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Effect of Smart Irrigation Technique on Water Use Efficiency for *Zea mays* under East Owainat Conditions

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ABSTRACT

Through deep percolation away from the plant's effective root zone, the smart irrigation technology minimizes irrigation water loss and chemical fertilizer rates, optimizing fertilizer and irrigation water use efficiency in sandy soil while preserving crop health and quality. Field experiment was conducted to cultivate two summer successive seasons of 2021 and 2022 in East Owainat area, new valley Governorate, Egypt to compare the effect of smart irrigation (SIT) and traditional manual irrigation (MIT) techniques at different chemical fertilizer rates (CFR=100, 85, 70 and 55% of recommended chemical fertilizer N, P, K rates) under sprinkler (SI) and surface drip (SDI) irrigation systems on crop quality parameters, grain yield (GY), seasonal actual evapotranspiration (ETa), water use efficacy (WUE) and irrigation water use efficiency (IWUE) for summer maize (*Zea mays* L.) hybrid variety, 30M84.The results reported that the quality parameters and grain yield of summer maize crop gave the maximum values under SIT at CFR=100% under SDI treatment for both the 1st and 2nd season respectively ,while the seasonal ETa gave the minimum values: 634.51and 625.92 mm for both seasons respectively, under SIT at CFR=100% under SDI treatment, finally, the highest values of summer maize crop WUE and IWUE were 1.36 and 1.27 kg m^{-3}; 1.43 and 1.33 kg m^{-3} for both seasons, respectively, under SIT at CFR=100% under SDI treatment. This study indicated that cultivating summer maize under the SIT at CFR=100% with SDI treatment could reduce applied irrigation water by approximately 27% and 28%, while increasing grain yield by about 33% and 35% in both seasons, respectively, compared to the control treatment (MIT at CFR=100% under SI). These findings show that smart irrigation can improve scheduled irrigation in a valuable and adaptable way. As a result, this method is advised for effective automated irrigation systems that significantly reduce water consumption while increasing production.

Keywords: Smart irrigation; Maize; Actual evapotranspiration; Water use efficiency; sprinkler; surface drip irrigation.

1. Introduction

The rapid population increase is driving up global food consumption, putting further strain on water resources (García *et al.,* 2018). After rice and wheat comes maize (*Zea mays*), a key crop that can grow in various soil types and climates but is susceptible to water stress (Zhao *et al.,* 2015). One of the main issues facing the agriculture sector in arid and semi-arid regions is the water crisis. Therefore, effective irrigation water management is essential to ensuring global water security. (Nazari *et al.,* 2018). Around 70% of all water withdrawals worldwide are used for irrigation, making the agricultural sector the largest consumer of water (Simionesei *et al.* 2020). In agriculture, the gap between water availability and demand is regarded as a problem that should be resolved by utilizing cutting-edge technologies to maximize irrigation water use. (Pereira *et al.,* 2020). Additionally, drought and water shortages are major obstacles restricting crop development in the world's arid and semi-arid regions. Therefore, innovations that attempt to improve water usage efficiency and conserve water in irrigated agriculture are vital in water-scarce regions. Farmers in Egypt have historically relied on manual irrigation control techniques, which led to unequal water distribution across fields. Adopting contemporary irrigation techniques is crucial to resolving this issue because it increases output, decreases the amount of water

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needed for irrigation, and improves water use efficiency (Acar *et al.,* 2010). A precision or intelligent irrigation system is a sustainable water-saving technique for increasing agricultural productivity and minimizing irrigation's adverse environmental effects (Mason *et al.,* 2019). Irrigated water has been reduced using various smart and traditional methods, such as optical sensors, DI, RS, ET, and SMS controllers. Smart irrigation devices were created to minimize excessive irrigation by measuring or estimating the SMC or CWSI. The impact of the aforementioned strategies on crop productivity and water conservation has been summarized in this review. In contrast to manual irrigation, the literature shows that smart irrigation controllers, particularly weather-based (ET) and on-site SMS, save water in several situations. The VMC threshold value that the farmers select determines the water consumption efficiency based on SMS. However, it has been demonstrated that SMS controllers can conserve 20% to 92% of water. On the other hand, ET controllers have been demonstrated to conserve 20–71% of water. Additionally, the accuracy of ET0 estimations affects ET controller performance. Water savings of 7% to 50% have been demonstrated with RS (Touil *et al.,* 2022). Smart irrigation technologies were evaluated, and results indicate up to 43% (average 38%) of water savings over conventional irrigation control methodologies (Dassanayake *et al.,* 2009). Currently, several smart irrigation systems can operate without human intervention. The smart controllers integrate many disciplines to significantly improve crop production and resource management (Norum and Adhikari 2009). The irrigation controller regulates the desired moisture level in agricultural soil by turning the irrigation pump on or off in response to sensor data. To maximize water usage in agricultural irrigation, the irrigation controller offers a scientific foundation for the use of water resources under the technologies of soil moisture sensors, temperature sensors, precision irrigation equipment, intelligent fuzzy controllers, and computer-controlled devices (Patil *et al.,* 2012). Combining the Internet of Things (IoT) with the sensors above makes intelligent irrigation systems possible. These connect to data platforms to offer real-time data and enable better decision-making. (Mousavi *et al.,* 2021b). Consequently, the IoT facilitates crop irrigation operations where water resources can be controlled and monitored to meet demand while reducing waste and cutting operational costs. The effect of three irrigation methods [subsurface drip (SSD), surface drip (SD) and sprinkler irrigation (SI)] on yields; water saving and irrigation water use efficiency (IWUE) on corn. The highest yield was obtained with SSD and the lowest was obtained with the SI method (Hassanli *et al.,* 2009). Numerous investigations have evaluated maize's water needs (Djaman and Irmak 2013). An essential metric in hydrological, environmental, and agricultural research, crop evapotranspiration (ETa) is crucial for planning and overseeing irrigation projects and controlling water in rain-fed and irrigated agriculture. Crop ETa is computed indirectly using reference crop evapotranspiration (ETo) and crop coefficients. However, it is also measured directly using lysimeters and Eddy covariance devices (Jensen 1968). Managing maize crop water in semiarid regions of northwest New Mexico and other places with comparable climates and management circumstances. To maximize maize irrigation needs and enhance maize water production, irrigation requirements for maize should be tailored to the local weather. The average maize irrigation water use efficiency (IWUE) was 1.74 kg/m3, with variations across the years (Koffi *et al.,* 2018). The marketable yield Ym of pepper and cucumber increased significantly by 12 and 13%, respectively, thanks to the smart irrigation SIT under drip irrigation SDI. According to the results, the WUE values for pepper and cucumber increased by almost 30 and 33% while utilizing SIT under SDI. The findings also demonstrated that, for cucumber and pepper, the IWUE values at SIT under SDI were dramatically raised by roughly 49% and 39%, respectively. The intelligent irrigation method might be a valuable tool for planning irrigation in producing peppers and cucumbers, and it might also be adaptable to other comparable crops. A versatile and valuable tool for enhancing scheduled irrigation would be the SIT. This method can thus be suggested for effective automated irrigation systems that increase production while conserving a significant amount of irrigation water (Abdel-Aziz 2016).

This paper examines the effects of smart irrigation technique and chemical fertilizer rates added on the water use efficiency of maize crops under sprinkler and surface drip irrigation systems compared to manual irrigation technique. The goal is to determine which treatment had the highest yield of maize production with the least irrigation water added.

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2. Materials and Methods

2.1. Experiment

Field experiments were implemented in the East Owainat area, New valley Governorate, Egypt at (23° 18` 36`` N: 29° 25` 13`` E. 57 m above sea level) during two summer successive seasons of 2021 and 2022. In split plot design with three replicates, the experimental was divided into 50 m^2 plots; each bounded by 2m wide barren to avoid horizontal infiltration. The obtained data were subjected to statistical analysis according to Snedecor and Cochran, (1989) using Co-state software program. The summer maize (*Zea mays* L.) hybrid variety, 30M84 was irrigated by two irrigating techniques; smart irrigation (SIT) , Rain Bird ST8I-2.0 Smart Indoor Wi-Fi, Water Sense Certified, 8 Zone/Station) compared to traditional manual irrigation (MIT) by added completely the amount of irrigation water (IR100%) which, calculated based on crop evapotranspiration; both techniques were tested at four chemical fertilizer rates added (CFR=100, 85, 70 and 55%) of recommended chemical fertilizer N, P, K rates) under sprinkler (SI) and surface drip (SDI) irrigation systems. The Plant height (PH) m, cob length (CL) cm, grain carbohydrate content (CC) %, grain oil content (OC) %, grain protein content (PC) %, grain starch content (SC) % and grain yield (GY) ton fed^{-1} were determined for summer maize crop. While, the seasonal actual evapotranspiration (ETa) mm, water use efficiency (WUE) kg m^{-3} and irrigation water use efficiency (IWUE) kg m^{-3} were calculated for both applied irrigating techniques at different chemical fertilizer rates under sprinkler and surface drip irrigation systems plots.

2.2. Soil characteristics

Samples were collected and analyzed to elucidate the soil's physical and chemical properties. As indicated in Tables (1 & 2), the methodological stages were based on the procedures described by Page *et al.,* (1982); (Klute, 1986).

Table 1: Physical characteristics of the experimental soil.

Soil Depth cm	Particle size distribution %					Textural class	OM %	ρb g/cm³	Ks cm /h	FC %	WP %	AW %
	C. sand	M. sand	F. sand	Silt	Clay							
0-20	21.19	53.27	9.45	9.31	6.78	S	0.45	1.54	10.72	9.07	3.21	5.86
20-40	21.26	53.43	9.71	8.95	6.65	S	0.41	1.57	11.15	8.69	3.08	5.61
40-60	21.54	53.60	9.83	8.62	6.41	S	0.38	1.61	11.49	8.34	2.96	5.38

C=Coarse; M=Medium; F=Fine

Table 2: Chemical characteristics of the experimental soil.

Soil depth cm	EC dS m^{-1}	pH	$CaCO_3$ %	CEC cmole kg^{-1}	Soluble ions (meq/l) in saturated soil paste extract							
					Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	HCO_3-	CO_3^{--}	SO_4^{--}
0-20	1.11	7.85	7.39	5.57	6.24	0.46	3.31	1.09	6.72	0.45	-	3.93
20-40	1.16	7.98	7.51	5.35	6.37	0.59	3.43	1.21	6.94	0.57	-	4.09
40-60	1.19	8.13	7.67	5.02	6.42	0.65	3.56	1.27	7.11	0.63	-	4.16

2.3. Quality of irrigation water

Chemical analyses of the irrigation water were conducted according to the methods described by Ayers and Westcot (1994) and are revealed in Table (3).

Table 3: Chemical analysis of irrigation water.

Sample	pH	EC dS m^{-1}	SAR	Soluble cations, meq/l				Soluble anions, meq/l			
				Na^+	K^+	Ca^{++}	Mg^{++}	CL^-	HCO_3^-	$CO_3^=$	$SO_4^=$
Mean	7.76	0.59	2.37	2.69	0.64	1.51	1.06	2.89	2.04	-	0.97

2.4. Mineral (chemical) fertilizer rates

All plots were fertilized as percentages of the recommended rates in the Ministry of Agriculture:

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- Ammonium sulfate $(NH_4)_2SO_4$ as a source of nitrogen with four rates of N100%= 400 kg/fed, N85%= 340 kg/fed, N70%= 280 kg/fed and N55%= 220 kg/fed was added after cultivation with 15 days during different growth stages by injection in irrigation water network.
- Calcium superphosphate (P2O5 15.5%) as a source of phosphorus with four rates of P100%= 200 kg/fed, P85%= 170 kg/fed, P70%= 140 kg/fed and P55%= 110 kg/ fed was added to the soil before cultivation.
- Potassium sulfate (K2O) as a source of potassium with four rates of K100%= 50 kg/ fed, K85%= 42.5 kg/fed, K70%= 35 kg/fed and K55%= 27.5 kg/fed was added to the soil after cultivation with 3 weeks.

2.5. Reference evapotranspiration (ETo)

The reference evapotranspiration (ETo) clarified in Table (4) was calculated by using the Penman-Monteith equation FAO 56 method (Allen *et al.,* 1998).

Table 4: Calculated reference evapotranspiration (mm day^{-1}) through summer maize crop growth period.

Seasons	Month	July	August	September	October	November
2021	ETo mm day^{-1}	9.53	9.29	8.76	6.61	4.94
2022		9.48	9.25	8.73	6.57	4.89

2.6. Crop evapotranspiration (ETc)

The crop evapotranspiration ETc be obvious in Table (5) was calculated by using the equation:

ETc = $Kc_{FAO} \cdot ETo$ mm day^{-1} Allen *et al.* (1998)

Where: Kc_{FAO} : Crop coefficient from FAO No.(56).
ETo : Reference crop evapotranspiration, mm day^{-1}

Table 5: Calculated crop evapotranspiration (ETc), mm through summer maize crop growth period.

Stages	Initial	Develop.	Mid	Late	Seasonal
Planting date	**16/7 to 4/8**	**5/8 to 8/9**	**9/9 to 18/10**	**19/10 to 17/11**	**16/7 to 17/11**
Period length (day)	20	35	40	30	125
Kc_{FAO} (-)	0.30	0.75	1.20	0.35	--------
			Season 2021		
ETo (mm)	189.64	320.91	311.70	169.91	992.16
$ETc_{100\%}$ (mm)	56.89	240.68	374.04	59.47	731.08
Eff. Rainfall (mm)	0	0	0	0	0
			Season 2022		
ETo (mm)	188.68	319.59	310.32	168.54	987.13
$ETc_{100\%}$ (mm)	56.60	239.69	372.38	58.99	727.67
Eff. Rainfall (mm)	0	0	0	0	0

2.7. Applied irrigation water IR

The amounts of applied irrigation water (IR) for the summer maize crop indicated in Table (6) were calculated by applying the equation

$IR_{100\%}$= (ETc - pe)Kr / Ea) + LR mm period^{-1} Keller and Karmeli (1974)

Where:
ETc: crop evapotranspiration, mm period^{-1}, table (5).
Pe: effective rainfall, mm season^{-1}, Table (5).
Kr: correction factor for limited wetting at maize present round coverage by canopy 80%, Kr = 0.90. (Smith 1992).

Ea: irrigation efficiency for surface drip irrigation = 90% and sprinkler = 75% (Allen *et al.*, 1998).
LR: leaching requirements, (0.11 x ETc), mm.

Table 6: Calculated applied irrigation water (IR), mm through summer maize crop growth period.

IS	Applied Irrigation water, mm ($IR_{100\%}$)				
	Growth Stages				
	Initial	Development	Mid	Late	Seasonal
	Season 2021				
SI	74.78	316.34	491.62	78.16	960.90
SDI	63.40	268.20	416.81	66.27	814.68
	Season 2022				
SI	74.40	315.04	489.44	77.53	956.41
SDI	63.08	267.10	414.96	65.73	810.87

ETa = (M2 % – M1 %) /100. db. D mm Doorenbos and Pruitt (1984)

Where:
M_2 : Moisture content after irrigation %.
M_1 : Moisture content before irrigation %.
d_b : Specific density of soil .
D : Mean depth, mm.

2.8. Water use efficiency

WUE = GY / ETa Kg m^{-3} Howell *et al*. (2001)

GY: grain yield of maize, (kg fed^{-1}).

2.9. Irrigation Water use efficiency

IWUE = GY / IR Kg m^{-3} Michael (1978)
Where:
IR : seasonal applied irrigation water, (m^3), Table (6).

3. Results and Discussion

3.1. Effect of IT and CFR on quality parameters for maize crop under SI and SDI irrigation systems

Data in Tables 7&8 indicate that the smart irrigation technique SIT at chemical fertilizer rate added CFR=100% under surface drip irrigation system SDI treatment gave the maximum values of quality parameters for summer maize crop such as Plant height (PH) m, cob length (CL) cm, grain carbohydrate content (CC) %, grain oil content (OC) %, grain protein content (PC) %, grain starch content (SC) % were 2.16 m, 27.52 cm, 67.61 %, 7.16 %, 10.37 % and 79.87 % for the 1st season; 2.19 m, 27.89 cm, 69.05 %, 7.36%, 10.56 % and 81.86% for the 2nd season respectively. While the manual irrigation technique MIT at chemical fertilizer rate added CFR=55% under sprinkler irrigation system SI treatment gave the minimum values of quality parameters for summer maize crop such as PH, CL, CC, OC, PC and SC were 1.38 m, 14.83 cm, 29.24 %, 4.25 %, 6.32 % and 40.69 % for the 1st season; 1.40 m, 15.07 cm, 29.83 %, 4.31 %, 6.39 % and 41.46 % for the 2nd season respectively.The results report that the SIT, CFR= 100% under SDI treatment significantly increased of PH, CL, CC, OC, PC and SC by about 13, 14, 11, 16, 13 and 16% for 1st season respectively, compared to that under MIT for the same treatment. The results for 2nd season recorded the same trend these results are in accordance with Norum and Adhikari (2009); Acar *et al.* (2010) and Abdel-Aziz (2016).

3.2. Effect of IT and CFR on GY for maize crop under SI and SDI irrigation systems

Data in Figure 1 illustrate that the SIT at CFR=100% under SDI treatment gave the maximum values of grain yield (GY) for summer maize crop were 3.63 and 3.76 ton fed^{-1} for both the 1st and 2nd season respectively. While the MIT at CFR=55% under SI treatment gave the minimum values of GY for summer maize crop were 1.23 and 1.29 ton fed^{-1} for both the 1st and 2nd season respectively. The results revile that the SIT, CFR= 100% under SDI treatment significantly increased of GY by about 23 and 25% for both the 1st and 2nd season respectively, compared to that under MIT for the same treatment. These increasing may be attributed to the smart irrigation technology gave the required amounts of irrigation water at the right time the plant needs, which positively reflected in increasing productivity of the maize crop compared to manual irrigation method. Also, the deficiency in adding chemical fertilizers causes a noticeable decrease in the corn crop. Moreover, the surface drip irrigation system provides a better regularity in distributing irrigation water compared to sprinkler irrigation system, which increasing productivity of the maize crop, these results were similar to those reported by Hassanli *et al.* (2009), Acar *et al.* (2010), Mason *et al.* (2019) and Abdel-Aziz (2016).

Table 7: Effect of IT and CFR on pH, CL and MC of maize crop under SI and SDI irrigation systems for seasons 2021 and 2022.

IT	IS	CFR (%)	PH (m)		CL (cm)		CC (%)	
			1st	2nd	1st	2nd	1st	2nd
MIT	SI	100	1.78h	1.80h	21.85f	22.06e	54.56e	57.72d
		85	1.69i	1.72i	19.58i	19.80h	49.41f	50.65f
		70	1.61j	1.63k	17.71j	17.94j	42.39h	43.41h
		55	1.38l	1.40m	14.83l	15.07k	29.24l	29.83l
	SDI	100	1.91f	1.93f	24.11c	24.36c	60.65c	61.71c
		85	1.83g	1.86g	22.15e	22.38e	55.43e	56.46e
		70	1.68i	1.70i	20.17h	20.42g	47.17g	48.21g
		55	1.53k	1.55l	17.32k	17.62j	32.79k	33.18k
SIT	SI	100	2.05c	2.08c	25.39b	25.74b	61.97b	63.45b
		85	1.97d	2.01d	23.05d	23.37d	56.73d	58.37d
		70	1.89f	1.92f	20.92g	21.25f	49.16f	50.63f
		55	1.63j	1.66j	17.74j	18.07i	34.13j	35.09j
	SDI	100	2.16a	2.19a	27.52a	27.89a	67.61a	69.05a
		85	2.09b	2.13b	25.64b	25.97b	62.34b	63.82b
		70	1.94e	1.97e	23.49d	23.84d	54.57e	55.98e
		55	1.78h	1.81h	20.31h	20.71g	38.85i	39.71i

IT: Irrigating techniques, **MIT:** Manual irrigation Technique, **SIT:** Smart irrigation technique, **IS:** Irrigation systems, **SI:** Sprinkler irrigation system, **SDI:** Surface drip irrigation system, **CFR:** Chemical fertilizer rates, **PH:** Plant height, **CL:** Cob length, **CC:** Grain carbohydrate content.

Table 8: Effect of IT and CFR on OC, PC and SC of maize crop under SI and SDI irrigation systems at seasons 2021 and 2022.

IT	IS	CFR (%)	OC (%)		PC (%)		SC (%)	
			1st	2nd	1st	2nd	1st	2nd
MIT	SI	100	5.71g	5.85h	8.36i	8.43h	62.96e	63.73f
		85	5.38i	5.47j	7.78k	7.87j	57.21g	58.24h
		70	4.94j	5.03l	7.09n	7.18l	49.23i	50.01j
		55	4.25l	4.31n	6.32o	6.39m	40.69k	41.46l
	SDI	100	6.19e	6.32f	9.14e	9.25e	68.67c	69.59d
		85	5.86f	5.98g	8.56g	8.63f	62.41e	63.36f
		70	5.50h	5.63i	7.98j	8.06i	54.95h	55.71i
		55	4.75k	4.85m	7.15m	7.22l	45.81j	46.58k
SIT	SI	100	6.72c	6.91c	9.65c	9.79c	74.59b	76.42b
		85	6.37d	6.54e	9.07f	9.23e	68.37c	70.17c
		70	5.89f	6.05g	8.34i	8.48h	59.76f	61.19g
		55	5.11j	5.24k	7.49l	7.62k	49.94i	51.22j
	SDI	100	7.16a	7.36a	10.37a	10.56a	79.87a	81.86a
		85	6.85b	7.03b	9.83b	9.98b	73.42b	75.28b
		70	6.47d	6.65d	9.21d	9.37d	65.54d	67.23e
		55	5.69g	5.84h	8.42h	8.54g	55.76h	57.14h

IT: Irrigating techniques, **MIT:** Manual irrigation technique, **SIT:** Smart irrigation technique, **IS:** Irrigation systems, **SI:** Sprinkler irrigation system, **SDI:** Surface drip irrigation system, **CFR:** Chemical fertilizer rates, **OC:** Grain oil content, **PC:** Grain protein content, **SC:** Grain starch content.

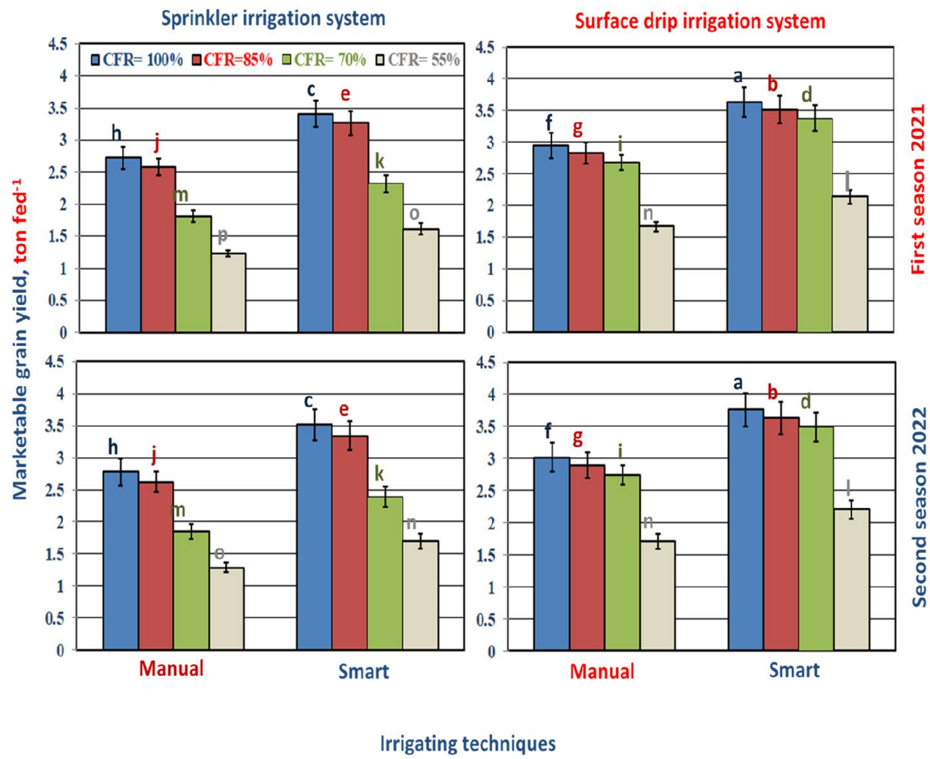

Fig. 1: Effect of IT and CFR on GY of maize crop under SI and SDI irrigation systems at seasons 2021 and 2022.

3.3. Effect of IT and CFR on ETa for maize crop under SI and SDI irrigation systems

Data in Table 9 report that the smart irrigation technique SIT under SDI treatment gave the lowest values of seasonal actual evapotranspiration (ETa) for summer maize crop were 634.51and 625.92 mm for both the 1st and 2nd season respectively. While the MIT under SI treatment gave the highest values of ETa for summer maize crop were 805.19, and 798.57 mm for both the 1st and 2nd season respectively. Noteworthy, chemical fertilizer rates CFR added did not have any effect on the values of ETa. The results show that the SIT for all CFR added under SDI treatments significantly increased of ETa by about 27 and 28% for both the 1st and 2nd season respectively, compared to that under MIT for the same treatments. This reduction of ETa may be attributed to that the smart irrigation system was powered by evapotranspiration models and wireless sensor networks, presents a promising and sustainable solution. It delivers accurate irrigation tailored to the specific water needs of crops, improving water efficiency and boosting overall yields. So that, smart irrigation using to tackle water scarcity and support sustainable agricultural practices. Moreover, apply surface drip irrigation system to irrigate maize crop provides irrigation water slowly, which limits the deep seepage of irrigation water, especially in sandy soil and thus reduces water evaporation from the soil surface and preserves soil moisture, which reduces the total actual water consumption of the maize crop compared to sprinkler irrigation system, these results are consistent with the findings of Jensen (1968), Dassanayake *et al.* (2009), Djaman and Irmak (2013), Abdel-Aziz (2016) and Touil *et al.* (2022).

3.4. Effect of IT and CFR on WUE and IWUE for maize crop under SI and SDI irrigation systems

Data in Table 9 show that the highest values of water use efficiency (WUE) and irrigation water use efficiency (IWUE) for summer maize crop were (1.36 and 1.27 kg m^{-3}); (1.43 and 1.33 kg m^{-3}) for both the 1st and 2nd season respectively, under SIT at CFR=100% under SDI treatment. While, gave the lowest values were (0.36 and 0.30 kg m^{-3}); (0.38 and 0.32 kg m^{-3}) for both the 1st and 2nd season respectively, under MIT at CFR=55% under SI treatment. Meanwhile, the values of WUE and IWUE

SIT at CFR=100% under SDI treatment were increased significantly by about (37 and 48 %); (40 and 49 %) for both the 1st and 2nd season respectively, compared to that under MIT for the same treatment. These results can be attributed to the fact that the application of smart irrigation techniques increases grain yield while simultaneously reducing the seasonal water consumption for irrigation. On the other hand, applying the surface drip irrigation system gives homogeneity and regularity in the distribution of irrigation water and thus saves large amounts of added irrigation water. It also helps the plant to absorb irrigation water loaded with chemical fertilizers better and does not wash it away from the affective root spread zone compared to sprinkler irrigation, which is positively reflected in increasing the maize crop and saving irrigation water added. Finally, the deficiency in chemical fertilizers rates added causes' maize crop shortage and then increases both WUE and IWUE for maize crop, these results are in agreement with Hassanli *et al.* (2009), Patil *et al.* (2012), Abdel-Aziz (2016) and Koffi *et al.* (2018**).**

Table 9: Effect of IT and CFR on ETa, WUE and IWUE maize under SI and SDI for seasons 2021 and 2022.

IT	IS	CFR (%)	ETa (mm season^{-1})		WUE (kg m^{-3})		IWUE (kg m^{-3})	
			1st	2nd	1st	2nd	1st	2nd
MIT	SI	100	805.19a	798.57a	0.80i	0.83i	0.67k	0.69k
		85	805.19a	798.57a	0.76k	0.78k	0.64l	0.65l
		70	805.19a	798.57a	0.54m	0.55m	0.45n	0.46o
		55	805.19a	798.57a	0.36n	0.38n	0.30o	0.32p
	SDI	100	709.35c	701.71c	0.99f	1.02f	0.86f	0.89f
		85	709.35c	701.71c	0.95g	0.98g	0.83g	0.85g
		70	709.35c	701.71c	0.90h	0.93h	0.78h	0.80h
		55	709.35c	701.71c	0.56l	0.58l	0.49m	0.50n
SIT	SI	100	711.87b	703.16b	1.14d	1.19d	1.04d	1.08d
		85	711.87b	703.16b	1.09e	1.13e	1.00e	1.03e
		70	711.87b	703.16b	0.78j	0.81j	0.71j	0.74j
		55	711.87b	703.16b	0.54m	0.58l	0.49m	0.52m
	SDI	100	634.51d	625.92d	1.36a	1.43a	1.27a	1.33a
		85	634.51d	625.92d	1.32b	1.38b	1.23b	1.28b
		70	634.51d	625.92d	1.27c	1.33c	1.18c	1.23c
		55	634.51d	625.92d	0.80i	0.84i	0.75i	0.78i

IT: Irrigating techniques**, MIT:** Manual irrigation technique, **SIT:** Smart irrigation technique, **IS:** Irrigation systems**, SI:** Sprinkler irrigation system, **SDI:** Surface drip irrigation system, **CFR:** Chemical fertilizer rates, **ETa:** Seasonal actual evapotranspiration, **WUE:** Water use efficiency, **IWUE:** Irrigation water use efficiency.

4. Conclusion

Egypt is one of the countries that suffer from severe drought and lack of water resources, which limits its horizontal expansion in reclaiming more desert lands and thus bridging the food gap from strategic crops such as corn. This study showed that the application of smart irrigation systems is one of the most important modern technologies that improve the irrigation water use efficiency for maize, which achieves a major economic return through providing irrigation water quantities added as well as increasing the productivity of maize crop under arid conditions compared to the traditional manual irrigation water addition method. Also, this study showed the importance of applying the drip irrigation system in growing maize crop and providing irrigation water added and increasing productivity it compared to the sprinkler irrigation system, which consumes larger quantities of irrigation water to no avail. Therefore, this study recommended to apply the smart irrigation technique SIT at chemical fertilizer rate added CFR=100% under surface drip irrigation system SDI treatment to cultivate maize crop under Toshka conditions to save about 27 and 28 % of applied irrigation water and increase grain yield production of maize by about 33 and 35 % for both seasons respectively, compared to that under control treatment (i.e. MIT at CFR=100% under SI). Also, applying smart irrigation technologies to more varieties of consumable crops worldwide should be further studied in the future. Finally, further research is needed related to the evaluation of the economic viability of the smart irrigation technique studied.

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