Response of Two-Row Malting Spring Barley to Water Cutoff under Sprinkler Irrigation

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Abstract

The last irrigation application time and its impact on crop yield, quality, and economic benefits were studied in the 2000, 2001, and 2002 cropping seasons. Irrigation was stopped for the season at Milk, pre-Soft Dough, Soft Dough, and post-Soft Dough grain formation stages. The Soft Dough treatment produced the highest grain yield of two-row malting spring barley. Water cutoff before or after Soft Dough stage reduced the grain yield significantly at $p<0.05$, but the quality of grain for malt production was not significantly different when water was cut off at pre-Soft Dough or post-Soft Dough stages. Irrigation cutoff at Milk stage produced the lowest grain yield with the lowest quality. It was observed that the decrease in grain yield at post-Soft Dough was due to the moisture related grain diseases that decreased the weight and quality of the kernels for malt extraction. Net return was 13% less for Soft Dough relative to the post Soft Dough cutoff treatment and 10% less for pre-Soft Dough cutoff relative to post Soft Dough cutoff. Water use efficiency during individual years was highest with cutoff at Milk stage, but the grain quality was the lowest.

Introduction

The quality of barley grain is an important consideration in malt production for the beer industry. Water application management during grain formation stages affects the quality of grains. Jackicik and Forster (2002) have reported that water applied by a sprinkler system close to the barley harvest caused moisture related diseases that reduced the grain test weight and quality required for malt production.

Increased costs of irrigation (water, energy, and labor) and other production inputs have reduced the economic return for a grain crop. Domestic and municipal water use is increasing with the population and expansion of urban areas. Drought periodically reduces surface water supplies and potential reduction in irrigation water supply due to water rights adjustments may reduce ground water supply. As a result, agricultural production in irrigated areas is becoming more water-constrained. The water shortage may be seasonal, year-round, or progressive, following increasing demands from additional agricultural uses or from other sectors. Uncertainty further complicates the situation, making the ability to manage water shortage a critical issue for irrigated agriculture.

Managing irrigation systems for maximum productivity under conditions of water shortage and uncertainty is a critically important challenge to agricultural scientists and irrigation engineers (English et al., 1982). Grain crops exhibit a different behavior to water stress at different crop development stages (Nelson et al., 1998; Robertson et al., 1993; Zhang et al., 1999). Boot and flowering are the most sensitive stages to crop water stress (Anderson et al., 1985; English, 1986). These stages, in combination with climatic parameters, are associated with varying water requirements (Ashley et al., 2001) and sensitivities. The amount of water applied at these stages greatly affects the yield and quality of a grain crop.

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Grain formation stages (Zedoks et al., 1974) offer an option to manage irrigation and soil water to conserve water application during the late season of crop development without adversely affecting yield quantity and quality. Standard practice in most of irrigated agriculture is to continue irrigation of spring grains almost up to harvest, with the belief that high water applications increase grain weight and yield during all crop growth stages. Experience 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 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.

Irrigation management practices during grain formation are required to maintain economic productivity while reducing the water applied and reducing the risk of moisture related diseases.   The purpose of this study was to determine the optimum time and amount of the last irrigation application without significantly effecting yield and quality of two-row malt barley.   Results from this study will be useful for different water-shortage crop production systems around the world especially those facing late season water shortages.

Materials and Methods

The experiment was conducted during the 2000, 2001, and 2002 growing seasons at the Coors Barley Research Center, at 113.8 W and 42.5 N, about four miles north of Burley Idaho.   The soil is classified as Buko-Pianogue sandy loam, which is a deep and well-drained soil with a moderate water holding capacity (SCS, 1979) of 38mm per 30cm (1.5in/ft) soil depth.   The soil profile has a hardpan at about 75cm depth that hampers the penetration of roots and water below 75cm.

The Coors Research Station personnel prepared the land, planted the crop using Morravion 37 seed, a high yielding malt barley variety developed at the Coors Research Station, and also applied fertilizer, herbicides, and pesticides throughout the growing season.   They also irrigated the crop from pre-planting to the time the first irrigation was applied during the experiment.

The experimental design had four replications, with each plot in a replication assigned a different treatment.   The plot size was 18.3 meters (60 ft) in length and 3.66 meters (12 ft) in width.   Due to the small plot size, conventional sprinkler irrigation systems were not used.   Instead, a special irrigation system was prepared to apply water to cover only the experimental area and the individual plot for each treatment.   Sprinkler heads used for these experiments were Nelson square pattern fixed non-rotating garden sprinklers with an average discharge of 30.5 mm/hr (1.2 inches/hour). Coverage area per sprinkler was approximately 3.66 meter by 3.66 meters (12x12 ft). The sprinklers were mounted on a vertical pipe riser at 1.2 m (4 ft) above ground level. During the experiment, soil moisture was observed by Watermark soil moisture sensors [3](gypsum blocks that measure electrical resistance to water) and by the feel and appearance method.   Soil samples were also collected to calculate the soil water balance during the grain formation period.

Watermarks were installed at three different soil depths: 30cm (12 in), 61cm (24 in), and 90cm (36 in). The 30cm depth watermark measured the soil moisture variation in the top water management layer of the soil profile, and was used to manage the soil moisture in the whole soil profile of 60cm.   Water was managed by considering the first 60cm (2-ft) soil depth, because almost 70% to 80% of the total water a grain crop can extract resides in the first 60cm soil depth (Doorenbos and Kasam, 1979).   Reports indicate that roots grow faster in soil depths where water contents are high (without creating an aeration problem) and soil strengths are lowest (Taylor, 1983), therefore, plant roots concentrate in soil zones with higher moisture contents (Bar-Yosef, 1977).

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[3]   Manufacturer names are for reader benefit and do not imply endorsement by the University of Idaho

The 60cm and 90cm depth watermarks were used to evaluate water losses due to deep percolation from the bottom of the soil profile of 90cm depth.

Watermarks were used as a tool to approximate the change in current soil water conditions and to determine the next irrigation time and amount.   Soil samples were also physically observed (feel and appearance method) to determine soil moisture conditions in relation to watermark readings.   Irrigation times and amounts were also calculated using previous soil moisture conditions and reference evapotranspiration (ETr) information downloaded from the Internet website http://mac1.pn.usbr.gov/agrimet/ for Rupert, Idaho. The Rupert weather station is located about 10.6 km north of the research station.   The reference evapotranspiration was multiplied with mean crop coefficient (K_{cm}) values taken from Wright (1981) to determine the maximum crop water requirement (ET_m), of the crop.

Gravimetric soil samples to 120cm soil depth, with 30cm increment were collected before the application of water.   Collected soil samples were used to calculate the actual water used (ETa) by the crop between two water applications and over the season.   The gravimetric soil moisture data were also used to calculate other soil water balance parameters in the soil profile system.   A simple water balance was calculated from Equations 1 & 2.

$$W_{ai} = W_r + I_i - E_s - I_{nt} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 1$$

$$ET_{a(bni)} = W_{ai} - W_{bni} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 2$$

Where:

W_{ai} = Soil water in the crop root zone after irrigation (close to field capacity), mm
W_r = Remaining soil water before the irrigation, mm
I_i = Irrigation water applied, mm
E_s = Soil surface evaporation after irrigation, mm
I_{nt} = Irrigation water intercepted by the upper surface of the crop canopy, mm
W_{bni} = Soil water in the crop root zone before next irrigation when soil water was depleted to the level
          where refill was needed, mm
$ET_{a(bni)}$ = Actual basal crop evapotranspiration or water used between irrigations, mm

Four treatments at kernel Milk, pre-Soft Dough (pre-SD), Soft Dough (SD), and medium Soft Dough (post-SD) stages were considered for irrigation cutoff.   The experiment hypothesis was that optimum crop yield and quality would occur when soft dough stage received the last irrigation, filling the 60cm soil profile to field capacity.   During 2000, only three treatments at pre-SD, SD, and post-SD were considered, and for the 2001 and 2002 cropping seasons, Milk stage cutoff treatment was also included as the fourth treatment.

Different cutoff stages were calculated by accumulating growing degree-days, a procedure suggested by Ashley et al., (2001) for southern Idaho.   Actual cutoff dates were determined by combining growing degree day information with field observation.   Daily growing degree-days (GDD) were calculated with Equation 3 as:

$$GDD = \frac{T_x + T_n}{2} - T_{base} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3$$

Where:

T_x = $\max(T_{max}, T_{base})$
T_n = $\max(T_{min}, T_{base})$

GDD $\qquad$ = growing degree days, $^{\circ}C$

T_{max} $\qquad$ = maximum air temperature, $^{\circ}C$

T_{min} $\qquad$ = minimum air temperature, $^{\circ}C$

T_{base} $\qquad$ = base temperature for the season, $^{\circ}C$

$\qquad$ If plant leaves ≤ 2, Tx   min(max (Tmax, Tbase), 21.1)

$\qquad$ If plant leaves > 2, Tx   min(max (Tmax, Tbase), 35)

Cumulative growing degree-days are the sum of daily growing degree-days from crop emergence to the respective water cutoff stage. Crop growth stages were considered according to the staging system outlined by Zedoks et al., 1974.

Grain yield was determined by machine harvesting a 1.4m x 6m center area of each plot.   Sub-samples from each plot (4 samples/treatment) were analyzed by Coors personnel to determine grain qualities of plumpness, protein content, and color.   Malting characteristics of the barley grain are important factors in the selection and purchase of barley for the production of high quality beer. Seed plumpness is the most important quality used to determine the malt characteristics and the price of the grain.   Other features include percent protein, color, moisture content, and absence of blacktip on grains.   The standard plumpness test uses a 6/64 mesh screen. Percent plumpness is calculated from the percent of kernels retained on the screen relative to total sample size.   A plumpness score between 75% and 80% is termed satisfactory, while 80%-90% indicate good quality and more desirable product. Brighter color (higher value in **Figure 5**) and lower protein content of grains are considered good qualities for malt production.

Results and Discussion

Weather

The climatic conditions of the three growing seasons were different during different crop growth stages. The 2000 season was hottest during initial crop stages, while 2002 was hottest during grain formation period.   2001 represents more "typical" climate conditions for the experiment area. Rainfall during the grain formation period was negligible, and wind speeds were moderate (3 km/hr).   Crop water use was at maximum from full crop cover in June to grain soft dough stage, with daily maximum evapotranspiration of 8-10mm **(Figure 1)**.

Soil moisture and crop water use

Average soil moisture variation patterns for Milk, pre-SD, SD, and post-SD treatments at different soil depths are presented in **Figure 2**. Moisture variation was similar in all the treatments, except that the soil was very dry at the time of harvest for the Milk stage cutoff treatment, and the soil profile had more remaining water when the last irrigation was applied at post-SD treatment.   The soil moisture analysis indicated that most of the root activity was in the top 60 to 75cm soil depth where most of the soil moisture changes occurred.   The 90cm depth showed minimal water change, but at the 120cm depth there was no significant change of water content throughout the water management season.   Insignificant water changes at 90cm and 120cm could be due to the presence of hardpan at the 75cm depth that restricted root penetration and water movement below 75cm.   Hardpan may have served as a water collecting surface for the water moving below the 60cm water management depth, and may have contributed towards total grain yield.

The simple water balance procedure **(Equations 1 & 2)** demonstrated that water stored by the Milk and pre-SD cutoff treatments was completely used by the crop at the time of crop harvest **(Figure 3)**. The water applied at SD and post-SD treatments was not utilized completely, and was more than the crop water requirement from respective cutoff stages to crop maturity.   This also suggested that the water applied at SD to refill the 60cm soil profile with moderate water holding capacity was sufficient to satisfy the water requirement between SD stage and crop harvest. Water applied after the SD stage was not used by the crop, but remained in the soil profile and

contributed to soil evaporation loss during the fallow period.

It is apparent from the data in **Table 2** that two-row malting barley did not use a significant amount of water after the post-SD treatment. During 2000 and 2002, water use difference between soft dough and post soft dough treatments was insignificant. The year 2001 indicated a difference of about 16mm, which is considerably different than the other two years. However, the crop did not use all of the water applied at post Soft Dough stage. It is also noticeable that soil moisture information indicated that the crop had used more water during 2002 than in 2001, but the total crop yield is significantly lower in 2002 than in the previous two years. Increased water use was due to higher ET demand in the 2002 grain formation period, which was the hottest season among the three years.

Water use efficiency for the three years is listed in **Table 3**. Highest water use efficiency occurred with the pre-SD stage water cutoff treatment in two out of the three years. Grain plumpness was almost the same among the last three treatments. Therefore, if highest grainyield per unit area is not desired, then water cutoff at the pre-SD stage could be a reasonable choice. Milk stage is not significantly different than the pre-SD stage in terms of water use efficiency and grain plumpness, but did show the highest protein level, a quality factor not favorable for malt production purposes.

Grain Yield

Grain yield results **(Figure 4)** on per hectare basis indicate that the yield increased significantly from Milk stage (Zedoks scale = 75) to Soft Dough cutoff (Zedoks = 85). Water cutoff at Milk stage produced the lowest grain yield of all the treatments **(Table 1)** due to light and small grain size. Grain matured one week earlier than on other three cutoff stages. Early Soft Dough (Zedok = 83) cutoff treatment produced 10% higher grain yield than the Milk stage but was 5% lower than the Soft Dough (SD) cutoff treatment. When water was applied at the late Soft Dough stage (Zedok = 86), the grain yield decreased almost 5% relative to the Soft Dough treatment, due to excess moisture related diseases (Robertson et al., 1993; Jakicic and Forster, 2002).

Blacktip is a fungal disease often associated with rain or irrigation after late Soft Dough. Examination of grain samples for blacktip showed 3% kernel damage for irrigation cutoff at Milk stage, 4% at Soft Dough, and 9% at post Soft Dough water treatments.

Grain characteristics presented in **Figure 5** are important in the determination of market value of the barley grains for malt production. Analysis of grain characteristics indicated that the plumpness was lowest when water supply was cutoff at Milk stage and was highest at post-SD cutoff, but the difference was not statistically significant. Protein content adversely affects the malt extraction process therefore, high protein is not a desirable characteristic of malting barley. Protein contents were highest for the Milk stage cutoff treatment, while the other three treatments were not significantly different. Similarly, grain color reflects the color of the final product (beer). Higher color index value means brighter color, which is a desirable characteristic. Darkest seed color was produced from the Milk cutoff, and brightest was from the Soft Dough treatment, but the difference is not statistically significant. Evaluation of grain yield and grain characteristics suggests that highest yield per unit area and desirable characteristics of barley grain were obtained when last irrigation was terminated at Soft Dough grain formation stage.

Economics

Comparison of production costs and yield/quality benefits indicated that net benefits of irrigation termination at pre-SD and SD treatments were 10% and 13%, respectively, higher than post-SD. The economic analysis indicated that the net income from different treatments is not largely affected by the grain production per unit area.

Rather, the cost of irrigation system operation and water management is the major difference among the four treatments. Grain production analysis has shown that, although yield differences are statistically significant **(Table 2)**, quantity and quality are not very different, especially among pre-SD, SD, and post-SD treatments. A reduction in the number of irrigations required among the last three treatments is the major economic difference. This difference will be greater as the lift from deep well pumping becomes greater. Last irrigation at the pre-SD or SD stages has a greater net economic benefit than post-SD cutoff under pressurized irrigation using surface water or low-lift ground water conditions.

Conclusion

Irrigation cutoff at pre-SD and Soft Dough stages had 10% and 13% higher net benefits over the last irrigation application at post Dough stages. The economic difference was due to higher electric and labor cost involved for the operation and management of water application and lower grain quality at the post Soft Dough cutoff.

Grain yield increased linearly, with the water application from Milk stage to Soft Dough stage and then decreased when water was applied after Soft Dough treatment. Lower grain yield and quality with post-SD treatment was due to the moisture related fungus diseases such as blacktip or smut. Although yield at pre-SD was lower than SD, the quality was as good as SD. During a very short water supply season, water termination at pre-SD would be desirable. Water cutoff at Milk stage produced lower quality grains than are required for malt extraction, but the grains could be useful for animal feed with higher protein content.

In conclusion, on sandy loam soils with moderate water holding capacities, refilling the 60-cm soil profile to field capacity with the last irrigation at SD eliminates the need for further irrigation to a malting spring barley crop without reducing its yield and quality for malt production. Last irrigation at pre-SD stage saved at least two irrigations, and still provided a reasonable yield and quality of spring barley grain.
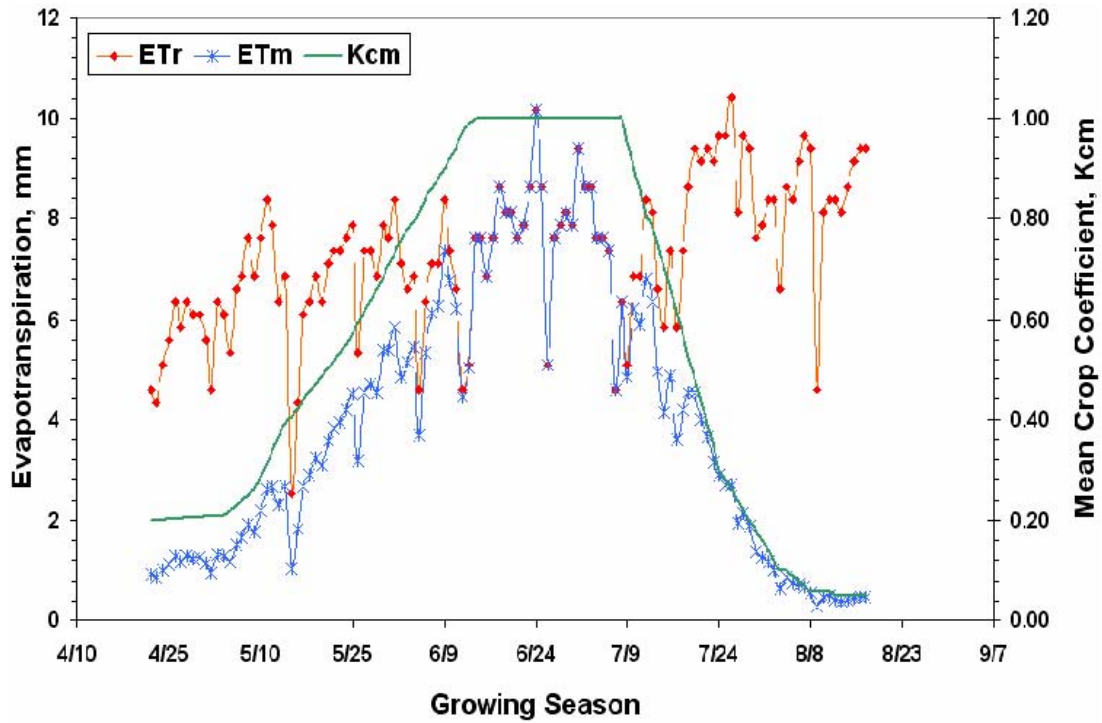
Figure 1. Mean daily reference evapotranspiration (ETr), crop evapotranspiration (ETm), and mean crop coefficients (Kcm) from planting to harvest.
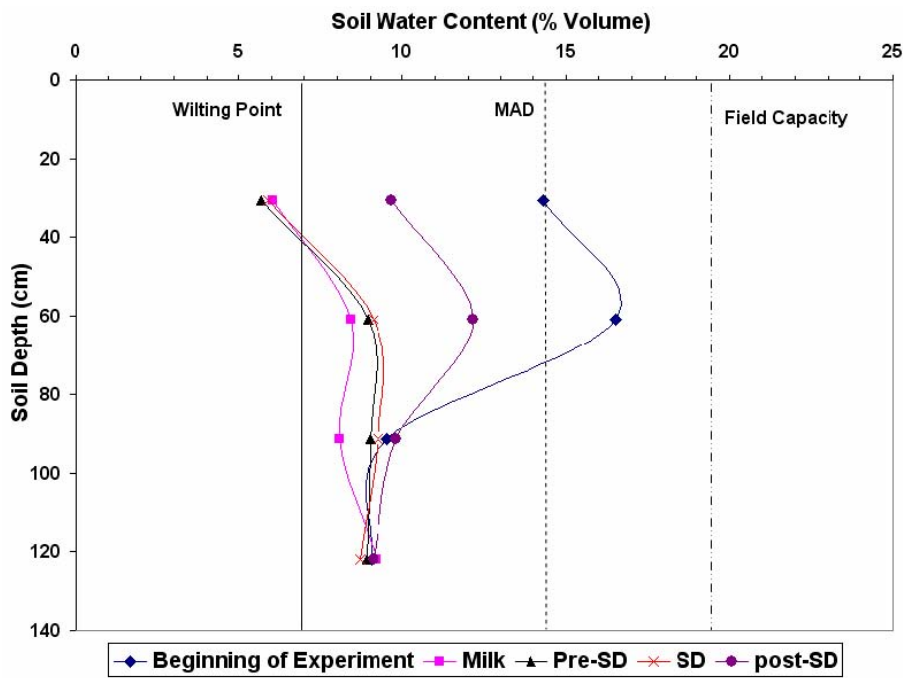

Figure 2. Average soil profile for the three years 2000, 2001, and 2002 at the beginning of experiment, after crop flowering stage, and at crop harvest for different water cutoff treatments.
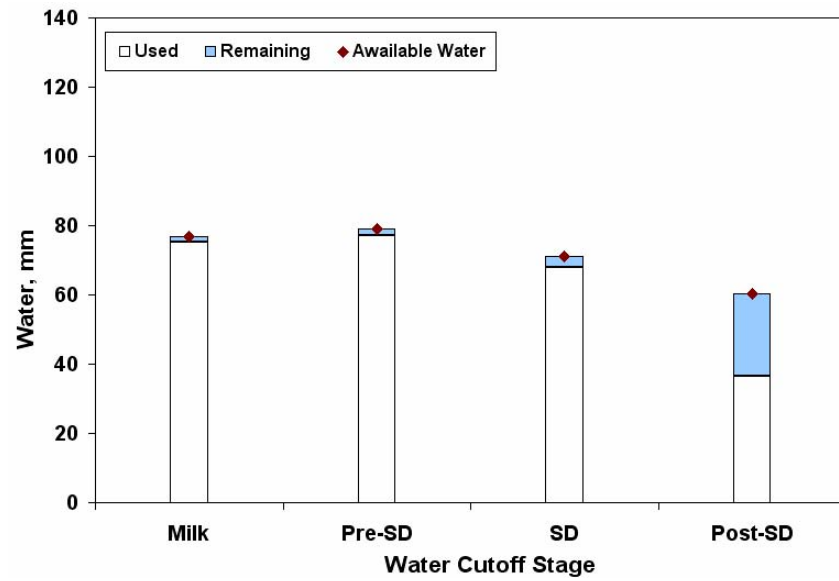
Figure 3. Available water at the time of respective cutoff, water used from cutoff to harvest, and remaining water in the soil profile of top 60cm at the time of crop harvest.
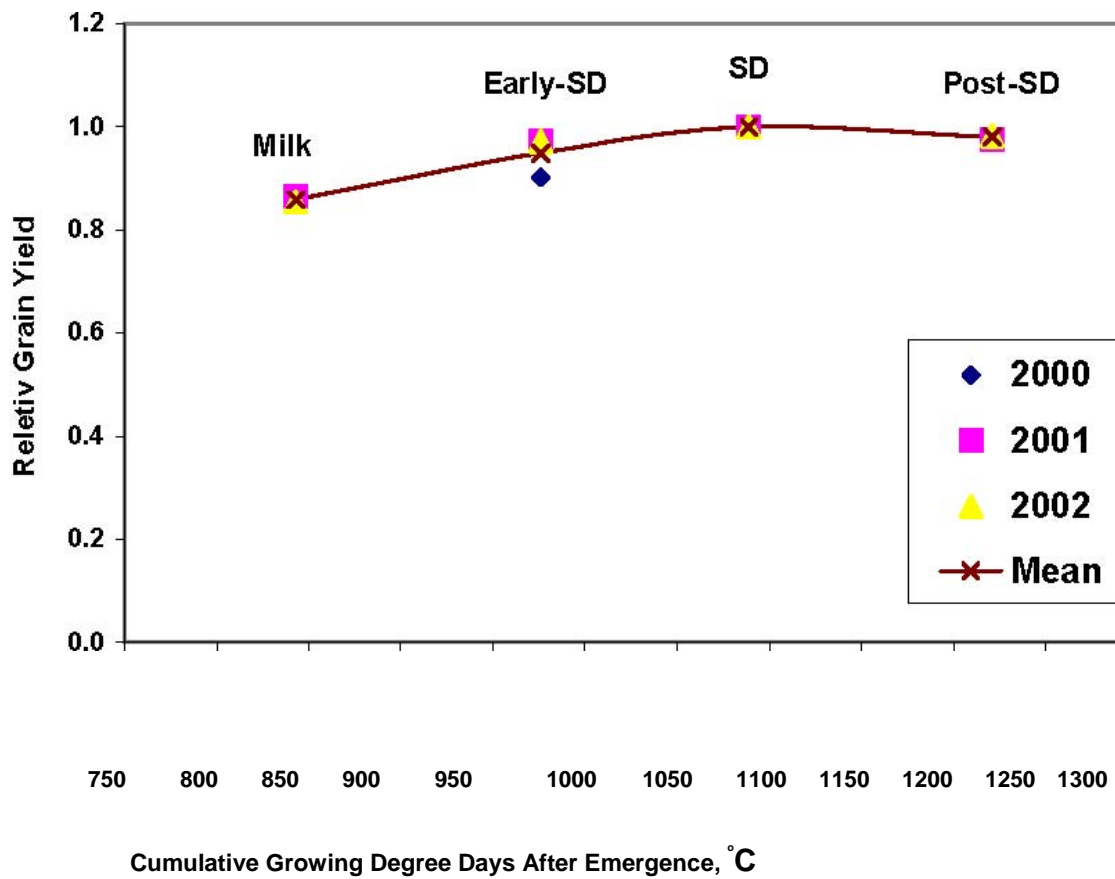

Figure 4. Barley grain yield relative to Soft Dough (SD) treatment in 2000, 2001, and 2002 cropping season.
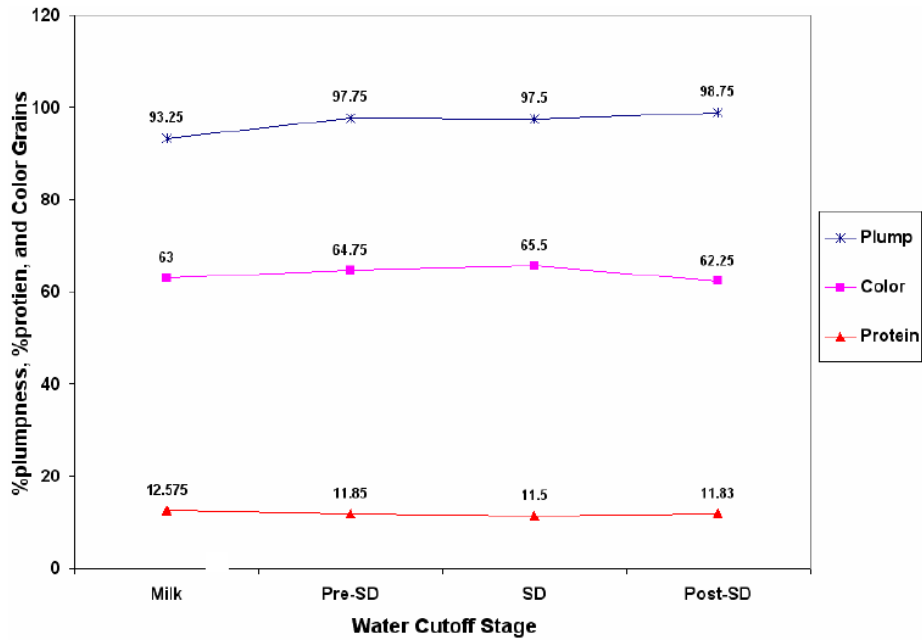
Figure 5. Average grain percent plumpness, percent protein content and color index for 2000, 2001, and 2002.

Table 1. Effect of water cutoff treatments on grain yield of malt barley

Treatment	Grain Yield, kg/ha		
	2000	*2001*	*2002*
Milk Pre Soft Dough Soft Dough Post Soft Dough	----6969c 7757a 7569b 6461c 7281b 7480a 7301b		5803d 6608c 6801a 6684b
Standard Error	4.509 6.904		8.546
A	<0.05 <0.05		<0.05

Duncan's Multiple Range Test ranks the yield at <0.05 significance level. Similar letters indicate no significant difference while different letters show statistical significant difference.

Table 2. Crop water used from first cutoff stage to crop harvesting, accumulated growing degree days from emergence, and Zadok scale of grain growth at different cutoff stages.

Zadoks Scale	Cutoff Stage	AGDD* oC	Measured crop water use mm		
			2000	2001	2002
73-77	Milk	843*	-------	67	75
80-83	Pre-SD	993	118	101	136
84-85	SD	1089	140	126	163
86-87	Post-SD	1221	145	142	164
Water used before first cutoff stage (ETm)			309	297	277
Seasonal crop water use (ETm)			483	464	473
Planting date			April 21	April 22	April 25
Harvesting date			August 04	August 15	August 07

*Values shown in the table are most representative. There is a difference of 05-20 GDD from year to year.

Table 3. Crop water use efficiency during the three growing seasons.

Treatment	Water Use Efficiency, kg/m$_3$			
	2000	**2001**	**2002**	Mean
Milk	_____	1.82	1.65	1.73
Pre-SD	1.78	1.87	1.60	1.75
SD	1.62	1.80	1.54	1.65
Post-SD	1.55	1.70	1.44	1.56

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