Effect of smart sprinkler irrigation utilization on water use efficiency for wheat crops in arid regions

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Abstract: The smart irrigation system (SIS) developed in this research is a valuable tool for scheduling irrigation and quantifying water required by plants. SIS was implemented and tested under sprinkler irrigation system to irrigate wheat crops (*YecoraRojo*). Results obtained from this system were compared with the control irrigation system (CIS), whose scheduling method was based on data from an automatic weather station. Results indicated significant savings in applied water using the SIS. In addition, the use of the SIS conserved 12% of irrigation water compared to CIS and obtained an economical yield. The water use efficiency (*WUE*) under SIS had generally higher values (1.64 kg/m^3) compared to CIS (1.46 kg/m^3). Hence, the application of SIS technology provides significant advantages on *WUE* and irrigation water use efficiency (*IWUE*). Relatively high *WUE* and *IWUE* were found for the irrigation treatment (80% of evapotranspiration under SIS). Results showed that the irrigation requirements of wheat increased (100% of *ETc* under CIS) with increasing evapotranspiration (*ETc*) but excessive irrigation could decrease *WUE* and *IWUE*. These results indicated that extreme irrigation might not produce higher yield or optimal economic benefit, thus, suitable irrigation schedules by using SIS must be established and extendable to other agricultural crops.

Keywords: smart irrigation system (SIS), sprinkler irrigation scheduling, water use efficiency, arid region, evapotranspiration, grain yield

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1 Introduction

Saudi Arabia is one of the countries that facing great challenges due to its limited water resources in an arid climate for wheat production, considering a strategic crop demand as the population increases greatly. Wheat is the most important staple crop produced in the Kingdom of Saudi Arabia (KSA). Its cultivation area was estimated at about 195 884 hectare in 2009, with total production of about 1.15 million tons per year. Wheat cultivated area was estimated at about 42% of the total cultivated area in KSA[1], and seasonal water consumption was estimated at 414 mm in Eastern Region[2]. This was quantified by 834.7 mm and 655.8 mm for the same region under flood and sprinkler irrigation systems condition, respectively, while the seasonal water consumption for the Central Region and northern border was estimated at 675 mm and 600 mm, respectively, by using sprinkler irrigation[3]. The author also reported the highest water consumption in the KSA, which was about 956.3 mm in Al Medina Region.

Proper scheduling of sprinkler irrigation is critical for efficient water management in crop production, particularly under conditions of water scarcity[4]. The study on the applied amount of sprinkler irrigation water, irrigation frequency and water use are particularly important in order to obtain higher yields[5]. Sprinkler

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irrigation can play a significant role in increasing the wheat water productivity in arid and semi-arid regions[6]. During the past ten years, smart irrigation controllers have been developed by a number of manufacturers and have been promoted by water purveyors in an attempt to reduce over-irrigation[7]. There are now many smart irrigation systems (SIS) computing applied water and evapotranspiration (*ETc*) based on climatic conditions[8,9].

One of the best approaches to achieve good water management program is to know the amount of actual *ETc* or crop consumptive use. The effects of irrigation on crop production are usually quantified using crop water production functions that relate crop yield to the amount of water applied[10]. These functions are used to optimise on-farm irrigation and economic evaluation of irrigation water application[11]. Many studies have shown that the relationship between wheat yield and seasonal *ETc* is linear[11,12]. However, some researches showed the curvilinear relationship with increasing evapotranspiration (*ETc*)[13]. Also, a previous study[14] reported that relationship between seasonal *ETc* and grain yield (GY) or water use efficiency (*WUE*) could be described by quadratic functions. While relationship between *ETc* and GY have been widely used for water conservation as a guideline for deficit irrigation; they cannot explain the effects of timing applications. So there has been an ongoing effort to reveal relationships between GY of wheat and soil water balance (including irrigation) and water-use efficiency.

There is an urgent need to improve *WUE* in crop production and promote sustainable use of water resources. To improve *WUE* on the basis of increasing crop yields, there must be a proper irrigation scheduling strategy that has been well studied and widely practiced for improving crop yield and/or increasing irrigation water use efficiency (*IWUE*)[14]. The *WUE* decreases with the increases in irrigation duration and amount applied over the growing season[15]. Smart irrigation technologies were evaluated in Dookie and Egypt, resulting in up to 38% water savings over conventional irrigation[16]. Several studies on winter wheat showed that crop yield and *WUE* in sprinkler-irrigated fields was higher than that in surface irrigated fields[17,18]. The *WUE* for wheat decreased with increasing *ETc*[13]. The use of frequent, but low water application volumes was seen to be superior to the more traditional scheduling method of using fewer applications of large volumes[19,20]. The effects of irrigation on crop production are usually quantified using crop water production functions which relate crop yield to the applied amount of water[11]. These functions are used to optimise on-farm irrigation and economic evaluation of irrigation water application[10].

Owing to prevailing climatic conditions and water shortages, optimal irrigation schedules for wheat in the aired region should be determined. In this study, we discussed the effects of water stress and irrigation regimes on *WUE*, GY, *ETc* and its components. On the basis of our results, guidelines would be provided to farmers and irrigation agencies to achieve water-saving irrigation practice and efficient use of water resources for wheat production in the Saudi Arabia. The objectives of this study were to investigate the effect of three levels of irrigation regimes by using schedule SIS on wheat *ET*, yield, *WUE* and *IWUE* in arid climatic conditions.

2 Materials and methods

2.1 Experimental site

This study was conducted at the King Saud University Experimental Farm of the College of Food and Agriculture Sciences, Riyadh, at 24°43′N latitude, 46°43′E longitude and 635 m altitude during the winter seasons of 2010 and 2011. Generally, the climate in this region is classified as arid, and the climatological data measured at the experimental site during this study period are provided (Table 1). The field experiments consisted of two irrigation methods and three different irrigation levels. The methods were SIS and control irrigation system (CIS). The three irrigation levels were crop *ETc* (100%, 80% and 60%) of full irrigation treatments. Irrigation level treatments were based on the application of the amount of water at full irrigation.

The weather station was used to measure the climate parameters that were used to compute *ETc*. These values were then compared with the values obtained from the SIS in the wheat crop fields. The SIS was programmed in situ, taking into account both of the crop type and environmental conditions of the area. This device was then calibrated and configured to implement the next phase of the study prior to collecting real data.

Table 1 Metrological data of the experimental site

Month	Max. Tem., °C	Min. Tem., °C	Max. relative humidity, %	Rain, mm	SR, $10^4 \cdot W^{-2}$	Wind speed, $m \cdot s^{-1}$	ETr, $mm \cdot d^{-1}$
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
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

2.2 Field features and evaluation of irrigation practices

The site of the study was divided into two equal plots: one with SIS which was irrigated automatically; the other one used for control experiment which was using irrigation manually based on *ETc* values. A strip of land, 10 m in width was used as a buffer zone between plots. The soil type in the plot area was sandy loam; some soil physical properties of the experimental field related to irrigation are shown in Table 2.

Solid sprinkler irrigation systems were installed for both wheat plots SIS and CIS. These systems were evaluated and found to be capable to achieve high performance and water uniformity for irrigated area. The field study was carried out in split plot designed with three replicates used with irrigation methods as main plots and irrigation levels as subplots. Each plot consists of eight sprinklers to cover cultivated area of 24 m × 9 m. Irrigation systems were equipped with controllers to control the pressure by using pressure regulators, and flow meters to measure the amount of water applied in each irrigation event. This sprinkler system has been designed and installed for each field plot with PVC laterals, and were connected to the sub main and main pipes. The sprinkler heads were fitted on the top of the sprinkler risers, which were galvanized steel pipes. The field evaluations of sprinkler system were carried out. Uniformity index values were found to be within acceptable results and representing good water distribution uniformity.

Table 2 Physical characteristic CIS of different soil layers under study

Layer depth/cm	Particle size distribution/%			Soil texture class	FC/% ($m^3 \cdot m^{-3}$)	PWP/% ($m^3 \cdot m^{-3}$)	BD/$g \cdot cm^{-3}$
	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

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

2.3 Components, functions, and installation of the smart system

The SIS chosen for this study was the Hunter ET-System (the use of the trade name does not imply promotion of this product; it is mentioned for research purposes only). The smart controllers integrate many disciplines to produce a significant improvement in crop production and resource management[21]. This system is not considered as the best system, but it was inexpensive and available on the local market. The SIS 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 drip types.

This type of system uses digital electronic controllers and modules, and its platform can be wired to an *ETc* module that can sense the local climatic conditions via different sensors that measure wind speed, rainfall, solar radiation, air temperature and relative humidity. The *ETc* module then receives data from the *ETc* sensor and applies it to the individual fields (zones) of irrigation. The SIS automatically calculates crop *ETc* for local microclimates based on a modified Penman equation and creates a scientific program that it downloads to the controller. Here, the *ETc* module was plugged into the irrigation controller Pro C, which was called the controller smart 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 SIS relayed data acquisition of environmental parameters as well as system parameters (pressure, flow, etc.). In the case of a decision taken by the *ETc* sensor to initiate irrigation, a signal will be transmitted to open the solenoid valve and pump to supply the required irrigation water. In the CIS, the climatic data are gathered from a weather station, and the daily reference is calculated and utilized in making irrigation decisions. Then, the calculated *ETr* data are integrated with the crop coefficient (*Kc*) to determine irrigation water to be added. The determined quantity is fed manually to the control panel, which in turn transmits a signal to the solenoid valve to provide the required water to the field.

2.4 Agronomic practices 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, while other cultivation practices were carried out following a certain scheduling program. Daily and weekly ET_c rates during the growing seasons were determined for SIS and CIS treatments. Hence, irrigation water depths (*Dg*) and accumulative depths were monitored and recorded. Irrigation processes were terminated on 9 April, 2010 and 14 April 2011. At wheat maturity, measurements were made on GY, biological yield (BY), plant height (PH). Harvest index (HI) was calculated as GY/BY. The GY was estimated as the weight of clean grain (taken from random seven samples with 1 m^2 and converted to GY per hectare). Moreover, 1 000 g weight is recorded as the average of samples taken at random from the harvested plants of each treatment. The PH was measured at maturity as the distance from soil surface to the top of the main spike.

2.5 Required operation time

To calculate ET_c and irrigation water requirement of wheat, daily *ETr* values were first determined by the meteorological station and then multiplied by *Kc* 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^{-3}/hr), the water quantity to be added in each specific event could be determined. Accordingly, the required actual operation time was then calculated. The irrigation system was turned on and off in control experiments manually in CIS plots. The D_g for SIS under sprinkler irrigation was calculated from the differences of flow meter readings before and after irrigation.

2.6 Irrigation water efficiencies

The *IWUE* (kg/m^3) was calculated as a ratio between *GY* (kg/m^3) and seasonal applied irrigation water, $(Dg)_t$ (m^3)[22]. While *WUE* (kg/m^3) is defined as the ratio of yield to the *ETc* (m^3)[23]. The *IWUE* and *WUE* were calculated by using Equations (1) and (2), respectively.

$$IWUE = \left(\frac{GY}{(Dg)_t} \right) \tag{1}$$

$$WUE = \left(\frac{GY}{ETc} \right) \tag{2}$$

where, *GY* is the grain yield, kg/m^3; *ETc* is crop evapotranspiration, mm; and $(Dg)_t$ is the amount of seasonally applied irrigation water, m^3.

2.7 Statistical analyses

The experimental design was a split plot and an analysis of variance was performed to analyze the data. The LSD test ($P \leq 0.05$) was used to compare treatment means. The CoHort software program version 6.311[24] was used for all the statistical analysis. The analyses were performed to find significant differences between SIS and CIS water treatments.

3 Results and discussion

3.1 Wheat evapotranspiration

Average of daily and weekly *ETc* rates for wheat crops in SIS and CIS experiments during growing seasons were calculated from daily records (Table 3).

Table 3 shows that the *ETc* determined for the SIS from the *Kc* multiplied by *ETr* for different stages of wheat crop development. The average weekly wheat *ETc* throughout growth period of the two seasons was obtained and recorded for both treatments. Hence the total *ETc* of wheat crops for SIS treatments (100%, 80% and 60%) were 466.75 mm, 382.00 mm and 285.31 mm, respectively. While the total *ETc* of wheat crops for CIS treatments were 562.26 mm and 438.19 mm and 323.82 mm, respectively.

Table 3 Average of daily and weekly wheat (*ETc*) rates during two seasons for SIS and CIS at different applied water quantity

Growth period (week)	*ETc* for SIS, mm·day^{-1}			*ETr*, mm·day^{-1}	*Kc*	*ETc* for CIS, mm·day^{-1}		
	100%	80%	60%			100%	80%	60%
1	1.98	1.56	1.20	2.88	0.70	2.02	1.68	1.24
2	2.21	1.76	1.36	3.38	0.70	2.37	1.93	1.50
3	2.38	1.97	1.44	3.12	0.99	3.09	2.60	1.98
4	2.68	2.15	1.54	3.15	0.99	3.12	2.60	1.88
5	2.78	2.34	1.69	3.60	0.99	3.57	2.94	2.26
6	2.69	2.22	1.64	3.49	0.99	3.45	2.90	2.11
7	2.84	2.45	1.98	3.63	0.99	3.59	2.99	2.15
8	3.58	2.78	2.16	3.38	0.99	3.34	2.71	2.05
9	3.78	2.95	2.32	3.86	1.10	4.25	3.58	2.68
10	3.58	3.29	2.57	4.18	1.10	4.59	3.83	2.81
11	4.69	3.76	2.7	4.38	1.10	4.82	3.97	2.95
12	4.78	3.98	2.87	4.76	1.10	5.24	4.37	3.35
13	4.92	4.10	2.95	5.11	1.10	5.62	4.74	3.38
14	5.44	4.42	3.29	5.50	1.10	6.05	5.04	3.65
15	5.28	4.28	2.99	5.35	1.10	5.89	4.84	3.61
16	4.49	3.66	2.59	6.72	1.10	7.39	6.22	4.51
17	3.58	2.99	2.45	6.24	0.35	2.18	1.82	1.31
18	2.45	2.02	1.58	6.84	0.35	2.40	2.02	1.45
19	2.27	1.79	1.39	6.29	0.35	2.20	1.81	1.39
Avg.	3.51	2.87	2.15			3.96	3.29	2.43
Sum.	466.75	382.00	285.31			526.26	438.19	323.82

The *ETr* rates for crop in control plot were calculated utilizing microclimatic data obtained from the local station and using modified Penman equation. Then the required water depth was determined from the soil water balance equation. Adjustments to *ETr* for wheat crop were made using *Kc*[25], where the crop *ETc* was calculated as the product of *Kc* and *ETr* for CIS experiments only. It is obvious from Table 3 that *ETc* values were small in the early three weeks under SIS treatment and then increased with the development of plants arriving the peak at around 70 - 105 days (10 - 15 weeks) after sowing time. In the case of CIS, the *ETc* decreased gradually with the senescence of leaves specifically during the 16-19 weeks, and the similar trend to SIS was taken place to rest of the season. The *ETc* values in both systems were taking the same pattern with an increase at the stage of crop maturity and convergence at the stage of harvest. However, the analysis of these data points out that the values were significantly differed from each other except in the initial development stages and getting nearly close in the late stages.

The highest total of *ETc* for the two seasons was 526.26 mm and was estimated with CIS treatments at full irrigation (100%) (Table 3). The CIS method caused higher *ETc* compared to SIS method during the two seasons; the overall difference was quite significant. As shown in Table 3, the accumulation of *ETc* value from smart irrigation is 12% lower than the value obtained from the control experiment. The *ETc* increased linearly with the increase in irrigation water. This result was consistent with the previous finding[26], in which a similar relationship between *ETc* and irrigation depth was also been found. Among the two seasons, seasonal *ETc* for the same treatment was similar in the first two seasons. In addition, the *ETc* in SIS was lower compared with CIS, these results are agreed with the results obtained[27].

3.2 Management of irrigation

Irrigation water was scheduled and applied for wheat field using SIS and CIS techniques. The water quantities and timings were monitored and recorded and averages weekly irrigation water added to wheat crop for SIS and CIS treatments were calculated and tabulated in Tables 4 and 5. From Table 4 the average total amounts of irrigation water applied during the two seasons for wheat in SIS treatments (100% of *ETc*, 80% of *ETc*, and 60% of *ETc*) were 528.89 mm, 444.77 mm and 317.33 mm, respectively. Also, average weekly irrigation water added to wheat crop for CIS treatments (100% of *ETc*, 80% of *ETc*, and 60% of *ETc*) were 600.35 mm, 504.82 mm and 360.21 mm, respectively.

However, irrigation amounts of the two irrigation methods were different during two growing seasons. These amounts are less than that of irrigation water practiced by the local framers in the area. The *Dg* applied for SIS treatment was 12% lower than that applied for the CIS treatment. Moreover, the analysis of these data points out that their values were close only in the initial development stages and vary gradually along the rest of season.

Table 4 Averages of irrigation water (*Dg*) and accumulative depths in two seasons added to wheat crop via smart irrigation system (SIS) under applied water quantities

Growth period (week)	SIS – *ETc* (100%)			SIS – *ETc* (80%)			SIS – *ETc* (60%)		
	Water added, m^3	Irrigation depth (*Dg*), mm	Accumulative depth (*Dg*)*t*, mm	Water added, m^3	Irrigation depth (*Dg*), mm	Acc. depth (*Dg*)*t*, mm	Water added, m^3	Irrigation depth (*Dg*), mm	Accumulative depth (*Dg*)*t*, mm
1	6.67	30.86	30.86	5.55	25.69	25.69	4.00	15.51	18.51
2	5.47	25.34	56.19	4.58	21.21	46.9	3.28	15.20	33.72
3	3.64	16.91	73.10	3.09	14.34	61.23	2.19	10.14	43.86
4	7.25	33.55	106.65	6.15	28.46	89.69	4.35	20.13	63.99
5	4.90	22.68	129.34	4.1	18.97	108.66	2.94	13.61	77.60
6	4.87	22.55	151.88	4.09	18.95	127.61	2.92	13.53	91.13
7	3.96	18.33	170.21	3.34	15.44	143.06	2.38	11.00	102.13
8	4.19	19.41	189.61	3.55	16.46	159.52	2.51	11.64	113.77
9	1.83	8.47	198.08	1.53	7.08	166.60	1.10	5.08	118.85
10	10.20	47.23	245.31	8.58	39.72	206.31	6.12	28.34	147.18
11	6.66	30.86	276.16	5.6	25.93	232.24	4.00	18.51	165.70
12	8.37	38.74	314.91	7.02	32.49	264.72	5.02	23.25	188.94
13	7.625	35.27	350.18	6.4	29.64	294.36	4.57	21.16	210.11
14	17.15	79.37	429.54	14.48	67.00	361.36	10.29	47.62	257.73
15	9.07	42.02	41.56	7.61	35.27	396.63	5.44	25.21	282.94
16	5.38	24.90	496.46	4.52	20.39	417.57	3.23	14.94	297.88
17	2.52	11.65	508.11	2.11	9.77	427.33	1.51	6.99	304.87
18	2.53	11.73	519.84	2.12	9.82	437.16	1.52	7.04	311.91
19	1.96	9.04	528.89	1.65	7.6	444.76	1.18	5.43	317.33
Sum	114.24	528.89		96.07	444.77		68.54	317.33	

Table 5 Averages of irrigation water (*Dg*) and accumulative depths in two seasons added to wheat crop via control irrigation system (CIS) under applied water quantities

Growth period /week	CIS– *ETc* (100%)			CIS – *ETc* (80%)			CIS – *ETc* (60%)		
	Water added, m^3	Irrigation depth (*Dg*), mm	Accumulative Depth (*Dg*)*t*, mm	Water added, m^3	Irrigation depth (*Dg*), mm	Accumulative Depth (*Dg*)*t*, mm	Water added, m^3	Irrigation depth (*Dg*), mm	Accumulative depth (*Dg*)*t*, mm
1	6.56	30.35	30.35	5.47	25.29	25.29	3.94	18.21	18.21
2	5.34	4.72	55.07	4.47	20.69	45.98	3.20	14.83	33.04
3	7.61	35.24	90.31	6.45	29.89	75.88	4.57	21.14	54.19
4	7.16	33.16	123.16	6.07	28.13	104.00	4.30	19.90	74.08
5	6.05	28.00	151.46	5.06	23.42	127.42	3.63	16.86	90.88
6	6.64	30.75	182.21	5.58	25.85	153.26	3.98	18.45	109.33
7	6.38	29.52	211.73	5.38	24.87	178.13	3.83	17.71	127.04
8	4.63	21.41	233.15	3.93	18.16	196.16	2.78	12.85	139.89
9	5.7	26.40	259.54	4.77	22.08	218.37	3.42	15.84	155.73
10	7.91	36.62	296.16	6.65	30.80	249.17	4.75	21.97	177.70
11	7.57	35.04	331.20	6.36	29.45	278.62	4.54	21.02	198.73
12	9.08	42.05	373.25	7.61	35.26	313.88	5.45	25.23	223.96
13	10.39	48.09	421.34	8.73	40.41	354.29	6.23	28.85	252.81
14	11.97	55.44	476.77	10.10	46.80	401.09	7.18	33.26	286.07
15	9.58	44.37	521.14	8.04	37.25	438.34	5.57	26.62	312.70
16	8.5	39.35	560.49	7.14	33.08	471.42	5.10	23.61	336.31
17	3.9	18.06	578.55	3.27	15.14	486.56	2.34	10.84	347.14
18	2.5	11.57	590.13	2.09	9.68	496.24	1.50	6.94	354.08
19	2.21	10.21	600.35	1.86	8.58	504.82	1.33	6.13	360.21
Sum	129.68	600.35		109.05	504.82		77.81	360.21	

3.3 Parameters of wheat growth

The effect of SIS scheduling on wheat growth and productivity parameters were investigated. Growth characters for wheat plants grown during the two seasons of 2009-2010 and 2010-2011 are shown in Table 6. Results of this study revealed that the CIS had a clear impact on the agronomical characteristic of plant such as the average PH, the average BY of wheat crop, the average GY during the two seasons, the average 1 000 kernel weight wheat crop and the average spike length as it can be seen in Table 6 was 9.9 cm, 9.6 cm, 8.5 cm and 10.6 cm, 9.9 cm, 8.9 cm.

Table 6 Growth characteristic analyses for wheat during the two seasons for smart irrigation system (SIS) and control irrigation system (CIS)

Measured character	Irrigation system	The first season, 2009-2010			The second season, 2010-2011		
		ETc (100%)	*ETc* (80%)	*ETc* (60%)	*ETc* (100%)	*ETc* (80%)	*ETc* (60%)
Grain yield (GY)	SIS	5.82	5.09	3.33	6.24	5.96	3.53
	CIS	6.23	5.68	3.63	6.59	6.48	3.96
Biological yield (BY)	SIS	13.92	13.47	11.57	16.54	15.87	13.76
	CIS	16.02	15.37	11.97	17.10	16.84	13.20
Harvest index (HI)	SIS	0.39	0.38	0.36	0.41	0.40	0.38
	CIS	0.39	0.37	0.35	041	0.39	0.39
1 000 kernel weight (Kw)	SIS	40.77	39.42	36.18	44.21	42.42	39.23
	CIS	47.68	45.75	41.03	48.66	46.69	44.33
Plant height (PH)	SIS	51.76	49.5	44.18	84.49	80.80	72.11
	CIS	67.52	63.35	46.18	85.0	79.70	73.50
Spike length (SPL)	SIS	9.80	9.50	8.40	9.90	9.70	8.60
	CIS	10.20	9.70	8.60	10.90	10.10	9.20
Water use efficiency (WUE) ($kg\cdot m^{-3}$)	SIS	1.18	1.27	1.10	1.42	1.64	1.32
	CIS	1.01	1.21	1.03	1.20	1.43	1.18
Irrigation water use efficiency (IWUE) ($kg\cdot m^{-3}$)	SIS	1.08	1.12	1.03	1.20	1.37	1.13
	CIS	1.02	1.12	0.97	1.01	1.16	1.00

The CIS was superior to SIS in increasing PH (cm), spike length (cm), average kernel weight (g), total BY (ton/h) and total GY (ton/h). An average over the two seasons, CIS treatment increased PH by 8%, Spike length by 5%, 1 000 kernel weight by 12%, average biological total yield by 6%, total GY by 8%. Nevertheless, the SIS was superior to CIS in increasing *WUE* (kg/m^3) by 11% and *IWUE* (kg/m^3) by 14% when compared with the CIS treatment. The reason that the CIS resulting in greater yield than SIS could be attributed to the difference of amount of water added to the two treatments, while the increase in moisture level in the root zone was reasonable for increasing the agronomical factors especially when more irrigation water was added in CIS treatment. The decrease of soil aeration with low irrigation water added in SIS treatment may be the reason of causing decrease in all agronomical parameters.

3.4 Water use efficiency

Table 7 illustrates the effects of SIS and CIS on wheat *WUE* during the two growing seasons. This table shows that the values of *WUE* and *IWUE* are higher with (80% of ETc _ SIS) compared to CIS, i.e., 1.27 kg/m^3 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. In general, the higher values of *WUE* under the SIS are attributed to the saving and timing of applied irrigation water. Consequently the maximum and minimum values of *WUE* are 1.64 kg/m^3 (80% of ETc _ SIS) and 1.10 kg/m^3 (60% of ETc _ SIS) is obtained in the second and the first years respectively. The (80% of ETc _ SIS) treatment gave higher mean GY in both the growing season compared to other treatments (100% of ETc _ SIS) and (60% of ETc _ SIS). These high values of GY for (80% of ETc _ SIS) treatment refer to adapt good conditions for wheat germination. It recorded the highest GY of 5.09 and 5.96 ton/h for the first and the second growing seasons respectively. The season ETc in CIS treatments was the highest and in SIS treatment was the lowest Table 7. The reason might be that under larger irrigation amounts soil surface was wetter which promoted higher soil evaporation. Generally with the increase in irrigation, evaporation was increased. But the evaporation beneath wheat canopy among the different irrigation level was similar between stem elongation and maturation for the plant factors [28].

Table 7 Effects of the for smart irrigation system (SIS) and control irrigation system (CIS) on wheat water use efficiency (*WUE*) during the growing season

Irrigation treatments	ETc mm	ETc $m^{-3}\cdot h^{-1}$	Applied irrigation water mm	Applied irrigation water $m^{-3}\cdot h^{-1}$	WUE, $kg\cdot m^{-3}$	IWUE, $kg\cdot m^{-3}$
2009-2010 growing season						
SIS - ETc 100%	492.81	4928.13	539.47	5394.70	1.18	1.09
SIS - ETc 80%	400.06	4000.60	453.29	4532.90	1.27	1.12
SIS - ETc 60%	302.42	3024.22	323.26	3232.62	1.10	1.03
CIS – ETc – 100%	538.25	5382.5	573.54	5735.40	1.01	1.02
CIS – ETc –80%	448.17	4481.77	480.85	4808.59	1.21	1.12
CIS – ETc – 60%	333.72	3337.21	349.84	3498.42	1.03	0.97
2010-2011 growing season						
SIS - ETc 100%	440.54	4405.43	518.34	5183.46	1.42	1.20
SIS - ETc 80%	363.94	3639.40	436.23	4362.30	1.64	1.37
SIS - ETc 60%	268.32	2683.22	311.25	3112.58	1.32	1.13
CIS – ETc – 100%	514.31	5143.10	627.17	6271.70	1.20	1.01
CIS – ETc –80 %	428.24	4282.44	528.85	5288.52	1.43	1.16
CIS – ETc – 60%	314.02	3140.22	370.61	3706.14	1.18	1.00

WUE of SIS irrigation methods had generally higher values than CIS irrigation methods. This result indicates that the water was used most effectively in SIS treatment and that agreed with the previous study[29]. The similar findings were also obtained[30], who found that the low irrigation frequency resulted in higher values in *WUE* as compared to high irrigation frequency.

The higher *IWUE* with smaller irrigation water added with SIS has also been reported for wheat by the previous studies[18,31,32]. The research[18] pointed out that the higher *IWUE* with lower irrigation depth (*Dg*) may be attributable to the efficient use of irrigation water and the available soil water in the root zone. Under increase in irrigation depth irrigation conditions, part of the irrigation water may not be used and left in the soil profile at harvest, deep percolation beyond the root zone due to over irrigation may also decrease the *IWUE*. Relatively high *WUE* and *IWUE* were found for the SIS treatment.

3.5 Statistical analysis

Averages of total yield for the two growing seasons were statistically analyzed and the least significant differences (LSD) test was used to compare means at the 5% level. Results clearly showed the high influence of CIS treatment on wheat yields and agronomical factors in both years. The data obtained pointed out a high significant effect of CIS treatment on the average PH, spike length, average kernel weight, total BY and total GY; whereas, there are no significant effect on HI as it is shown in Table 8. The results indicated that 100% of *ETc* for all the CIS and SIS at different levels was highly significant for all growth characters wheat crop except *WUE* and *IWUE* in Table 8.

The ANOVA test for the two seasons of wheat yield data indicates that there is a significant effect of CIS for agronomical factors (Table 9). In general, results showed that all agronomical characteristic for CIS were significantly superior compared to SIS treatment. The *WUE* and *IWUE* were significantly affected by the SIS (P > 0.05) in the two growing seasons as shown in Tables 8 and 9. Their averages were different depending on schedule SIS. The results of two seasons indicated that SIS treatment (80% of ETc _ SIS) was better for higher *WUE* and *IWUE*. The results were consistent with the previous study[33].

Table 8 Seasonal crop *ETc*, yield components, water use efficiency (*WUE*) and irrigation water use efficiency (*IWUE*) for each treatment in two seasons

Treatments	Grain yield (GY), $ton\cdot h^{-1}$	Biological yield (BY), $ton\cdot h^{-1}$	Harvest index (HI), %	Kernel weight (KW), g	Plant height (PH), cm	Spike length (SPL), cm	WUE, $kg\cdot m^{-3}$	IWUE, $kg\cdot m^{-3}$
2009-2010								
ETc 100%	6.025 a*	14.97a	0.39 a	44.23 a	60.64 a	10.05 a	1.13 b	1.08 b
ETc 80%	5.384 b	14.42 b	0.38 ab	42.59 b	58.93 b	9.55 b	1.20 a	1.27 a
ETc 60%	3.478 c	11.77 c	0.37 b	38.61 c	56.18 c	8.62 c	1.07 c	0.99 c
2010-2011								
ETc 100%	6.425 a	15.79 a	0.41 a	46.44 a	84.75 a	10.45 a	1.31 b	1.12 a
ETc 80%	6.219 a	15.36 b	0.39 b	44.56 b	80.25 b	9.90 b	1.51 a	1.32 a
ETc 60%	3.746 b	12.53 c	0.38 c	42.27 c	72.81 c	9.00 c	1.23 c	1.10 c

Note: Values are means of three replicates (treatment *ETc* with three replicates). *Letters indicate statistical significance at p = 0.05 level within the same column; with “a”, “b”, c” and so on, show the statistical difference from the highest to the lowest.

Table 9 Component growth characteristic analyses of wheat evapotranspiration (*ETc*) at different levels under smart (SIS) and control (CIS) irrigation systems in two seasons

Systems	Grain yield (GY), $ton \cdot h^{-1}$	Biological yield (BY), $ton \cdot h^{-1}$	Harvest index (HI), %	Kernel weight (KW), g	Plant height (PH), cm	Spike length (SPL), cm	WUE, $kg \cdot m^{-3}$	IWUE, $kg \cdot m^{-3}$
2009-2010								
SIS	4.747 b	12.987 b	0.38 a	38.82 b	53.48 b	9.31 b	1.18 a	1.13 a
CIS	5.178 a	14.533 a	0.38 a	44.82 a	63.68 a	9.50 a	1.08 b	1.05 b
2010-2011								
SIS	5.243 b	13.403 b	0.39 a	41.95	74.13 b	9.50 b	1.46 a	1.29 a
CIS	5.676 a	15.713 a	0.39 a	46.88 a	79.40 a	10.07 a	1.23 b	1.06 b

Note: Letters indicate statistical significance at $p = 0.05$ level within the same column, with “a”, “b”, c” and so on showing the statistical difference from the highest to the lowest. [a] values are means of three replicates (treatment ETc with three replicates).

Yields for the SIS treatment were significantly lower than those of irrigation CIS treatment in the two seasons, the highest yield was found for CIS treatment (Table 9). It also shows that the *IWUE* generally decreased for CIS treatment with the increase in irrigation depth irrigation water added to wheat crop.

4 Conclusions

As a result of this two-year field study for wheat crop under arid region, it can be concluded that the SIS method under sprinkler irrigation offered significant advantage for both seasons. In this study, *ETc* was linearly related to the amount of irrigation. In comparison to the control treatment CIS, the SIS managed to significantly reduced water consumption and saved irrigation water by creating a good moisture distribution in the root zone depth. The least water supply was recorded in SIS while the highest value was obtained from CIS treatments during the two seasons. Therefore, the SIS irrigation method would be recommended due to its easy application and more water saving. Also, the results indicated that the values of *WUE* and *IWUE* were higher with SIS than those with CIS. This result indicated that the water was used most effectively with the SIS treatment.

Consequently, the results of ANOVA in both years showed that SIS had significant effects on *WUE* and *IWUE*. Maximal yield was obtained when the optimal amount of irrigation was 600.35 mm and *ETc* was 466.75 mm, averagely for the two seasons. The results showed that, with the increase in irrigation, *ETc* increased and *WUE* decreased. The SIS technique conserved irrigation water by 12% less than that provided by CIS. Therefore, conserving water was very important in areas experiencing severe drought such as Saudi Arabia. This study has resulted in possible modification and developments on proposed system for better and more efficient scheduling control. It can be concluded that an economic amount of yield can be produced with saving large amount of irrigation water when applying advance scheduling irrigation techniques such as SIS under arid conditions. The SIS technique reduced optimal amount of irrigation to deal with water scarcity in Saudi Arabia through virtual water import. Policies dealing with water scarcity should be taken into account.

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