WATER RELATIONS AND YIELD OF WINTER WHEAT GROWN UNDER THREE WATER REGIMES IN THE HIGH PLAINS*

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Five cultivars of winter wheat (*Triticum aestivum* L. em. Thell.) were grown in the field under two ridge-and-furrow irrigation treatments in the Panhandle of Oklahoma to determine if yields could be increased by applying irrigation water at different times in the spring than it is normally applied. The plants grown under the "modified" irrigation schedule received 15.2 cm of irrigation water in the spring added in 7.6-cm increments on 20 March and 24 April, while the plants grown under the "normal" irrigation schedule received 22.8 cm of irrigation water added in 7.6-cm increments on 20 March, 3 April, and 24 April. Control plants were grown dryland. Plant water potential, osmotic potential, stomatal resistance, and leaf temperature were monitored monthly in the spring on plants under the three watering regimes to quantify plant water stress.

Yields were highest for the modified treatment (average yield: 4470 kg/ha) and were 23% more than yields for the plants under the normal irrigation schedule (average yield: 3640 kg/ha). Average yield of dryland plants was 1660 kg/ha. After March, plants grown under the modified treatment showed more plant water stress than plants grown under the normal irrigation treatment. Dryland plants showed more stress than irrigated plants throughout the experiment. Yield and water use efficiency were maximum when irrigation water was applied under the modified regime, which received 7.6 cm less water, than under the normal regime.

INTRODUCTION

Wheat farmers in the High Plains of Oklahoma often over-irrigate and lose precious ground water, which is being depleted from the Central Ogallala Formation (9, 10, 11, 13, 18). Yet other farmers are abandoning the land because they no longer can afford to pump water from the deepening ground water source. Irrigation water must be conserved and applied at times which will maximize yield.

Most wheat farmers in the High Plains irrigate in the following manner (5, 8, 15). They apply one irrigation in the fall before planting wheat in September or October. After planting, they apply another irrigation. In the spring, they apply two to three irrigations, starting about the first part of April and ending before harvest in late June or early July. In the Panhandle, flowering occurs mid- to late May. Total amount of irrigation water used is 30.4 cm or 7.6 cm per irrigation (furrow irrigation). Similar irrigation practices are used on small grains other than wheat (17).

Irrigation scheduling often is based on meteorological factors, such as evapotranspiration rate. However, determination of evapotranspiration rate is not always an accurate method with which to plan irrigations. Research on corn, for example, shows that an irrigation early in the flowering period greatly increases yield, but this timing is not indicated by evapotranspiration measurements (2). For high yield, therefore, irrigation water should be added when the plant needs it, and not at times based on meteorological conditions.

It is generally believed that flowering (anthesis) is the stage at which water should be applied to wheat to insure high yields (8, 15, 16). However, work in Egypt suggests that, if enough water is applied at planting to establish the wheat, yields are maximum if irrigation water is applied at the time of stem extension rather than at flowering (1). Flowering was the second most critical period in the Egyptian study. Stem extension for wheat in the Panhandle starts about mid-March.

Little information has been published concerning irrigations in the Panhandle. Therefore, this experiment was conducted to determine the effect of an alternate irrigation schedule on wheat yield in the Panhandle of Oklahoma. Yield was compared to plants grown under the normal

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irrigation regime for the region. Plants under the normal irrigation regime received 7.6 cm more water than did plants under the modified regime. Wheat also was grown without irrigation water ("dryland" treatment). Plant-water measurements (leaf water potential, osmotic potential, and stomatal resistance) were obtained to quantify plant water stress under the three watering conditions.

MATERIALS AND METHODS

The experiment was carried out at the Panhandle Research Station, Goodwell, Oklahoma during the 1977-1978 growing season. Certified hard red winter wheat (*Triticum aestivum* L. em. Thell.) seed was planted in east-west rows on 13 Oct. 1977, for the three treatments (normal irrigation schedule, modified irrigation schedule, and dryland). The land for each treatment measured 90 meters long and 4.3 meters wide. The treatments were adjacent to each other. The normally irrigated plots were on the north side of the experimental area receiving the modified irrigation schedule. The dryland plots were on the south side of the experimental area receiving the modified irrigation schedule. A John Deere DRB-20-8 grain drill was used to plant the seeds. There were 20 cm between the rows. Six rows of wheat were planted between each two irrigation furrows. There were three beds (three ridges of plants) for each treatment and each bed was 142 cm in width. Nitrogen fertilizer was applied at the rate of 110 kg/ha. An application (0.6 kg/ha) of an ester of 2,4-D was made on 17 March for the control of tansy mustard (*Descurainia pinnata*).

Each of the three plots was divided into five subplots, each containing a cultivar of wheat commonly grown in the Panhandle. The five cultivars were: 'Centurk' (CI 15075), 'Scout 66' (CI 13996), 'Tam W101' (CI 15324), 'Triumph 64' (CI 13679), and 'Vona' (CI 17441). The cultivars were randomly distributed within each treatment. The plots receiving the normal and modified irrigation schedules were planted with 30.5 kg seed/ha and the dryland plots were planted with 15.3 kg seed/ha. The soil type was a Richfield clay loam (12), which is classified as a Aridic Argiustoll.

The plots receiving the normal and modified irrigation schedule were irrigated on 20 September 1977 (pre-planting irrigation), and on 3 November 1977 (post-emergence irrigation), each time with 7.6 cm water. In the spring, these plots received water, as follows:

Treatment	Amount and Date of Water Added
Normal irrigation schedule	7.6 cm water, 20 March
	7.6 cm water, 3 April
	7.6 cm water, 24 April
Modified irrigation schedule	7.6 cm water, 20 March
	7.6 cm water, 24 April
Dryland	See Table 1 for rainfall

Therefore, the plants under the modified schedule received 7.6 cm less irrigation water than did the plants under the normal irrigation schedule.

On four days in the spring (13 March, 12 April, 10 May, 5 June), measurements of height, leaf water potential, leaf osmotic potential, stomatal resistance, and leaf temperature were taken between 08:00 and 10:00 hr on three plants in the center bed of each cultivar within each of the three treatments, as follows. [The center of the bed was measured to avoid border effects (19).] First, height was measured from the ground to the top of the tallest leaf. When heads emerged (mid- to late May), height was measured to the tip of the head, excluding the awns.

Second, leaf temperature of the upper surface was measured using a hand-held, fine-wire thermocouple unit (chromel- constantan, 0.0762 mm diameter, Omega Engineering, Inc., Stamford, Conn.). The hand-held probe was attached to a Keithley Model 155 Null Detector-Microvoltmeter (Keithley Instruments, Cleveland, Ohio). The leaf-temperature measuring device is described by Perrier (14). Air temperature was measured with a thermometer at the top of the canopy.

Resistance of the stomata on the upper leaf surface was measured, immediately after leaf temperature was measured, with a calibrated stomatal diffusion porometer (7) (Model LI-60 and Sensor LI-15S, Lambda Instrument Corp., Lincoln, Neb.).

After stomatal resistances were measured, leaves were sampled for potential measurements. Water and osmotic potentials were determined with thermocouple psychrometers designed by Dalton and Rawlins (3), using the technique described by Ehlig (4). Leaves used for potential, stomatal resistance, and temperature determinations were flag leaves for the May and June measurements.

The wheat was harvested on 26 June 1978, 256 days after planting, with a Hege Model No. 125 combine which cut four rows (90 cm). Three 3-meter samples were taken from each subplot to provide three replications. The center bed of the three beds in each treatment was sampled to avoid errors due to edge effects on rows bordering different treatments. At harvest, height, test weight, and yield were determined.

Meteorological data (Table 1) were provided by the official weather station located 351 m northwest of the plots at the Panhandle Research Station (20). Data in Table 1 also were obtained directly at the field plots on the four days of measurements in the spring. Wind speed was measured with a handheld anemometer (Model A10962 anemometer, Short and Mason, Ltd., Walthamstow, London, England). The anemometer was held 30 cm above crop height to obtain the reported values. Solar radiation was measured using Model No. LI-170 Quantum Sensor attached to Model No. LI-185A Quantum/Radiometer/Photometer of Lambda Instrument Corp., Lincoln, Neb. The quantum sensor was placed at crop height to measure the listed values. Soil water tension at the 50-cm depth was determined with a "Quick Draw" tensiometer (Model 2900, Soilmoisture Equipment Corp., Santa Barbara, Calif.). Soil temperature at the 10-cm and 20-cm depths was obtained with Weston Model 2261 thermometers (Weston Electrical Instrument Corp., Newark, N.J.).

RESULTS

No significant difference in either level or seasonal pattern of leaf water potential,

TABLE 1. *Environmental conditions during experiment. Monthly data and data obtained on the four days of measurements in the spring of 1978 are given. Monthly data came from the official weather station located 351 m northwest of the experimental plots. Daily data were obtained at the plots.*

Monthly data

Month	Rain (cm)	Average temperature (C) Max.	Min.	Average evapotranspiration (cm)	Soil temperature, 10 cm (C) Max.	Min.	Wind (km)[a]
Oct. 1977	0.28	24.2	5.3	----[b]	----	----	5775
Nov.	1.63	16.1	—2.1	----	----	----	----
Dec.	0.08	12.0	—6.5	----	----	----	----
Jan. 1978	0.28	3.0	—10.8	----	----	----	----
Feb.	2.16	1.8	—10.7	----	----	----	----
Mar.	0.56	15.1	—1.1	----	----	----	----
Apr.	1.52	23.7	5.3	----	----	----	8893
May	15.34	22.8	9.0	25.1	21.9	14.6	7648
June	6.71	30.3	15.9	35.5	29.6	21.7	6803

Daily data

Date	Air temperature at soil surface (C)	Photosynthetically active radiation (μE m^{-2}sec^{-1})	Sky	Wind speed & direction (m sec^{-1})	Soil temperature, 20 cm (C) Nor.	Mod.	Dry[c]	Soil water tension, 50 cm (centibar) Nor.	Mod.	Dry[c]
13 Mar. 1978	18	----	Clear	28.2(W)	9	9	7	1	1	21
12 Apr.	22	1800	Clear	10.9(NW)	14	19	20	15	27	35
10 May	17	600	Partially overcast	10.9(SW)	12	13	14	7	16	21
5 June	16	65	Overcast	2.0(E)	18	18	18	<1	<1	<1

[a]Values totaled for month
[b] Data not available
[c] Normal irrigation, modified irrigation, dryland

osmotic potential, stomatal resistance, or leaf temperature was found among the five cultivars. Therefore, measurements of each parameter taken during the spring have been averaged.

Height

Figure 1 shows the average height of the five cultivars during the spring. After 13 March, when the different irrigation schedules began, plants receiving the modified irrigation were shorter than plants receiving the normal irrigation regime. As expected, the dryland plants were the shortest.

Potentials

Figures 2 and 3 show average leaf water potential and osmotic potential, respectively, of the five cultivars. Turgor potential can be estimated by subtracting osmotic potential from leaf water potential. On 10 May, water potential of the plants receiving the normal irrigation treatment was higher (less negative) than that of the plants receiving the modified irrigation treatment. On 13 March, 12 April, and 5 June, irrigated plants had similar potentials. On 9-10 April, 1.5 cm of rain fell and the ground was wet for all treatments. Dryland plants had the lowest water potential, except on 5 June, when potentials were similar among all treatments. The ground was wet on this day due to 2.9 cm of rain which fell until an hour before the plants were sampled. Osmotic potential results (Fig. 3) paralleled water potential results, except that the osmotic potentials were more negative. Hence, turgor potentials were positive at all times.

Stomatal Resistance

Figure 4 shows the average stomatal resistance of the five cultivars. Dryland plants had a high resistance on 13 March because of little rainfall (Table 1). The rain that fell on 9-10 April and 5 June resulted in low resistances for dryland plants. On 5 June, all plants had low resistances because moisture was plentiful in the soil in all the plots. On 12 April and 10 May, plants receiving the modified irrigation schedule had a higher stomatal resistance than plants receiving the normal irrigation regime.

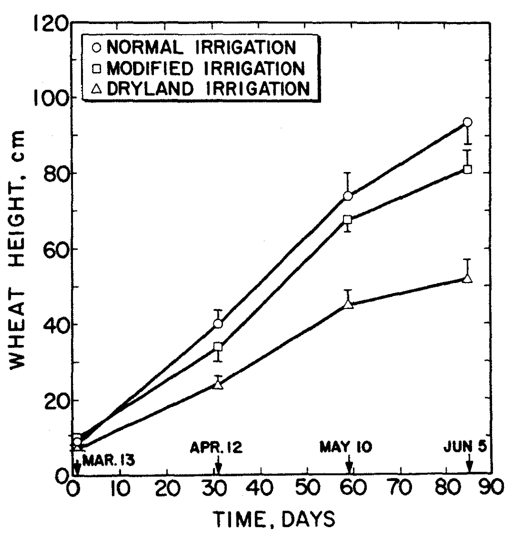

FIGURE 1. Average height of five cultivars of winter wheat grown under three watering regimes. The plants under the normal and modified irrigation schedules received 7.6 cm water per irrigation at different times in the spring (for normal irrigation: 20 March and 3 and 24 April; for modified irrigation: 20 March and 24 April). Vertical lines indicate standard errors. Only half the standard-error line has been drawn to avoid cluttering the figure.

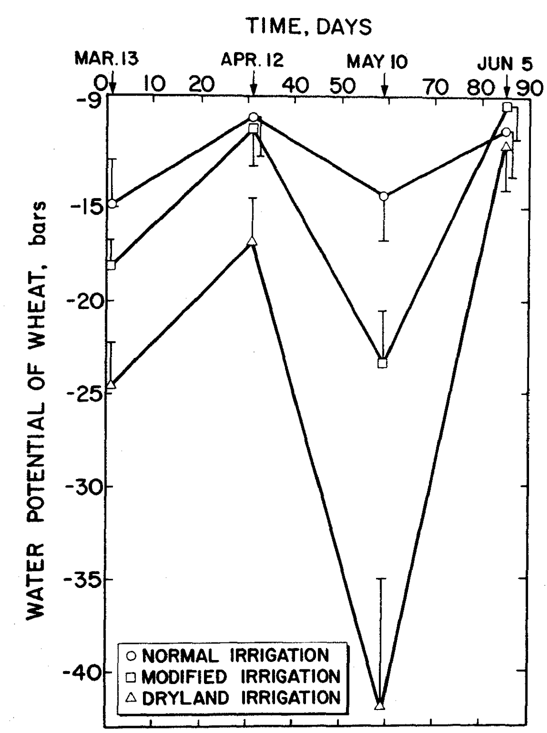

FIGURE 2. Average leaf water potential of five cultivars of winter wheat grown under three watering regimes. For details, see legend of Fig. 1.

Leaf Temperature

Figure 5 shows the average leaf temperature of the five cultivars of winter wheat. On 5 June, just after the rain fell, all leaves were the same temperature. The plants receiving the modified irrigation schedule were warmer than the plants receiving the normal irrigation schedule. This correlates with their higher stomatal resistance (Fig. 4). If stomata are closed or partly closed, less water can be transpired to cool leaves (6).

Grain Harvest

Table 2 shows the height, test weight, and yield of the five cultivars at harvest. Height results were similar to the values taken before harvest (dryland, shortest; normal irrigation treatment, tallest; modified irrigation treatment, intermediate in height).

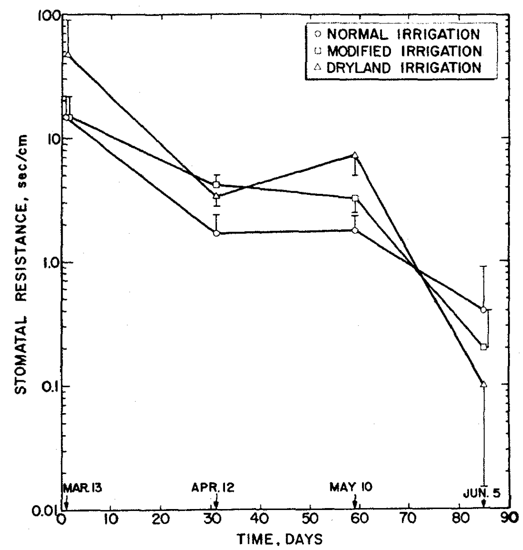

FIGURE 4. Average stomatal resistance of five cultivars of winter wheat grown under three watering regimes. For details, see legend of Fig. 1.

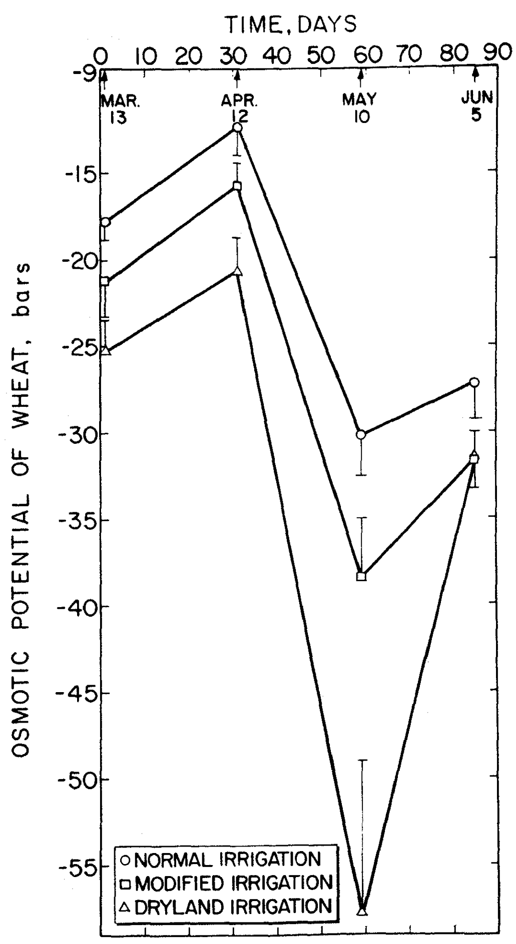

FIGURE 3. Average osmotic potential of five cultivars of winter wheat grown under three watering regimes. For details, see legend of Fig. 1.

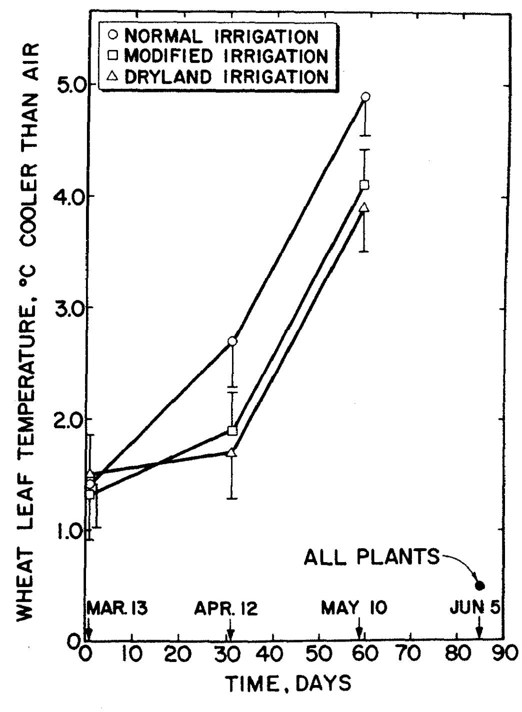

FIGURE 5. Average leaf temperature of five cultivars of winter wheat grown under three watering regimes. For details, see legend of Fig. 1.

The test weight of the dryland plants was lower than that of the irrigated plants. Plants receiving the modified irrigation had a higher test weight than that of the plants receiving the normal irrigation, although the difference was not significant.

Dryland plants yielded the poorest, as expected. However, the plants receiving the modified irrigation treatment yielded 23% more than the plants receiving the normal irrigation treatment (4470 vs. 3640 kg/ha, Table 2).

DISCUSSION

The modified irrigation regime yielded more than the normal regime, even though 7.6 less water was applied to the modified one. The shorter height, lower water potential, lower osmotic potential, higher stomatal resistance, and warmer leaf temperature of the plants receiving the modified irrigation schedule showed that plants were under water stress when measurements were taken in April and May. These plants were showing signs of stress which plants irrigated on 3 April were not. The stress that the plants under the modified irrigation treatment experienced, after water was given at the apparently critical stage in mid-March, was not severe enough to reduce yield.

In Kansas (15) and Texas (8), it is suggested (without supporting data) that irrigation water not be applied to wheat early in the spring because this "causes rank, luxurious vegetative growth and wet conditions which can cause plant lodging and seriously reduce yields" (15). In this experiment, lodging was similar for the two irrigation treatments. Contrary to the Kansas and Texas recommendations, the results of the experiment, although based on limited measurements, showed that wheat yielded well when water was applied early in the spring (mid-March).

Less fuel was needed to pump water for the modified regime because less water was used. Consequently, the modified regime was less costly than the normal regime.

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TABLE 2. *Height before harvest, test weight, and yield of five cultivars of winter wheat grown under three watering regimes.*

	Normal irrigation			Modified irrigation			Dryland		
Cultivar	Height (cm)	Test wt. (kg/hl)	Yield (kg/ha)	Height (cm)	Test wt. (kg/hl)	Yield (kg/ha)	Height (cm)	Test wt. (kg/hl)	Yield (kg/ha)
Centurk	102	74	3660	76	78	4280	53	72	2070
Scout 66	92	75	3540	88	77	4700	62	72	1630
Tam W101	67	76	3570	68	79	4650	44	74	1740
Triumph 64	108	78	2740	73	79	3520	58	76	1750
Vona	90	76	4710	80	79	5200	44	73	1090
Average	92	76	3640	77	78	4470	52	73	1660
L.S.D. (5%)	2	2	230	2	1	920	2	2	190
C.V., %	1.2	1.5	3.6	1.2	0.8	11.8	2.8	1.4	6.5

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