pivots would be a substantial savings.

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”

USDA-NRCS “Estimating Soil Moisture by Feel and Appearance”

Robertson, L.R. “Spring Barley & Spring Wheat Weekly Growth Stages”
http://www.ag.uidaho.edu/scseidaho/growstage/growth_stage_index.htm