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Optimizing Maize Crop Production in Northern Egypt Under Changing Climate

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ABSTRACT
Agriculture plays a vital role in sustaining food security and improving the economy of many countries. Maize is one of the most important crops grown globally, and its production is affected by several factors, including microclimate, sowing dates, irrigation, and nitrogen fertilization. In this study, a field experiment was conducted at Sakha Agricultural Research Station in Kafr El-Sheikh Governorate, Egypt, during two consecutive summer seasons in 2020 and 2021. The experiment aimed to investigate the impact of microclimate and water deficit conditions on maize crop production and quality. The findings of the study revealed that nitrogen fertilization at 120 kg N Fad^{-1} with irrigation at 90% of the entire furrow length produced the best yield and quality for maize crops under the study conditions. The study findings can provide valuable insights to farmers and agricultural researchers to optimize maize crop production and improve crop yields under similar conditions. Future research could explore the impact of these factors on maize crop production in different regions and under different environmental conditions to further validate these findings.

Keywords: Cut-off irrigation, Maize, yield, yield components, water productivity

1. Introduction
Crop yield prediction is critical for investigating the yield gap and potential adaptations to environmental and management factors in arid regions (Attia *et al.,* 2022). Maize (*Zea mays* L.) is an important cereal crop that is widely cultivated in different parts of the world. Maize is one of the main summer crops in Egypt. The area planted for Maize is about 2,215,000 acres in 2016 with a production of 7.177.000 tons of grain (Agricultural Statistical Yearbook, 2017). Maize ranks third in the world after rice and wheat (WMO, 2012). Multi-use (as a food source, feed source, and fuel source) as it contributes significantly to food security, and food self-sufficiency, due to its economic value. World production of maize has increased dramatically over the past few decades and is now the most widely produced cereal crop with a total production of about 1006.18 million tons (FAOAMIS, 2016). However, production constraints, dependence on natural resource bases such as rainfall, insufficient water for irrigation, insufficient infrastructure or limited technological options, and lack of financial resources are some of the challenges facing many developing countries in maize production, resulting in often to production levels (WMO, 2012).

Irrigation scheduling is the decision about when and how much water should be used in a field, to maximize productivity and profit. In addition, increasing irrigation efficiency by using the exact amount of water needed to replenish the soil moisture to the required level, thus saving water and

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energy: reduces water logging problems by reducing drainage requirements, and controlling root zone salinity problems through controlled filtration. Additional revenue is generated by using the saved water to irrigate non-cash crops, which cannot be irrigated during periods of water shortage. This requires knowledge of the water requirements of the crops, the limitations of each irrigation method, the limitations of the irrigation water supply system, and the financial and economic implications of the irrigation practice (Van der Westhuizen *et al*.,1996).

The objective of the irrigation issue is to seek to increase productivity and reduce costs while using less water, where irrigation efficiency is a critical criterion. Moisture stress is an important factor affecting maize growth, especially in arid and semi-arid regions (Issa *et al*., 2013). The effects of different seasons and locations vary directly on the actual use of water by crops depending on the characteristics of the crops, and conditions of atmospheric evaporation. Therefore, knowing the optimum quantities of water required, to achieve maximum production with high quality is important and urgent. Water stress affects metabolism, reducing cell bulge, leaf area size, and the number of potential storage sites for dry matter produced (Nabila *et al*., 2014). It is well known that water supply affects the growth and production of cultivated crops, and limited soil moisture critically affected maize plants, by (reducing plant height, weight, leaf area, and dry matter accumulation) (Mahrous, 1991 and Hefni *et al*. 1993), and similar results were reported by Ibrahim *et al*. (1992) and Al-Sheikh (1994) that plants that were exposed to water stress or skipped one watering during before or after silk removal, reduced grain yield, by 9 and 10% compared to conventional irrigation, respectively. However, Egyptian maize cultivars may differ in their assimilation capacity and distribution of photosynthetic between the various plant organs which could be referred to as the "source and sink relation".

Water stress can influence maize developmental and physiological processes resulting in reduced biomass and consequently yield, due to a reduced number of kernels per ear or kernel weight (Payero *et al.*, 2009). Aiad *et al*. (2014) Found that irrigation at 60% depletion of available soil moisture saved the amount of seasonal water applied by 11.64% (355 m3 fed-1), and achieved the highest water application efficiency (89.60%) with splitting N fertilization at 90 kg N fed-1 into three equal doses. Abdel-Hafez *et al*., (2008) stated that irrigation Maize at 1.3 ETc (evapotranspiration) gave the highest value of grain yield compared with irrigation compared to 1 and 0.7 ETc. Also Mahmoud and Abo-Marzoka (2023) found that irrigation scheduling when accumulate 1.0 of pan evaporation with potassium foliar spray 3.0 gL^{-1} K2O twice, 30 and 45 days after planting on Maize crop. as it achieved the maximum values of stomatal resistance, kernels number per ear, shelling percentage, 100 kernel weight, biological yield and grain yield.

Ma *et al.* (1999) suggested that fertilizer N is the most expensive input in corn production and its effective management is a major specialty that challenges improve productivity and environmental sustainability. Abo El-Atta, (2006) reported that an increase in nitrogen application had a positive effect on field water use efficiency, and grain and stalk yields. Wajid *et al.* (2007) found that increasing N fertilization levels resulted in maximum stem length, 100-grain weight, and grain yield of maize.

To improve maize production and optimize crop yields, various factors, including microclimate, sowing dates, irrigation, and nitrogen fertilization, need to be considered. Understanding the impact of these factors on maize crop production can provide valuable insights for farmers and agricultural researchers to improve crop productivity and sustainability. Therefore, the main objectives of this study were to know the appropriate sowing date, irrigation water regime, and water productivity for Maize in the study area, the effect of nitrogen doses on Maize yield, and its components. The findings of the study can provide useful information for optimizing maize crop production and improving crop yields under similar environmental conditions.

2. Materials and Methods

2.1. Experimental site:

A field experiment was performed at Sakha agricultural research station (affiliated with the Agricultural Research Center - Egypt), Kafr El-Sheikh governorate, Egypt during the 2020 and 2021 growing seasons to study the effect of deficit irrigation treatments and yield, quality, and some water relations of cabbage under a drip irrigation system. The metrological characteristics data for the two studied seasons were collected from the Sakha agro-metrological station as shown in Table (1).

Table 1: Some agro-meteorological data for the Sakha region, (31° 07' N Latitude, 30° 55' E Longitude), during the 2020 and 2021 seasons.

Months		Temp (c°)			RH (%)			WS, km Day^{-1}	Pan Evap. (mm/day)	R.F mm/ month
		Min.	Max.	Mean	Max.	Min.	Mean			
2020	June	25.8	31.10	28.45	78.0	42.6	60.30	111.8	8.44	0.00
	July	27.3	33.7	30.50	84.2	51.4	67.80	101.7	8.77	0.00
	August	28.8	34.6	31.70	85.3	49.6	67.45	92.4	8.03	0.00
	September	27.1	34.6	30.85	86.7	47.7	67.20	93.3	6.24	0.00
	October	24.6	31.5	28.05	84.4	47.1	65.75	72.7	4.12	0.00
Mean 2020		**26.72**	**33.10**	**29.91**	**83.72**	**47.68**	**65.70**	**94.38**	**7.12**	**0.00**
2021	June	25.52	32.04	28.78	80.27	50.23	65.25	106.7	8.92	0.00
	July	27.00	34.69	30.85	84.77	50.62	67.70	99.2	8.60	0.00
	August	27.99	35.66	31.83	85.32	46.72	66.02	83.18	7.53	0.00
	September	25.10	32.51	28.81	83.97	49.5	66.74	96.70	7.58	0.00
	October	22.3	28.50	25.4	76.50	61.20	68.85	80.49	5.03	0.00
Mean 2021		**25.58**	**32.68**	**29.13**	**82.17**	**51.65**	**66.91**	**93.25**	**7.53**	**0.00**

The mean of thirty years of Some agro-meteorological data for the Sakha region, during Maize growing season according to CLIMWAT 2.0 for CROPWAT is a joint publication of the Water Development and Management Unit and the Climate Change and Bioenergy Unit of FAO.

Agriculture is strongly dependent on water resources and climatic conditions, particularly in regions of the world that are particularly sensitive to climatic hazards, such as Egypt, and agriculture is a complex sector involving different driving parameters (environmental, economic, and social). So, study the difference between maximum and minimum temperatures, mean humidity, wind speed, and pan evaporation in order to determine the extent of these factors' change and their impact on the crop. Therefore, we find that the slight temperature rise significantly in the years of cultivation, as well as the rise in bone temperature, although it was not significant, and the results also indicate the decrease in relative humidity as well as the increase in evaporation transpiration. All of this change prompted us to change the planting date and delay it by about 15 days from the last half of May, the recommended date for the region, to the first third of June.

Table 2: Mean of last twenty years for some agro-meteorological data for the Sakha region, (31° 07' N Latitude, 30° 55' E Longitude).

Month	Temp (c°)		RH	WS	Sun	Rad	Pan Evap.	R.F
	Min	Max	(%)	Km Day-1	hours	MJ/m²/day	mm/day	mm/month
June	17	32	58	130	10.8	26.1	7.40	0.00
July	19	34	63	112	10.5	25.5	7.36	0.00
August	18.3	33.5	67	112	10.2	24.2	6.85	0.00
September	17.6	32	71	95	9.5	21	5.60	0.00
October	15.5	29.8	73	86	8.5	16.9	4.21	0.00
Average	**17.48**	**32.26**	**66.40**	**107.00**	**9.90**	**22.74**	**6.28**	**0.00**

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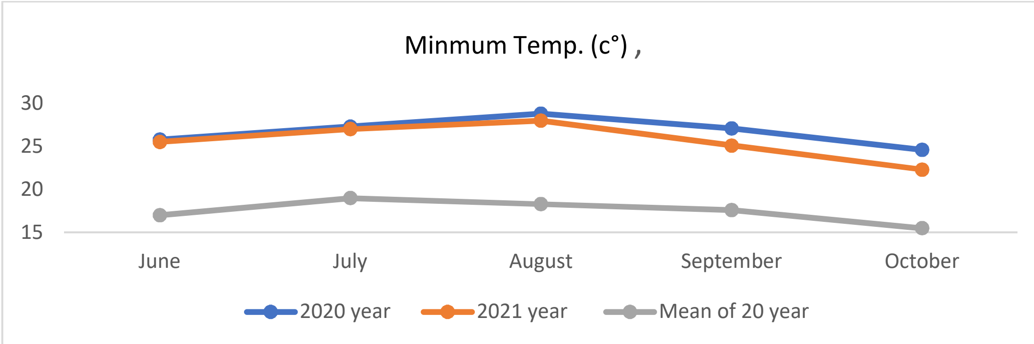

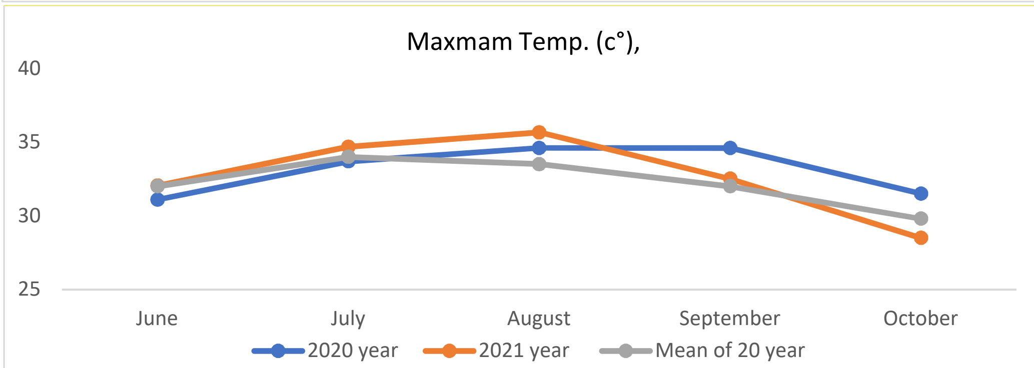

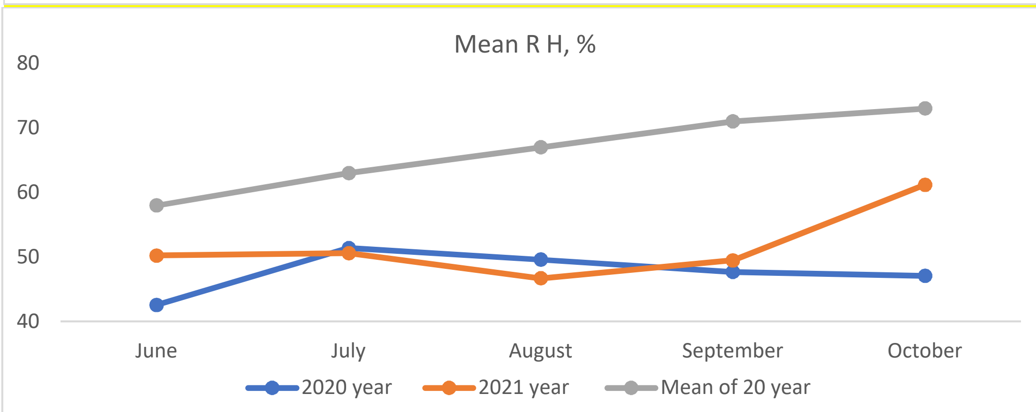

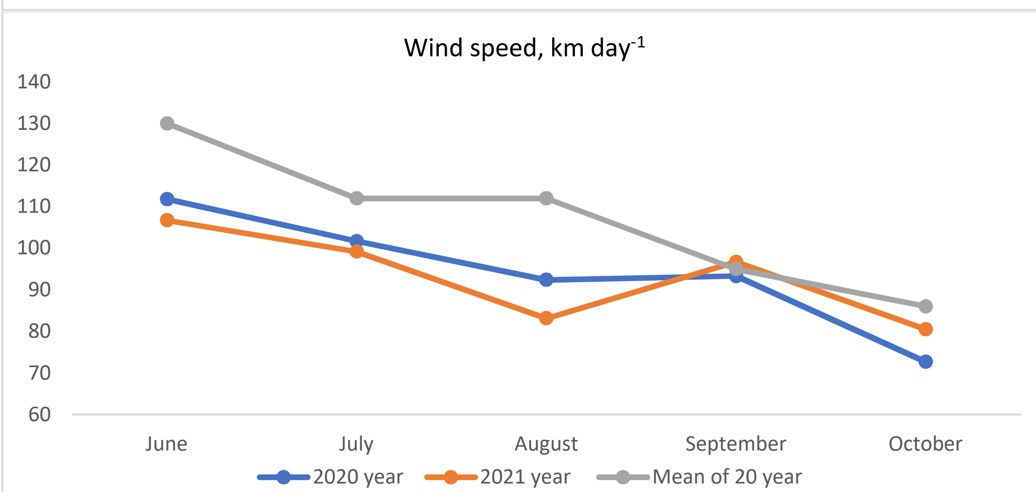

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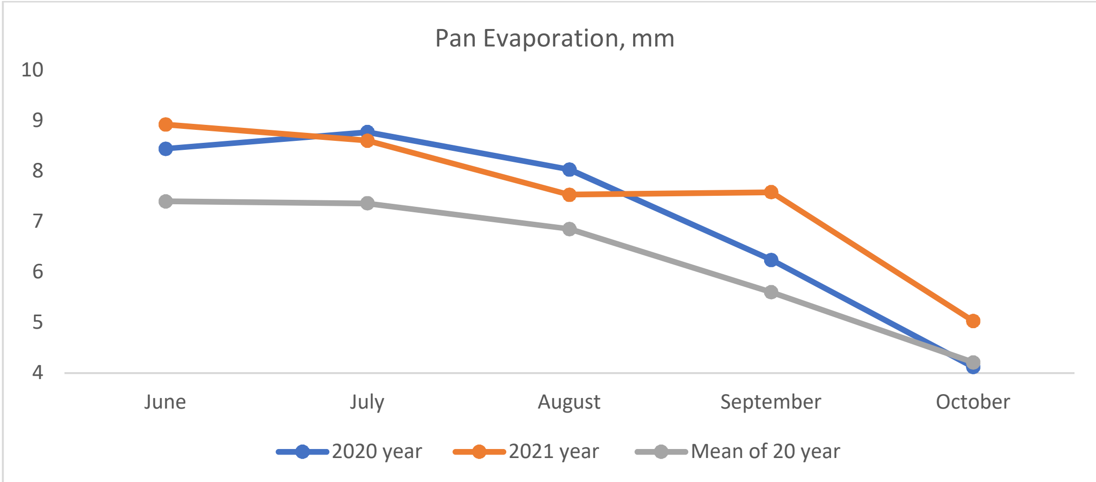


Fig. 1: Comparing between last twenty year and two growing seasons for some agro-meteorological data for the Sakha region.

Soil samples were analyzed at Soils, Water and Environment Research Institute (SWERI), Agricultural Research Center (ARC), Giza, Egypt. Soil particle size distribution and bulk density were determined as described by Klute, (1986). Field capacity, permanent wilting point, and available water characters were determined according to James, (1988). Chemical characteristics of soil were determined as described by Jackson, (1973) as shown in Table (2).

Table 2: Average values of some physical and chemical soil properties for the experimental site as mean values of the two growing seasons.

Soil layer depth (cm)	**Particle size distribution (%)**			**Texture**	**Bulk density (Kgm^{-3})**	**Soil-water constant**		
	Sand	**Silt**	**Clay**			**F.C [1] (%,wt/wt)**	**P.W.P [2] (%,wt/wt)**	**A.W [3] (%,wt/wt)**
0-20	14.25	33.70	52.05	Clay	1.03	44.62	24.55	20.07
20-40	20.30	37.80	41.90	Clay loam	1.07	38.90	21.80	17.10
40-60	20.70	41.50	37.80	Clay loam	1.14	37.11	20.24	16.87
Mean	18.41	37.67	43.92	Clay loam	1.08	40.21	22.20	18.01

Chemical Soil characteristics

Soil layer depth (cm)	**pH[4] 1:2.5**	**EC dSm^{-1}**	**Soluble cations, $meqL^{-1}$**				**Soluble anions, $meqL^{-1}$**			
			Ca^{++}	**Mg^{++}**	**Na^{+}**	**K^{+}**	**CO_3^{--}**	**HCO_3^{-}**	**Cl^{-}**	**SO_4^{--}[5]**
0-20	8.49	2.93	4.70	9.60	14.78	0.22	--	4.55	12.60	12.15
20-40	8.47	3.50	7.70	7.50	19.59	0.21	--	4.05	11.83	19.12
40-60	8.44	3.59	10.55	4.70	20.45	0.20	--	4.02	11.52	20.36
Mean	8.47	3.34	7.65	7.27	18.27	0.21	--	4.21	11.98	17.21

1 = Soil field capacity, **2** = Permanent wilting point, **3** = Available soil water, **4** = soil water suspension, and **5**= SO_4^{--} calculated by difference

The seeds of Maize *cv*., single hybrid 10 were sown on the 2nd and 4th of June in the first and the second seasons, respectively, the seeds were planted in hills at a 25 cm distance on rows 60 cm apart and the plot area was (30 m length x 4.2 m width) = 126 m^2. All other agricultural practices were done according to the recommendations of the Ministry of Agriculture, Egypt.

2.2. Experimental design and treatments:

The experiment was designed as a split- plot with three replications as follows:

- Main plot: three sowing dates: *i.e.* May 15th, June, June 15th
- Sub-sub plot: Cut-off irrigation scheduling treatments (I):
  i. Traditional furrow irrigation, where the entire furrow length was irrigated (100%FL, control).
  ii. Irrigation cut-off as waterfront reached 90 % of furrow length, (90% FL), and
  iii. Irrigation cut-off as waterfront reached 80 % of furrow length, (80% FL).

The cultivated furrows were 30m in length and irrigation was stopped as the waterfront reached 30, 27, and 24 m for 100%FL (control), 90, and 80%FL irrigation regimes, respectively.

- Sub-sub plot: Nitrogen fertilizer Doses (N):
  i. N_1 = 120% of recommended dose of nitrogen =144 kg N fed^{-1}
  ii. N_2 = 100% of recommended dose of nitrogen =120 kg N fed^{-1} and
  iii. N_3 = 80% of recommended dose of nitrogen =96 kg N fed^{-1}

Soil-water relationships:

- **Irrigation water (I.W):**
- **Irrigation applied water (AW):**

A submerged flow orifice with a fixed dimension was used to convey and measure the irrigation water applied, as the following equation (Michael, 1978).

$$q=CA\sqrt{2gh}$$

Where; q = Discharge of irrigation water (cm^3/s), C = Coefficient of discharge = 0.62 (determined by experiment), A = Inner cross-section area of the irrigation spiel (cm^2), g = Gravity acceleration (cm/s^2) and h = Average effective head (cm).

The volume of water delivered for each plot (7m×7.5m = 52.5 m^2) was calculated by substituting Q in the following equation:

$$Q= q \times T \times n$$

Where; Q = volume of water m^3/ plot, q = discharge (m3/min), T = total irrigation time (min), and n = number of spiels tube per plot.

- **Water consumptive use, cm:**

Water consumptive use was calculated as soil moisture depletion (SMD) according to Hansen *et al*. (1979).

$$Cu = SMD = \sum_{i=1}^{i=N} \frac{\theta_2 - \theta_1}{100} * Dbi * Di * A$$

Where; CU = Water consumptive use in the effective root zone (60 cm), Θ_2 = Gravimetric soil moisture percentage 48 hours after irrigation, Θ_1= Gravimetric soil moisture percentage before irrigation, Dbi = soil bulk density (Mg m^{-3}) for the given depth, D_i = soil layer depth (20 cm), i = the number of soil layers each (15 cm) depth and A= irrigation area (fed.).

- **Crop-water relations:**

- Water productivity (WP):

Water productivity is generally outlined as crop yield per cubic meter of water consumption. It was calculated according to Ali *et al*. (2007)

$$WP = \frac{GY}{ET}$$

Where:

WP = water productivity (kg m^{-3}),
GY = yield (kg fed^{-1}) and
ET = Total water consumption of the growing season (m^3 fed^{-1}.).

- Productivity of irrigation water (PIW):
The productivity of irrigation water (PIW) was estimated according to Ali *et al.* (2007).

$$PIW = \frac{GY}{AW}$$

Where:

PIW = productivity of irrigation water (kg m^{-3}),
Gy = yield kg/fed and
AW = applied water (m^3/fed.). (Irrigation water + effective rainfall)
(Irrigation water + effective rainfall)
Note: effect rainfall = rianfall*0.7 (Novica, 1979)

Economic productivity of irrigation water and economic water productivity (L.E. m^{-3})

Irrigation productivity of irrigation water can be expressed as economical productivity (EPIW) and (EWP) according to Molden, 1997. It was calculated as follows:

$$EPIW = \frac{Gross\ value\ of\ product\ L.E.fed^{-1}}{total\ amount\ of\ irrigation\ applied\ water\ (\ m^3 fed^{-1}}$$

$$EWP = \frac{Gross\ value\ of\ product\ L.E.fed^{-1}}{total\ amount\ of\ irrigation\ cosumed\ water\ (\ m^3 fed^{-1)}}$$

- Crop yield and its attributes.

- Maize grain yield was recorded in ton/ fed
- Weight of 100 grains, (gm)
- Ear length, cm
- Ear diameter, cm
- No. of rows/ear
- No. of grains/row

Statistical analysis

All data were statistically explored according to the technique of analysis of variance (ANOVA) as published by Gomez and Gomez, (1984). Means of the treatment were compared by the least significant difference (LSD) at a 5% level and 1 % level of significance which was developed by Waller and Duncan, (1979).

3. Results and Discussion

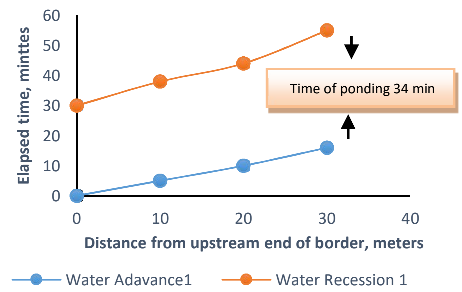
3.1. Advance, recession, and opportunity times:

Data in Fig 1 revealed that the shortest time to stop irrigation 8-12% was attained under the 90% FL irrigation cut-off regime, while under both 80 % FL regimes, the time was extended to 19-21%. In addition, the distances still non-irrigated, just after irrigation stopping, were longer by 100 % with 80 %FL regimes, than that under 90% FL regime. Furthermore, after irrigation stopping, under a 90% FL regime, waterfront advancement proved to be sufficient to irrigate the non-irrigated distance (3m), whereas, under 80% FL regimes, the distances irrigated due to waterfront advancement, represented ~75% out of non – irrigated distance, respectively.

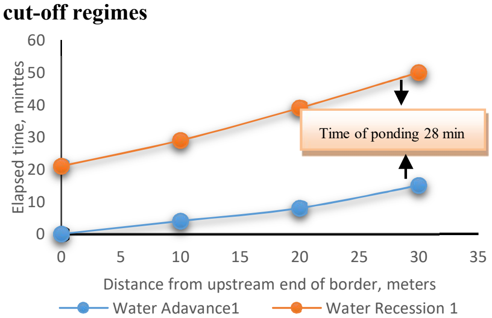
To choose the most proper irrigation cut-off regime, two items should be taken into consideration and must be evaluated the first is the amount of water saving and the second is the crop yield potentiality along with the productivity of the applied water unit. On such basis, irrigating with a 90% FL regime, the corresponding time is less than that recorded with a 100% FL regime and this means less water could be drained underneath the root zone. These results are in agreement with Darwesh and Farag, (2014).

Cut-off irrigation regime	Time to stop waterfront (min)	Non-irrigated distance (m)	Waterfront advancement after stopping irrigation (m)
100% FL (control)	None	None	None
90% FL	8-12%	3.0	= 3
80% FL	19-21%	6.0	~4

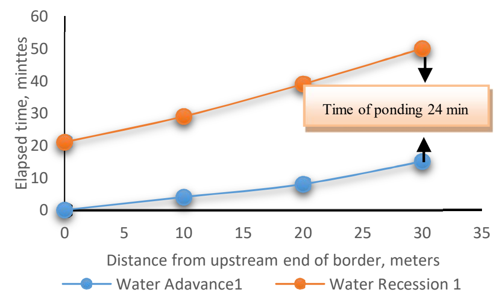
Average of times to stop irrigation, none irrigated distance, and waterfront advancement under the adopted irrigation cut-off regimes



100%FL



90%FL



80%FL

Fig. 1: Average of times to stop irrigation, non-irrigated distance, waterfront, irrigated length, and elapsed time for 100, 90, and 80 % of furrow length regime.

The direction of curves of water advance and recession times are almost parallel under the adopted irrigation regimes, fig. 1 Time of ponding, intake opportunity time, which equals the consumed time needed to infiltrate 2 the accumulated water at each station from the soil surface to inside soil, is affected by the adopted irrigation cut-off regimes. Ponding times under 90, 80 %FL regimes were lower by 17.65, and 29.41 %, respectively, as compared with 100%FL regime. The opportunity time has an adverse trend with furrow length to stop irrigation. In other words, by increasing the length of the irrigation run (traditional, without cut-off) the highest opportunity time results and vice versa.

3.2. Water relations

3.2.1. Applied water (AW) Water consumptive use:

Seasonal waters applied are consisting of irrigation water (IW). Under the two seasons, the highest water applied values 63.27 cm (2675.5 m^3 / fed.) and 63.90 cm (2683.7 m^3 / fed.,) were recorded for May 15th sowing date in the first and second seasons, respectively, While, the lowest values were recorded under June 15th in the two growing seasons. The water savings when compared with irrigation for May 15th were 5.92 and 3.73 % decrease in IW in the first and second seasons, respectively for June 1st, and 8.04% and 7.28% decrease in WA in the first and second seasons, respectively for June 15th. This decrease in WA in the second and third sowing dates is because decreasing in the growing season with 15 and 30 days for June 1st and June 15th respectively. Irrigation till the tail end of the furrow (100% FL, Trt., I_1) received the highest irrigation water. Mean values of applied irrigation water as shown in Table (3) could be arranged in descending order as; 2782.66, 2549.00, and 2362.35 m3/fed., for Treatments I_1, I_2, and I_3, respectively.

3.2.2. Water consumptive use (Cu):

Consumptive water use is water removed from available supplies without return to a water resource. Seasonal Cu for Maize is affected by both the sowing date and cut-off irrigation scheduling treatments in the two growing seasons. Concerning the effect of sowing date treatments, the highest values were recorded under the May, 15th sowing date compared with the other treatments the second and third one, the highest mean value of 55.92 cm was recorded by May, 15th sowing date, and the lowest 50.84 cm was recorded by June 15th, Table 3. The increasing value of consumptive use for treatment (May, 15th) which received a high number of irrigations in comparison with other treatments was due to the increasing amount of applied water which resulted in increasing soil moisture content. On the other hand, the cut-off irrigation scheduling on CU showed that the full irrigation without cut-off recorded the highest values with overall mean 61.0, 58.19, and 55.57 cm under S_1, S_2, and S_3 respectively for all sowing dates.

Table 3: Seasonal applied water and consumptive use as influenced by sowing date, deficit irrigation, and nitrogen doses treatments during the two growing seasons.

Sowing date (S)	Deficit irrigation (I)	Nitrogen doses (N)	Applied water, season						CU, cm		
			m³ fed.⁻¹			cm					
			1st Season	2nd Season	Overall mean	1st Season	2nd Season	Overall mean	1st Season	2nd Season	Overall mean
S1	I1	N1	2890.0	2918.5	2904.3	68.81	69.49	69.15	60.55	61.45	61.00
		N2	2890.0	2918.5	2904.3	68.81	69.49	69.15	60.55	61.45	61.00
		N3	2890.0	2918.5	2904.3	68.81	69.49	69.15	60.55	61.45	61.00
	I2	N1	2640.0	2652.5	2646.3	62.86	63.15	63.01	55.28	56.77	56.025
		N2	2640.0	2652.5	2646.3	62.86	63.15	63.01	55.28	56.77	56.025
		N3	2640.0	2652.5	2646.3	62.86	63.15	63.01	55.28	56.77	56.025
	I3	N1	2442.5	2480.0	2461.3	58.15	59.05	58.60	50.25	51.21	50.73
		N2	2442.5	2480.0	2461.3	58.15	59.05	58.60	50.25	51.21	50.73
		N3	2442.5	2480.0	2461.3	58.15	59.05	58.60	50.25	51.21	50.73
	Mean S1		2675.5	2683.7	2670.5	63.27	63.90	63.59	55.36	56.48	55.92
S2	I1	N1	2718.0	2798.5	2758.3	64.71	66.63	65.67	57.44	58.94	58.19
		N2	2718.0	2798.5	2758.3	64.71	66.63	65.67	57.44	58.94	58.19
		N3	2718.0	2798.5	2758.3	64.71	66.63	65.67	57.44	58.94	58.19
	I2	N1	2487.0	2563.5	2525.3	59.21	61.04	60.13	52.48	54.00	53.24
		N2	2487.0	2563.5	2525.3	59.21	61.04	60.13	52.48	54.00	53.24
		N3	2487.0	2563.5	2525.3	59.21	61.04	60.13	52.48	54.00	53.24
	I3	N1	2343.5	2383.6	2363.6	55.80	56.75	56.28	49.78	50.06	49.92
		N2	2343.5	2383.6	2363.6	55.80	56.75	56.28	49.78	50.06	49.92
		N3	2343.5	2383.6	2363.6	55.80	56.75	56.28	49.78	50.06	49.92
	Mean S2		2517.0	2581.9	2549.0	59.91	61.47	60.69	53.23	54.33	53.78
S3	I1	N1	2670.0	2701.0	2685.5	63.57	64.31	63.94	55.11	56.02	55.565
		N2	2670.0	2701.0	2685.5	63.57	64.31	63.94	55.11	56.02	55.565
		N3	2670.0	2701.0	2685.5	63.57	64.31	63.94	55.11	56.02	55.565
	I2	N1	2461.5	2489.5	2475.5	58.61	59.27	58.94	49.85	50.85	50.35
		N2	2461.5	2489.5	2475.5	58.61	59.27	58.94	49.85	50.85	50.35
		N3	2461.5	2489.5	2475.5	58.61	59.27	58.94	49.85	50.85	50.35
	I3	N1	2250.0	2274.5	2262.3	53.57	54.15	53.86	46.01	47.20	46.605
		N2	2250.0	2274.5	2262.3	53.57	54.15	53.86	46.01	47.20	46.605
		N3	2250.0	2274.5	2262.3	53.57	54.15	53.86	46.01	47.20	46.605
	Mean S3		2460.5	2488.3	2474.4	58.58	59.24	58.91	50.32	51.35	50.84
	Mean S		2551.0	2584.6	2564.6	60.58	61.54	61.06	52.97	54.05	53.51

The linear regression equations between irrigation water applied, cm overall sowing dates on consumptive use, cm is shown in Fig. (1), these equations show that the relationship between applied irrigation water and plants water consumed, cm is more reliable in the two seasons.

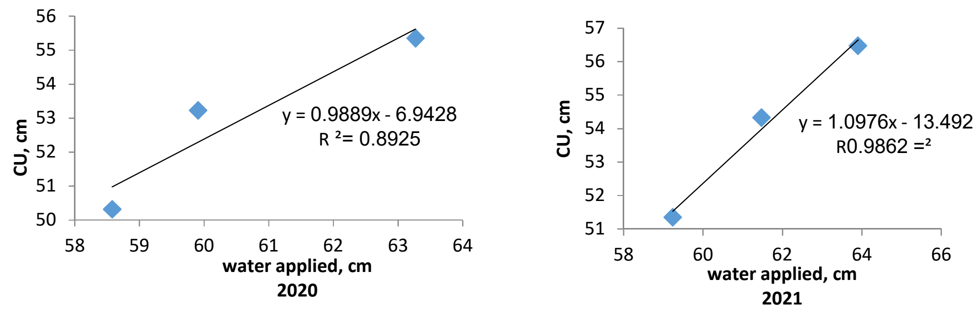


Fig. 2: Correlation between irrigation water applied, cm and sowing date on consumptive use, cm (plant water consumption) in the two growing seasons.

Productivity of irrigation water PIW, kg m^{-3}, water productivity WP, kg m^{-3} and economic water productivity EWP, L.E. m^{-3}

The productivity of irrigation water, water productivity, and economic water productivity was computed to evaluate the treatments for maximum yield and economic return per unit of water applied in the field. Data presented in Table (4) differs significantly between different sowing dates and cut-off irrigation scheduling treatments, as well as the interaction between them.

Table 4: Effect of sowing date, deficit irrigation, and nitrogen doses on the productivity of irrigation water (kg m^{-3}) and water productivity (WP, kg m^{-3}) for Maize crop in the two growing seasons.

Sowing date (S)	Deficit irrigation (I)	Nitrogen doses (N)	PIW, kg m^{-3} 1st Season	PIW, kg m^{-3} 2nd Season	WP, kg m^{-3} 1st Season	WP, kg m^{-3} 2nd Season	EPIW, L.E. m^{-3} 1st Season	EPIW, L.E. m^{-3} 2nd Season	EWP, L.E. m^{-3} 1st Season	EWP, L.E. m^{-3} 2nd Season
S1	I1	N1	1.95	1.73	2.05	1.96	4.34	4.52	4.93	5.11
		N2	2.29	2.04	2.41	2.31	5.10	5.32	5.79	6.01
		N3	2.21	1.96	2.32	2.22	4.90	5.11	5.57	5.77
	I2	N1	2.46	2.19	2.83	2.68	5.99	6.28	6.81	6.98
		N2	2.40	1.81	2.77	2.21	5.84	5.18	6.64	5.76
		N3	2.32	2.07	2.67	2.54	5.6	5.95	6.43	6.62
	I3	N1	2.12	1.88	2.69	2.56	5.57	5.78	6.46	6.67
		N2	2.10	188	2.66	2.55	5.53	5.75	6.40	6.63
		N3	2.01	1.79	2.55	2.44	5.29	5.50	6.13	6.34
Mean S1			2.21	1.93	2.55	2.39	5.30	5.47	6.10	6.19
S2	I1	N1	2.99	2.64	3.12	2.98	6.66	6.88	7.50	7.77
		N2	2.95	2.60	3.08	2.94	6.57	6.77	7.40	7.66
		N3	2.83	2.50	2.96	2.82	6.31	6.50	7.11	7.35
	I2	N1	3.19	2.81	3.33	3.47	7.77	8.00	8.77	9.04
		N2	3.12	2.75	3.56	3.39	7.58	7.81	8.55	8.82
		N3	3.01	2.65	3.44	3.28	7.32	7.54	8.27	8.53
	I3	N1	2.72	2.39	3.27	3.19	7.01	7.33	7.86	8.30
		N2	2.70	2.37	3.25	3.16	6.95	7.26	7.80	8.23
		N3	2.58	2.27	3.11	3.03	6.66	6.95	7.47	7..88
Mean S2			2.90	2.56	3.24	3.15	6.97	7.21	7.84	8.16
S3	I1	N1	2.69	2.63	3.11	3.02	6.47	6.84	7.47	7.86
		N2	2.62	2.56	3.03	2.94	6.30	6.67	7.27	7.66
		N3	2.60	2.54	3.00	2.92	6.25	6.62	7.21	7.59
	I2	N1	2.89	2.82	3.69	3.57	7.53	7.97	8.86	9.29
		N2	2.65	2.58	3.38	3.27	6.90	7.30	8.11	8.51
		N3	2.69	2.62	3.43	3.32	7.01	7.41	8.24	8.65
	I3	N1	2.44	2.39	3.38	3.25	6.97	7.38	8.11	8.47
		N2	2.33	2.27	3.22	3.10	6.64	7.04	7.47	8.07
		N3	2.28	2.23	3.16	3.04	6.51	6.89	7.58	7.91
Mean S3			2.58	2.52	3.27	3.16	6.72	7.11	7.83	8.21
Mean S			2.56	2.34	3.02	2.90	6.22	6.58	7.13	7.49

The highest values of PIW, WP EPIW, and EPW were recorded under the second sowing date (June 15th) in the two growing seasons. On the other hand, the cut-off irrigation scheduling showed that recorded the best values with irrigation cut-off as waterfront 90%FL under all sowing dates. And also, the interaction between 90 % FL cut-off irrigation and the 1st June sowing date giving the highest PIW, WP EPIW, and EPW in the two growing seasons. Nitrogen doses from 96, 120 to 144 N/fed resulted in a high increase in PIW, WP EPIW, and EPW in both seasons. Table (4). The increase in the doses of nitrogen fertilization led to an increase in the yield of the crop and thus the economic return compared to other levels. This increase in PIW, WP EPIW, and EPW may be due to the decrease in the amount of water consumption and water applied under the conditions of I_2 compared with I_1 irrigation treatments. These results are in line with those obtained by Awad *et al*. (2009) and Morsi *et al*. (2011).

Data from Figs (2) and the concomitant equations reveal that water productivity and economic water productivity for Maize inversely correlated with water applied. The correlation coefficient values were 0.9426 and 0.7806 for water productivity and 0.9216 and 0.7891 for economic water productivity in the first and second seasons respectively.

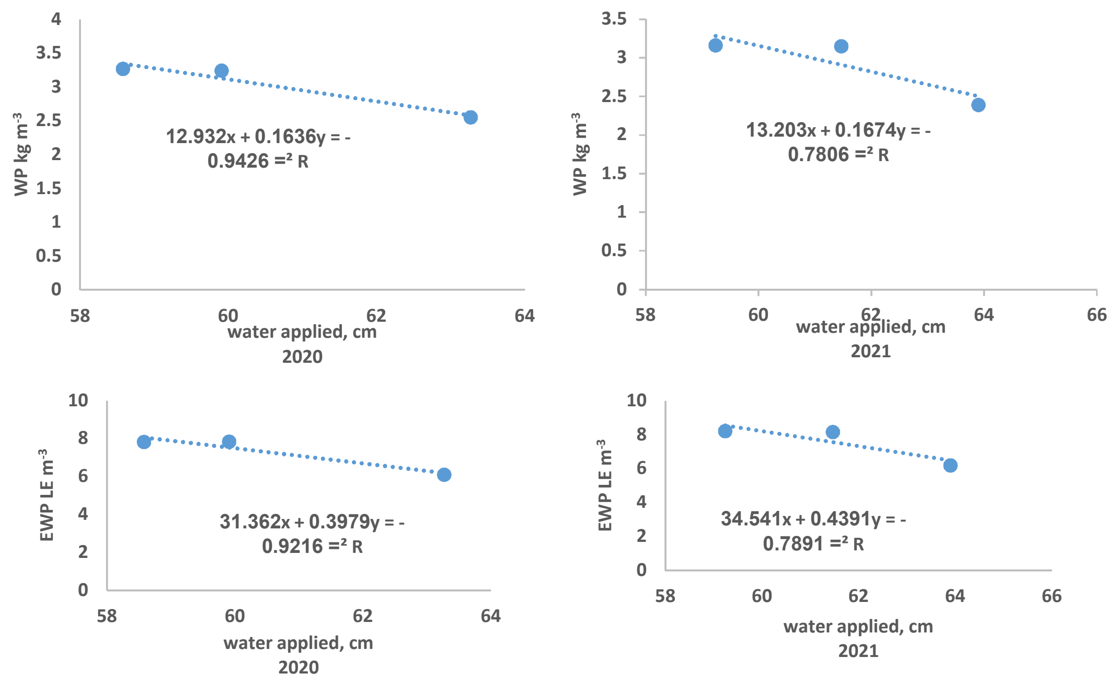


Fig. 3: Correlation between irrigation water applied, cm, and sowing date on water productivity, kg m^{-3}, and economic water productivity LE m^{-3} in the two growing seasons.

3.3. Maize growth parameters

Results in Table (5) indicated that maize crops exhibited significant differences for all studied yield attributes in both seasons and they are combined.

The combined analysis data in Table (5) revealed that June 1st sowing date significantly surpassed another sowing date in No. of rows/ear, ear length, cm, and ear diameter, cm. June 1st sowing date gave the highest values of No. of rows/ear (14.85 and 14.58) followed by June 15th (14.82 and 15.56), and May 15th gave the lowest values (14.73 and 14.36) in the first and second seasons, respectively. June 1st sowing date gave the highest values of ear length (25.26 and 24.76 cm) followed by June 15th (24.78 and 24.46 cm), May 15th gave the lowest values (24.29 and 23.63 cm) in the first and second seasons, respectively. Also, ear diameter takes the same trend for ear length and June 1st sowing date gave the highest values of ear diameter (4.98 and 4.88 cm) followed by June 15th (4.89 and 4.79 cm), May 15th gave the lowest values (4.80 and 4.66 cm) in the first and second season, respectively.

For deficit irrigation, the results in Table (5) indicate that irrigation by the I_2 i.e., (90 % cut-off irrigation) significantly increased No. of rows/ear, ear length, cm, and ear diameter, cm compared to other deficit irrigation treatments. It could be attributed that treatment saved adequate water enough to grow plants well as a result of an increase in the availability of soil moisture content because the availability of water is an important factor in the growth of maize plants which increases yield attributes.

Nitrogen doses from 96, 120 to 144 N/fed resulted in a highly significant increase in yield attributes (No. of rows/ear, ear length, cm, and ear diameter, cm) in both seasons. Table (5). Significant reductions were recorded for N1 and N3 compared with the N1 treatment. This indicates that increasing the N level up to 120 kg N/fed increased significantly the yield attributes and that N applied over 120 kg/ fed., had no significant effect on the grain and straw yield. These results are in harmony with those of El Sharkawy (2006).

Table 5: Effect of sowing date, deficit irrigation, and nitrogen doses on No. of rows ear^{-1}, Ear length and diameter, cm for Maize crop in the two growing seasons.

Sowing date (S)	Deficit irrigation (I)	Nitrogen doses (N)	No. of rows ear^{-1}		Ear length, cm		Ear diameter, cm	
			1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
		N_1	14.93abc	14.53 ab	24.58 f-j	23.88 f-k	4.60 op	4.47 kl
	I_1	N_2	15.33ab	14.93 ab	24.19 i-l	23.55 h-l	4.54 p	4.39 l
		N_3	15.00abc	14.60 ab	23.51 klm	22.86 lm	4.53 p	4.39 l
		N_1	15.31ab	14.91 ab	26.42 abc	25.75 abc	5.11 de	4.92 d
S_1	I_2	N_2	14.60bc	14.23 ab	25.15 d-g	24.49 efg	5.09 ef	4.92 d
		N_3	14.09 c	13.73 b	24.61 f-j	23.97 f-j	5.02 fg	4.90 d
		N_1	14.67bc	14.30 ab	23.78 jkl	23.14 jkl	4.93 h	4.79 e
	I_3	N_2	14.67bc	14.33 ab	23.54 klm	22.92 lm	4.74 klm	4.62 hi
		N_3	14 c	13.66 b	22.82 m	22.15 m	4.68 mn	4.58 ij
	Mean S_1		14.73	14.36	24.29	23.63	4.80	4.66
		N_1	15.33ab	15.04 ab	25.36 def	24.86 de	4.83 ij	4.73 efg
	I_1	N_2	16.0a	15.70 a	25.10 d-h	24.60 efg	4.78 jkl	4.68 fgh
		N_3	15.0abc	14.70 ab	24.26 h-k	23.78 g-k	4.72 lmn	4.62 hi
		N_1	14.60bc	14.31 ab	27.06 a	26.52 a	5.31 a	5.21 a
S_2	I_2	N_2	15.31ab	15.00 ab	26.42 abc	25.89 ab	5.25 ab	5.17 ab
		N_3	14.09c	13.81 b	25.95 bcd	25.43 bcd	5.19 bc	5.10 bc
		N_1	14.67bc	14.36 ab	24.66 f-j	24.19 e-i	4.97 fg	4.91 d
	I_3	N_2	14.67bc	14.37 ab	24.66 f-j	24.17 e-i	4.90 hi	4.77 e
		N_3	14.00c	13.72 b	23.90 jkl	23.43 i-l	4.85 ij	4.74 ef
	Mean S_2		14.85	14.58	25.26	24.76	4.98	4.88
		N_1	14.6bc	15.13 ab	24.97 e-i	24.66 def	4.71 lmn	4.64 ghi
	I_1	N_2	15.32ab	15.12 ab	24.64 f-j	24.32 e-h	4.64 mn	4.57 ij
		N_3	14.15c	14.80 ab	23.87 jkl	23.56 h-l	4.60 no	4.53 jk
		N_1	14.67bc	15.11 ab	26.70 ab	26.35 a	5.17 cd	5.08 bc
S_3	I_2	N_2	14.70bc	14.41 ab	25.78 bcd	25.46 bcd	5.17 cd	5.10 bc
		N_3	14.00c	13.91 b	25.32 def	24.97 cde	5.10 de	5.02 c
		N_1	15.33ab	14.48 ab	24.31 g-k	23.98 f-k	4.89 hi	4.80 e
	I_3	N_2	15.33ab	14.48 ab	24.09 i-l	23.78 g-k	4.80 jk	4.72 efg
		N_3	15.32ab	13.81 b	23.36 lm	23.06 kl	4.73 klm	4.65 ghi
	Mean S_3		14.82	14.56	24.78	24.46	4.89	4.79
	Mean S		14.80	14.50	24.78	24.28	4.89	4.78

3.4. Maize yield and yield component

3.4.1. Yield Kg Fed^{-1}

The effect of sowing date, deficit irrigation (cut-off irrigation), and nitrogen doses on yield is presented in Table 6, sowing date was recorded as highly significant on grain yield, the highest values were recorded under sowing date (S_2), and the values are 7309.3 and 7163.1 kg Fed^{-1} in the first and second growing season respectively and decreased with about 5.0% for the third date (S_3) and about 19.0-21.0% for the first date (S_1), this refers June 1st is suitable sowing date for Maize in North Nile Delta followed by June 15th then May 15th. As for grain yield, the highest figures (7193.3 and 6949.01 Kg fed^{-1}) were still recorded with irrigation at 90% FL regime without significant difference compared with 100% FL regime. In addition, yield reduction values reached (6.42 and 4.98%) and (13.91 and 12.59%) due to irrigating with 100 and 80% FL regimes, in the first and second seasons, comparable with 90% FL regimes, respectively.

Table 6: Effect of sowing date, deficit irrigation, and nitrogen doses on Yield kg Fed^{-1}, 100-grain weight, gm, and No. of grain, row for Maize crop in the two growing seasons.

Sowing date (S)	Deficit irrigation (I)	Nitrogen doses (N)	Yield kg Fed^{-1}		100-grain weight, gm		No. of grain, row	
			1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
S_1	I_1	N_1	5228 o	5076 o	40.40 k	39.31 o	46.17 f-i	44.93 g-j
		N_2	6139 klm	5970 j-m	39.84 l	38.68 p	48.00 cde	46.70 c-f
		N_3	5904 j-m	5734 k-n	39.68 l	38.59 p	45.44 i	44.77 hij
	I_2	N_1	6591 f-k	6406 g-j	42.74 c	41.57 f	48.50 bc	44.44 ij
		N_2	6433 h-l	5286 no	42.02 e	40.89 g	46.67 e-i	47.20 cd
		N_3	6218 i-m	6068 h-m	41.64 f	40.54 ij	45.50 i	45.46 f-j
	I_3	N_1	5677 mno	5514 l-o	41.40 f	40.30 jkl	47.50 c-f	44.26 j
		N_2	5628 mno	5487 mno	40.74 ij	39.65 n	46.17 f-i	46.25 d-j
		N_3	5392 no	5249 no	40.32 k	39.25 o	47.16 c-g	44.95 g-j
	Mean S_1		5912.2	5643.3	40.98	39.86	46.79	45.44
S_2	I_1	N_1	7543 a-d	7400 a-d	41.61 f	40.79 hi	47.16 c-f	46.25 d-g
		N_2	7441 a-d	7292 a-e	41.11 fg	40.31 jkl	50.50 a	49.52 a
		N_3	7144 c-g	7001 c-g	40.95 hi	40.16 kl	47.17 c-g	46.23 d-g
	I_2	N_1	8050 a	7891 a	44.11 a	43.25 a	47.17 c-g	46.25 d-g
		N_2	7855 ab	7696 ab	43.37 b	42.53 c	50.50 a	49.36 a
		N_3	7593 f-k	7440 a-d	42.98 c	42.16 d	48.00 cde	47.05 cde
	I_3	N_1	6852 e-i	6715 e-h	42.73 c	41.90 de	46.17 f-i	45.02 g-j
		N_2	6796e-j	6659 e-i	41.99 e	41.18 g	49.50 ab	48.54 ab
		N_3	6510 g-l	6374 g-k	41.61 f	40.79 hi	47.00 d-h	46.08 d-h
	Mean S_2		7309.3	7163.1	42.27	41.45	48.13	47.14
S_3	I_1	N_1	7207 b-f	7114 b-f	41.05 h	40.56 ij	46.67 e-i	46.09 d-h
		N_2	7018 d-h	6932 d-g	40.53 jk	40.02 lm	49.50 ab	48.87 a
		N_3	6960 d-h	6874 d-g	40.35 k	39.85 mn	46.33 f-i	45.76 e-i
	I_2	N_1	7728 abc	7631 abc	43.40 b	42.86 d	46.33 f-i	45.75 e-i
		N_2	7077 c-h	6988 d-g	42.70 c	42.19 d	49.50 ab	48.88 a
		N_3	7192 c-f	7102 b-f	42.34 d	41.81 ef	47.33 c-g	46.75 cde
	I_3	N_1	6536 f-l	6456 f-j	42.11 de	41.59 f	46.00 ghi	45.42 f-j
		N_2	6233 i-m	6156 h-l	41.34 fg	40.83 hi	48.16 cd	47.58 bc
		N_3	6107 klm	6030 i-m	40.96 hi	40.45 jk	46.67 e-i	46.08 d-h
	Mean S_3		6895.3	6809.3	41.64	41.13	47.39	46.80
	Mean S		6610.8	6538.7	41.63	40.81	47.44	46.46

Regarding the influence of nitrogen fertilization, data in Table 6 show that, the grain yield of the two nitrogen levels in both growing seasons significantly differed. Therefore, the highest values of these traits were achieved by 120 kg N fed^{-1} (N_2), while the rate of 96 kg N fed^{-1} (N_1) gave the lowest one. This indicates that increasing the N level up to 120 kg N/fed significantly increased the yield attributes and that N applied over 120 kg/ fed., had no significant effect on the grain and straw yield. These results are in harmony with those of El Sharkawy, (2006).

3.4.2. 100-grain weight, gm

As shown in Table 6, data illustrate that the mean values of the weight of 100 grains were significantly affected by the sowing date. Whereas the average values of the weight of 100 grains were decreased with the sowing date of May 15th and June 15th (S_1 and S_3) compared to the sowing date of June 1st (S_2).

Concerning the effect deficit irrigation significantly affects the weight of 100 grains. Whereas the highest mean weight of 100 grains was recorded under deficit irrigation (I2). These results are in agreement with that obtained by Khan *et al*., (2006), El-Atway and Eid (2010), Morsi *et al*., (2011), and Zhou *et al*., (2011). Also, of N doses, the averages for the weight of 100 grains were significantly increased with the application of N-doses up to normal doses, N_2 (120 kg N/fed). This increase in maize grain yield might be due to the low soil available N that reflected on responses of plants to the application of N-rate and increasing doses to 144 kg N fed^{-1} increasing vegetative growth and it makes a shortage of yield and its component like 100 grain, gm. These results are following that obtained by Nofal *et al*., (2005), Abo El-Atta (2006), and Beshara (2012).

4. Conclusion

Based on the results of the field experiment, it can be concluded that the best sowing date for maize crop under the study conditions is June 1st (S_2) with deficit irrigation (cut-off as waterfront reached 90% of furrow length, FL) being the most effective treatment compared to other sowing dates and deficit irrigation treatments. The study also found that dividing nitrogen fertilizer at rates of 120 kg fed^{-1} was more effective in increasing grain yield, water productivity, economic water productivity, and other yield components. Therefore, it is recommended that maize crops should be irrigated with 90% FL and nitrogen fertilization at 120 kg N fed^{-1} under the same study conditions to achieve the best yield and quality. These findings could be helpful for farmers and agricultural researchers to optimize maize crop production and improve crop yields under similar environmental conditions.

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