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COMPARISON OF TWO IRRIGATION SCHEMES FOR SURFACE-IRRIGATED MAIZE WITH CONVENTIONAL IRRIGATION IN THE MIDDLE NILE DELTA

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ABSTRACT

Fixed-furrow irrigation (FFI_{14} with 14 days interval and FFI_7 with seven days interval) were used to investigate the impacts of deficit irrigation on yield, crop-water relations and economic return at Middle Nile Delta area in comparison with every furrow irrigation (EFI, conventional method with 14 days interval). The results indicated that grain yield was increased with FFI_7, whereas it tended to decrease under FFI_{14}, in comparison to EFI. The water applied was reduced with FFI_7 and FFI_{14} when compared to EFI. The crop water use decreased under the FFI_7 and FFI_{14} techniques as compared to EFI. The FFI_7 scheme exhibited improved crop water use efficiency values, compared to EFI. The results indicated also that FFI_7 treatment does not only increase grain yield, benefit-cost ratio and net return, but also save irrigation water.

Keywords: Maize, Zea mays L., Fixed-furrow irrigation, Maize-water relations, Benefit-cost ratio (BCR)

INTRODUCTION

Water resources in Egypt are limited, which restrict crop production in the newly reclaimed lands because of the present intensive agricultural production in the Nile Delta and valley area and agriculture in Egypt relies heavily on irrigation. The agricultural sector consumes more than 84 % of the available water resources (El-Beltagy and Abo-Hadeed, 2008).

Maize is one of the major cereal crops in Egypt. It is the most important foodstuff, which provides the daily bread for the indigenous population of rural areas. Thus, it can be considered as the second feed crop after wheat. Maize production in Egypt is about 12 million tons of grain (USDA, 2011). Improving maize production with saving irrigation water and maximizing profits, could be achieved by determine water- yield relationships and choose the most appropriate irrigation method.

The common irrigation method used for maize production in the Middle Nile Delta of Egypt is surface furrow irrigation. Such irrigation scheme characterized by low application efficiency (45-60%) and causes significant water losses mainly due to excess deep percolation from the irrigated fields (Mitchell *et al*. 1995; Raine and Bakker 1996). Accordingly, irrigation methods require fundamental changes in water management in order to use the limited water resources efficiently.

Deficit irrigation has been used as water saving method in agricultural production to increase benefit and water use efficiency as mentioned by (Mitchell *et al*. 1991; Behboudian and Mills 1997). Deficit irrigation, under furrow irrigation, can be induced via different irrigation techniques such as fixed-furrow. Fixed-furrow irrigation is a way to save water and showed a small improvement over the alternate furrow irrigation (Slatnia *et al*. 2011). Fixed-furrow irrigation is a preferable irrigation water management in areas with a scare amount of irrigation water and rainfall (Sepaskhah and Hosseini, 2008). In this regard, every-other furrow irrigation saved water and increased maize yield (Shayannejad and Moharrey 2009; Rafiee and Shakarami 2010).

The economical and environmental benefits of using every-other furrow irrigation method are higher than any other irrigation methods, because of less water is applied and a greater economic return can be obtained (Nelson and Al-Kaisi, 2011).

The objective of this research is to study the effects of deficit irrigation, under furrow irrigation technique, via fixed-furrow (FFI), with two different schemes, in comparison with every furrow irrigation (EFI) on maize yield, water relations and economical returns.

MATERIALS AND METHODS

Description of the studied area

The field experiment was conducted at a private farm, lies 15 km north to Tanta city, Al-Gharbiya governorate during the 2010 and 2011 seasons. The soil of the studied area is characterized by a clay texture with water table deeper than three meters. Hydro-physical characteristics of the soil at the experimental field are determined as outlined by Ryan *et al*. (2001) and shown in Table (1).

Treatments and experimental design

The irrigation treatments were:

1) Every-furrow irrigation (conventional irrigation method, EFI), in which irrigation was applied at 14-day intervals after Mohyah irrigation.
2) Fixed every other furrow irrigation (FFI_7) in which irrigation was fixed to one of the two neighboring furrows and watering was applied at 7-day intervals.
3) Fixed every other furrow irrigation (FFI_{14}) which was similar to AFI_7, but watering was applied at 14-day intervals.

The experimental plot size is 45.5 m^2 (9.1 m width × 5 m length). Each treatment included 15 furrows and 14 planting ridges (rows), spaced 0.65 m apart. The experimental plots were separated by earthen banks (1.3 m wide and 0.5 m high) to reduce the lateral movement of irrigation water.

Table (1): Hydro-physical characteristics of the soil at the experimental field

Characteristics		2010			2011	
	Soil depth, cm					
	0-30	30-60	60-90	0-30	30-60	60-90
Sand (%)	24.36	21.86	25.10	22.9	19.6	23.10
Silt (%)	26.58	27.75	40.10	31.88	32.25	40.20
Clay (%)	49.06	50.39	34.80	47.22	48.15	36.70
Soil Texture	Clay	Clay	Clay Loam	Clay	Clay	Clay Loam
Bulk density (g cm^{-3})	1.26	1.40	1.49	1.24	1.38	1.47
FC [a] (%, ww^{-1})	41.60	38.60	38.20	41.30	38.60	38.00
PWP [b] (%, ww^{-1})	21.78	20.84	20.51	21.81	20.54	20.10
AW [c] (mm depth)	74.92	74.59	79.07	72.50	74.77	78.94

[a] FC is moisture content at field capacity
[b] PWP is moisture content at wilting point
[c] AW is available water content

Agronomic practices

Maize (*Zea mays* L.) seeds (TWC 324) were sown at 36 kg ha^{-1} seeding rate in May 25 in the two growing seasons. All agronomic practices e.g. plant density, N- fertilization weed and insect control…etc were kept normal and performed at the appropriate time. The experimental treatments were imposed after the second pre-treatment irrigation in both seasons. Maize was harvested at 123 days after planting (DAP) by cutting the aboveground biomass, and left for further drying before removing the cobs from the stalks. Then, grains were threshed and the grain yield (at 15 % moisture content) was measured.

Irrigation management

A polyvinyl chloride pipe of 15 cm internal diameter and 40 cm length was used to convey the water into each plot. This pipe was installed to give a free water flow. The discharge was calculated according to the following formula:

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

Where:

Q is the discharge rate (cm^3 sec^{-1}); C is the discharge coefficient of the orifice (0.61); g is the acceleration of gravity (cm sec^{-2}); A is the orifice cross sectional area (cm^2) and h is the effective water head above the orifice center. The effective water head was measured several times during the pre-treatment irrigation, estimated to be 8.3 cm, and was used to calculate the discharge of the pipes in this study. At the time of irrigation, water enters the plot through the pipe till it fills the furrows as the local farmers irrigating their fields, and the time is recorded using a stopwatch. Furrows, which is subjected to irrigation are open ended, whereas the others which is not subjected to irrigation are close ended or diked. The pipe discharge and the duration of the irrigation determine the total amount of applied water, which should match the crop water requirement in the ideal situation. The depth of the applied water was calculated using the following formula: d = $Qt \times 1000 / A$ Where d is the depth (mm); Q is the discharge (m^3 min^{-1}); t is the time (min) and A is the plot area (m^2). Total applied irrigation water (AIW) was calculated by summing the amounts of water added at each irrigation event during the entire growing season.

Maize-water relation parameters

Soil samples were taken by screw auger at planting, before and two days after each irrigation, and at harvest. Samples were taken on the beds and in the furrows at three depths: 0-30, 30-60 and 60-90 cm. In fixed furrow irrigation treatments, the soil samples were taken for both the irrigated and dry furrows. The samples were used to measure the volumetric soil-water content in the root zone using the gravimetric method, based on the conventional oven-dry weight, and multiplied by the bulk density. Then next parameters were calculated.

1. Crop water use (CWU) was calculated based on the soil moisture depletion (Michael, 1978) as follows:

$$CWU = \sum_{i=1}^{n}\left(VMC_{1i} - VMC_{2i}\right) \times D_i$$

Where:

CWU is the Crop Water Use (mm); VMC_{1i} is the Volumetric Moisture Content at the time of the first sampling in the i^{th} layer; VMC_{2i} is the Volumetric Moisture Content at the time of the second sampling in the i^{th} layer; D is the Depth of the i^{th} layer of the soil (mm); and n is the number of soil layers. Total crop water use was obtained as a summation of CWU for each irrigation cycle.

2. Crop water use efficiency (CWUE) or so-called in other references crop water productivity (CWP) was computed by dividing the maize yield on crop water use. Irrigation water use efficiency (IWUE) or so-called in other references irrigation water productivity (IWP) was determined as the ratio of maize yield to the applied irrigation water for a particular treatment (Howell *et al*. 1990) according to the following equations.

$$CWUE = Y/CWU$$

$$IWUE = Y/Wa$$

Where:

Y is the grain yield (kg ha^{-1}); CWU is the Crop Water Use (m^3 ha^{-1}) and Wa is the applied water (m^3 ha^{-1}).

Benefit-cost ratio (BCR) and net return (NR)

The farming cost includes mainly the operating and variable costs. The operating cost (labor, land preparation, seeds, fertilizers, and chemicals) were based on the planted area. Therefore, the operating costs of the two fixed furrow irrigation treatments were the same as the conventional every furrow irrigation treatment and it was 2500 Egyptian pound (LE) per hectare (Exchange rate: 1 LE ≈ 0.17US$; rate, in 2011). The variable costs depended on the number of irrigations and price per unit of water. The indigenous irrigation farmers in the studied area do not pay for water used in their farms. Therefore, they bear only the costs of labor used in irrigation (estimated 250 LE ha^{-1} based on the irrigated area and the man-day labor cost of 50 LE), as well as the price of fuel used to run a pump to withdraw water from irrigation canals. The price of water unit was estimated to be 0.25 LE m^{-3}. The total cost of water for each season was calculated by multiplying the price of water unit to total quantity of irrigation water required for the maize crop. The gross revenue has been calculated by multiplying the total yield in kilogram per hectare and market price of maize per kilogram. In this study the farm-gate price for maize grain was 1.6 LE kg^{-1} (a locally price). The net profits and benefit-cost ratio (BCR) due to irrigation were calculated according to (Sampath and Nobe 1983; Li *et al*. 2005**)** as follows:

$$\text{Net profits} = \text{Gross revenue} - \text{Farming costs}$$

$$BCR = \text{Net profits}/\text{Farming costs}$$

The net return (NR) from the irrigation treatment that lead to increase the grain yield was calculated by summing the cost of saved water and the revenue increase due to yield increase. On the other hand, the NR from the irrigation treatment that lead to decrease the grain yield was calculated as the difference between the cost of water saved and the revenue lost due to yield decrease. This was expressed as:

$$NR = (c \times WS) \pm (p \times YL)$$

Where:

WS is the volume of water saved per hectare; YL is the yield increase or decrease per hectare; c is the unit price per m^3 of water; and p is the unit price per kg of grain yield.

RESULTS AND DISCUSSIONS

Data in Table (2) showed that the yield under FFI_7 and EFI treatments were higher than that obtained from FFI_{14}, which reached 8.40 and 8.12 t ha^{-1} (average over the two seasons), respectively. The grain yield as average over the two seasons under the FFI_7 treatment increased by 0.28 t ha^{-1}, whereas FFI_{14} decreased the yield by 1.64 t ha^{-1} in comparison to the EFI. This might be due to the less amount of applied irrigation water under FFI_{14}, which did not match full maize water requirements. This caused water stress and consequently reduced crop yield. This result is in parallel with those reported by Rafiee and Shakarami (2010). However, The FFI_{14} treatment was more in water saving (76 mm) than the AFI_7 (47 mm) as average over the two seasons. In general, more frequent irrigation interval (7 day) in fixed furrow resulted in higher grain yield than less frequent irrigation interval (14 day). Ibrahim and Kandil (2007) reported the same results. Moreover, Sepaskhah and Ghasemi (2008) found that more frequent irrigation (10-days interval) with higher air evaporation potential resulted in higher application of irrigation water and grain and top yields of grain sorghum.

The results of 2-years average (Table 2) showed that AIW under the FFI_7 (1017 mm) was not equal to that applied under EFI (1063 mm); however, grain yield increased (0.28 t ha^{-1}). On the other hand, not acceptable grain yield decrease (1.64 t ha^{-1}) was observed with less amount of IWA (988 mm) under FFI_{14} treatment in comparison to conventional irrigation (EFI). The small amount of AIW with the FFI_{14} and AFI_7 treatments compared to the EFI, could be attributed to the nature of the two treatments, which they supply water in a manner that greatly reduces the amount of surface wetted, leading to less evapotranspiration and less deep percolation. On the other hand, the amount of AIW was more with fixed furrow irrigation at 7-day intervals than at 14-day intervals. This can be attributed to more frequent irrigation, which resulted in higher evaporation from the soil surface, and high available soil moisture, which subjected to more absorption and consequently increased transpiration, especially during the early part of the growing season with incomplete ground cover. In addition, less crop water use efficiency and irrigation water uses efficiency under fixed furrow irrigation at 14-day intervals scheme.

Table (2): Applied irrigation water (AIW), crop water use (CWU), crop water use efficiency (CWUE) and irrigation water use efficiency (IWUE) under different irrigation treatments

Treatments [a]	EFI			FFI_7			FFI_{14}		
	1st S [b]	2nd S	Avg. [c]	1st S	2nd S	Avg.	1st S	2nd S	Avg.
Grain yield ($t\ ha^{-1}$)	7.84	8.40	8.12	8.10	8.70	8.40	6.50	6.80	6.70
Yield increase (+) or loss (-) ($t\ ha^{-1}$)	-	-	-	0.26	0.30	0.28	- 1.64	- 1.60	- 1.62
AIW (mm)	1058	1068	1063	1010	1023	1017	985	990	988
Water saving ($m^3\ ha^{-1}$)	-	-	-	48	45	47	73	78	76
CWU (mm)	825	833	829	795	803	799	752	772	762
CWUE ($kg\ m^{-3}$)	0.95	1.01	0.98	1.02	1.08	1.05	0.86	0.88	0.87
IWUE ($kg\ m^{-3}$)	0.74	0.79	0.77	0.80	1.08	0.94	0.66	0.69	0.68

[a] EFI, AFI7, and FFI14 are referred to Every Furrow Irrigation, Fixed-Furrow Irrigation with 7-day intervals, and Fixed-Furrow Irrigation with 14-day intervals, respectively
[b] 1st S, 2nd S and 3rd S are referred to first seasons, second season and third season, respectively
[c] Avg. are referred to average over the two seasons

The results of 2-years average (Table 2) showed that the highest CWU (829 mm) was recorded under EFI. This is followed by 799 mm under FFI_7. The lowest value (762 mm) was obtained under FFI_{14} treatment. The CWU under EFI and FFI_7 was higher than the FFI_{14} treatment, which could be attributed to the sufficient soil moisture in the effective root zone with the EFI and FFI_7 treatment, which received regular watering during the growing season. The lowest CWU observed under the FFI_{14}, may be due to that maize plants, grown under the condition of the FFI_{14} treatment were subjected to moisture stress resulted from less frequent irrigation and less quantity of applied water according to the nature of such technique.

On the other hand, from the 2-years average the highest CWUE value was 1.05 kg m^{-3} as recorded with FFI_7 treatment, followed by 0.98 and 0.87 kg m^{-3} with EFI and FFI_{14}, respectively, Table 2. The highest IWCU obtained under FFI_7 is 0.94 kg m^{-3}, followed by 0.77 kg m^{-3} obtained from EFI treatment, whereas the lowest IWUE reached 0.68 kg m^{-3} under FFI_{14} treatment. These results indicated that fixed-furrow irrigation at 7-days interval is appropriate method to increase CWUE and IWUE, because it allows to apply of less irrigation water, under the present trial. This finding confirms the finding of Slatni *et al*. (2011) who conducted field experiment to evaluate three irrigation techniques e.g. AFI, FFI and CFI for a potato crop. The author added that application and irrigation efficiency were the highest in FFI and lowest in CFI. The CWUE obtained from various irrigation treatments confirm the potency of deficit irrigation in enhancing the CWUE criterion. The high CWUE value obtained with fixed-furrow irrigation at 7-days interval compared to EFI could be due to the high yield obtained with this treatment. The IWUE offers a clear picture of the effectiveness of irrigation water applied. In general, the IWUE was high with the fixed furrow irrigation at 7-days interval. This could be due to less amount of applied water compared to EFI treatment.

The maximum BCR was 1.80 and 1.61 obtained from FFI_7, followed by 1.60 and 1.44 from EFI, whereas the minimum was 1.07 and 1.15 observed with FFI_{14} in the 1^{st} and 2^{nd} seasons, respectively (Table 3). The maximum NR were 625 and 598 LE ha^{-1} as obtained from FFI_7, compared to the EFI, in the 1^{st} and 2^{nd} seasons, respectively. The other treatment FFI_{14} did not achieved any NR in both seasons (Table 3).

Table (3): Benefit-cost ratio (BCR) and net return (NR) associated with the adopted irrigation treatments

Treatments [a]	Season	Cost of water applied LE ha^{-1}	Farming cost LE ha^{-1} [c]	Gross revenue LE ha^{-1}	Net profit LE ha^{-1}	(BCR)	(NR) LE ha^{-1}
EFI	1^{st}	2645	5145	12544	7399	1.44	-
	2^{nd}	2670	5170	13440	8270	1.60	-
FFI_7	1^{st}	2463	4963	12960	7997	1.61	598
	2^{nd}	2475	4975	13920	8945	1.80	625
FFI_{14}	1^{st}	2525	5025	10400	5375	1.07	- 2024
	2^{nd}	2558	5058	10880	5822	1.15	- 2448

[a] EFI, AFI7, and FFI14 are referred to Every Furrow Irrigation, Fixed-Furrow Irrigation with 7-day intervals, and Fixed-Furrow Irrigation with 14-day intervals, respectively
[c] Calculated as summing of operating cost (2500 LE ha^{-1}) and farming cost

Khan *et al*. (2005) reported that the economic importance of the used water could be worked out for specific situation prior to the large-scale adoption for commercial plant production. However, the use of irrigation intervals for better growth and higher yield could be economically attractive to reduce the drought stressed conditions in water limiting areas. Among different irrigation treatments, fixed furrow irrigation with 7-days interval (FFI_7) resulted in the maximum return and the highest BCR in both seasons of study. These results could be due to developing and improving CWUE with the FFI_7, which leads to high yield.

CONCLUSIONS

Deficit irrigation treatments; i.e. fixed-furrow (FFI_7 with 7 days interval and FFI_{14} with 14 days interval) for irrigated maize were investigated at the Middle Nile Delta area of Egypt compared with every furrow irrigation (EFI, conventional method with 14 days interval). It can be concluded that the FFI_7 treatment controlled stress irrigation without grain yield reduction risk. Moreover, it increased the benefit-cost ratio (BCR), net return (NR), and saved irrigation water. The preference between FFI_7 treatment and other treatments depends on the value of water with relation to crop returns. Therefore, it is recommended that if water was available with no high cost, and the excess water delivery to the field did not require additional expense, then the fixed furrow irrigation with 7-days interval will practically be the best choice under the conditions of the studied area.

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مقارنة اثنان من مخططات الري السطحي بالري السطحي العادي لمحصول الأذرة بوسط دلتا النيل

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تم دراسة ري عدد من الخطوط الثابتة (نصف الخطوط فقط) باستمرار خلال فترات ري كل 7 أيام وكذلك كل 14 يوم وتأثيرها علي محصول الأذرة الشامية وعلاقاته المائية المختلفة مقارنة بالري السطحي العادي (الري العادي لجميع الخطوط كل 14 يوم)

وكانت النتائج كالتالي:

1-تحت ظروف الري لنصف الخطوط الثابتة (كل 7 أو 14 يوم) انخفضت كميات المياه المضافة مقارنة بالري العادي لجميع الخطوط كل 14 يوم.

2-انخفض محصول الحبوب تحت ظروف الري لنصف الخطوط الثابتة كل 14 يوم بينما ازداد مع ظروف الري لبعض الخطوط الثابتة كل 7 أيام وذلك مقارنة بالري العادي لجميع الخطوط كل 14 يوم.

3-تحسنت كفاءة استخدام مياه الري تحت نظام الري لنصف الخطوط الثابتة كل 7 أيام وذلك مقارنة بالري العادي لجميع الخطوط كل 14 يوم.

4-أدي الري لنصف الخطوط الثابتة كل 7 أيام إلي زيادة قيمة الفائدة للتكاليف وقيمة العائد الاقتصادي.

5-أدي الري لنصف الخطوط الثابتة كل 7 أيام إلي توفير مياه الري.

قام بتحكيم البحث

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