Data Acquisition System for Scheduling Irrigation. II. Irrigation Scheduling of Wheat Crop*

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Abstract

Two growing seasons of wheat crop were conducted. The field experiments on each growing season were divided into two parts, one for the basin irrigation treatments and the other for the center pivot irrigation treatments. Experiments were carried out at the Experimental Research Station at King Faisal University, AL-hassa, Saudi Arabia.

The basin irrigation treatments were in a split plot design and four replications. The irrigation intervals occupied randomly the whole plots and the water volumes occupied randomly the sub-plots. The basin experiments included three irrigation intervals: 5, 10 and 15 days and three irrigation volumes per irrigation: 400, 600 and 800 m^3/ha/irrigation (i.e. 4, 6 and 8 cm total irrigation depth per each watering respectively).

The center pivot irrigation experiments were in a random block design with four replications and four treatments. The four irrigation treatments were 2400, 4800, 7200 and 9600 m^3/ha/growing season (i.e. 24, 48, 72 and 96 cm total irrigation depth/growing season respectively).

Plant growth characters (plant height, Leaf Area Index) at tillering stage and at the yield formation stage were quantified under different treatments. The Proline content (drought indicator) in plants tissues were also measured. The yield components, the biological yield, the harvest index and the water use efficiency were also estimated under different treatments.

* Series No. I can be seen in Reference No. 20

Introduction

Wheat is the most important grain crop in the world. It is also the main food crop in the Kingdom of Saudi Arabia (KSA), and due to its strategic nature, it has been receiving considerable support from the Government of the Kingdom. Normally wheat is irrigated by center pivot irrigation systems in the KSA, however there are some farmers still using the conventional surface irrigation. Where a cycle of short, intensive applications of water follow by long periods of soil moisture depletion is applied. Wheat is moderately tolerant to soil salinity (Doorenbos et al., 1979).

Bunyolo *et al.* (1985) studied the influence of different levels of irrigation on the grain yield of wheat at the National Irrigation Research Station at Nanga, Zambia. They used irrigation every week, every two, and every three weeks at a rate of 70, 60 and 50 percent, respectively, of the total class A pan evaporation during the whole irrigation interval. Apparent water use by wheat increased with shorter irrigation intervals. However, none of the above schedules was deemed satisfactory for obtaining maximum wheat yields

Recently, several investigators have looked into benefits of irrigating at intervals much shorter or longer than in conventional practices. It may be possible, in cases where irrigation costs are high or water is limited, to increase net income by increasing the irrigation intervals while deliberately under-irrigating the crop.

The relatively small amount of research done in this area has not demonstrated definitively the effects which different irrigation intervals have on crop yields. Variation in results from different approaches demonstrate the need to further investigate the effects of irrigation intervals.

Extending the irrigation interval will generally force the crop to use water deeper in the soil profile compared to mere frequent irrigations. One advantage of short intervals or high frequency irrigation is that water is supplied to the plant as it is needed; hence there is little need to store water deeper in the soil profile. Under this irrigation regime, the root system will tend to not develop in the lower part of the soil profile, so the crop will be more vulnerable to stress should a serious water deficit occur.

Crop yields under short irrigation intervals have been found to be maximum when the full evapotranspiration requirements of the crop are met.

A good yield of wheat under irrigation was reported by Doorenbos *et al.* (1979) as 4 to 6 ton/ha (12 to 15% moisture). For high yields, water requirements (ET_c) were 450 to 650 mm depending on climate and length of growing period. The water utilization efficiency for harvested grain yield was about 0.8 to 1.0 kg/m^3. Rahman, *et al*. (1984) evaluated the growth, yield, and quality of wheat grown in sand and sandy soil under irrigation. Wheat was grown in sand or sandy soil in large earthenware boxes especially designed to give differing irrigation treatments. Data on plant height, leaf area, leaf area index (LAI), root length and surface area and yields of roots, straw and grain were presented. Increased top-watering and free drainage decreased yields in both soils. It was concluded that supplying nutrients directly to irrigation water, rather than to soil, may improve the yield and quality of wheat in soils subject to high leaching.

Majumdar and Mandal (1984) found that wheat irrigated at irrigation water cumulative pan evaporation ratios of 0.6, 0.8 and 1 (2, 3 and 4 irrigations, respectively) gave grain yields of 2.99, 4.14 and 4.83 tons/ha, consumed 230.8, 291 and 343.4 mm water and showed water use efficiencies (WUE) of 12.86, 14.24 and 14.04 kg. grain/ha, mm, respectively.

Hefni, *et al*. (1983) investigated the effect of irrigation at different growth stages on yield of wheat growing on clay loam soil. Plant height was greatest in control treatments and lowest when irrigation was at tillering and elongation stages.

Stegman and Soderlund (1992) indicated that irrigation scheduling for spring wheat requires information on different irrigation timing methods. Irrigation timing based on allowable root zone available water depletion and selected crop water stress index thresholds were evaluated in terms of their effect on spring wheat yield.

The objective of this work aimed to determine the water requirements of wheat crop. In addition, determination of the optimum quantity of irrigation water and the most suitable watering interval for wheat crop grown under a wide range of different irrigation treatments using basin and center pivot irrigation were considered.

MATERIALS AND METHODS

In order to fulfill the objectives of this paper, two growing seasons of wheat crop were conducted. The field experiments on each growing season were divided into two parts, one for the basin irrigation treatments and the other for the center pivot irrigation treatments.

The Experimental design :

Basin Irrigation treatments

The basin irrigation experiments were in a split-plot design and four replications. The irrigation intervals occupied randomly the whole plots and the volume occupied randomly the sub-plots. The experiments included three irrigation intervals: 5, 10 and 15 days and three irrigation volumes per irrigation: 800, 600 and 400 m^3/ha/irrigation (i.e. 8, 6 and 4 cm total irrigation depth per each watering respectively). The nine irrigation intervals were replicated four times. The experiment thus comprised 36 subplots. The subplots were separated by wide borders in which heavy plastic sheets were embedded to a depth of one meter in order to prevent seepage of water movement among plots.

Center Pivot Irrigation experiment:

The center pivot irrigation experiments were in a random block design with four replications and four treatments. The four irrigation treatments were 2400, 4800, 7200 and 9600 m^3/ha/growing season (i.e. 24, 48, 72 and 96 cm total irrigation depths/growing season respectively).

The Experiments Methods

Two experiments sites were chosen at the experiments research station of King Faisal University to carry out the experiments. One site was specified to the basin irrigation treatments and the other site was devoted to the center pivot irrigation treatments.

Land preparation, crop established and cultural practices Before hand, the two sites were irrigated to restore soil to field capacity. Two days later the sites were ploughed, where a disc harrow plough was used with the center pivot site; manual ploughing was carried out in the basin irrigation plots. This operation was conducted twice to ensure the disposal of weeds as well as having good seed bed for planting. The necessary soil surface leveling was also considered of great importance specially with the basin irrigation treatments, where irrigation water should move on soil surface in a smooth way. The plots of the two sites received all cultural practices used by the local farmers.

The application rate along the pivot arm was regulated for elliptical sprinkler pattern using Heerman and Hein (1968) formula :

$$D_s = \sum_{i=1}^{N} \frac{2h_i}{\omega r_i} \int_0^{\omega T_i} [r_i^2 - S^2 R_i^2 + 2R_i S \cos\alpha]^{1/2} \, d\alpha$$

Where :

D_s= the application depth at a distance S from the pivot.
T = the application time
S = the distance from the center of the pivot to the path of travel.
r = the effective radius of the sprinkler.
R = the distance (radius) to the sprinkler.
α = the angular velocity of rotation.
ω = the ratio of application.

Water distribution of the sprinklers was evaluated for the best uniformity following the methods described by Meriam and Keller (1979).

Samples and observations :

Plant samples were taken at random from each sub-plot at two stages of growth viz at tillering and at maturity. Grain yield was obtained from the middle six rows of each sub-plot. Samples were taken at random from the mature heads of each sub-plot.

Soil samples were taken from all sub-plots at a depth of 0-30 and 30-70 cm to determine the levels of salinity. Salinity was determined by laboratory analysis as EC in dS/m. Water pH, soluble cations and anions, meq/L as well as sodium adsorption ratio (SAR) were also determined. (Tables 1-6).

Soil moisture content in the root zone was measured **in situ** by a Neutron moisture probe 3300 series at the end of each irrigation cycle and again 2-3 days after irrigation and once more before starting irrigation. The probe was calibrated using methods described by Eeles (1969) and Bell (1973 & 1976).

Weather Station :

Ramadan and AL-Naeem (1999) installed and calibrated an automatic weather station to collect the weather data required for irrigation scheduling of wheat crop grown at the site.

Table (1)
Soil Profile description at the center pivot location

Depth, (cm)	Profile description
0-40	Sand
40-120	Loamy sand
120-200	Silty loam

Table (2) Soil profile description at the basin irrigation site

Depth, (cm)	Profile description
0-15	Sandy loam
15-70	Sandy loam
70-200	Sandy clay

Table (3) Physical and chemical properties of soil under center pivot irrigation site

Depth (cm)	Mechanical analysis			Soil texture*	S.P.	F.C.	P.W.P	A.W.	Bulk density	$CaCO_3$
	Sand %	Silt %	Clay %		%	%	%	%	gm/ cm^3	%
0-30	92	8	0	S	24	12	6	6	1.487	8.81
30-70	54	42	4	SL	62	31	15.5	15.5	1.432	12.13

Table (4) Chemical properties of the (1 : 2.5) soil : water ratio extract for the soil under center pivot irrigation site

Depth (cm)	pH	EC mS/cm	Soluble cations and anions, meq/L								SAR**
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO^{2-}_3	HCO^{-}_3	SO^{2-}_4	Cl^{-}	
0-30	7.53	0.469	1.76	0.27	1.21	0.35	0	1.15	3.1	1	1.19
30-70	7.52	2.79	22.8	0	3.87	1.42	0	1	26.1	1.2	1.14

Table (5) Physical and chemical properties of studied soil under basin irrigation site

Depth (cm)	Mechanical analysis			Soil texture*	S.P %	F.C %	P.W.P %	A.W. %	Bulk density gm/cm^3	$CaCO_3$ %
	Sand %	Silt %	Clay %							
0-30	68	28	4	SL	40	20	10	10	1.473	6.938
30-70	60	36	4	SL	48.3	48.3	24.2	24.2	1.451	3.181

Table (6) Chemical properties of the (1 : 2.5) soil : water ratio extract for the soil under basin irrigation site

Depth (cm)	pH	EC mS/cm	Soluble cations and anions, meq/L								SAR**
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO^{2-}_{3}	HCO^{-}_{3}	SO^{2-}_{4}	Cl^{-}	
0-30	7.54	2.59	24.2	0.88	2.22	0.45	0	1.1	24	0.6	0.6
30-70	7.53	2.83	23.8	0	4	0.6	0	1.05	26.9	1.15	1.1

* S = Sand
SL = Sandy loam

**SAR Sodium adsorption ratio $= \frac{Na^{+}}{\sqrt{\frac{ca^{2+} + Mg^{2+}}{2}}}$

RESULTS AND DISCUSSIONS

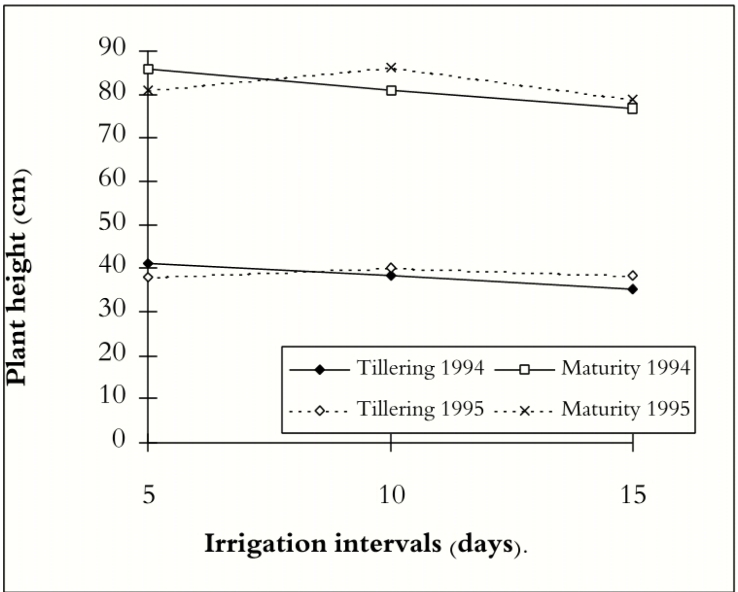
Plant height:

Measurements of the plant height under the different irrigation treatments showed an almost consistent tendency for plant height to increase with the ten-day watering interval. There was also a clear observation in the field that plants under this treatment were generally taller (Figure 1). From Figure (1), for the first sampling, at the stage of tillering, did not show statistical significance. However, at all levels of the amount of water per irrigation, the treatment in which the water was applied at intervals of 10 days resulted in taller plants. The differences between the amount of water treatments were negligible.

The effects of irrigation treatments on final plant height in the second sampling occasion, at the time of maturity, were more obvious from presented in Figures (1), (2) and (3). Plant height at maturity was highly significant at the 1% level. The ten-day interval showed clearly taller plants followed by the five-days interval. Applying the water every two weeks consistently resulted in shorter plants. There was also a consistent and a statistically significant increase for final plant height to increase with the increase in the amount of water applied per irrigation. Figure (1) showed that both plant heights at tillering and at maturity were highly significant. Plant height at tillering was reduced from 41.02 , 38.32, to 35.33 cm for the 5, 10 and 15 days intervals, respectively. Figure (1) also showed that plant height at tillering was significantly reduced as water volumes decreased at both tillering and maturity.

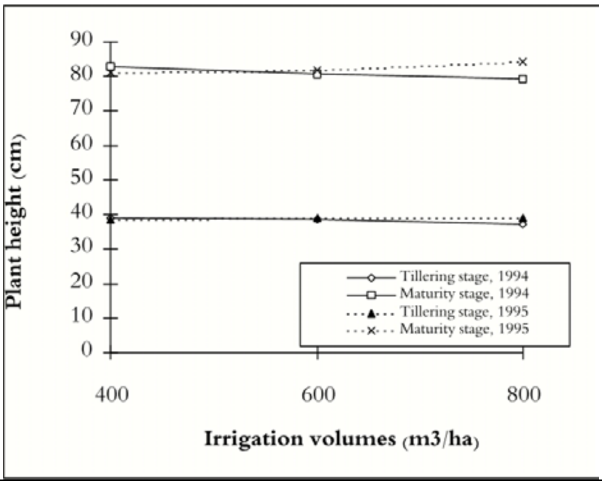
Figure (3) shows the effect of irrigation volumes on vegetative growth under center pivot. All vegetative characteristics studied, namely (1) plant height at tillering and at maturity, (2) LAI at tillering and at yield formation increased significantly at 1.0% level as the irrigation volume increased from 2400 to 9600 m^3.

Sayed and Sayed (1982) indicated that barley plant height was severely affected by with holding irrigation during boot stage. While others morphological characteristics such as day to headings and to maturity, and spike length varied in their response but the effects were not pronounced.



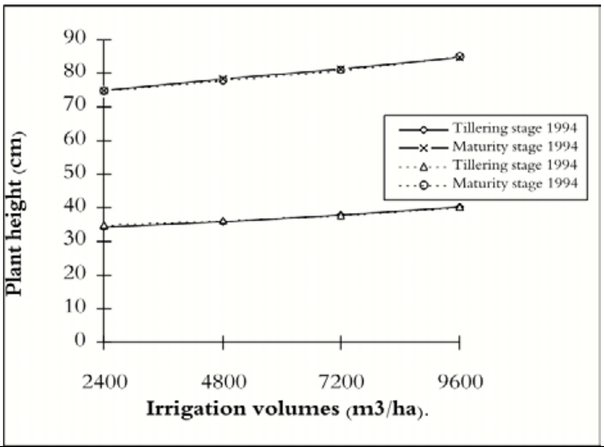
	1994	1995		
	Tillering	Maturity	Tillering	Maturity
LSD 5%	0.11	0.38	N.S.	1.28
LSD 1%	0.17	0.17	N.S.	1.75

Fig. (1) : Effect of the irrigation intervals (days) on plant height (cm) at tillering and maturity stages under basin irrigation for the years of 1994 and 1995.



	1994		1995	
	Tillering	Maturity	Tillering	Maturity
LSD 5%	0.11	0.26	N.S.	2.08
LSD 1%	0.16	0.36	N.S.	3.14

Fig. (2) : Effect of the irrigation volumes (m3/ha) on plant height (cm) at tillering and maturity stages under basin irrigation for the years of 1994 and 1995.



	1994		1995	
	Tillering	Maturity	Tillering	Maturity
LSD 5%	0.29	0.26	N.S.	2.01
LSD 1%	0.41	0.38	N.S.	3.04

Fig. (3) : Effect of the irrigation volumes (m3/ha) on plant height (cm) at tillering and maturity stages under center pivot irrigation for the years of 1994 and 1995.

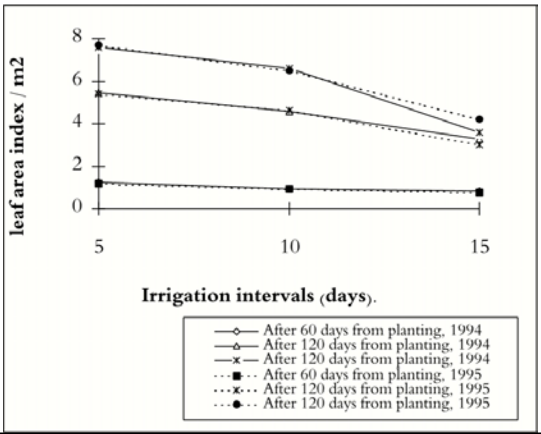
Leaf Area Index (LAI) :

Leaf area index was determined at 60, 90 and 120 days from sowing date (Figures 4 and 5). Results were highly significant at the 0.01 % level. Leaf area was both greater under the shorter intervals and higher water volumes. Same trends were found for the 60, 90 and 120 days. The highest value of LAI was found with shorter interval at the 120 days (LAI=7). Figure (6) shows the leaf area index under center pivot irrigation. Similar results to that obtained for the basin irrigation were found for the water volumes treatment. The greater the amount applied the higher was the LAI.

Cellular growth is the plant function most sensitive to water deficits. Decrease in water potential (ψ) causes a reduction in protein synthesis, cell water synthesis, and cell enlargement, which may account for the observation that many species have their greatest growth at night when the (ψ) is greatest (Boyer, 1968).

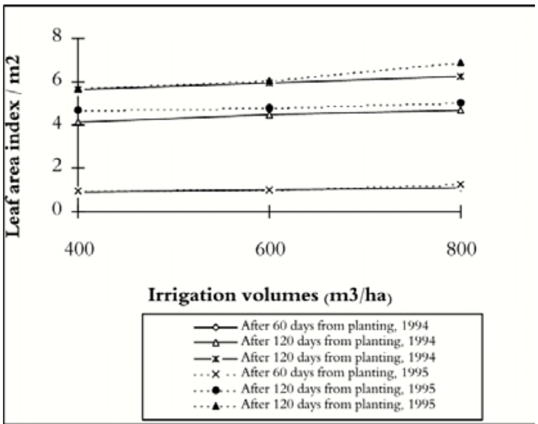
The effect of stress during the vegetative stage is the development of smaller leaves which can reduce the LAI at maturity and result in less light interception by the crop.

Stress that is mild enough not to affect photosynthesis can reduce the development of leaf surface area. Whether such reduction will affect dry matter yield dependence on whether leaf area, i.e. LAI, is limiting the crop’s assimilation of CO_2. One implication of the above consideration is that sensitivity of dry matter yield to stress should be greater in a growing crop with a low LAI than in a crop with a high LAI. It should also be noted that studies of stress effects on harvestable yield often give inadequate attention to another important factor namely, which leaves on the plant supply of most of the assimilates to the harvestable organ.



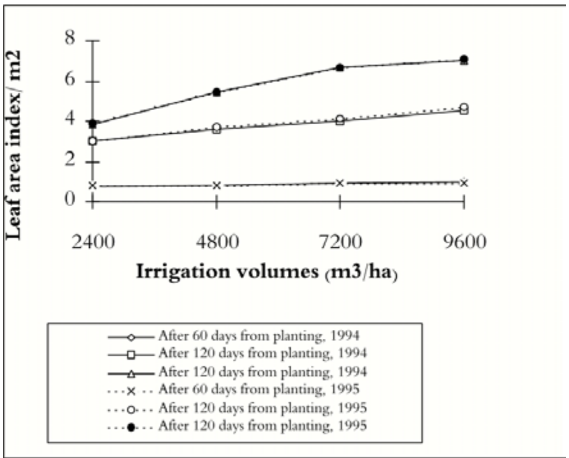
	1994			1995		
	(After days from planting)			(After days from planting		
	60 days	90 days	120 days	60 days	90 days	120 days
LSD 5%	0.023	0.013	0.043	0.025	0.014	0.033
LSD 1%	0.035	0.019	0.066	0.035	0.024	0.069

Fig. (4) : Effect of the irrigation intervals (days) on leaf area index /m2 after 60, 90 and 120 days from planting under basin irrigation for the years of 1994 and 1995.



	1994			1995		
	(After days from planting)			(After days from planting)		
	60 days	90 days	120 days	60 days	90 days	120 days
LSD 5%	0.023	0.013	0.043	0.025	0.014	0.033
LSD 1%	0.035	0.019	0.066	0.035	0.024	0.069

Fig. (5) : Effect of the irrigation volumes (m3/ha) on leaf area index /m2 after 60, 90 and 120 days from planting under basin irrigation for the years of 1994 and 1995.



	1994			1995		
	(After days from planting)			(After days from planting)		
	60 days	90 days	120 days	60 days	90 days	120 days
LSD 5%	0.013	0.02	0.030	0.020	0.010	0.030
LSD 1%	0.020	0.03	0.050	0.032	0.024	0.052

Fig. (6) : Effect of the irrigation volumes (m3/ha) on leaf area index /m2 after 60, 90 and 120 days from planting under center pivot irrigation for the years of 1994 and 1995.

Grain yield :

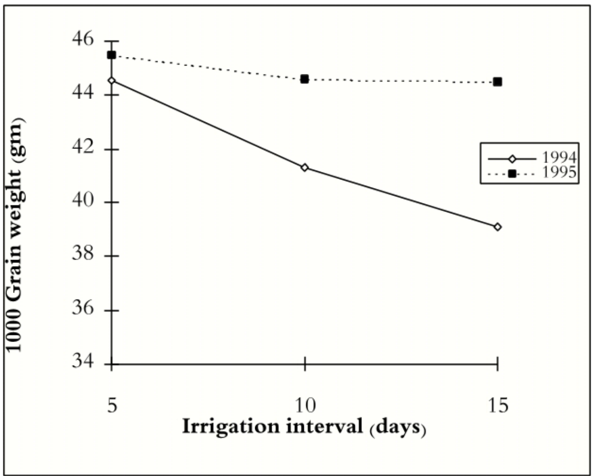
The yields of grain obtained from each one of the nine basin irrigation treatments are shown in Table 7. The effects of treatments and their interactions are not significant statistically. The differences between amount of water treatments are negligible. There are, however, differences between irrigation interval treatments. The ten-day interval gave the highest grain yield, followed by the five-day interval and then the bi-weekly interval.

It is noteworthy that this trend of the effect of treatments on grain yield is in close harmony with the previous trends shown by plant height and straw yield. Final grain yield is known to depend and to relate closely to these growth attributes. It seems logical that the effect of irrigation on those growth attributes and yield components has ultimately resulted in the observed effect on grain yield.

It is also evident that in all the parameters studied there was an effect of varying magnitude resulting from a change in the interval of irrigation and that the effect of varying the amount of water applied per irrigation was consistently negligible. Further explanation of this phenomenon will be made in the discussion of the consumptive water use that follows.

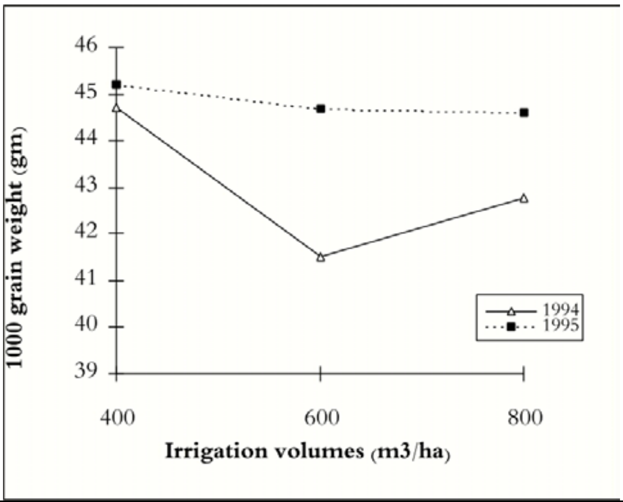
In the second season, the effect of irrigation intervals and volumes on yield and yield components is shown in Table (7) and Figures (7), (8) and (9). Results indicated highly significant effect (0.01 level) of both the irrigation intervals and volumes for all characters studied, namely, 1000 grain weight (gm), grain yield, biological yield (ton/ha) and harvest index. Expanding irrigation intervals caused a significant reduction in all characters studied where the 10 and 15 days intervals increased from 33.78, 35.44 and 38.50. The grain yield was 7.24, 6.45 and 5.82 ton/ha for the 5, 10 and 15 days intervals, respectively.

The effect of irrigation water volumes on yield and the yield components under center pivot was highly significant (Table 8). 1000 grain weight (gm), grain yield (ton/ha), biological yield (ton/ha) and harvest index increased as the irrigation volumes increased.



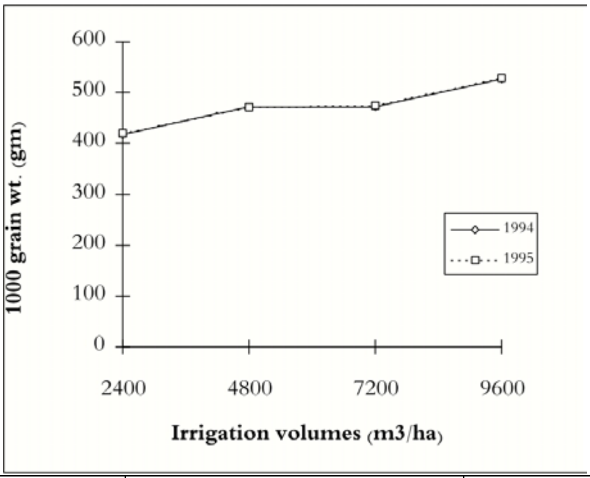
	1994	1995
LSD 5%	N.S.	N.S
LSD 1%	N.S.	N.S.

Fig. (7) : Effect of the irrigation intervals (days) on 1000 grain weight (gm) under basin irrigation for the years of 1994 and 1995.



	1994	1995
LSD 5%	0.011	0.021
LSD 1%	0.016	0.012

Fig. (8) : Effect of the irrigation volumes (m3/ha) on 1000 grain weight (gm) under basin irrigation for the years of 1994 and 1995.



	1994	1995
LSD 5%	0.406	0.11
LSD 1%	0.584	0.26

Fig. (9) : Effect of the irrigation volumes (m3/ha) on 1000 grain weight (gm) under center pivot irrigation for the years of 1994 and 1995.

Harvest Index

Harvest index is shown in Figures (10), (11) and (12). There was an increase in harvest index with short irrigation intervals and higher water volumes. Same results were found for the center pivot (Figure 12) where harvest index was higher with higher irrigation volumes.

The effects of water on yield are manifold. During vegetative development even minor stresses can reduce the rate of leaf expansion and LAI at later stages of development. The most dramatic effect of the early vegetative moisture deficit was reduction in LAI. Seed yield was not affected as drastically as the vegetative yield, possibly reflecting the greater water availability during seed fill and remobilization of assimilate stored in the vegetative parts. For seed yield the timing of water stress may be as important as the degree of stress.

A relatively short but severe stress may have no influence on grain yield if imposed during the vegetative stage of development. Longer periods of less severe stress might have a greater influence on yield. In considering yields in relation to water stress, the simplest to analyse is production of total dry matter. This situation is still more complex when the yield considered only part of the total plant material, such as grain or storage organs. Then yield will usually depend more on the developmental stage at which stress is applied and on sensitivity to stress in the different developmental stages.

Using semi-dwarf wheat in a wide row systems was successful in reducing crop water deficit and increasing plant height, grain yield was reduced in wide-row systems compared to narrow-row systems for both tall and semidwarf wheat (Winter and Welch, 1987).

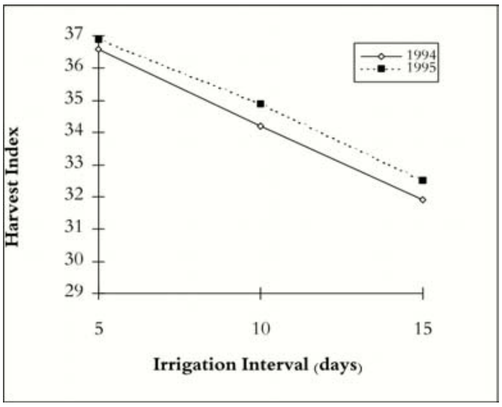
The possibility has not been examined that the influence of stress on translocation may be partly mediated by metabolic modulation of phloem loading and unloading, that is, the transport of sugars into and out of the long distance conducting system. In addition, detrimental after effects of severe stress could be physical as well as metabolic.

Evans and Wardlaw (1976) indicated that variation in the duration in the vegetative period accounted for 5 to 10 % of the variation in grain yield, where as, Bingham (1969) concluded that duration of the vegetative period was equally as important as the duration of the grain filling period in determining grain yield. Getenet *et al*. (1985) supported this motion as they found a positive relationship between grain filling duration and yield in

Durum (Triticum tergidem L.). They attributed this relationship to the positive effects of grain filling duration and vegetative growth period on kernels per spike and kernel weight, which in turn had positive effects on yield.

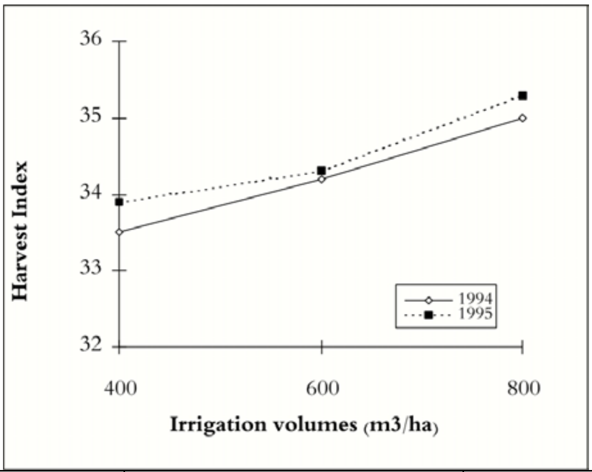
It is note-worthy to mention that final yield is known to depend and to relate closely to growth attributes. The effects of the water stress period were very severe on grain yield and its related trait number of kernels/spike. The highest amount of reduction in grain yield occurred, in genotypes reaching the heading stage after the termination of the water stress period.

The relationship between carbon accumulation and the amount of water transpired and correlation between translocation of assimilates can be important in the performance of a crop under drought, and can be analysed in terms of source/sink relationship in plant between harvest index (HI) and post-anthesis water which suggest that grain yield is strongly dependent on biomass accumulation after synthesis in water-limited environments (Turner; and Sinclair, 1983). Whereas, some workers have suggested that the contribution to yield of pre-anthesis reserves is enhanced under drought stress (Blum *et al*. 1983; Turner and Nicolos, 1986). There is also a suggestion that there might be useful genetic variation in remobilization of photosynthates (Blum *et al*., 1982).



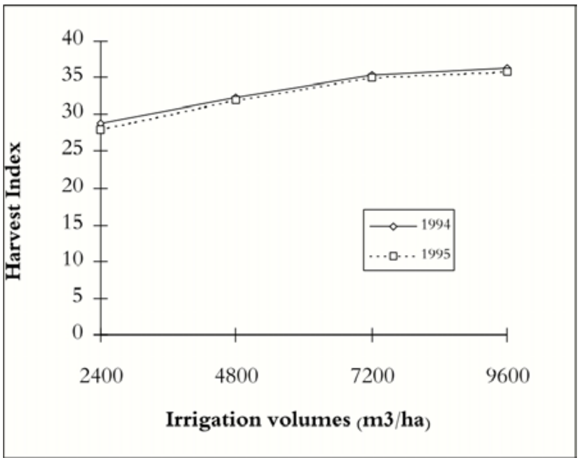
	1994	1995
LSD 5%	0.0028	0.0030
LSD 1%	0.0042	0.0051

Fig. (10) : Effect of the irrigation intervals (days) on harvest index under basin irrigation for the years of 1994 and 1995.



	1994	1995
LSD 5%	0.0021	0.0032
LSD 1%	0.0029	0.0048

Fig. (11) : Effect of the irrigation volumes (m3/ha) on harvest index under basin irrigation for the years of 1994 and 1995.



	1994	1995
LSD 5%	0.007	0.002
LSD 1%	0.010	0.030

Fig. (12) : Effect of the irrigation volumes (m3/ha) on harvest index center pivot irrigation for theyears of 1994 and 1995.

Proline content

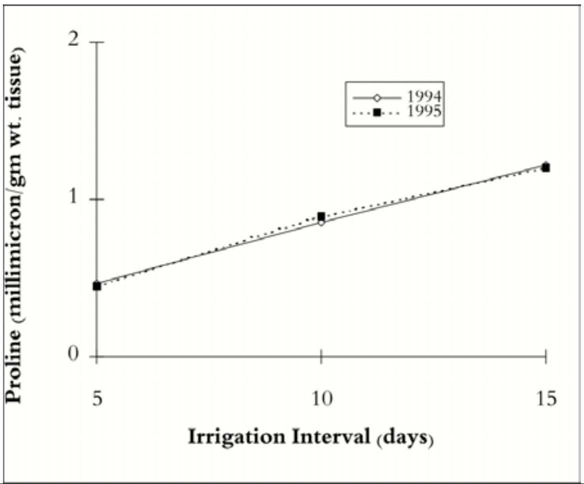
In this study, the highest proline content was 1.216 millg/gm leaves for the 15 days interval and 1.052 millg/gm for the water volume 400 m^3/ha, respectively (Figures 13 and 14). Several workers (Barnett and Naylor, 1966 and Steward *et al*. 1966) suggested that proline may serve as a storage compound for reduced carbon and nitrogen during stress.

Under center pivot as expected, under the various irrigation volumes used in this study, the greater the volumes the lower was the proline content which was reduced from 1.855 to 0.611 millimic/gm (Figure 15).

As previously mentioned it is well known that in case of subjecting plants to drought, most of the drought resistant crops form several organic compounds in order to attract much water through forming the hydrogen bond which consequently increases the bound water within the plant parts especially leaves. The amino acid proline is considered as the most efficient and thereby it is known as drought indicator. The ability of 10 barley varieties to accumulate proline under severe stress has been positively correlated with their drought resistance (Singh *et al*., 1972). The higher the proline content the higher the plant resistance.

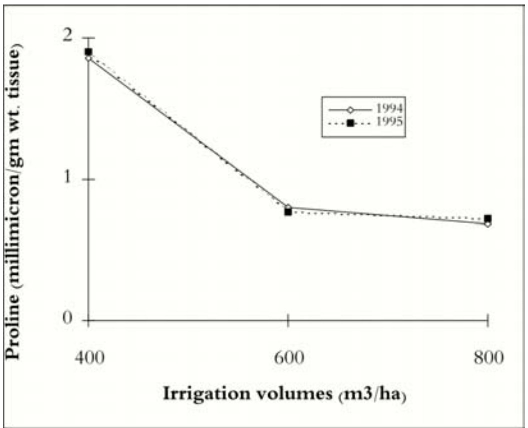
Results of this study agrees with those of Gardener *et al*. (1985) who reported the amino acid proline that under moderate to severe stress conditions the amino acid proline increased. Barnet and Naylor (1966) also found that total free amino acids in leaves increased if water stress lasts several days. Amides also frequently increase but proline has the most pronounced rise. The increase in proline can account to as much as 1% of the leaf dry matter of several plant species (Routley, 1966 and Singh *et al*., 1972).

Amino acids including proline, were greater in pressurised TAM-101 wheat cultivar than surdy leaves (Johnson *et al*. 1984). This seem in agreement with this study where plants stressed for 15 days accumulated high proline content as compared with those unstressed plants which were irrigated every 5 days.



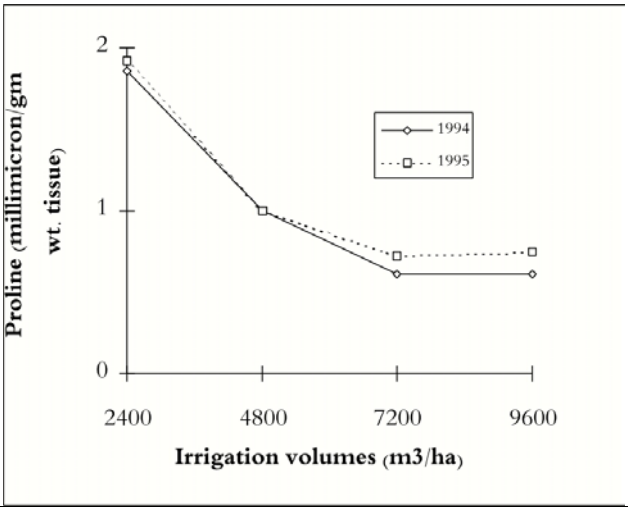
	1994	1995
LSD 5%	0.00035	0.00024
LSD 1%	0.00052	0.00083

Fig. (13) : Effect of the irrigation intervals (days) on proline (millimicron/gm wt. tissue) under basin irrigation for the years of 1994 and 1995.



	1994	1995
LSD 5%	0.00089	0.0082
LSD 1%	0.0012	0.0010

Fig. (14) : Effect of the irrigation volumes (m3/ha) on proline (millimicron/gm wt. tissue) under basin irrigation for the years of 1994 and 1995.



	1994	1995
LSD 5%	0.0046	0.0023
LSD 1%	0.0092	0.0085

Fig. (15) : Effect of the irrigation volumes (m3/ha) on proline (millimicron/gm wt. tissue) under center pivot irrigation for the years of 1994 and 1995.

Water use efficiency (wue):

An important determination which combines the grain yield obtained under each treatment and the amount of water applied to that treatment is the efficiency of the water used in kg grain/m^3 of water. This is particularly important where water resources are of limiting factors. Table 7 shows the water use efficiency (WUE) for grain yield (kg grain/m^3 of applied water) and for the biological yield (grain + straw kg/m^3 of water) of the different irrigation treatments in basin irrigation experiment of the first and second seasons respectively. The general trend of WUE for grain yield and / or the biological yield as was related to the total amount of irrigation water applied is that as the total irrigation water applied increases the WUE decreases. This relationship was described in a linear correlation model with significant coefficient of determination (r^2 being in the range of 0.76 to 0.92). Examining grain yield at the 5 days and 10 days interval proved that no significant differences were achieved at either each interval level and/or among irrigation volumes (800, 600, 400 m^3/ha). Applying water every five days, therefore, leads to a lot of water in excess of the needs of the crop and resulted in very low water efficiency values ranging from 0.36 to 0.68 and from 0.87 to 1.78 kg/m^3 for grain yield and biological yield of first season experiment respectively (Table 7). Where the same values of WUE for the second season had the range of 0.38 to 70 and from 1.00 to 1.95 kg/m^3 for the grain yield and the biological yield respectively (Table 7). Results of WUE over the two seasons also revealed that, at each water interval, the WUE had a significant inverse correlation with the total irrigation depth applied. This is may be attributed to the fact that the differences in grain yield were negligible and consequently not significant. Data presented in Table 7 also revealed that the highest WUE for grain was achieved by applying irrigation every 10 or 15 days. The 10 days intervals, however, resulted in higher grain yield than that obtained with the 15 days interval. Applying irrigation water at the rate of 400 m^3 every 10 days is therefore, seems about optimum. This would in fact achieve relatively higher grain yield associated with highest water use efficiency.

Table (7) Water use efficiency (WUE) for the grain yield (Kg grain/m^3 of water) and for the biological yield of the different irrigation treatments under the basin irrigation for the year of 1994 and 1995.

Total amount of irrigation depth applied (cm/season)	Irrigation Interval (days)	Grain yield (t/h)		WUE for the grain yield kg/m^3 water		Biological yield (grain+straw) (t/h)		WUE for the biological yield (Kg/m^3 water)	
		1994	1995	1994	1995	1994	1995	1994	1995
200	5	7.29	7.47	0.36	0.38	17.49	20.0	0.87	1.00
150		7.13	7.25	0.48	0.48	17.49	19.80	1.17	1.32
100		6.79	7.01	0.68	0.70	17.75	19.50	1.78	1.95
104	10	7.62	6.75	0.73	0.65	20.88	14.14	2.01	1.84
78		7.45	6.39	0.96	0.82	20.12	18.72	2.58	2.40
52		7.55	6.2	1.45	1.19	20.25	18.56	3.89	3.57
72	15	6.45	6.01	0.90	0.83	17.0	18.43	2.36	2.56
54		6.75	5.83	1.25	1.08	18.0	18.25	3.33	3.38
36		6.92	5.63	1.92	1.56	17.0	18.11	4.72	5.03
Simple correlation model		Y1=6.94 + 0.002X	Y1=5.42 + 0.012X	Y2=1.74 + 0.008X	Y2=1.44 + 0.006X	Y3=18.9 + 0.05X	Y3=17.8 + 0.012X	Y4=4.56 + 0.02X	Y4=4.53 + 0.021X
R^2		0.95	0.86	0.76	0.78	0.93	0.89	0.81	0.76

Table 8 show the water use efficiency for grain yield (Kg grain/m^3 of applied water) and for the biological yield (kg grain+straw/m^3 of water) of the different irrigation treatments in the center pivot irrigation experiment of the first and second seasons respectively. Relatively speaking, the same results were obtained with the center pivot irrigation experiment except for the acquired magnitudes of WUE. Increasing the total amount of irrigation volume from 2400 to 9600 m^3/season increased the grain yield from 3.79 to 5.28 ton/ha and from 5.33 top 7.1 ton/ha in the first and second seasons respectively. The same irrigation volumes had also the same effect on the biological yield; where it increased from 13.79 to 22.16 ton/ha in the first growing season and from 18.50 to 19.53 ton/ha in the second growing season.

WUE data shown in Tables 8 also proved that the highest WUE values were achieved with total application rate of 2400 and 4800 m^3/ha; being 1.58 and 0.88 kg grain/m^3 water in the first growing season and 2.22 and 1.27 kg grain/m^3 water respectively. As for the biological yield; the WUE values were 5.75 and 3.75 kg grain and straw/m^3 water for the same irrigation volumes and first season respectively where it was 7.71 and 3.94 kg grain and straw/m^3 for the second season and total application rate of 2400 and 4800 m^3/ha respectively. The conclusion which may be deduced is that, with center pivot irrigation system, 48 cm total irrigation depth/ha/season (i.e. 4800 m^3/ha/season) sounds about optimum to satisfy potential yield as well as higher WUE (1.27 kg/m^3; Table 8).

Table (8) : Water use efficiency (WUE) for the grain yield (Kg grain/m^3 of water) and for the biological yield of the different irrigation treatments under the center pivot irrigation for the year of 1994 and 1995

Total irrigation depth applied (cm/season)	Grain yield (t/h)		WUE for the grain yield kg/m^3 water		Biological yield (grain+straw) (t/h)		WUE for the biological yield (Kg/m^3 water)	
	1994	1995	1994	1995	1994	1995	1994	1995
24	3.79	5.33	1.58	2.22	18.00	18.50	5.75	7.71
48	4.23	6.10	0.88	1.27	18.20	18.85	3.75	3.94
72	5.05	6.78	0.70	0.94	18.67	19.15	3.01	2.66
96	5.28	7.1	0.55	0.72	18.80	19.53	2.31	2.03
Simple correlation model	Y1=3.27 + 0.02X	Y1=4.83 + 0.025X	Y2=1.75 + 0.01X	Y2=2.50 + 0.02X	Y3=17.7 + .012X	Y3=18.2 + 0.014X	Y4=6.47 + 0.05X	Y4=8.66 + 0.076X
R^2	0.96	0.97	0.86	0.89	0.97	0.99	0.92	0.89

X = total irrigation depth.
Y1 = Grain yield.
Y2 = WUE for the grain yield.
Y3 = Biological yield.
Y4 = WUE for the biological yield.
* Total irrigation volume (m^3/season = total irrigation depth (cm/season) X 100.

CONCLUSSIONS AND RECOMMENDATIONS

Based on the results obtained from this work, the following conclusions:

1. Irrigation intervals are relatively more important and significantly have the impact on crop yield than volumes.
2. Irrigation interval of 10 days for wheat crop grown under basin irrigation system was considered the most suitable irrigation period beyond which significant adverse effects on crop yield was observed. From the irrigation management point of view, 10 days irrigation cycle may substantiate a very convenient application time, where, the crop water use required for the 10 days irrigation interval may be applied in 7 days actual operation; giving 3 days off for other management practices, possible rest time for workers and probable downtime due to mechanical failure of irrigation equipment.
3. 400 m^3/ha/irrigation (i.e. 4 cm total irrigation depth/irrigation/ha or 52 cm total irrigation depth/ha/season) sounds an optimum amount of water to be applied with basin irrigation to achieve the highest yield possible as well as higher water use efficiency.
4. For farmers using center pivot irrigation systems, 48 cm total irrigation depth/ha/season (i.e. 4800 cubic meter/ha/season) has given the highest yield possible associated with higher water use efficiency.
5. Using center pivot irrigation system may save a total of 400 m^3/ha/season accordingly compared with using basin irrigation system under the conditions of the Eastern Province of Saudi Arabia. For about one hundred thousand irrigated hectare of wheat crop grown the Eastern Province of Saudi Arabia; the total amount which may be saved is therefore equivalent to 40 million cubic meter/season. This preserved amount of water may be directed towards planting other winter crops and/or retained in ground water aquifers for future use.

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نظام تسجيل البيانات لجدولة الري
٢. جدولة الري لمحصول القمح

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الملخص :

تم إجراء التجارب على محصول القمح في موسمين زراعيين وذلك بمقر محطة التدريب والأبحاث الزراعية والبيطرية التابعة لجامعة الملك فيصل بالأحساء، حيث تم تقسيم التجارب الحقلية في كل موسم زراعي إلى قسمين، قسم يختص بمعاملات الري الحوضي وقسم أخر يعتني بمعاملات الري بالرش المحوري.

وضعت معاملات تجارب الري الحوضي في تصميم القطع المنشقة في أربعة مكررات، حيث شغلت معاملات فترات الري الوحدة التجريبية الرئيسية بصورة تحقق النظام العشوائي، بينما وزعت معاملات كميات مياه الري عشوائياً على القطع المنشقة في الوحدة التجريبية الرئيسية. وقد خصص للري الحوضي ثلاثة معاملات لفترات الري شملت ٥، ١٠، ١٥ يوم بينما كانت معاملات كميات الري المضافة ٤٠٠، ٦٠٠، ٨٠٠ م^{٣}/هكتار/رية (تعادل على الترتيب ٤، ٦، ٨ سم ارتفاع كلي لعمق مياه الري/رية).

وقد وضعت معاملات تجارب الري بالرش المحوري في تصميم القطاعات الكاملة عشوائياً في أربعة مكررات وأربعة معاملات، حيث كانت معاملات الري أربعة هي ٢٤٠٠، ٤٨٠٠، ٧٢٠، ٩٦٠٠ م^{٣}/هكتار/فصل النمو (تعادل على الترتيب ٢٤، ٤٨، ٧٢، ٩٦ سم ارتفاع كلي لعمق مياه الري/فصل النمو).

تم قياس وتقدير مظاهر نمو النباتات خضرياً وثمرياً للمعاملات قيد الدراسة. حيث شملت قياس النمو الخضري طول النبات و دليل مساحة الأوراق عند فترات مختلفة من مراحل النمو. وتم أيضاً تقدير محتوى البرولين (دليل الحصاد) ومحصول الحبوب (المحصول الاقتصادي) والمحصول الكلي وكفاءة استخدام المياه تحت مختلف المعاملات.