Scheduling Wheat Irrigations Using Infrared Thermometers and the Crop Water Stress Index in Arizona

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Abstract

Durum wheat (Triticum turgidum L. var. durum) is grown as a winter annual crop, normally in rotation with cotton, and in 1989, comprised 121,500 acres in Arizona. Winter rainfall is insignificant, therefore water is supplied totally through surface irrigation. The relationship between the timing and amount of irrigation water applied and grain yields have not been well-defined. Field plot studies were conducted in 1986 and 1987 to test the feasibility of using the Crop Water Stress Index (CWSI) to time wheat irrigations and also to determine the relationship among the CWSI, grain production, and water applied. The study was repeated at the commercial production level with a grower cooperator in 1989 to determine the usefulness of CWSI scheduling on large farms. Highest grain production was attained when irrigations were scheduled when the CWSI averaged 0.37 and 0.30 units on small plots for 1986 and 1987, respectively. At the grower production level, highest yields were attained when irrigations were scheduled when the CWSI averaged 0.17 units. In 1986 and 1987 scheduling irrigations at lower CWSI values did not significantly increase grain production while requiring more applied water than the optimum CWSI values. Scheduling irrigations at CWSI's exceeding the optimum values did significantly reduce grain production from the optimum, but required less applied water in all three years.

Introduction

Cultivation of wheat ranks third behind cotton and alfalfa in acreage planted in Arizona. It is produced primarily under irrigated conditions for use in food products for human consumption or planted as a green manure in rotation with cotton. With the rapidly increasing urban population, competition between cities and agriculture for the limited supplies of surface and groundwater had reached an impasse. Passage of the 1980 Groundwater Law broke that impasse, resulting in restrictions intended to eventually stop overpumping of groundwater by agricultural users through the introduction of water allocations which are intended to more closely match individual crop water needs. In addition, irrigation efficiencies which are now near 55% will have to be increased to 85% placing even more pressure on agricultural water users. Proper timing of irrigation can increase water use efficiency resulting in an immediate impact in reducing total water usage while maintaining or increasing crop production.

Previous studies on timing irrigation of wheat have been dependent primarily on various plant growth stages. Eck (1988) conducted a 2-yr irrigation-fertilizer study where irrigations were applied or withheld to allow the crop to be nonstressed, stressed during nonheading and grain filling, stressed during tillering and jointing, and stressed throughout spring. He reported highest yields for both years were attained on the nonstressed treatment. Water use efficiency (WUE) in 1981 was highest in the nonstressed treatment and lowest in the stressed throughout spring treatment, but WUE was reversed in 1982 with the highest WUE in the stressed throughout spring and lowest in the nonstressed treatment.

Schneider et al. (1969) determined that the most critical period for irrigation was from the booting through grain filling stages. In addition they found that timing of the irrigation was as important as the total amount of water applied with one well-timed spring irrigation being as effective as two or three irrigations.

Mogensen et al. (1985) conducted a study where water stress occurred during tillering and jointing and during grain formation. When water stress occurred before heading, the development of late tillers was promoted which contributed up to 50% of the final grain yield. They concluded that drought sensitivity appeared to be greatest during the booting-heading stage of development.

Singh et al. (1984) also investigated how time and frequency of irrigation affect grain yields at different stages of development. Highest yields were attained from four irrigations, one at crown-root initiation, jointing, flowering, and milk stages, although two irrigations either at crown-root initiation + flowering or jointing + milk stage also resulted in a substantial yield. They reported that the WUE decreased with an increase in irrigation frequency since the yield increase was not proportional to water use.

Heitholt (1989) investigated the use of WUE and the distribution of dry matter to the roots in wheat as a potential selection criteria for improving yield under water stress. Water treatments consisted of maintaining a potted soil mixture between 15 to 35% of water holding capacity (stressed) to above 50% of capacity (well watered). The shoot:root ratio was not affected by water stress and he concluded that mild water stress did not consistently affect WUE.

The use of plant-based measurements such as crop canopy temperatures to detect plant water stress as opposed to timing of irrigation by development stage, soil moisture content or calendar schedule was proposed by Jackson (1982). Ehrler et al. (1978) determined that the canopy temperature minus the air temperature of the atmosphere above the crop outside of the crop boundary layer was directly related to the atmospheric vapor pressure deficit (VPD). Idso et al. (1981) normalized the crop canopy-air temperature differential for the environmental interactions on alfalfa at various locations and microenvironments to develop the crop water stress index to quantify plant water stress. Non-water-stressed baselines were developed for 26 different plant species under clear skies by Idso (1982). He proposed that baselines of particular species were like plant "fingerprints" and that different baselines could be measured at different phenological stages of growth for some plant species which included wheat. Blum et al. (1982) proposed that canopy temperature was genetically controlled and the technique could be useful to screen wheat varieties for drought avoidance. Idso's work led to proposals to utilize the CWSI to determine the timing of irrigations (Geiser et al. 1982; Reginato, 1983).

Howell et al. (1986) measured canopy temperature of winter wheat under four irrigation regimes: irrigation at tillering, jointing, heading, and grain filling. They also measured two baselines based on phenology at the pre- and post-heading stages as did Idso (1982). In addition, they found the CWSI was related to midday leaf water potential, although the relationship also depended on stage of development. They concluded that the CWSI was a useful tool to assess crop water stress in wheat and should be useful to time irrigations of wheat.

The purpose of these tests were to determine the feasibility of using the CWSI to schedule irrigation of wheat and the resulting relationships between CWSI scheduling levels, grain production, and applied water.

Materials and Methods

Wheat studies were conducted on four replicated plots (51.0 X 20 ft) per CWSI irrigation scheduling treatmentof 'Aldura' durum wheat in 1986 and 1987 at the Marana Agricultural Center, Marana, Arizona, and on four replicated commercial fields (1 ac in size) per treatment of 'Aldente' durum wheat on the Tim Wells Farm in Casa Grande, Arizona, in 1989.

In order to define an optimum CWSI irrigation scheduling value, attempts were made to schedule irrigations of four CWSI water stress treatments covering a range of CWSI values representing low to high water stress for all three years. Irrigations were scheduled when the CWSI value of the four replicated plots of each treatment approached or exceeded 0.20, 0.35, 0.65, and 0.80 in 1986; and 0.10, 0.25, 0.35, and 0.50 in 1987. In 1989, irrigations were scheduled when the average CWSI values of the four replicated fields of each treatment approached or exceeded 0.15, 0.30, and 0.45, in addition to monitoring a fourth treatment which represented the normal grower irrigation schedule.

The CWSI was calculated from infrared canopy temperature and vapor pressure deficit (VPD) measurements using the empirical method proposed by Idso et al., 1981. Infrared canopy temperature measurements were collected two to three times per week when skies were clear between 1100 and 1500 hours (Mountain Standard Time) with an Everest Interscience Inc. Model 112 handheld infrared thermometer with a 15 degree field of view measuring a wavelength of 8 to 14 microns. The VPD was calculated in kilopascals from wet and dry bulb measurements obtained at 15 minute intervals using an aspirated psychrometer (Environmental Tectonics Corp., Psychro-Dyne model). The pre- and post-heading baselines used to calculate the CWSI were $y = 3.38 - 3.25(x)$ and $y = 2.88 - 2.11(x)$, respectively (Idso, 1982).

In 1986 and 1987, two infrared temperature measurements were collected from the east and west sides perpendicular to the north-south planting of each plot and averaged. In 1989, two infrared temperature measurements were collected from the southeast and northeast corners (ditchside) of the east-west planted 1 ac fields and averaged. Readings collected from the southwest and northwest corners were excluded because the CWSI readings were influenced by irrigation water spilling over irrigation borders separating adjoining fields within the test.

When irrigated, the Marana plots were basin irrigated to field capacity based on soil moisture deficits determined by subtracting the actual soil moisture content measured with a neutron moisture meter (Campbell Pacific Nuclear 503DR) from the predetermined field capacity of the top four foot soil profile in each plot. The applied water amounts were measured using an inline propeller meter. Water applied to the larger 1 ac fields at the Tim Wells Farm were approximated from flow rates and application times for each irrigation scheduling treatment. The center 12 feet of each of the Marana plots were mechanically harvested using a plot combine. The center 27 feet of each of the 1 ac fields were combined by a commercial operator.

The results were statistically analyzed as a randomized complete block design using the SAS ANOVA procedure.

Results and Discussion

The CWSI proved to be a useful tool to quantitate wheat water stress for scheduling irrigations in agreement with Howell et al., 1986. Highest grain production occurred at mild water stress levels with CWSI at irrigation values of 0.37 and 0.30 units in 1986 and 1987, respectively (Table 1). Irrigations scheduled at lower CWSI values increased irrigation frequency and water applied thereby decreasing WUE with a concurring decrease in grain production. Singh et al. (1984) also reported similar decreases in WUE with increasing irrigation frequency.

Significant differences were measured in total water applied (Table 1). Better timing of irrigation saved one irrigation in 1986 and two irrigations in 1987 without a decrease in grain production. Schneider et al. (1969), reported similar results where one well-timed irrigation was as effective as two or three untimed irrigations.

At the commercial level in 1989, highest grain production occurred at a CWSI scheduling value of 0.17 units, although no significant decrease in grain production was measured when irrigations were scheduled at 0.27 units (Table 1). The normal grower irrigation pattern resulted in an average CWSI at irrigation of 0.40 units with a significant decrease in grain production when compared to lower CWSI scheduling values.
Irrigation WUE was highest at the 0.27 unit treatment requiring two less irrigations than the 0.17 unit treatment without a significant decrease in grain production.

In addition, strong linear correlations were measured among CWSI irrigation scheduling levels for grain production and applied water in all three years. Grain production was negatively correlated to increasing CWSI irrigation scheduling values with correlation coefficients of r = -0.952, -0.942, and -0.969 for the years 1986, 1987, and 1989, respectively. The CWSI at irrigation values were negatively correlated to decreasing water applications with correlation coefficients of r = -0.982, -0.988, and -0.960 for the years 1986, 1987, and 1989, respectively. Grain production was positively correlated to increasing water applications with correlation coefficients of r = 0.922, 0.909, and 0.939 for the years 1986, 1987, and 1989, respectively.

The discrepancy between the optimum CWSI irrigation scheduling value of the small plots and large commercial fields could be attributed to the deletion of the southwest and northwest corner readings in the CWSI calculation of the large 1 ac fields (Table 1). Generally the west ends of the large fields had higher CWSI values than the east ditchside ends. If these higher west end values had been averaged with the lower east end values, the overall CWSI at irrigation value would have been increased.

The relationships among CWSI at irrigation values and % grain moisture, % grain protein, grain test weight, % grain yellow berry, and % shriveled grain in 1989 are presented in Table 2. Higher CWSI at irrigation values (0.40 and 0.56 units) significantly increased % grain protein at the 0.01 level. The lowest CWSI at irrigation value of 0.17 units significantly decreased the percent of shriveled grain. No significant differences were measured among CWSI irrigation values and % grain moisture, test weights, or % yellow berry.

Summary

The use of infrared thermometers to quantitate water stress of wheat using the crop water stress index can be a useful tool in assisting the irrigation manager in irrigation scheduling decisions. Grain production and total applied water were strongly correlated to CWSI at irrigation values. Highest grain production occurred when irrigations were scheduled at CWSI values less than 0.37 units. More frequent irrigations based on lower CWSI values did not significantly increase grain production, but required more irrigation water. In 1989, % grain protein increased with increasing CWSI values, although lower CWSI values produced less shriveled grain. The University of Arizona will continue efforts to better define the relationship between wheat water stress and grain production.

The authors wish to dedicate this manuscript in memory of Mr. Tim Wells a fine grower/cooperator.

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Table 1. The relationships amon CWSI at irrigation and grain yield, water applied, and number of irrigation, in 1986 and 1987 at Marana, Arizona, and 1989 at Casa Grande, Arizona.

Year	CWSI	Grain Yield (lb/ac)	Water Applied (in)	# Irr.
1986	0.22 d	5304 a	32.9 a	5
	0.37 c	5411 a	30.3 b	4
	0.66 b	4089 b	25.6 c	3
	0.82 a	3857 b	19.6 d	2
1987	0.11 c	4018 a	18.6 a	5
	0.26 b	4205 a	15.5 b	3
	0.30 b	4375 a	16.3 b	3
	1.07 a	2330 b	8.5 c	1
1989	0.17 c	6000 a	67.9	11
	0.27 bc	5661 a	55.5	9
	0.40 b	4580 b	49.4	8
	0.56 a	4241 b	43.2	7

Means followed by different letters are significantly different at the 0.01 level. (Duncan's Test)

Table 2. The relationships among CWSI at irrigation and % moisture, % protein, bushel weight, % yellow berry, and % shriveled in 1989 at Casa Grande, Arizona.

Year	CWSI	% Grain Moisture	% Grain Protein	Test Weight (lb/bu)	% Grain Yellow Berry	% Grain Shriveled
1989	0.17 c	8.3	13.9 b	68.2	2.0	2.3 b
	0.27 bc	8.3	14.2 b	64.3	1.5	4.8 a
	0.40 b	8.1	15.0 a	62.8	1.8	4.8 a
	0.56 a	8.2	14.9 a	65.1	1.5	5.0 a

Means followed by different letters are significantly different at the 0.01 level. (Duncan's Test)