A technical and economic study for the effect of irrigation water scheduling on cotton yield productivity

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Abstract: To find out the impact of different scenarios of irrigation scheduling i.e. when to irrigate and how much water should be applied using the **CropWat** computer model which reflects the response of yield to water, particularly under the water deficit status. The aim of the present work was to improve the productivity of each unit of water and land for cotton crop (Gossypium barbadence L) in Kafr El-Sheikh Governorate, which represents the circumstances and conditions of North Nile Delta region. That governorate has the largest cotton cultivated acreage in Egypt. So, in this regard, twenty different scenarios of irrigation scheduling were tested using **CropWat** model during the two successive cotton growing seasons of 2016 and 2017. Four different irrigation intervals of 8, 12, 16 and 20 days were the selected intervals, while 20, 30, 40, 50, and 60 mm were the net applied irrigation water under each investigated irrigation timing. Therefore, by using **CropWat** model in evaluating the impact of different scenarios of irrigation scheduling on the economic return of water and land in North Nile Delta region, following are the main findings: (1) Ripening growth stage or said the last season stage is the most sensitive stage regarding water deficit, increasing water applied and/or shortening the irrigation interval during the second half of the growing cotton season becomes recommended. (2) Under each irrigation interval, reduction in percentages of ET, CWP and economic return of water unit are decreased with increasing net irrigation. On the other hand, cotton yield and net revenue are increased. (3) By elongating irrigation interval from 8, 12, 16 and 20 days under each net irrigation, percentage reduction in Et and cotton yield, CWP but return of water unit are increased. (4) Further studies using **CropWat** computer model should be done to find out the impact of different scenarios of irrigation scheduling on crop water productivity for different crops.

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1. Introduction:

Under the present severe water shortage, facing Egypt, which led to the capita share from water for different purposes becomes less than the water poverty edge of 1000 m^3 per annum and it is expected to reach the water scarcity level of less than 500 m^3 in the few coming decades. At this situation of water deficit, it is very difficult to make progress in any national sector of development. In addition, irrigated agriculture is the dominant due to the prevailing high aridity conditions of Egypt.

Therefore, in this regard, effective on farm irrigation management becomes a must. One of the most tools to achieve that target is to find out the suitable irrigation scheduling for irrigated crops i.e. when to irrigate and how much water should be applied.

Crop-water models becomes more useful to facilitate the interaction effects between field irrigation and/or crop water use from one side and the predicted crop yield from the other side. **CropWat** model is one of the most practical and applicable model worldwide which reflects the response of crop yield to water under different status of water availability. On the other hand, cotton (Gossypium barbadence L.) is the most important cash industrial crop for fiber, edible oil and feeding stuff for animals. Another obstacle facing Egypt is the rapidly decrease in the agricultural land due to the high annual increase of population. Consequently, Egypt is facing two main problems regarding the agricultural production i.e. less of both available water and cultivated land. Herewith, maximizing crop productivity and increasing net revenue per unit of water and land becomes a principal national strategy. **CropWat** model facilitate the solution of that target which enable the planners, technical advisors, extension officers, water users associations (WUA) as well as end users to solve the problems facing them.

The present study was carried out in Kafr EL-Sheikh Governorate, North Nile Delta region due to its rank as the largest governorate in the cotton cultivated area of 47,232 and 79,307 fed. (19,845 and 33,322 ha, 1ha = 2.38 fed) in 2016 and 2017, respectively (MLAR., 2016, 2017).

by In general, because of the increasing of population worldwide, water demand for different purposes is increased. Deficit irrigation under the status of water shortage could be applicable when the net revenue is feasible. Irrigation system and its performance, crop yield, its production costs are the main factors that associated with the economic returns under water stress and its role on crop yield.

The impact of interaction effects of different irrigation scheduling and computer modeling programs on crop yield are investigated by many researchers worldwide. **Rahouene (2013)** pointed out that arid and semi-arid areas are suffered from water shortage or said water scarcity status which is marked by hot summer, cold winter and low rainfall (200 to 400 mm per annum) with a high variability.

Computer programs are dealing with deficit irrigation to manage stress such that yield decline is loss. In addition, in regions where water is limit, the main target of farmers may not be to obtain maximum yield but the main objective is keep water to a positive return from the irrigated crop and ensure sustainability for irrigation **(Fereres and Soriano, 2007 & Rodrigues and Pereira, 2009). Heng et al. (2007)** pointed out that modeling is a useful tool to study and develop promising deficit irrigation strategies. It has been used to facilitate more efficient incorporation of new scientific advance to analyze crop responses to environmental stresses. Moreover, **Heng et al. (2009)** reported that crop models are useful for effective field management as decision support tools. On the other hand, the effect of irrigation scheduling on cotton yield was investigated by many researchers, among them **Yagoub et al (2013**) who pointed out that irrigation interval every 15 days throughout growth had the greatest values of cotton yields and its components. However, 30 days interval at early flowering and 30 days interval at early boll ripening showed the lowest values. Meanwhile, fiber characteristics had no clear evidence due to irrigation intervals. **Zounemat-Kermani and Asadi (2018)** in two-year comparison study showed that cotton yield, water use efficiency, boll weight, number of bolls and plant height in subsurface drip irrigation system (S2) were increased 10.8, 11, 7.45, 12.8 and 11.2 percent compared to surface drip irrigation system (S1), respectively. Economic analysis showed that applying 100 percent of crop water requirement in subsurface drip irrigation was superior to the other treatments of 80 and 60%. The results of **Zonta et al (2016)** revealed that the highest seed cotton yield (5707 kg ha-1) was reached with 130% ETc and 210 kg N ha-1. The treatment 70% ETc showed significant benefits in terms of irrigation water savings. Results of **Hameed et al. (2017)** indicated that inter culturing + chiseling produced the highest significant seed cotton production (17.8%), more bolls plant^{-1} (14.3%) and water intake (17.7%) than no chiseling with inter culturing. However, irrigation interval after eight days produced the maximum yield of seed cotton (14.2%), more 14.3% bolls plant-1and water retention (35.6%) than 12 days irrigation interval. The study of **Snowden et al. (2013)** suggested that a cotton cultivar with later maturity characteristics could be successful in both hot and heat-limited environments such as water deficit.

So, the main objective of the present work was to improve the productivity of cotton crop per each unit of water and land using **CropWat model.** In addition, net revenue under different scenarios of irrigation scheduling was identified. In general speaking, the principal target of this study was to achieve **"more crop per drop"** or so-called **"more for less"** (from the viewpoint of water and economic).

2. Procedures

Used model in the present study

CROPWAT 8.0 has been developed by Joss Swennenhuis for the Water Resources Development and Management Service of FAO. CROPWAT 8.0 is based on the DOS versions CROPWAT 5.7 of 1992 and CROPWAT 7.0 of 1999.

Background of the model

In the late seventies, FAO addressed the relationship between crop yield and its water use by proposing a simple equation where relative yield reduction is related with the corresponding relative reduction in water use or evapotranspiration (ET). In this regard, the yield response to ET is expressed as:

$$\left(1 - \frac{Ya}{Yx}\right) = Ky \left(1 - \frac{ETa}{ETx}\right)$$

Where Yx and Ya are the maximum and actual yields, ETx and ETa are the maximum and actual evapotranspiration, and Ky is a yield response factor representing the effect of a reduction in evapotranspiration on yield losses.

This approach and the calculation procedures for estimating yield response to water were published in the *FAO Irrigation and Drainage Paper* No. 33 **(Doorenbos and Kassam, 1979)**, which was considered one of FAO's milestone publications, and were used widely worldwide for a broad range of applications.

Crop water productivity (CWP)

Crop water productivity reflects the capability of crop water used (ETc) in producing marketable yield **(Bos, 1980):**

$$CWP = \frac{y}{ETc}$$

Where:

CWP : crop water productivity, kg/m3 water consumed

y : marketable yield, kg ETc : crop-water consumed, m^3

Net revenue (NR)

Net revenue as known is the difference between gross income minus total cost, both in L.E/ha (1$ = L.E.16.6).

Economic efficiency

Economic efficiency is defined in terms of two condition, Necessity, and sufficiency. Necessary condition is met in the production process when there is producing the same amount with fewer inputs or producing more with the same amount of inputs. But, the sufficient condition encompasses individual or social goals and values (John and Frank, 1987).

Economic return of water unit (ERWU)

Economic return of water unit is the product of CWP multiplied with the price of each unit of crop yield and expressed as L.E/ m3 water consumed.

Climatological elements of the studied area

Tables 1 present the monthly weather data at Kafr El-Sheikh Governorate during cotton growing period in the two seasons of 2016 and 2017. Weather data were recorded from Rice Agro-climatological station, elements included precipitation (rainfall), air temperature, relative humidity, sunshine hours and wind speed.

Table (1): Monthly weather data during cotton growing season 2016 & 2017

Year	Month	Precip. (mm/month	Temp. Oct. max	RH (%)				Sunshine (hrs.)	WS
				Tmin.	Max. RH	Min. RH	Av. RH		m/ sec
2016	Apr	0	30	18.6	82	42	62	9.6	1.01
	May	0	30.4	22.8	71	46	59	10.6	1.12
	Jun	0	33.6	26.3	76	47	62	11.9	1.31
	Jul	0	33.7	26.1	83	57	70	11.6	1.22
	Aug	0	33.6	26	84	56	70	11.3	1.07
	Sep	0	32.6	24.3	83	52	68	10.3	1.1
2017	Apr	10.6	26.5	21.6	79	51	65	9.6	1.03
	May	0	30.6	25.8	78	46	62	10.6	1.23
	Jun	0	32.5	28.1	80	51	66	11.9	1.19
	Jul	0	34.2	29	84	58	71	11.6	0.94
	Aug	0	33.9	28.3	86	55	71	11.3	0.81
	Sep	0	32.5	25.9	86	50	68	10.3	0.99

Soil properties

Soil samples were collected from successive depths: 0-15, 15-30, 30-45 and 45-60 cm to determine some physical properties of the experimental field such as soil field capacity (F.C) and permanent wilting point (WP) according to **James (1988)** as well as soil bulk density (Db) and particle size distribution were determined according to **Klute (1986).** The obtained results indicated that the soil texture is clayey as shown in Table 3. Chemical properties of total soluble salts (soil Ec, dS/ m), soil reaction (pH), both soluble cations and anions were determined according to **Jackson (1973).** So_4^{--} was calculated by the difference between soluble cations (meq/ L) and anions (meq/ L) as tabulated in Table 4.

Table (2): Particle Size distribution and soil water constants of the studied experimental site

Soil Depth.cm	Particle Size Distribution			Texture	F.C	W.P	AW	Db,
	Sand%	Silt %	Clay %	Class	%	%	(%)	Mg/m^3
0 – 15	15.07	28	56.93	Clay	44.39	26.65	17.74	1.03
15 – 30	17.6	30.1	52.3	Clay	40.02	22.44	17.58	1.07
30 – 45	20.1	33.4	46.5	Clay loam	38.07	20.06	18.01	1.1
45 – 60	22.08	37.09	40.83	Clay loam	36.03	19.38	16.65	1.15
Mean	18.71	32.15	49.14	Clay loam	39.63	22.13	17.5	1.09

Where: F.C % = soil field capacity, W.P % = wilting point, AW % = available soil water, and Db, Mg/m^3 = soil bulk density.

Table (3): Some chemical properties of the studied experimental site

Soil Depth.cm	Ec,ds/m	PH (1: 2.5)	Soluble ions, meq/L							
		soil water suspension	Cations				Anions			
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}
0-15	1.7	8.41	6.9	2.55	7.15	0.4	0	3.53	8.47	4.99
15-30	2.35	8.34	9.1	4.8	8.16	1.42	0	2.9	7.55	13.13
30-45	2.9	8.55	9.46	5.3	9.25	1.07	0	2.87	7.55	14.66
45-60	2.37	8.6	8.6	6.45	10.9	0.9	0	2.8	6.5	19.69
Mean	2.33		8.52	4.77	8.86	0.94	0	3.03	7.52	13.12

Irrigation scheduling scenarios

The concept of irrigation scheduling is identified as when to irrigate or so-called **irrigation timing** (irrigation at fixed interval, days) and how much water should be applied as **application depths** (fixed depths "net irrigation", mm). Applied irrigation water in that study equaled to net irrigation divided by 60% as surface irrigation efficiency.

Treatments: Twenty irrigation scheduling (irrigation timing and net irrigation) scenarios were tested as follows:

1. 8 days + 20 mm	11. 16 days + 20 mm
2. 8 days + 30 mm	12. 16 days + 30 mm
3. 8 days + 40 mm	13. 16 days + 40 mm
4. 8 days + 50 mm	14. 16 days + 50 mm
5. 8 days + 60 mm	15. 16 days + 60 mm
6. 12 days + 20 mm	16. 20 days + 20 mm
7. 12 days + 30 mm	17. 20 days + 30 mm
8. 12 days + 40 mm	18. 20 days + 40 mm
9. 12 days + 50 mm	19. 20 days + 50 mm
10. 12 days + 60 mm	20. 20 days + 60 mm

3. Results and Discussion

1. Net and gross irrigation

The following Table 5 represents net and gross irrigation of cotton under different suggested irrigation scheduling scenarios, both in mm. It should be notified that net irrigation was calculated from CropWat model, while gross irrigation is equaled to net irrigation divided by 60% as surface irrigation efficiency.

2. Reduction in water use at different growth stages

Table 6 viewed the impact of different irrigation scheduling on the reduction percentage of cotton water use at different growth stages. In that regard, the most sensitive growth stage is the late season stage (the fourth or ripening stage) followed by the mid season (the third stage). Moreover, as simulated by **CropWat,** the reduction in cotton water use as illustrated in Figure 1 has the same direction of elongation irrigation interval and vice versa in connection with net irrigation.

Table (4): Net irrigation and gross irrigation for irrigation scheduling scenarios

Irrigation scenarios	Net irri. (mm)	Gross irri. (mm)
8 days + 20 mm	440	733.3
8 days + 30 mm	660	1100
8 days + 40 mm	880	1466.7
8 days + 50 mm	1100	1833.3
8 days + 60 mm	1320	2200
12 days + 20 mm	280	466.7
12 days + 30 mm	420	700
12 days + 40 mm	560	933.3
12 days + 50 mm	700	1166.7
12 days + 60 mm	840	1400
16 days + 20 mm	220	366.7
16 days + 30 mm	330	550
16 days + 40 mm	440	733.3
16 days + 50 mm	550	916.7
16 days + 60 mm	660	1100
20 days + 20 mm	160	266.7
20 days + 30 mm	240	400
20 days + 40 mm	320	533.3
20 days + 50 mm	400	666.7
20 days + 60 mm	480	800

3. Reduction in seed cotton yield

Decreasing in seed cotton yield as affected with different irrigation scheduling scenarios is clarified in Table 6. Herewith, from the tabulated data, it is obvious that the last stage of ripening is the most sensitive stage in connection with water deficit following with that of the mid season stage. Therefore, it is highly advisable to implement such findings for effective cotton irrigation management by non-elongate irrigation interval and/or increasing irrigation water during the second half of the growing season in comparison with that of the first half of the cotton growing season.

As shown in Figure 2 which obtained from running **CropWat** model, the reduction in seed cotton yield has the same direction with increasing irrigation interval in days and has the opposite direction with net irrigation.

The obtained results are in the same direction with that obtained by **Yagoub et al (2013), Snowden et al (2013), Zonta et al (2016) and Hameed et al (2017)**

Table (5): Impact of irrigation scheduling scenarios on cotton- ETc reduction per stage (%) through the two seasons of 2016 and 2017.

Irrigation scheduling	2016				2017			
	Growth stages				Growth stages			
	A	B	C	D	A	B	C	D
8 days + 20 mm	0	0	24.4	34.7	0	0	20	32.1
8 days + 30 mm	0	0	1.5	8.6	0	0	0	3.1
8 days + 40 mm	0	0	0	0	0	0	0	0
8 days + 50 mm	0	0	0	0	0	0	0	0
8 days + 60 mm	0	0	0	0	0	0	0	0
12 days + 20 mm	0	0	45.1	56.4	0	0	41.2	54.5
12 days + 30 mm	0	0	25	35.7	0	0	20.6	33.3
12 days + 40 mm	0	0	9	19.3	0	0	5	15.7
12 days + 50 mm	0	0	0.5	3.4	0	0	0	0.2
12 days + 60 mm	0	0	0	0	0	0	0	0
16 days + 20 mm	0	0	58.5	66.3	0	0	54	65
16 days + 30 mm	0	0	41.9	51.1	0	0	37.9	49.2
16 days + 40 mm	0	0	27.3	36.4	0	0	22.9	33.8
16 days + 50 mm	0	0	15.7	23.3	0	0	11.4	20.5
16 days + 60 mm	0	0	5.8	12.2	0	0	2.6	8.3
20 days + 20 mm	0	1	67.1	75	0	0	61.7	73.8
20 days + 30 mm	0	0	51.6	62.4	0	0	46.9	60.7
20 days + 40 mm	0	0	39.6	50.1	0	0	35.6	47.9
20 days + 50 mm	0	0	28.8	38.4	0	0	24.6	35.8
20 days + 60 mm	0	0	18.6	28.1	0	0	14.4	25.6

Growth stages: a = initial, b = development, c = mid season and d = ripening (late season)

Table (6): Impact of irrigation scheduling scenarios on cotton yield reduction per stage (%) through the two seasons of 2016 and 2017

Irrigation scheduling	2016				2017			
	Growth stages				Growth stages			
	A	B	C	D	A	B	C	D
8 days + 20 mm	0.0	0.0	12.2	19.8	0.0	0.0	10.0	17.2
8 days + 30 mm	0.0	0.0	0.8	2.9	0.0	0.0	0.0	0.8
8 days + 40 mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 days + 50 mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 days + 60 mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12 days + 20 mm	0.0	0.0	22.6	33.5	0.0	0.0	20.6	31.4
12 days + 30 mm	0.0	0.0	12.5	20.3	0.0	0.0	10.3	17.8
12 days + 40 mm	0.0	0.0	4.5	9.1	0.0	0.0	2.5	6.4
12 days + 50 mm	0.0	0.0	0.3	1.1	0.0	0.0	0.0	0.0
12 days + 60 mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 days + 20 mm	0.0	0.0	29.3	41.0	0.0	0.0	27.0	38.8
16 days + 30 mm	0.0	0.0	20.9	31.0	0.0	0.0	19.0	28.9
16 days + 40 mm	0.0	0.0	13.6	21.5	0.0	0.0	11.5	18.9
16 days + 50 mm	0.0	0.0	7.9	13.2	0.0	0.0	5.7	10.5
16 days + 60 mm	0.0	0.0	2.9	5.9	0.0	0.0	1.3	3.3
20 days + 20 mm	0.0	0.5	33.9	46.3	0.0	0.0	30.8	43.6
20 days + 30 mm	0.0	0.0	25.8	37.4	0.0	0.0	23.5	35.1
20 days + 40 mm	0.0	0.0	19.8	29.8	0.0	0.0	17.8	27.6
20 days + 50 mm	0.0	0.0	14.4	22.6	0.0	0.0	12.3	20.1
20 days + 60 mm	0.0	0.0	9.3	15.7	0.0	0.0	7.2	13.1

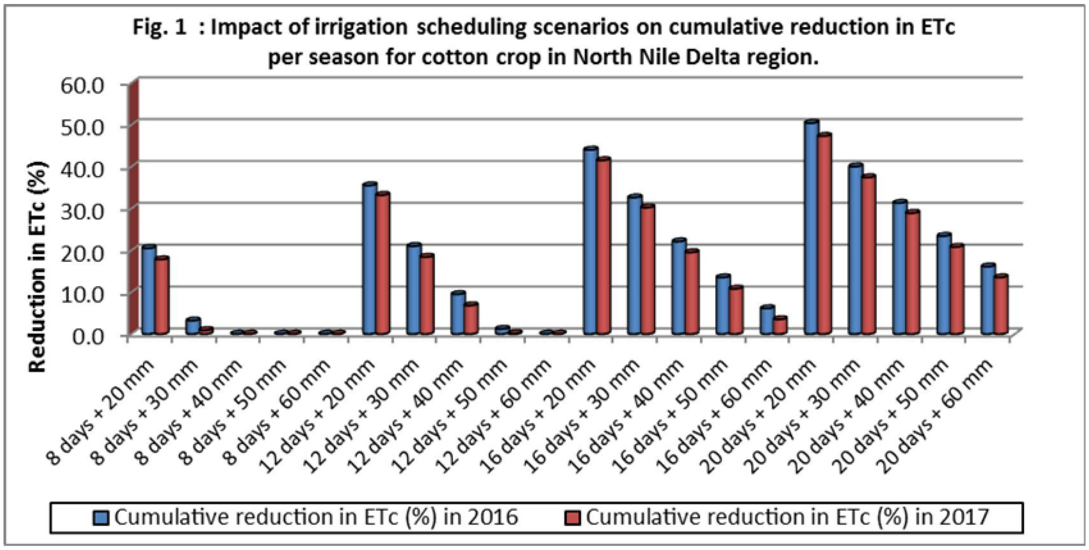


Fig. 1 : Impact of irrigation scheduling scenarios on cumulative reduction in ETc per season for cotton crop in North Nile Delta region.

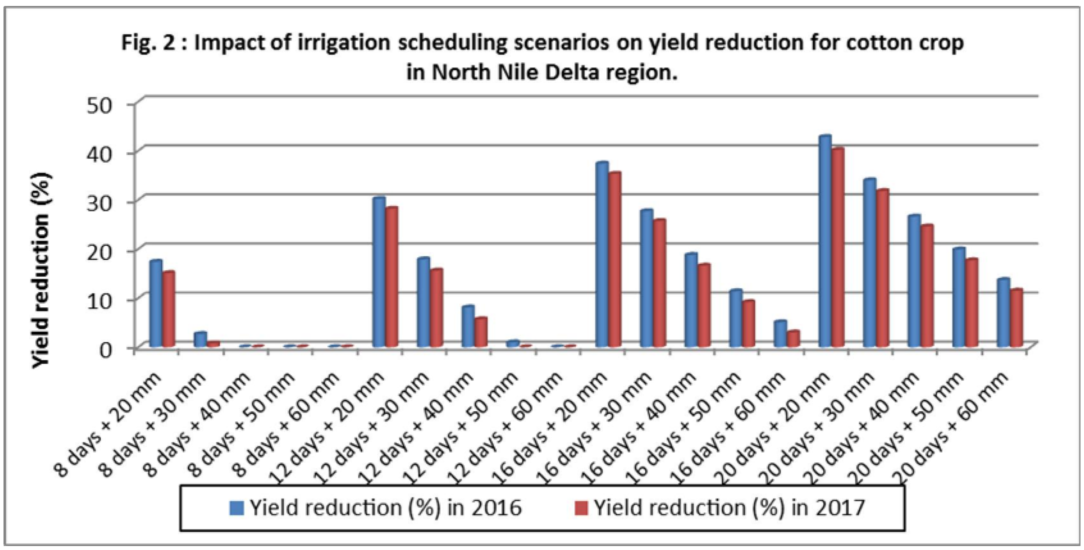


Fig. 2 : Impact of irrigation scheduling scenarios on yield reduction for cotton crop in North Nile Delta region.

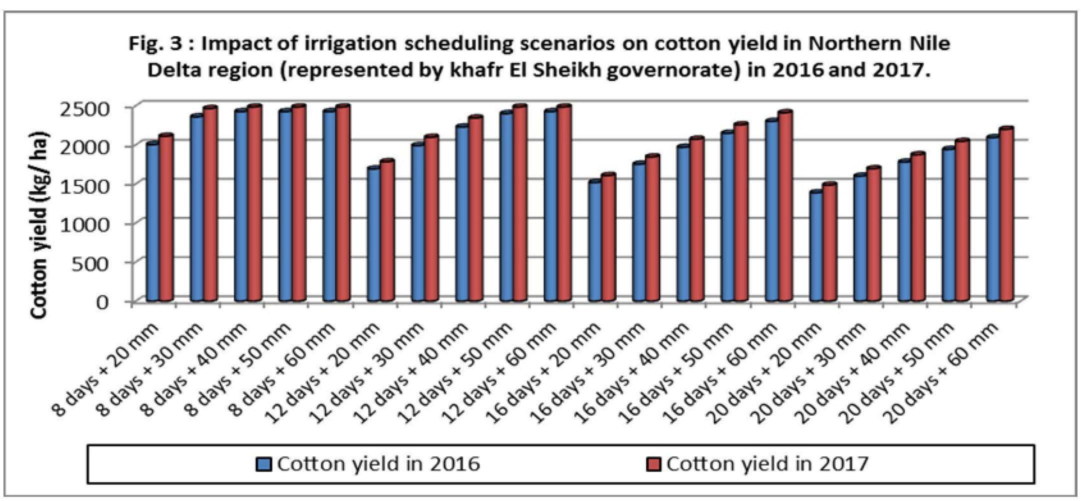


Fig. 3 : Impact of irrigation scheduling scenarios on cotton yield in Northern Nile Delta region (represented by khafr El Sheikh governorate) in 2016 and 2017.

Fig. 4 : Impact of irrigation scheduling scenarios on crop water productiity (CWP) for cotton crop in Northern Nile Delta region (represented by khafr El Sheikh governorate) in 2016 and 2017.

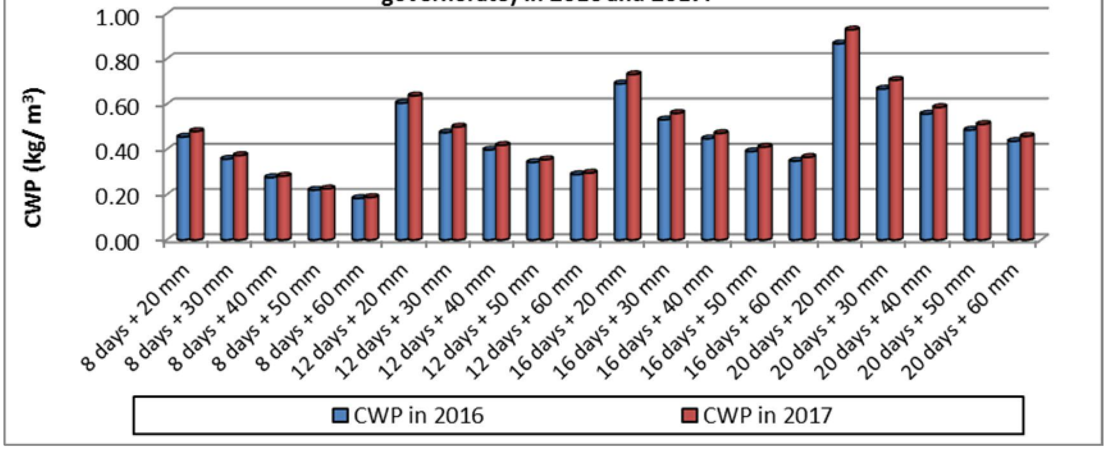


Fig. 5 : Impact of irrigation scheduling scenarios on net revenue for cotton crop in Northern Nile Delta region (represented by khafr El Sheikh governorate) in 2016 &2017.

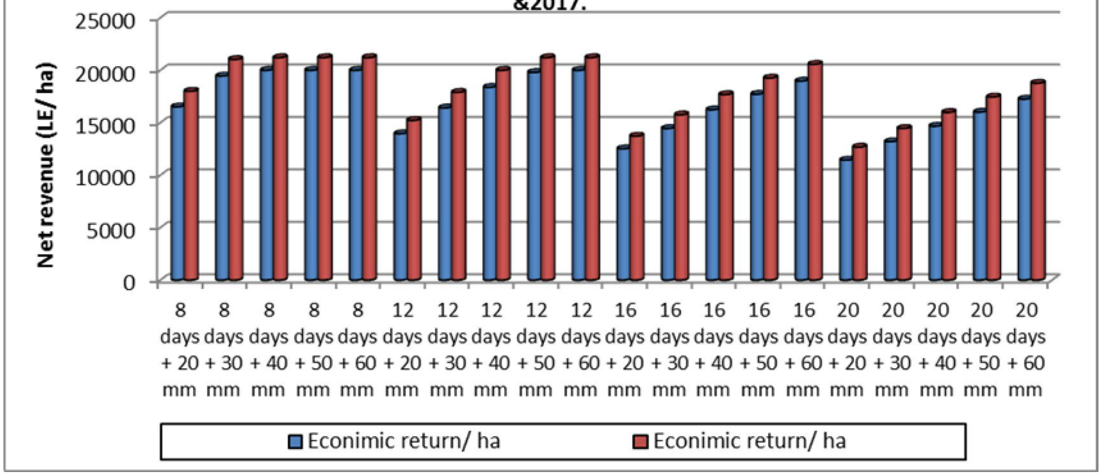
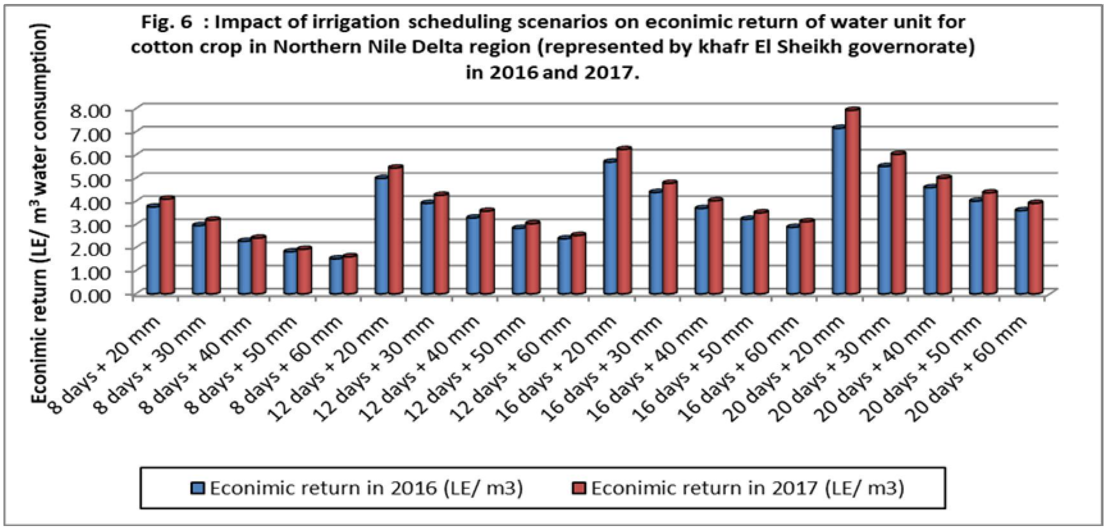


Fig. 6 : Impact of irrigation scheduling scenarios on econimic return of water unit for cotton crop in Northern Nile Delta region (represented by khafr El Sheikh governorate) in 2016 and 2017.



3. **Cotton yield (kg/ha)**

Values of cotton yield as shown in Figure 3 revealed that this trait is higher under irrigation timing of 8 and 12 days comparing with that of 16 and 20 days. This finding could be attributed to the abundance of availability of soil moisture in the root zone comparing with that of the third and fourth irrigation interval which resulted in healthy growing plants and consequently increasing crop yield. Regarding the impact of net irrigation or so-called crop water use on cotton yield, it is obvious that that the highest cotton yield was resulted from the 50 or 60 mm net irrigation under all irrigation timing. So, in this manner, to get high cotton yield, it is advisable to implement cotton irrigation scheduling of 8 or 12 days with net irrigation of 50 mm instead of 60 mm. Herewith, reasonable amount of water saving could be achieved.

4. **Crop water productivity (CWP)**

Data of crop water productivity (CWP) as presented in Figure 4 emphasized 3 main remarks as:

First, under each irrigation interval, a reverse relation between CWP and increasing the depth of net irrigation i.e. the lowest value of CWP was accompanied with the highest value of net irrigation of 60mm and vice versa with other values of net irrigation. That is true as the net irrigation is the dominator of the equation of computing the CWP as stated before.

Second, the highest values of CWP were obtained under the 20 days irrigation timing followed by that of 16 days, while the lowest values were recorded with 8 followed by the 12 days. That result could be attributed to the decrease in cotton yield under 16 and 20 days. It should be notified that cotton yield is the nominator of CWP equation.

Values of CWP during the two seasons of study are nearly the same, that finding might be due to the strengthen the capability of **CropWat** model in predicting the response of crop yield to crop water use, particularly under water deficit status.

Herewith, it should be notified that to get a reasonable evaluation of different irrigation scheduling scenarios, the crop yield should be taken into consideration, In other words, which factor is the critical one in crop production, is it, water or soil? Meaningfully, under water deficit, the crop yield per each unit of water becomes the most critical element in strategy of crop production and vice versa under the high availability of irrigation water. The obtained findings are in the same line with that stated by **Zounemat-Kermani and Assadi (2018).**

5. Economic Irrigation indicators for cotton crop in Kafr Al sheikh Governorate:

Table (7) shows that economic Irrigation indicators for cotton crop for two seasons 2016 and 2017 as follow:

- **Returns to irrigation costs (L.E)** decreased from 31.16 L.E. in 2016 to 22.35 L.E. in 2017, down by 26.88%.
- **Returns to one pound of irrigation costs (L.E)** it presented the relationship between net revenue and irrigation cost, it decreased from 13.37 L.E in 2016 to 9.02 L.E. in 2017, down by 32.54%.
- **The irrigation Cost** of Kg for cotton crop increased from 0.62 L.E/Kg in 2016 to 0.95 L.E. / Kg in 2017, up by 53.51%.
- **Returns to one cubic meter of irrigation water** increased from 3.97 L.E /m^3 in 2016 to 4.64 L.E. / m3 in 2017, up by 17.04%.
- **Water profitability (L.E/m^3)** increased from 1.70 L.E. /m^3 in 2016 to 1.84 L.E / m^3 in 2017, up by 7.97%.
- **Contribution of irrigation to the variable costs (%)** estimated about 10.24% in 2016, reached at 10.88%, up by 6.25%.
- **Contribution of irrigation to the total costs of production (%)** increased from 5.80% in 2016 to 7.26%, up by 25.18%. The water productivity, increased from 20.67 ha/ m3 in 2016 to 21.55 ha/ m3 in 2017, up by 4.26%.
- **Water productivity** increased from 0.21 Kg/m^3 in 2016 to 0.22%, up by 4.26%.
- **Economic efficiency** decreased from 0.78 in 2016 to 0.66 in 2017 for each Egyptian pound (L.E) spend for production while the rate of change was obtained -15.56% due to the percentage increase in total cost is greater than the percentage increase in net revenue.

Table (7): Economic indicators for cotton crop irrigation in Kafr Al sheikh governorate during 2016 & 2017

Item	2016	2017	Aver. (2016-2017)	Rate of change
yield (Kg/ha)	2426	2486	2456	2.47
Amount of irrigation water (m^3/ha)	11738	11537	11638	-1.72
Total costs of production (L.E/ha	25766	32378	29072	25.66
Irrigation costs (L.E/ha)	1495	2352	1924	57.3
Variable costs (L.E/ha)	14599	21614	18107	48.05
Total revenue (L.E/ha)	46586	53587	50087	15.03
Net revenue (L.E/ha)	19987	21209	20598	6.11
Returns to irrigation costs (L.E)	31.16	22.78	26.97	-26.88
Returns to one pound of irrigation costs (L.E)	13.37	9.02	11.19	-32.54

Item	2016	2017	Aver. (2016-2017)	Rate of change
Irrigation costs per one kilogram of output (L.E/Kg)	0.62	0.95	0.78	53.51
Returns to one cubic meter of irrigation water (L.E/ m^3)	3.97	4.64	4.31	17.04
Water profitability (L.E/m^3)	1.7	1.84	1.77	7.97
Contribution of irrigation to the variable costs (%)	10.24	10.88	10.56	6.25
Contribution of irrigation to the total costs of production (%)	5.8	7.26	6.53	25.18
Water productivity (Kg/m^3)	0.207	0.215	0.211	4.26
Economic efficiency	0.78	0.66	0.71	-15.56

1- Returns to irrigation costs (L.E) = Total revenue/ irrigation costs

2-Returns to one pound of irrigation costs (L.E) = Net revenue / irrigation costs

3- Irrigation costs per one kilogram of output (L.E/Kg) = irrigation costs / Yield

4- Returns to one cubic meter of irrigation water (L.E/m3)= Total revenue/ Amount of irrigation water

5- Water profitability = Net revenue/ Amount of irrigation water

6- Contribution of irrigation to the variable costs = (irrigation costs/ variable costs)*100

7- Contribution of irrigation to the total costs of production (%) = (irrigation costs/ Total costs)*100

8- Water productivity (Kg/m3) = (Yield/ Amount of irrigation water)

9- Economic efficiency = Net profit / Total costs

Source: Collected and calculated from Ministry of Agriculture and Land Reclamation, The Central Administration for Agricultural Economics, Statistics Department's Records, Unpublished Data, (Ministry of Public Works and Water Resources), for the period (2016-2017).

6- The Economic Evaluation:

For the economic evaluation, the twenty different scheduling approaches were compared in terms of economic return for the land unit, crop water productivity, and economic return of the water unit, for two seasons 2016 and 2017, cotton crop seasons simulations are presented in table (8).

Economic Return of land unit:

According to reduction in gross irrigation water use, yields decrease with water deficits thus the return of land unit decreased. The return of land unit is lower for the strategies under intervals 8, 12, 16 and 20 days with net irrigation 20 mm, it reached about 16519,13959, 21519 and 11439 Kg/ha (respectively season 2016). While reached about 18006, 15228, 13722 and 12683 Kg/ha (Respectively season 2107). They are corresponding to decrease in gross irrigation water use.

Economic Return of water unit:

The economic return of water also increases with deficit irrigation because yields decrease with water deficits and according to increased CW are presented in Table (5). Thus, the return of the water unit is higher for the strategies under each irrigation intervals 8, 12, 16 and 20 days with net irrigation 20 mm approximately 3.75, 4.99, 5.69, and 7.15 L. E/./m^3 (respectively season 2016). While reached about 4.09, 5.44, 6.24 and 7.15 L. E/./m^3 (respectively season 2017).

Table (8) Impact of irrigation scheduling scenarios on crop water productivity, return of land unit and return of water unit for cotton crop in khafr El Sheikh governorate through the two seasons of 2016 and 2017.

irrigation scheduling scenarios	Return of land unit/ ha 2016	Return of land unit / ha 2017	CWP in 2016	CWP in 2017	Return of water unit in 2016 (L.E./ m^3)	Return of water unit in 2017 (L.E./ m^3)
8 days + 20 mm	16519	18006	0.46	0.48	3.75	4.09
8 days + 30 mm	19459	21039	0.36	0.37	2.95	3.19
8 days + 40 mm	19999	21209	0.28	0.28	2.27	2.41
8 days + 50 mm	19999	21209	0.22	0.23	1.82	1.93
8 days + 60 mm	19999	21209	0.18	0.19	1.52	1.61
12 days + 20 mm	13959	15228	0.6	0.64	4.99	5.44
12 days + 30 mm	16419	17900	0.47	0.5	3.91	4.26
12 days + 40 mm	18379	20000	0.4	0.42	3.28	3.57
12 days + 50 mm	19799	21209	0.34	0.36	2.83	3.03
12 days + 60 mm	19999	21209	0.29	0.3	2.38	2.52
16 days + 20 mm	12519	13722	0.69	0.73	5.69	6.24
16 days + 30 mm	14459	15758	0.53	0.56	4.38	4.78
16 days + 40 mm	16239	17688	0.45	0.47	3.69	4.02
16 days + 50 mm	17719	19258	0.39	0.41	3.22	3.5
16 days + 60 mm	18979	20573	0.35	0.37	2.88	3.12
20 days + 20 mm	11439	12683	0.87	0.93	7.15	7.93
20 days + 30 mm	13199	14465	0.67	0.71	5.5	6.03
20 days + 40 mm	14679	15992	0.56	0.59	4.59	5
20 days + 50 mm	16019	17455	0.49	0.51	4	4.36
20 days + 60 mm	17259	18770	0.44	0.46	3.6	3.91

Conclusions

By using **CropWat** model in evaluating the impact of different scenarios of irrigation scheduling on the economic return of water and land in North Nile Delta region, following are the main remarks:

- The last season or ripening growth stage is the most sensitive stage for water deficit, increasing water applied and/or shortening the irrigation interval during the second half of the growing cotton season becomes essential.
- Under each irrigation interval, reduction in percentages of both ETc and cotton yield, CWP and economic return of water unit are decreased with increasing net irrigation. On the other hand, cotton yield and net revenue are increased.
- By elongating irrigation interval from 8, 12, 16 and 20 days under each net irrigation, percentage reduction in ETc and cotton yield, CWP and return of water unit are increased.
- Further studies should be carried out to find out the impact of different irrigation scheduling scenarios on crop water productivity for different crops using **Cropwat model.**

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