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EFFECT OF INTELLIGENT IRRIGATION ON WATER USE EFFICIENCY OF WHEAT CROP IN ARID REGION

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ABSTRACT

The intelligent irrigation technique is a valuable tool for monitoring and quantifying irrigation water added for plants as well as for irrigation scheduling. So, an intelligent irrigation system (IIS) was implemented and tested under sprinkler irrigation system to irrigate wheat crop (*Yecora Rojo*) at experimental farm of College of Food and Agriculture Sciences, the King Saud University, Riyadh. The, results obtained with this system were consequently compared with the irrigation control system (ICS), which was based on automatic weather station. The results indicated that the applied water saving was significantly affected by IIS irrigation. The water use efficiency under IIS was generally higher (1.37 kg m^{-3}) compared to that under ICS (1.21 kg m^{-3}), resulting maximal irrigation water use efficiency for both growing seasons (average 1.25 kg m^{-3}). It was found that IIS technology provided significant advantages on WUE. In addition; IIS was conserved 26% of irrigation water compared to ICS and an economic yield was obtained. In general; results showed that implementing this technique proved to be an easy flexible practical tool to schedule irrigation. Overall; this technology is recommended for efficient automated irrigation systems and the IIS technique may provide a valuable tool for conserving water planning and irrigation scheduling for wheat and which is extendable to other similar agricultural crops.

Keywords: Arid region, evapotranspiration, intelligent irrigation, sprinkler irrigation, wheat yield, water use efficiency.

INTRODUCTION

Proper scheduling of sprinkler irrigation is critical for efficient water management in crop production, particularly under conditions of water scarcity (Pereira *et al*., 2002). The effects of the applied amount of sprinkler irrigation water, irrigation frequency and water use are particularly important in order to obtain higher yields (Sezen and Yazar, 2006). Using the sprinkler irrigation system played a significant role in increasing the wheat water productivity in arid and semi-arid regions (Montazar and Sadeghi, 2008).

In the past 10 years, intelligent irrigation controllers (IICs) have been developed by a number of manufacturers and have been promoted by water purveyors in an attempt to reduce over-irrigation (Michael and Dukes, 2008). There were many intelligent irrigation systems computing applied water and evapotranspiration (ET) that based on climatic conditions (Macready *et al*., 2009; Mendez-Barroso *et al*., 2008; Lozano and Mateos, 2008). Some other researchers also used tensiometers sensors in irrigation scheduling for wheat under sprinkler irrigation system (Van der Gulik 2004; Shock 2006).

To improve water use efficiency **(**WUE) on the basis of increasing crop yields there must be a proper irrigation scheduling strategy (Li *et al*., 2000). Scheduling irrigation have been well studied and widely practiced for improving crop yield and/or increasing irrigation water use efficiency, IWUE (Wang *et al*., 2002; Kang *et al*., 2002).WUE has been reported to be decreasing with increasing in irrigation times and amount of irrigation water applied per growing season (Qiu *et al*., 2008). Intelligent irrigation technologies were evaluated in Dookie, Egypt and resulted water saving up to 38% over conventional irrigation (Dassanayake *et al*. 2009). Several studies on winter wheat showed that crop yield and water use efficiency in sprinkler-irrigated fields was higher than that in surface irrigated fields (Wang *et al*., 2002; Zhang *et al*., 2004; Yang *et al*., 2000). Aggarwal *et al*. (1986) showed that WUE for wheat decreased with increasing ET. The use of frequent, but low water application volumes is superior to the more traditional scheduling of few applications of large irrigation volumes in terms of IWUE (Dukes *et al*., 2010; Locascio 2005; Zotarelli *et al*., 2009).

Therefore, owing to prevailing conditions and water shortages, the optimum irrigation schedules for wheat in the region should be determined. The objectives of this study was to investigate the effect of different target of this schedule intelligent irrigation system on wheat ET, yield, water use efficiency (WUE) and irrigation water use efficiency (IWUE) in arid climatic conditions Almarshadi and Ismail (2011).

MATERIAL AND METHODS

Experimental site: Field experiments were carried out at experimental farm, of College of Food and Agriculture Sciences, the King Saud University, Riyadh, at 24°43´N latitude, 46°43´ E longitude and 635 m altitude during the winter seasons of (2009-2010 and 2010-2011). In general, the soil type in both plots was sandy loam. The climate in this region was classified as arid, and the climatological data, such as temperature, relative humidity, rain, solar radiation, and wind speed are measured at the experimental site during the course of the study are given in (Table 1). The weather station was used to measure the climate parameters that were used to compute reference evapotranspiration (ET_r). Its values were then compared with those obtained from the IIS in wheat crop field. The IIS device was programmed in situ, taking into account; type of crop and the environment prevailing conditions in the area. The system was calibrated and configured to implement the next phase of the study before collecting real data.

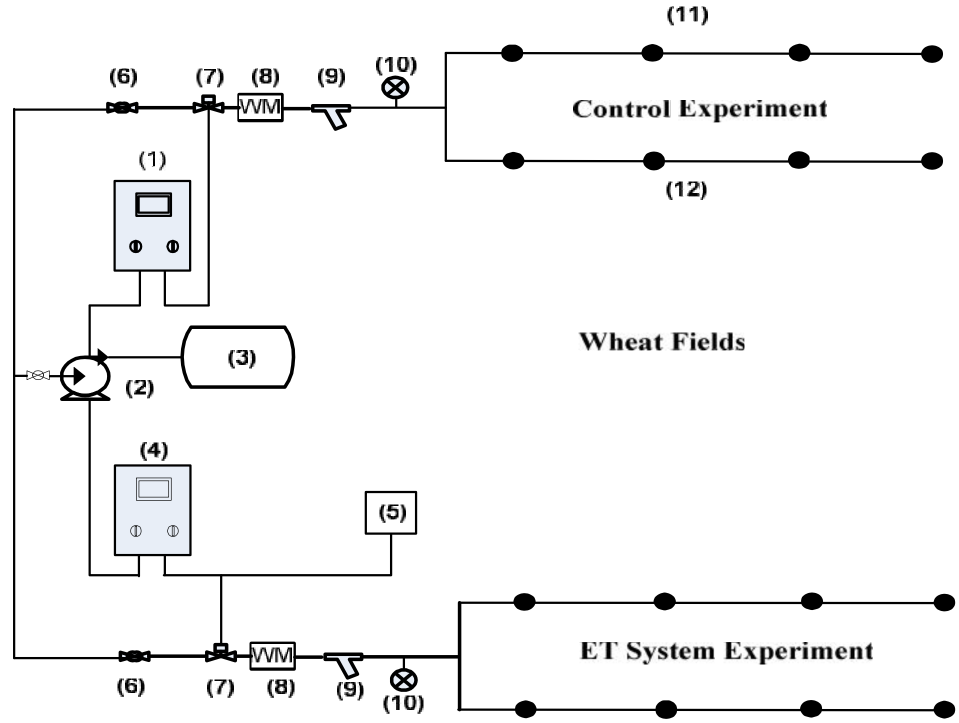
Table 1. Metrological data of the experimental site.

Month	Tmax. (c°)	Tmin. (c°)	Max. RH %	Rain mm	S.R 10^4W^{-2}	WS (m/s)	ET_r $mmday^{-1}$
Season 2009 – 2010							
December	22.26	11.57	43.82	0.00	38.36	5.20	3.57
January	22.43	10.12	34.39	0.00	42.29	5.74	4.14
February	26.28	13.40	26.96	0.00	41.29	5.76	4.62
March	30.03	16.39	19.02	0.01	51.51	5.53	5.97
April	32.86	21.41	43.82	0.27	46.01	6.94	6.20
Season 2010- 2011							
December	22.19	9.91	27.15	0.00	33.01	1.07	2.99
January	19.28	10.51	52.70	0.78	30.62	1.44	2.87
February	23.44	12.41	36.23	0.00	38.71	1.53	4.29
March	25.39	14.77	31.69	0.54	40.34	1.94	5.28
April	29.84	19.22	23.40	0.03	38.32	1.86	5.82

RH; Relative Humidity, S. R: Solar Radiation, WS: Wind Speed

Experimental layout and irrigation treatment design: The site of the study was divided into two equal plots; one with intelligent irrigation system (IIS), which was irrigated automatically. The second used for control experiment, which was using irrigation manually based on crop evapotranspiration (ET_c) values. A strip of land, 10 m wide was used as a buffer zone between plots. Solid sprinkler irrigation systems were installed for both wheat plots IIS and irrigation control system (ICS). These systems were evaluated and found to be capable to achieve high performance and water uniformity for irrigated area. Each plot consisted of 8 sprinklers to cover cultivated area of 24×9 m (Fig. 1). Irrigation systems were equipped with controllers to control the pressure by using pressure regulators, and flow meters to measure the amount of water added in each irrigation event. This sprinkler system has been designed and installed for each field plot with PVC laterals, and were connected to sub main and main pipes. The sprinkler heads were fitted on the top of the sprinkler risers, which were galvanized steel pipes.

The selection of the sprinklers were primarily depended upon the diameter of coverage required, pressure available and capacity of the sprinkler. The sprinklers used in the design are rotary impact sprinklers (type: Mini Bird, by Rain Bird[1]), which can be adjusted to irrigate, full circle or part circle during the irrigation. Sprinkler system was evaluated in the fields according to the methodology of ASABE Standard, S436.1 (2007). The intelligent irrigation system required a complete database for each station (or "zone") to be controlled. It was easy to set up this database with little effort, and the operator was completely responsible for the accuracy of both input information and output results from the database. Every system was observed and monitored after initial installation for the best results. Generally, most systems require adjustment, at the station level, for some time after installation to provide ideal results. Evaluation tests were conducted for each irrigation system by checking values of the performance indexes under operating field conditions. Indexes values were found to be within acceptable results and representing good water distribution uniformity (over 90%). The control experiment was used for comparison purposes.



(1)	ICS Control panel	(5)	ET sensor (Fig 2)	(9)	Filter
(2)	Pump	(6)	Solenoid Valve	(10)	Pressure Gauge
(3)	Water Tank	(7)	Water Meter	(11)	Lateral Line
(4)	IIS Control panel	(8)	Filter	(12)	Sprinkler

Fig. 1. Schematic diagram of wheat field using sprinkler irrigation systems for both intelligent irrigation (IIS) and control (ICS) systems.

Some physical properties of the experimental field soil are presented in Table 2.

Table (2): physical characteristics of different soil layers under study area

Layer depth cm	**Particle size distribution (%)**			**Soil texture class**	**FC % $m^3\ m^{-3}$**	**PWP % $m^3\ m^{-3}$**	**BD $g.cm^{-3}$**
	Sand	Silt	Clay				
0 – 20	74.81	11.77	13.42	Sandy loam	14.74	5.32	1.64
20 – 30	72.64	11.65	15.71	Sandy loam	17.27	6.54	1.61
30 –60	70.35	14.82	14.83	Sandy loam	15.90	6.58	1.59
Average	72.60	12.75	14.65	Sandy loam	15.97	6.15	1.61

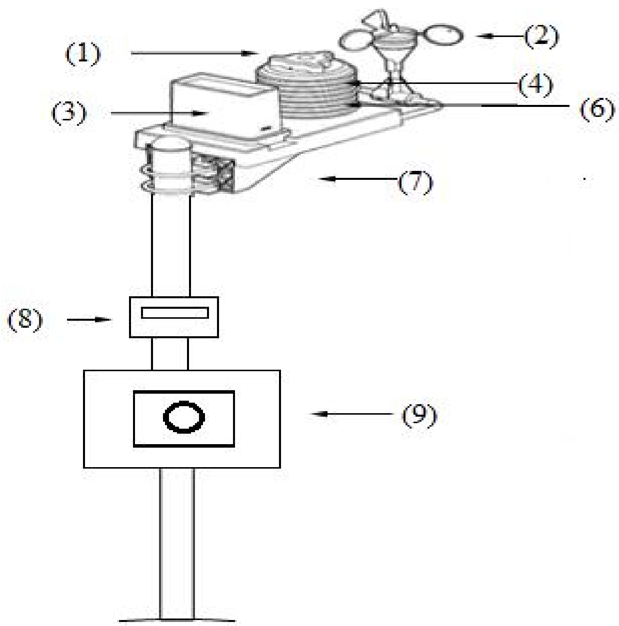
BD = bulk density, PWP = permanent welting point, FC = field capacity

Intelligent system components, functions, and installation: The intelligent irrigation system chosen for this study was the Hunter ET-System.[1] The smart controllers integrate many disciplines to produce a significant improvement in crop production and resource management (Norum and Adhikari 2009).This system is not considered the best system, but it was inexpensive and available on the local market. The IIS was installed according to the manufacturer's instructions in the field for the planned experiments. It can be customized by station (or "zone") for specific plants, soils and sprinkler types.

This type of system uses digital electronic controllers and modules, and its platform can be wired to an ET module that can sense the local climatic conditions via different sensors that measure wind speed, rainfall, solar radiation, air temperature and relative humidity (Fig. 2). The ET module then receives data from the ET sensor and applies it to the individual fields (zones) of irrigation. The IIS automatically calculates crop evapotranspiration (ET_c) for local microclimates based on a modified Penman equation (Allen *et al.*, 1998) and

1, 2 Trade names does not mean the promotion of that product, but mentioned for research purposes only.

creates a scientific program that it downloads to the controller.



1	Solar Radiation	6	Relative Humidity
2	Wind Speed	7	Sensor Base
3	Rain Gauge	8	ET Module
4	Air Temperature	9	Irrigation Controller (Pro C)

Fig. 2. The Smart System components used in the study

Here, the ET module was plugged into the irrigation controller Pro C, which was called the Controller Intelligent Port, and adjusted the irrigation run times to only replace the amount of water the plants had lost, at a rate at which could be effectively absorbed by the soil. Hence, the IIS relayed data acquisition of environmental parameters as well as system parameters (pressure, flow, etc.). The state of the system was compared against a specified desired state, and a decision as to whether or not to initiate an action was based on this comparison. In the case of a decision taken by the ET sensor (Fig. 2) to initiate irrigation, a signal was transmitted to open the solenoid valve and pump to supply the required irrigation water. In the ICS, the climatic data are gathered from a weather station, and the daily reference evapotranspiration rate (ET_o) was calculated and utilized in making irrigation decisions. Then, the calculated ET_o data were integrated with the Kc of crops to determine irrigation water to be added. The determined quantity was fed manually to the control panel, which in turn transmitted a signal to the solenoid valve to provide the required water to the field.

However, the IIS was used here to irrigate the wheat crops under the sprinkler irrigation system. Daily wheat ET_c data measured from the IIS and ICS experiments to irrigate were monitored and recorded. For ICS, the daily ET_o measurements were multiplied by adequate crop coefficients to provide ET_c and used efficiently to schedule the automated sprinkler systems. Furthermore, the total ET_c for the intelligent and control irrigation experiments were compared together, and the overall difference was quite significant.

Field operation and observations: Wheat (*YecoraRojo*) was sown in the field on December 9, 2009 and December 4, 2010, respectively. The seeding rate was 180 kg/ha with 20 cm distance between rows, whiles other cultivation practices were carried out following a certain scheduling program. Daily and weekly (ET_c) values of wheat during the growing seasons were determined for IIS and ICS treatments. Hence, irrigation water depths (D_g) and accumulative depths were monitored and recorded. Irrigation processes were terminated in 9 and 14 April for both first and second seasons, respectively. Fertilizers containing nitrogen, phosphorus, potassium elements and other elements were applied at the rate of 100 kg/ha for both wheat plots. At wheat maturity, grain yield (GY), biological yield (BY) and plant height (PH) were calculated. Grain and biological yields were determined from the 5 rows x 1m. Harvest index (HI) was calculated as grain yield/ biological yield. Grain yield was estimated as the weight of clean grain (taken from random seven samples with one square meter and converted to grain yield per hectare). Moreover, 1000 grain weight is recorded as the average of samples taken at random from the harvested plants of each treatment. Plant height was measured at maturity as the distance from soil surface to the top of the main spike, excluding the awns.

Operation time required: To calculate ET_c and irrigation water requirement of wheat, daily reference evapotranspiration (ET_r) values were first determined by the meteorological station and then were multiplied by crop coefficients and water application efficiency. Hence, by knowing the area of each field (216 m^2) and the discharge rate from the eight sprinklers (4.88 m^3h^{-1}), the water quantity was added in specific each event was determined. Accordingly, the actual operation time required was then calculated. The irrigation system was manually turned on and off in ICS plots. The depth of irrigation water (Dg) for IIS under sprinkler irrigation was calculated from the differences of flow meter readings before and after irrigation.

Water use efficiencies: The Irrigation water used efficiency (IWUE) and water use efficiency (WUE) were calculated using Equations 1 and 2, respectively.

$$IWUE = \left(\frac{Y}{(Dg)_t} \right) \quad \text{(Michael, 1978) (1)}$$

$$WUE = \left(\frac{Y}{ETc}\right)$$ (Wanga *et al*., 2007) (2)

Where, in these equations, Y is the grain yield (kg m^{-3}), ET_c is evapotranspiration (mm) and $(Dg)_t$ is the amount of seasonally applied irrigation water (mm).

Statistical analysis: The data obtained from the two growing seasons were tabulated and subjected to analysis of variance and least significant difference (LSD) using CoHort Software program version 6.311 (2005). The treatment's means were compared using the least significant difference test (LSD) at 5% probability level. A *t*- test was used to compare the average of the two methods following a normal distribution. This test was done to find significant differences between IIS and ICS water treatment.

RESULTS

ETc of wheat crops: Daily and weekly averages of ETc rates of wheat crops for both treatments during growing seasons were calculated from daily records are shown in Table 3.

Table 3. Average of daily and weekly wheat (ETc) rates during the two seasons for both systems

Growth Period (Week)	ET_c for IIS (mm/day)	ET_o (mm/day)	Kc	ET_c for ICS (mm/day)
1	1.65	2.88	0.70	2.02
2	1.76	3.38	0.70	2.37
3	1.97	3.12	0.99	3.09
4	2.15	3.15	0.99	3.12
5	2.34	3.60	0.99	3.57
6	2.22	3.49	0.99	3.45
7	2.45	3.63	0.99	3.59
8	2.78	3.38	099	3.34
9	2.59	3.68	1.10	4.25
10	3.29	4.18	1.10	4.59
11	3.76	4.38	1.10	4.82
12	3.98	4.76	1.10	5.24
13	4.10	5.11	1.10	5.62
14	4.42	5.50	1.10	6.05
15	4.28	3.35	1.10	5.89
16	3.66	6.72	1.10	7.39
17	2.99	6.24	0.35	2.18
18	2.02	6.84	0.35	2.40
19	1.79	6.29	0.35	2.20
Avg.	2.87			3.96
Sum.	382.00			526.28

As shown in this table, the ETc for control experiment was higher than IIS during entire growing season especially after three weeks from cultivation was initiated. It was obvious that ETc values were small in early 3 weeks under IIS treatment and then increased with the development of plants arriving the peak at around 70-105 days (10 -15 weeks) after sowing time. In case of ICS, the ETc decreased gradually with the senescence of leaves specifically during the weeks 16 to 19, and similar trend to IIS took place to rest of the season. Total rainfalls during growing seasons were insignificant and equal to 6.2 mm and 24.2 mm.

Irrigation Scheduling: The irrigation initiated and terminated according to the data collected and processed by IIS usually shown on the monitor. The ET_r for ICS was determined using modified Penman method, FAO version (Allen *et al*., 1998). Hence ET_c was efficiently used daily after being determined by multiplying ET_r with K_c to schedule automated irrigation systems for different growth stages. Based on local experience, stages lengths were approximately of 15, 30, 60, and 25 days, respectively, and were considered in evaluation of K_c. The stages were initial, crop development, mid-season, and late season.

Comparing the total ETc of IIS (382.0 mm) and ICS experiments (526.28 mm), the overall difference was quit significant. Also from table (3) can be depicted that ET_c for ICS experiment is higher than that of IIS with similar trend during whole growth season. As shown in table 3, the accumulation of ET_c value from Intelligent Irrigation is 27% less than the value obtained from the control experiment. Averages weekly irrigation water (Dg) added to wheat crop for IIS and ICS treatments were calculated and tabulated in Table 4. From this table the average total amounts of irrigation water applied during the two seasons for wheat in both treatments were 444.76 and 600.34 mm, respectively. These amounts are less than the amount of irrigation water practiced by the local framers in the area. The Dg applied for IIS treatment was 26% less than that applied for the ICS treatment. Table 4 shows the weekly accumulative irrigation water added to wheat throughout crop growing seasons for both systems.

Growth parameters: Growth characters of wheat plants grown during the two seasons of 2009 - 2010 and 2010 - 2011 and average combined analyses are shown in Table 5. Results of this study revealed that the irrigation control system (ICS) had a clear impact on the agronomical characteristics of plant such as the average plant heights which were 75.63 and 65.13 cm for ICS and intelligent irrigation system (IIS), respectively. The average biological yields and average grain yields wheat crop were (17.31 and 14.61 tons ha^{-1}) and (6.83 and 5.53 tons ha^{-1}) for ICS and IIS, respectively. The average 1000 kernel weigh and average spike length wheat crop were (40.77 and 48.17 g) and (9.5 and 10.4 cm) for ICS and IIS respectively.

Table 4. Averages of irrigation water (Dg) and accumulative depths in two seasons added to wheat crop via intelligent and control systems.

Growth Period (week)	Avg. (Dg) for Wheat, IIS: Water Added (m^3)	Irrigation Depth Dg (mm)	Acc. depth $(Dg)_t$ (mm)	Avg. (Dg) for Wheat, ICS: Water Added (m^3)	Irrigation Depth Dg (mm)	Acc. depth $(Dg)_t$ (mm)
1	5.55	25.69	25.69	6.56	30.35	30.35
2	4.58	21.21	46.90	5.34	24.72	55.07
3	3.09	14.34	61.23	7.61	35.24	90.31
4	6.15	28.46	89.69	7.16	33.16	123.47
5	4.10	18.97	108.66	6.05	28.00	151.46
6	4.09	18.95	127.61	6.64	30.75	182.21
7	3.34	15.44	143.06	6.38	29.52	211.73
8	3.55	16.46	159.52	4.63	21.41	233.15
9	1.53	7.08	166.60	5.70	26.40	259.54
10	8.58	39.72	206.31	7.91	36.62	296.16
11	5.60	25.93	232.24	7.57	35.04	331.20
12	7.02	32.49	264.72	9.08	42.05	373.25
13	6.04	29.64	294.36	10.39	48.09	421.34
14	14.48	67.00	361.36	11.97	55.44	476.77
15	7.61	35.27	396.63	9.58	44.37	521.14
16	4.52	20.93	417.57	8.50	39.35	560.49
17	2.11	9.77	427.33	3.90	18.06	578.55
18	2.12	9.82	437.16	2.50	11.57	590.13
19	1.65	7.60	444.76	2.21	10.21	600.34
Sum	**95.71**	**444.76**		**129.67**	**600.34**	

Table 5. Comparison of yield components and efficiencies for IIS and ICS.

Character	Treatment: 2009 -2010 Season IIS	2009 -2010 Season ICS	t- sign	2010 - 2011 Season IIS	2010 - 2011 Season ICS	t- sign
Grain yield (GY)	5.07	6.10	**	5.98	7.56	**
Biological yield (BY)	13.35	16.02	**	15.87	18.60	**
Harvest index (HI)	0.38	0.38	ns	0.40	0.38	ns
1000 Kernel weight (KW)	39.12	47.68	**	42.42	48.66	**
Plant height (PH)	49.50	66.25	**	80.80	85.0	ns
Spike length (SPL)	9.50	10.00	**	9.50	10.88	**
WUE (kg m^{-3})	1.27	1.13	**	1.64	1.47	**
IWUE (kg m^{-3})	1.12	1.06	**	1.37	1.21	**

*,** t is significant at 0.05 and 0.01, respectively
ns = Not Significant

Water use efficiency: Table 6 illustrates the effects of IIS and ICS on wheat water use efficiency. It was found that the values of WUE and IWUE were higher with IIS compared to ICS, i.e. 1.27 and 1.12 kg m^{-3} in the first season, respectively. Whereas the corresponding values for the second season were 1.64 and 1.37 kg m^{-3}, respectively. Since the yields of wheat for both seasons under IIS treatment were increased from 5.07 to 5.98 ton h^{-1} and similar trend was also noticed for WUE and IWUE. The minimum and maximum values of WUE were 1.13 kg m^{-3} and 1.64 kg m^{-3} in first and second years, respectively under the two treatments. This result indicated that the water was used most effectively in IIS treatment. The results presented in table 6 also showed that the highest value of IWUE (1.37 kg m^{-3}) was obtained from IIS treatment, while, the smallest value (1.06 kg m^{-3}) was recorded in ICS during the first season. The IWUE between the two treatments where increased from 6% to 22% for the two seasons, respectively.

Table 6. Effects of the IIS and ICS on wheat water use efficiency during the growing season.

Irrigation treatments	ET_c (mm)	ET_c m^{-3} h^{-1}	AIW (mm)	AIW m^{-3} h^{-1}	WUE (kg m^{-3})	IWUE (kg m^{-3})
2009 - 2010 growing season						
IIS	400.06	4000.56	453.29	4532.90	1.27	1.12
ICS	538.25	5382.53	573.51	5735.06	1.13	1.06
2010 - 2011 growing season						
IIS	363.94	3639.43	364.23	4362.30	1.64	1.37
ICS	514.31	5143.07	627.17	6271.75	1.47	1.21

Statistical analysis: Results clearly showed that high influence of ICS treatment on wheat yields and agronomical factors in both years. The data obtained pointed out that a high significant effect of ICS treatment on the average plant height (cm), spike length (cm), average kernel weight (g), total biological yield (ton h^{-1}) and total grain yield (ton h^{-1}), whereas, there was no significant effect on harvest index (HI). While, the IIS had a high significant effect on the averages of WUE (kg m^{-3}) and IWUE (kg m^{-3}) compared to ICS treatment Table 5.

DISCUSSION

The saving in irrigation water in the case of IIS compared to ICS is due to the some options with IIS to choose for supplying more water or less according to the needs of plants. Moreover, the analysis pointed out that ET_c value of ICS was higher than that of IIS treatment during the entire season. This was due to the more accurate irrigation scheduling with IIS as compared to ICS, which leads to the availability of enough water in the root zone. The differences could be also resulted from the application of K_c values which were selected from literature and used for prediction of ET_c. The other reason was due to the fact that the irrigation system designed especially for landscape scheduling irrigation, although it gave satisfactory results when used to irrigate wheat crop. Results of the second season were found to be consistent with findings of the first season within each treatment, but a significant difference found among treatments. The consistency was a result of non-significant differences in microclimatic parameters in the sites of experiments and due to minor variation of available soil moisture depletion levels.

The total applied irrigation water, Dg for IIS and ICS were 444.76 and 600.34 mm, respectively. This indicated that there was a 26% saving in irrigation water in case of IIS compared to control treatment. The result indicated that much irrigation water was utilized under ICS treatment. Hence, change in irrigation frequency and application stage could significantly affect the available soil water during wheat growing seasons. Anyway, these amounts are greater than the amount of irrigation water practiced by the framers in the area.

This study revealed that both irrigation scheduling techniques used were having a clear impact on the agronomical characteristics of plant. The reason that the ICS resulting in greater yield than IIS could be attributed to variation of amount of water added to the two treatments. While, the increased in moisture level in the root zone was reasonable for increasing the agronomical factors especially at more irrigation water added (Dg) in ICS treatment. The decrease of soil aeration with low irrigation water added for IIS treatment may be responsible for affecting all agronomical parameters. The results indicated that each 1 mm water depth applied by IIS and ICS to the wheat crop produced for first and second seasons were 11.18 and 13.71 kg/mm for IIS, while ICS were 10.64 and 12.10 kg/mm and the combined averages for two seasons for both systems were 12.45 and 11.35 kg/mm respectively. Therefore, conserving water is very important in areas experiencing severe drought such as Saudi Arabia.

In general the higher values of water use efficiency under IIS are attributed to the saving of applied irrigation water. Therefore, the lower amount of water received was resulting in obtaining higher water use efficiency. Generally, IWUE can be increased by reducing irrigation water losses, soil type, cultural and management practices. The variation in WUE was not consistent in the two growing seasons, which may be due to the differences in weather conditions for both treatments. Under conditions of the two irrigation treatments in the both growing seasons, IIS resulted in the highest WUE and IWUE, followed by ICS. It was apparent that the WUE of wheat decreased with more of water applied irrigation.

Conclusions: As a result of this two-year field studied for wheat crop under arid region, it was concluded that the IIS method under sprinkler irrigation offered significant advantage for seasons, its easiness application and more water saving. The results pointed out that ET_c value of ICS was higher than that of IIS treatment during the two seasons. The result indicated that much irrigation water was utilized under ICS treatment. The ICS treatment resulting in greater yield than IIS could be attributed to variation of amount of water added to the two treatments. Therefore, the IIS irrigation method would be recommended due to its easiness application and more water saving. Also, the results indicated that the values of WUE and IWUE were higher with IIS than ICS. Consequently, the results of statistical analysis in both years showed that IIS had significant effects and most effectively on WUE and IWUE. The IIS technique conserved irrigation water by 26% more than that provided by control system ICS. Therefore, conserving water was something very important in areas experiencing severe drought such as Saudi Arabia.

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