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Enhancing Irrigation Water Productivity of Rice Using Irrigation Intervals, Transplanting Methods and Weed Control in North Nile Delta

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ABSTRACT

Water is the main limiting factor for agricultural expansion in arid and semi-arid regions as well as Egypt. So two field experiments were carried out during 2015 and 2016 summer season at the experimental farm of Sakha Agricultural Research Station, Egypt to enhance water productivity of rice using irrigation intervals, transplanting methods and weed control treatments. Strip split-plot design with three replicates was used in infested weedy soils. Irrigation intervals were in the horizontal plots, it was irrigate every three days as a farmer practices (I_1), every six days (I_2) and every nine days (I_3). Transplanting methods were located in vertical plots contained; transplanting in flat soil as a traditional method (M_1) and transplanting in bottom of raised-bed (M_2). While weed control treatments were assigned in sub-plots, it was penoxsulam (Granite) 24% SC (W_1), penoxsulam + orthosulfamuron 50% WG (Kelion) (W_2), thiobencarb50% EC (Citron) ***fb*** penoxsulam (W_3), weedy check (W_4) and hand weeding twice (W_5). Results showed that treatment of I_1 was the best in weed management, rice dry weight, number of panicles/m^2, number of filled grain/panicle, 1000-grain weight and grain yield. Irrigation treatments of I_2 and I_3 saved about 20.7 % and 29.9 % of irrigation water compared to I_1, while the highest productivity of irrigation water (PIW) were recorded by treatment of I_2 compared to I_1 and I_3. The lowest fresh and dry weights of total weeds and the highest values of rice dry weight, number of panicles/m^2, number of filled grains/panicle, 1000-grain weight were recorded by M_1 as compared to M_2, in addition rice grain yield of M_1 was increased by 7.1 % compared to M_2 as mean of the two growing seasons. Transplanting method of M_2 saved about 21.2 % of irrigation water and increased PIW by 18.4 % compared to M_1. The best weed management beside the highest values of number of panicles/m^2, number of filled grain/panicle, 1000-grain and grain yield of rice were obtained by W_3 compared to rest weed control treatments and it take the descending order $W_3 > W_5 = W_2 > W_1 > W_4$ in the two seasons of study. The interaction of $I_2 \times M_1 \times W_3$ was superior treatment for rice grain yield. But, under shortage of water, increasing irrigation water productivity of rice could be achieved by the superior interaction of $I_2 \times M_2 \times W_3$ because it resulted in the highest irrigation water productivity of rice to be 0.98 kg m^{-3}.

Keywords: Rice, transplanting methods, weed control, irrigation intervals, water productivity.

INTRODUCTION

Rice consider the main source of calories for more than half of the world's population(Carrijo *et al.*, 2017). The per capita consumption of rice is more than 50 kg per year Globally(FAOSTAT, 2016). Traditional transplanting method of rice as flooded paddy soils, requires higher water inputs than other cereal crops(Pimentel *et al.*, 2004 and Carrijo *et al.*, 2017).So many researchers around the world as well as in Egypt tested renewly transplanting methods and different irrigation regimes to find ways to save some of irrigation water without any considerable reduction in productivity to cope with the rapidly population increase and water shortage.

Seedling rice plant in beds and furrows saved about 60 cm of irrigation water compared to seedling in the traditional flat puddles (Devinder *et al.*, 2005 and Jagroop *et al.*, 2007) moreover, it increased water productivity by about 44 -50% compared to traditional transplanting (Jagroop *et al.*, 2007). Transplanting rice on the bed is the best transplanting technique because it increased yield and yield components compared to others transplanting methods(Khattak *et al.*, 2006). Transplanting rice on wide raised beds saved about 15%–24% form irrigation water compared to continuously flooded (Naresh *et al.*, 2014). In Egypt, transplanted rice in bottom of beds increased rice yield by 3 - 20 % and water productivity by 58 - 66%. Moreover, it saved about 27 - 38% from irrigation water compared to transplanting in traditional flat soil (Meleha *et al.*, 2008; El-Atawy, 2012 and Mahmoud, 2015).

Irrigation intervals once every 5 - 6 days recorded on par yield that irrigation once every 8-9 days and irrigation once every 11-12 days. While, it recorded significantly higher yield than irrigation once every 13-14 days and irrigation once every 16-17 in aerobic rice(Murali, 2009). Grain yield was statistically the same under 8 days intervals and continuous flooding however, water consumption decreased by about 18% under 8 days interval, but the lowest grain yield were of 11 days interval (Ashouri, 2012 and Ashouri, 2014).

Alternate wetting and drying for rice saved about 15% - 50% from irrigation water (Naresh *et al*., 2014) and increased irrigation water productivity by 5-35% compared to continuous flooding (Romeo *et al*., 2004). It could affect positively or negatively on rice grain yield depending on the degree or the period of wetting and drying cycles. There were no significant differences in grain yield among alternate wetting and drying and continuous flooding (Liang *et al*., 2016). Rice grain yield and number of productive tillers were significantly greater under alternate wetting compared to continuous flooding (Norton *et al*., 2017). On the other hand, there were significant decrease in rice grain yield when use severe alternate wetting and drying compared to continuous flooded (Carrijo *et al*., 2017; Kumar *et al*., 2017). While the amount of saved irrigation water and water productivity increased when using alternate wetting and drying (Liang *et al*., 2016; Carrijo *et al*., 2017; Kar *et al*., 2017 and Kumar *et al*., 2017).

Weeds is one of the most serious problems in rice production system especially in aerobic conditions and water shortage leading to wide irrigation intervals which motivate weed seeds germination and growth to compete with the crop on water, nutrients, place and light resulting in undesirable growth conditions for rice causing yield losses in the economic yield of rice (Abd El-Naby *et al.,* 2017).

Bajavathiannan *et al*., (2011) concluded that weed management was higher in the flooded transplanting than furrow-irrigation method (up to 20% greater), because flooding effectively prevented the germination of most terrestrial weeds. In addition, rice grain yields were 13 to 14% greater in flooded compared with furrow-irrigated plots. Applying the mixture of fenoxaprop-ethyl + ethoxysulfuron at rate of 50 + 18 g ai ha^{-1} at 21 days after seeding (DAS) or pendimethalin followed by (*fb*) chlorimuron + metsulfuron at rate of 1000 and 4 g ai ha^{-1} applied at 3 *fb* 21 DAS was the most effective and economical herbicides to manage both of grassy and broadleaves weeds (Singh *et al*., 2008).

The main objective of this study was to enhance productivity of irrigation water and rice yield using transplanting methods, irrigation intervals and weed control treatments.

MATERIALS AND METHODS

Two field experiments were conducted during 2015 and 2016 rice growing seasons at the experimental farm of Sakha Agricultural Research Station, Kafr El-Sheikh governorate, North Nile Delta of Egypt. It allocated at 31° 07' N Latitude, 30° 57' E Longitude. The weather data were taken from Sakha agro-meteorological station during 2015 and 2016 seasons as shown in Table (1).

Table 1. Sakha agro-meteorological data, (31° 07' N Latitude, 30° 05' E Longitude), during 2015 and 2016 seasons.

Seasons	Months	Air temperature			Relative humidity			Wind speed	Pan evaporation
		Max. °C	Min. °C	Mean °C	Max. %	Min. %	Mean %	Mean km d^{-1}	Mean mm d^{-1}
	May	30.90	18.79	24.49	77.30	46.10	61.70	114.60	7.10
	June	30.85	21.40	26.13	78.80	51.20	65.00	105.30	6.90
2015	July	33.00	22.40	27.70	85.20	54.30	69.75	97.30	6.90
	Aug.	35.10	25.00	30.05	83.80	51.70	67.75	91.20	8.10
	Sept.	34.60	23.80	29.20	82.70	46.50	64.60	98.30	6.60
	May	30.40	22.80	26.60	71.00	45.80	58.40	97.00	6.47
	June	33.60	26.30	29.95	75.70	46.60	61.15	112.80	8.07
2016	July	33.70	26.10	29.90	82.70	56.80	69.75	105.50	7.84
	Aug.	33.60	26.00	29.80	84.30	56.30	70.30	92.80	7.74
	Sept.	32.60	24.30	28.45	83.10	51.80	67.45	95.10	5.91

The mean values of some soil properties of the experiments site were determined before cultivation process, soil chemical properties were determined according to Page *et al*., (1982). Soil physical properties i.e., , bulk density, total porosity, field capacity, permanent wilting point and particle-size distribution were determined according to Klute, (1986) as shown in Table (2).

Table 2. Some soil physical and chemical properties of the experimental site as mean values of the two growth seasons.

Soil depth (cm)	Field capacity (%)	Wilting point (%)	Bulk density (Mg m^{-3})	Total porosity (%)	Sand (%)	Silt (%)	Clay (%)	Texture class	EC_e (dS m^{-1})	pH
0-15	46.34	25.72	1.14	56.98	20.40	25.12	54.48	Clayey	2.16	7.89
15-30	41.05	20.97	1.22	53.96	21.13	26.53	52.34	Clayey	2.49	7.96
30-45	39.48	21.24	1.38	47.92	21.27	27.13	51.60	Clayey	3.34	8.00
45-60	38.91	20.66	1.41	46.79	20.68	26.81	52.51	Clayey	3.91	8.25
Mean	41.45	22.15	1.27	51.41	20.87	26.40	52.73	Clayey	2.98	

Experimental design and treatments:

The experiment was laid out in a strip split-plot design with three replicates in infested weedy soils. Irrigation intervals were in horizontal plots included; irrigation every three days as a farmer practices (I_1), irrigation every six days (I_2) and irrigation every nine days (I_3). Transplanting methods were located in vertical plots, it was transplanting in flat soil as a traditional method (M_1) and transplanting on bottom of raised-beds (M_2). While weed control treatments were randomly allocated in sub-plots contained; penoxsulam 24% SC (Granite) (W_1), penoxsulam 24% SC + orthosulfamuron 50% WG (Kelion) (W_2), thiobencarb 50% EC (Citron) *fb* penoxsulam (W_3), weedy check (W_4) and hand weeding two times (W_5).

Irrigation water applied to each plot was determined using spile tubes, one spile of 10 cm inner diameter tubes to let water from field canal into every plot. The effective head of water above the cross section center of irrigation spile was measured several times. Stage gauges were located in each plot to measure water depth flowing through the spile. The amount of irrigation water in each application was added until it reaches the optimum submerged depth (7 cm), and the time of the water applied was recorded by a stop watch.

The amount of water delivered through the spile tube was calculated according to Majumdar (2002) by the equation (1)

$$q=CA\sqrt{2gh} \qquad (1)$$

Where:

q is irrigation discharge water (cm^3/s), C is a discharge coefficient equal 0.62 (determined by experiment), A is the inner cross section area of the irrigation spile (cm^2), G is a gravity acceleration (cm/s^2), and H is the mean effective head (cm).

The volume of water delivered for every plot was calculated by substituting Q in the following equation (2)

$$Q= q \times T \times n \qquad (2)$$

Where:

Q is the volume of water m^3/ plot, q is the discharge (m^3/min), T is total irrigation time (min) and n is number of spiles tube per each plot.

Seedlings of Sakha 107 cultivar as a new released rice cultivar was transplanted on the 1st of June in 2015 and 5th of June in 2016. Twenty-five days old seedlings were transplanted in hills spaced 20 x 20 cm for M_1 and 10 x 40 cm in the two rows at the bottom of beds for M_2. All treatments had 25 hills m^{-2}. Agricultural practices were applied as recommended.

Citron (thiobencarb 50% EC) at rate of 2.380 Kg ai ha^{-1} was added mixed with sand on flooded land at 4 days after transplanting (DAT) then kept soil flooded for three days after herbicidal application. Penoxsulam alone (W_1) at rate of 0.020 Kg ai ha^{-1} or mixed with Kelion (orthosulfamuron 50% WG) at rate of 0.0143 (W_2) were applied at 10 DAT, while Penoxsulam application after thiobencarb (W_3) was applied at 20 DAT. The three treatments were sprayed in 300 litter of water per hectare on wet land by using Knapsack sprayer then the soil was flooded after 24 hours from herbicidal application. Hand weeding (W_5) was applied two times at 20 and 40 DAT.

The collected data

At 30 days after herbicidal application, weeds were taken from 50 x 50 cm quadrate replicated four times per plot, weeds were cleaned then fresh weighted, air dried then oven dried to stable weight, dry weight as g m^{-2} was determined.

Also, rice dry weight was evaluated by the same method. Before harvest, panicles were counted in two random quadrates of 50 x 50 cm and number of panicles per square meter was recorded. After rice maturity, plant of the central 5 m^2 from each plot were manually harvested to assess grain yield then rice grain yield recorded at 14% moisture content.

Productivity of irrigation water (PIW)

The Productivity of irrigation water in kg grain /m^3 was calculated according to (Ali *et al.*, 2007), as follows:

$$\textbf{PIW (kg m}^{-3}\textbf{)} = \frac{\text{Grain yield in kg ha}^{-1}}{\text{Amount of applied water in m}^{3}\ \text{ha}^{-1}} \quad (3)$$

The statistical analysis

The collected data were exposed to proper statistical analysis of variance by the method described by Snedecor and Cochran (1971). Weed data were statistically analyzed by MSTATC program after transformed according to square-root transformation ($\sqrt{[x + 0.5]}$), while collected data were analysed by MSTATC program then the means of both weeds and rice characters were compared by Duncan´s Multiple Range Test (Duncan, 1955).

RESULTS AND DISCUSSION

A- Weed parameter:

The major weed species related with rice crop during the two growing seasons were grassy weeds including; *Echinochloa colona* (jungle rice) and *Dinebra retroflexa* and sedges included *Cyperus difformis* (small flower) in addition to broad leave weeds including (*Ammania baccifera*). Fresh and dry weights per square meter for each weed species then fresh and dry weights of total weeds were calculated and used as reliable indicators for weed distribution in rice plots.

1- Effect of irrigation intervals, transplanting methods and weed control treatments and their interactions on fresh and dry weights of total weeds during 2015 and 2016 seasons.

Data in Table (3) shows the effects of irrigation intervals, transplanting methods, weed control treatments and their interactions on fresh and dry weights of total weeds in 2015 and 2016 seasons. Irrigation every three days (I_1) recorded the lowest fresh and dry weights of total weeds followed by irrigation every six days (I_2), while the heaviest fresh and dry weights of total weeds were obtained from irrigated every nine days (I_3) in both seasons. It might be due to the continuous high moisture content of the soil under irrigation every three days which reduced weed seeds germination as compared to wide irrigation intervals. These findings are in agreement with those reported by Bagavathiannan *et al.*, (2011) and Naresh *et al.*, (2014).

In respect to transplanting methods, data displayed in Table (3) also revealed that there were significant variations between traditional and raised-bed transplanting methods in fresh and dry weights of total weeds during 2015 and 2016 seasons. Traditional transplanting method (M_1) recorded the lowest values of both fresh and dry weights of total weeds as well as the best weed management as compared to raised-bed transplanting method (M_2) in the two growing seasons. Higher weed biomass under raised-bed technique might be due to irregular distribution of water beside low and up spots in the field which encourage weed seeds germination especially in high spots and produce higher weed growth and biomass. On the opposite, traditional transplanting on flat and leveled land keep regular distribution of water on soil surface delayed or reduced germination of weeds.

Table 3. Means of fresh and dry weights of total weeds as affected by irrigation intervals, transplanting methods, weed control treatments and their interactions in 2015 and 2016 seasons. Weed data were subjected to square-root ($\sqrt{[x + 0.5]}$) transformation before analysis; transformed values are shown in parentheses.

Factor	Rate (Kg a.i ha^{-1})	Time of Application (DAT)	Total weeds fresh weight (g m^{-2})		Total weeds dry weight (g m^{-2})	
A-Irrigation interval			2015	2016	2015	2016
I_1	-	-	471.27 (17.49 c)	418.13 (16.5 c)	75.68 (7.4 c)	70.39 (7.0 c)
I_2	-	-	665.53 (21.30 b)	588.47 (20.3 b)	88.26 (8.2 b)	79.93 (7.5 b)
I_3	-	-	892.00 (23.82 a)	794.34 (23.4 a)	103.86 (8.9 a)	102.06 (8.3 a)
F. test	-	-	**	**	**	**
B-Transplanting method						
M_1	-	-	481.91 (18.43 b)	450.14 (17.8 b)	76.77 (7.2 b)	81.03 (7.4 b)
M_2	-	-	828.62 (23.31 a)	750.22 (22.3 a)	101.76 (9.1 a)	87.22 (7.8 a)
F. test	-	-	**	**	*	*
C- Weed control						
W_1	0.020	10	280.44 (16.38 b)	269.26 (16.1 b)	58.59 (7.6 b)	46.16 (6.8 b)
W_2	0.020 + 0.0143	10	220.78 (14.59 c)	210.4 (14.2 c)	43.97 (6.5 c)	32.41 (5.7 c)
W_3	2.380 *fb* 0.020	4 *fb* 20	116.44 (10.42 d)	105.23 (9.9 d)	17.62 (4.0 e)	7.13 (2.7 e)
W_4	-	-	2448.22 (48.60 a)	2221.44 (46.2 a)	294.22 (17.1a)	305.37 (17.4a)
W_5	twice	20 *fb* 40	210.44 (14.38 c)	194.22 (13.8 c)	31.92 (5.6 d)	29.55 (5.5 d)
F. test	-	-	**	**	**	**
Interactions						
I x M	-	-	NS	NS	NS	NS
I x W	-	-	NS	NS	**	**
M x W	-	-	NS	NS	**	**
I x M x W	-	-	**	*	NS	NS

***, **, N.S indicates P< 0.05, P< 0.01 and not significant, respectively. Means of transformed data followed by the same letter are not significantly different at 5% level, using Duncan's Multiple Range Test. ai = active ingredient. DAT= days after transplanting.**

Regarding weed management treatments, it is obvious from data in Table (3) that weed control treatments had significant effects on total weeds fresh and dry biomass in both seasons of the study. Application of W_3 weed control treatment (thiobencarb 50% at 4 DAT ***fb*** penoxsulam 24% at 20 DAT) gave the highest efficient weed management as well as the lowest values of both fresh and dry biomass of total weeds followed by hand weeding twice in the two growing seasons. On the other hand, the highest values of fresh and dry weights of total weeds were obtained by untreated plots (weedy check) in both seasons. These findings are in harmony with data obtained by Singh *et al*., (2006) and Chongthan *et al*., (2016).

2- Effect of the interaction between irrigation intervals and weed control treatments on dry weight of total weeds in 2015 and 2016 seasons.

It could be observed from obtained data in Figure (1) that the interaction among irrigation intervals and weed management treatments was markedly influenced dry weights of total weeds over the two seasons. Application of W_3 in plots irrigated every three or six as well as irrigation every nine days recorded the lowest total weeds dry weight and best weed management in the two seasons, this may be due to high efficiency of sequential application of herbicides which inhibit weed seeds germination and kill the germinated weeds. While, the heaviest dry weight of total weeds was detected from untreated plots irrigated every nine days (I_3) in 2015 and 2016 seasons. Abou El-Darag *et al*., (2017) cited that the least dry weights of *Echinochloa crus-galli*, *Cyperus difformis* and total weeds, number of panicles / hill and the maximum rice grain yields were recorded under flooded plots received Thiobencarb at two rates of 2.4 and 3.6 kg ai ha^{-1} as compared to saturated land and irrigation 4 days on+ 6 days off.

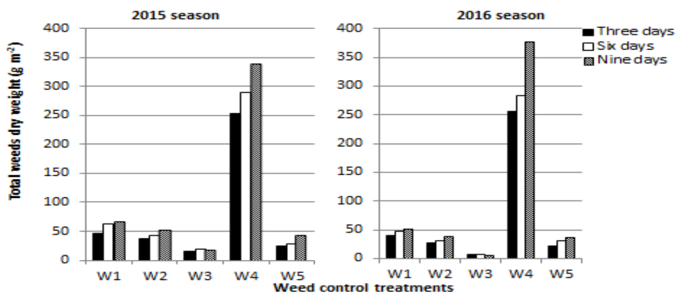

Figure 1. Effect of the interaction between irrigation intervals and weed control treatments on dry weight of total weeds during 2015 and 2016 seasons

3- Effect of the interaction among irrigation intervals, transplanting methods and weed control treatments on fresh weight of total weeds in 2015 and 2016 seasons.

The fresh weight of total weeds as affected by the interaction between irrigation intervals, transplanting methods and weed control treatments are presented in Table (4). Traditional transplanting plots which irrigated every three days and treated with W_3 weed control treatment achieved the best weed control and lowest values of total weeds fresh weights over the two seasons. While, the heaviest fresh weight of total weeds was detected by untreated plots irrigated every nine days under raised-bed transplanting method in both seasons of study. The superiority of I_1 x M_1 xW_3 may be due to integration among uniformity of water distribution which increases herbicide efficiency in inhibition and killing weeds under traditional transplanting conditions, which reduce weed-crop competitiveness resulting in maximizing rice growth and yield.

Table 4. Effect of the interaction among studied factors on fresh weight of total weeds during 2015 and 2016 seasons.

Irrigation interval	Transplanting method	Weed control treatment W_1	W_2	W_3	W_4	W_5
2015 season						
I_1	M_1	117.3 (10.8 op)	110.7 (10.5 p)	32.0 (5.6 r)	1214.0 34.8 f)	269.3 16.4 hi)
	M_2	228.0 (15.1 h-k)	141.3 (11.9 m-p)	70.7 (8.4 q)	2364.0 (48.6 c)	165.3 (12.8 l-o)
I_2	M_1	209.3 (14.5 i-l)	211.3 (14.5 i-l)	110.7 (10.5 p)	1798.7 (42.4 e)	137.3 (11.7 m-p)
	M_2	386.7 (19.6 g)	256.0 (16.0 hij)	186.7 (13.7 klm)	3165.3 (56.3 b)	193.3 (13.9 j-m)
I_3	M_1	285.3 (16.9 h)	230.7 (15.2 h-k)	126.6 (11.3 n-p)	2150.0 (46.4 d)	225.3 (15.0 h-k)
	M_2	456.0 (21.4 g)	374.7 (19.4 g)	172.0 (13.1 k-n)	3997.3 (63.2 a)	272.0 (16.5 hi)
2016 season						
I_1	M_1	109.3 (10.5 o)	102.7 (10.2 o)	26.7 (5.1 q)	1037.3 (32.2 e)	225.3 (15.0 ijk)
	M_2	213.3 (14.6 ijk)	134.7 (11.6 l-o)	56.0 (7.5 p)	2116.0 (46.0 c)	160.0 (12.7 k-o)
I_2	M_1	198.7 (14.1 i-l)	202.7 (14.2 ijk)	104.7 (10.3 o)	1703.3 (41.3 d)	121.3 (11.0 mno)
	M_2	360.0 (19.0 fg)	237.3 (15.4 hij)	170.7 (13.1 j-n)	2600.6 (50.8 b)	181.3 (13.4 j-m)
I_3	M_1	308.00 (17.6 gh)	220.0 (14.8 ijk)	114.7 (10.7 no)	2060.0 (45.4 c)	217.33 (14.7 ijk)
	M_2	428.0 (20.7 f)	365.3 (19.1 fg)	158.7 (12.6 k-o)	3811.33 (61.7 a)	260.0 (16.1 hi)

Means of transformed data followed by the same letter within a season are not significantly different at 5% level, using Duncan's Multiple Range Test.

B- Rice growth, yield and some yield attributes:

1- Effect of irrigation intervals, transplanting methods and weed control treatments and their interactions on number of panicles/m², number of filled grains per panicle, 1000-grain weight and grain yield of rice during 2015 and 2016 seasons.

Data in Table (5) show that there are highly significant effects of irrigation intervals, transplanting methods and weed control treatments on dry weight, number of panicles/m², number of filled grains/panicle, 1000-grain weight and grain yield of rice in the two growing seasons.

Irrigation every three days (I_1) exceeded the two rest irrigation intervals in all above mentioned traits in both seasons, except for number of panicles per square meter in the first season which significantly equalled with I_2. Irrigation interval of I_3 reduced rice grain yield by 17.6 % and 14.2 % compared to I_1 and I_2, respectively as mean of the two growing seasons. These results are similar to those reported by Bagavathiannan *et al*., (2011) Mahmoud (2015) and Abou El-Darag *et al*., (2017).

Table 5. Means of rice dry weight, number of panicles, filled grains per panicle and 1000-grain weight and grain yield of rice as affected by irrigation intervals, transplanting methods and weed control and their interactions in 2015 and 2016 seasons.

Factor	Rice dry weight ($g\ m^{-2}$)		No. of panicles/m²		No of filled grains per panicle		1000-grain Weight (g)		Rice grain yield (tons ha^{-1})	
A-Irrigation interval:	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
I_1	1124.7 a	1277.5 a	473.0 a	505.2 a	89.9 a	90.6 a	25.7 a	27.1 a	8.00 a	8.52 a
I_2	1076.4 b	1225.1 b	471.1 a	493.8 b	89.0 b	88.3 b	25.5 a	26.5 b	7.65 b	8.20 b
I_3	920.0 c	1112.2 c	435.3 b	452.2 c	85.1 c	82.7 c	24.8 b	25.4 c	6.45 c	7.15 c
F. test	**	**	**	**	**	**	**	**	**	**
B-Transplanting method:										
M_1	1087.4 a	1298.9a	475.0 a	507.3 a	89.5 a	88.5 a	25.6 a	26.9 a	7.78 a	8.11 a
M_2	993.3 b	1110.8 b	444.6 b	460.1 b	86.6 b	85.9 b	25.0 a	25.8 b	6.96 b	7.80 b
F test	**	*	*	*	**	*	NS	*	**	*
C- Weed control:										
W_1	970.8 d	1185.5 c	443.0 c	485.7 c	84.3 c	82.7 c	24.6 d	26.0 c	7.77 c	7.75 c
W_2	1111.1 c	1304.4 b	494.5 b	518.2 b	91.9 b	89.5 b	26.3 c	27.1 b	8.42 b	8.60 b
W_3	1327.6 a	1450.3 a	517.7 a	563.0 a	103.7 a	103.1 a	28.1 a	28.7 a	9.04 a	10.20 a
W_4	589.9 e	763.0 d	318.8 d	329.2 d	68.9 d	70.9 d	21.2 e	22.7 d	3.29 d	4.55 d
W_5	1202.6 b	1321.3 b	495.0 b	522.4 b	91.3 b	89.9 b	26.6 b	27.1 b	8.33 b	8.67 b
F test	**	**	**	**	**	**	**	**	**	**
Interactions:										
I x M	NS	NS	**	**	NS	NS	NS	NS	NS	NS
I x W	*	*	NS	NS	NS	NS	NS	NS	**	**
M x W	*	**	NS	NS	NS	NS	NS	NS	*	**
I x M x W	NS	NS	NS	NS	NS	NS	NS	NS	*	**

***, **, N.S indicates P< 0.05, P< 0.01 and not significant, respectively. Means of each factor within each column, values followed by the same letters are not significantly different at 5% level, using DMRT.**

The ordinary analysis of variance (Table 5) displayed significant differences of yield and its components between transplanting methods. The highest values of dry weight, number of panicles/m², number of filled grains/panicle and grain yield of rice in addition to 1000-grain weight were recorded by traditional transplanting method (M_1) through both growing seasons compared to raised-bed transplanting (M_2). Grain yield of transplanting method (M_1) increased by 7.1 % compared to (M_2) as mean of the two growing seasons. Bagavathiannan *et al*., (2011) found that rice grain yields recorded by flooded plots were higher than yields of furrow-irrigated plots by 13 to 14%.

Data in Table (5) also showed that there are significant differences of rice dry weight, number of panicles/m², number of filled grains/panicle, 1000-grain weight and grain yield among different weed control treatments. The highest significant positive effect on grain yield, number of panicles/m², number of filled grains/panicle and 1000-grain weight was recorded by W_3 weed control treatment compared with rest weed control treatments of the two growing season. Rice grain yield and its components had the descending order $W_3 > W_5 = W_2 > W_1 > W_4$ in the two growing seasons. Rice dry weight appeared significant response to the interaction of I x M and M x W in both seasons of the study. Except for I x M interaction, number of panicles/m² didn't show any significant response under rest interactions, number of filled grains per panicle and 1000-grain weight also didn't show any significant differences under all interactions in the two growing seasons as shown in Table (5). While, grain yield was significantly affected by I x W, M x W and I x M x W interactions in both growing seasons. Bagavathiannan *et al*., (2011) reported that weed control was superior in the flooded system compared with the furrow system (up to 20% greater), because flooding successfully prevented the emergence of greatest terrestrial weeds. These findings are in agreement with those obtained by Singh *et al*., (2006) and Abd El-Naby *et al*., (2017).

2- Effect of the interaction between irrigation intervals and weed control treatments on dry weight of rice during 2015 and 2016 seasons.

The interaction between irrigation intervals and weed control treatments significantly affected rice dry weight in the two growing seasons (Figure 2). The highest values of rice dry weight were recorded by I_1 x W_3 followed by I_2 x W_3 interactions in the two growing seasons, while the lowest values of rice dry weight were found at I_3 x W_4 interaction in the two growing seasons. Hassan (2002) and Ahmed *et al*. (2014).

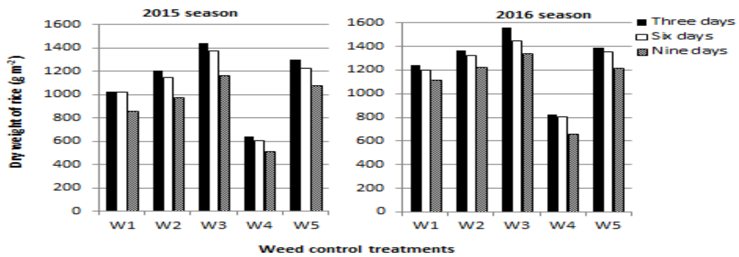

Figure 2. Effect of the interaction between irrigation intervals and weed control treatments on dry weight of rice during 2015 and 2016 seasons

3- Effect of the interaction between transplanting methods and weed control treatments on dry weight of rice during 2015 and 2016 seasons.

Data in Figure (3) showed that dry weight of rice was significantly influenced by the interaction between transplanting methods and weed control treatments in 2015 and 2016 seasons. The desirable values were recorded by M_1 x W_3 interaction, while the lowest values of rice dry weight were recorded after M_2 x W_4 interaction in both growing seasons. These results are similar to those reported by Chhokar *et al*. (2014) and Azme *et al.* (2016)

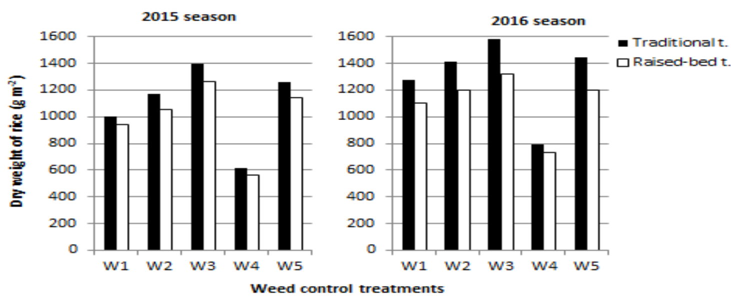

Figure 3. Effect of the interaction between transplanting methods and weed control treatments on dry weight of rice during 2015 and 2016 seasons

4- Effect of the interaction between irrigation intervals and transplanting methods on number of rice panicles per unit area during 2015 and 2016 seasons.

The interaction between irrigation intervals and transplanting method had significant differences of number of panicles/m^2 and grain yield of different interactions treatment. The highest values of number of panicles/m^2 and grain yield were detected from I_1 x M_1 and I_2 x M_1 interactions without any significant differences between them in the first season, while in the second season the highest values of them were obtained by I_1 x M_1 interaction. The lowest values of number of panicles/m^2 and grain yield were obtained by I_3 x M_3 in the two growing seasons as shown in Figure (4). These results are similar to those found by Ahmed *et al*. (2014) and Abou El-Darag *et al*., (2017).

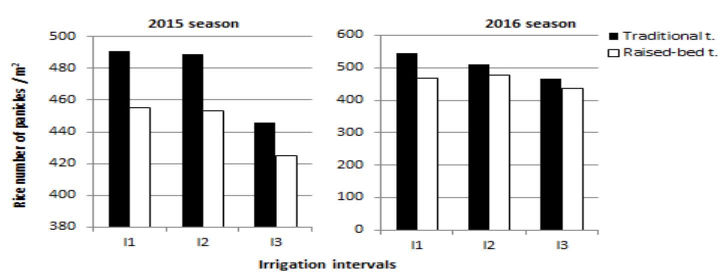

Figure 4. Effect of the interaction between irrigation intervals and transplanting methods on number of panicles of rice per square meter during 2015 and 2016 seasons.

5- Effect of the interaction between irrigation intervals and weed control treatments on rice grain yield during 2015 and 2016 seasons.

The interaction between irrigation intervals and weed control treatments had significant effects on grain yield of rice in both seasons of study (Figure 5). The highest values of grain yield were obtained from I_1 x W_3 and I_2 x W_3, this may be due to the high efficiency of W_3 in managing weeds under irrigation every three or six days which save more oxygen to root respiration and good vegetative growth and yield. While, the lowest values were recorded by I_3 x W_4 in the two growing seasons as shown in Figure (5). These findings are in agreement with those reported by Norton *et al.,* (2017).

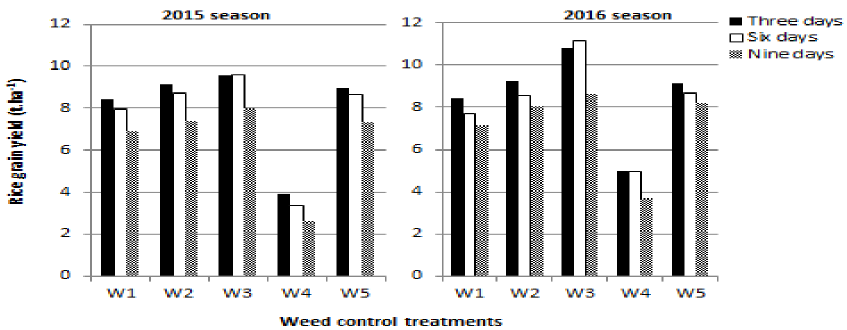

Figure 5. Effect of the interaction between irrigation intervals and weed control treatments on rice grain yield during 2015 and 2016 seasons.

6- Effect of the interaction between transplanting methods and weed control treatments on rice grain yield during 2015 and 2016 seasons.

Rice grain yield were affected significantly by the interactions between transplanting methods and weed control treatments in the two seasons of the study. The highest values of grain yield were found at M_1 x W_3 followed by M_2 x W_3 interactions in the two growing seasons. While, the lowest values of grain yield were recorded by M_2 x W_4 interaction in the two growing seasons as shown in Figure (6).

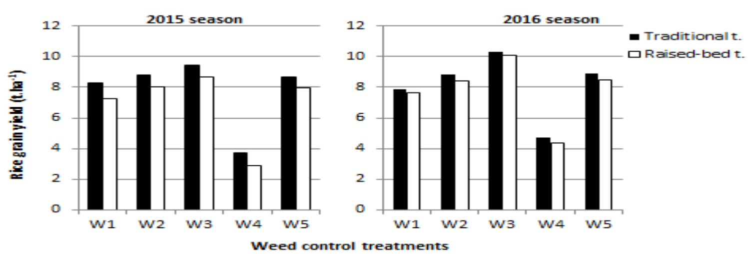

Figure 6. Effect of the interaction between transplanting methods and weed control treatments on rice grain yield during 2015 and 2016 seasons.

7- Effect of the interaction among irrigation intervals, transplanting methods and weed control treatment on rice grain yield during 2015 and 2016 seasons.

Data in Table (6) showed that the highest values of grain yield were found of I_1 x M_1 x W_3 and I_2 x M_1 x W_3 in 2015 and 2016 seasons on the same significance degree with I_2 X M_2 X W_3 in the second season. While, the lowest values of grain yield were recorded by I_3 x M_2 x W_4 interaction in the two growing seasons. Higher yield was obtained under these conditions may be due to good rice growth under short or medium irrigation intervals in addition to high efficiency of W_3 which gave the chance for rice to grow and maximize yields under both transplanting methods (Carrijo *et al.*, 2017 and Kumar *et al.*, 2017).

Table 6. Effect of the interaction among irrigation intervals, transplanting methods and weed control treatments on grain yield of rice during 2015 and 2016 seasons.

Irrigation interval	Transplanting method	Weed control treatment				
		2015 season				
		W_1	W_2	W_3	W_4	W_5
I_1	M_1	9.05 d	9.52 b	9.88 a	4.33 o	9.34bc
	M_2	7.83 i	8.72 e	9.20 cd	3.52 q	8.62 ef
I_2	M_1	8.49 efg	9.09 cd	10.01 a	3.75 p	9.12 cd
	M_2	7.42 jk	8.35 gh	9.13 cd	2.92 r	8.23 h
I_3	M_1	7.30 kl	7.83 i	8.40 fgh	3.00 r	7.57 j
	M_2	6.52 n	6.98 m	7.60 ij	2.22 s	7.11 lm
		2016 season				
I_1	M_1	8.84 d	9.91 c	10.95 a	5.24 l	9.70 c
	M_2	8.00 i	8.52 fg	10.65 b	4.76 m	8.57 efg
I_2	M_1	7.51 j	8.54 fg	11.19 a	5.26 L	8.64 def
	M_2	7.90 i	8.55 fg	11.09 a	4.68 m	8.65 def
I_3	M_1	7.15 k	7.97 i	8.82 de	3.73 n	8.33 gh
	M_2	7.12 k	8.13 hi	8.46 fg	3.63 n	8.15 hi

Means followed by a common letter within a season are not significantly differed at 5% level, using Duncan's Multiple Range Test.

C- Water use parameters:

1- Irrigation water applied (IWA).

Data in Table (7) show that the highest values of irrigation water applied were observed with I_1 to be 15097 m^3 ha^{-1}, while the lowest values were obtained from I_3 in the two growing seasons to be 10587 m^3 ha^{-1}. It means that increasing irrigation intervals, irrigation water applied decrease. Irrigation intervals of I_2 and I_3 saved irrigation water by 20.7 % and 29.9% compared to I_1 as a mean of the two growing seasons.

Table 7. Monthly and seasonal irrigation water applied (m^3 ha^{-1}) as related to irrigation intervals, transplanting methods and weed control treatments for2015 and 2016 growing seasons.

Treatments			2015					2016				
			Nursery and land preparation	June	July	August	Seasonal IWA (m^3 ha^{-1})	Nursery and land preparation	June	July	August	Seasonal IWA (m^3 ha^{-1})
I_1	M_1	W_1	2440	3077	5776	5241	16534	2682	4208	6328	3506	16724
		W_2	2440	3077	5780	5244	16541	2682	4208	6331	3508	16729
		W_3	2440	3077	5773	5239	16529	2682	4208	6322	3503	16715
		W_4	2440	3077	5783	5248	16548	2682	4208	6336	3511	16737
		W_5	2440	3077	5776	5240	16533	2682	4208	6328	3504	16722
	M_2	W_1	2109	2218	4636	4322	13285	2156	3085	5524	3070	13835
		W_2	2109	2218	4638	4326	13291	2156	3085	5527	3072	13840
		W_3	2109	2218	4633	4318	13278	2156	3085	5519	3068	13828
		W_4	2109	2218	4642	4329	13298	2156	3085	5531	3076	13848
		W_5	2109	2218	4636	4320	13283	2156	3085	5523	3070	13834
I_2	M_1	W_1	2440	3077	4255	3627	13399	2682	4208	4603	2306	13799
		W_2	2440	3077	4258	3629	13404	2682	4208	4607	2309	13806
		W_3	2440	3077	4251	3627	13395	2682	4208	4599	2303	13792
		W_4	2440	3077	4261	3632	13410	2682	4208	4611	2312	13813
		W_5	2440	3077	4253	3627	13397	2682	4208	4603	2304	13797
	M_2	W_1	2109	2218	3070	2549	9946	2156	3085	3641	1847	10729
		W_2	2109	2218	3074	2551	9952	2156	3085	3643	1848	10732
		W_3	2109	2218	3067	2548	9942	2156	3085	3638	1844	10723
		W_4	2109	2218	3078	2552	9957	2156	3085	3649	1848	10738
		W_5	2109	2218	3072	2549	9948	2156	3085	3643	1846	10730
I_3	M_1	W_1	2440	3077	3249	2937	11703	2682	4208	3406	1780	12076
		W_2	2440	3077	3252	2938	11707	2682	4208	3409	1782	12081
		W_3	2440	3077	3247	2935	11699	2682	4208	3403	1776	12069
		W_4	2440	3077	3254	2941	11712	2682	4208	3413	1784	12087
		W_5	2440	3077	3250	2937	11704	2682	4208	3406	1778	12074
	M_2	W_1	2109	2218	2292	2211	8830	2156	3085	2975	1518	9734
		W_2	2109	2218	2295	2214	8836	2156	3085	2978	1520	9739
		W_3	2109	2218	2289	2208	8824	2156	3085	2971	1515	9727
		W_4	2109	2218	2296	2215	8838	2156	3085	2982	1521	9744
		W_5	2109	2218	2292	2211	8830	2156	3085	2973	1517	9731
Overall Mean			M_1 = 13881 M_2 = 10689					M_1 = 14201 M_2 = 11434				
			I_1 = 14912 I_2= 11675 I_3= 10268					I_1 = 15281 I_2= 12266 I_3= 10906				
			W_1= 12282 W_2= 12289 W_3= 12278 W_4 = 12294 W_5 = 12282					W_1= 12816 W_2= 12821 W_3= 12809 W_4 = 12828 W_5 = 12815				

These results agree with those obtained with Bouman and Tuong (2001); Naresh *et al*., (2014); Marria *et al.,* (2016) and Basha and Sarma, (2017) who found that using irrigation periods, intermittent irrigation and alternative wetting and drying could be reduce irrigation input of rice crops compared to continuous flooding. Also, irrigation water applied of M_1 is higher than M_2 in the two growing seasons, M_2 saved about 21.2 % compared to M_1 as a mean of the two growing seasons, these result agree with those obtained by Jagroop *et al*., (2007); Meleha *et al*., (2008); El-Atawy (2012); Naresh *et al*., (2014) and Mahmoud, (2015) who reported that transplanting rice in raised bed saved applied irrigation water from 15 % to 38 % compared to traditional flat transplanting method.

Slight differences in applied irrigation water among different weed control treatments were observed in the two growing seasons. The lowest values were obtained from W_3, while the highest values of irrigation water applied were found with W_4. This may be due the highest recorded values of weed plants on plots as shown in Tables (3 and 7).

2- Productivity of irrigation water (PIW).

It is clear from the obtained data that irrigation interval of I_2 produced the highest value of PIW compared with the other irrigation intervals in the two growing seasons

Table 8. Influence of irrigation intervals, transplanting methods and weed control treatment on productivity of irrigation water (PIW) for 2015 and 2016 growing seasons.

Irrigation	Transplanting methods X Weed control treatments										Over all means
	M_1					M_2					
	W_1	W_2	W_3	W_4	W_5	W_1	W_2	W_3	W_4	W_5	
First season 2015											
I_1	0.55 k	0.58 jk	0.60 ijk	0.26 L	0.56 k	0.59 jk	0.66 gh	0.69 efg	0.26 L	0.65 ghi	0.54 c
I_2	0.63 g-j	0.68 fgh	0.75 de	0.28 L	0.68 fgh	0.74 de	0.84 bc	0.92 a	0.29 L	0.83 bc	0.67 a
I_3	0.62 hij	0.67 fgh	0.72 ef	0.26 L	0.65 ghi	0.74 de	0.79 cd	0.86 b	0.25 L	0.81 c	0.64 b
Over all means	M_1= 0.57 b					M_2= 0.66 a					
	W_1 = 0.65 c		W_2 = 0.70 b		W_3 = 0.76 a		W_4= 0.27 d		W_5= 0.70b		
Second season 2016											
I_1	0.53 k	0.59 ij	0.65 gh	0.31 n	0.58 ijk	0.58 ijk	0.62 hi	0.77 de	0.34 mn	0.62 hi	0.56 b
I_2	0.54 jk	0.62 hi	0.81 cd	0.38 m	0.63 hi	0.74 ef	0.80 cd	1.03 a	0.44 L	0.81 cd	0.68 a
I_3	0.59 ij	0.66 gh	0.78 ef	0.34 n	0.69 fg	0.73 ef	0.83 bc	0.87 b	0.37 m	0.84 bc	0.66a
Over all means	M_1= 0.57 b					M_2= 0.69 a					
	W_1 = 0.62 c		W_2 = 0.69 b		W_3 = 0.81 a		W_4= 0.36 d		W_5= 0.69 b		

Means followed by a common letter within a season are not significantly differed at 5% level, using Duncan's Multiple Range Test.

Irrigation interval of I_2 and I_3 increased PIW by 22.7% and 18.2% compared to irrigation interval treatment of I_1 as a mean of the two growing seasons. This finding can be explained on the base of increasing grain productivity of rice and lower water losses using transplanting method and weed control. These results are in harmony with those obtained by Bouman and Tuong, (2001); Romeo *et al*., (2004); Naresh *et al*., (2014); Mahmoud (2015); Marria *et al*., (2016); Basha and Sarma, (2017) who found that using irrigation periods, intermittent irrigation, alternative wetting and drying could reduce irrigation input of rice crops compared to continuous flooding as shown in Table (8) .

Transplanting method of M_2 increased PIW by 23.6% compared to M_1 as a mean of the two growing seasons. These result are in harmony with those obtained by Jagroop *et al*., (2007); Meleha *et al*., (2008); El-Atawy (2012); Naresh *et al*., (2014) and Mahmoud (2015) who found that transplanting rice in raised beds increased productivity of irrigation water from 44% to 66% compared to traditional flat planting method. Productivity of irrigation water at different weed control treatments had the descending order W_3> W_2= W_5 >W_1>W_4 in the two growing seasons. It increased of W_1, W_2 and W_3 by 101.6 %, 120.6% and 149.2% compared to W_4 as a mean of the two growing seasons. The increases in PIW values due to the fact that W_3 increases growth characters, photosynthetic activity and provide adequate nutrition for rice crop plants which play a major role in the efficient use and conservation of water resources. PIW determines the capability of the plants to convert the water applied to yield. The increases in PIW was mainly related to the role of weed control and planning method to promote and support growth which was the result of raising photosynthesis assimilation in building metabolites and consequently yield is enhanced.

The interaction between irrigation intervals, transplanting methods and weed control treatments showed significant differences in PIW between all interactions in the two growing seasons. The highest values of PIW resulted from I_2 x M_2 x W_3 flowed by I_3 x M_2 x W_3 interactions in the two growing seasons. It increased after these two interactions by 71% and 51.8% respectively compared to I_1 x M_1 x W_5 also, it increased after the same two interactions by 283.9% and 203.5% respectively compared to I_1 x M_1 x W_4 as a mean of the two growing seasons. While, the lowest values of PIW resulted from I_1 x M_1 x W_4 and I_3 x M_1 x W_4 to be 0.29 and 0.30 kg m^{-1} as mean of the two growing seasons. These results are in agreement with those obtained by (Mahmoud, 2015) who found that irrigation intervals every six days and transplanting rice in raised beds increased water productivity compared to traditional flat transplanting and irrigation intervals every three days as shown in Table (8).

CONCLUSION

Irrigation every six days (I_2) using traditional transplanting method (M_1) treated with thiobencarb 50% EC *fb* penoxsulam 24% SC as weed control treatment (W_3) recorded the highest rice grain yield (10.60 tons ha^{-1}). But under water shortage, irrigation water productivity of rice could be increased by the superior interaction of irrigation every six days (I_2) with cultivating rice in bottoms of raised-bed (M_2) treated with thiobencarb 50% EC ***fb*** penoxsulam 24% SC as weed control treatment (W_3) which produced the highest irrigation water productivity of rice to be 0.98 kg m^{-3} as mean of the two growing seasons.

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تحسين انتاجية المياه للأرز باستخدام فترات للري وطرق شتل ومعاملات مكافحة الحشائش في شمال دلتا النيل

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تعتبر المياه العامل الرئيسى المحدد للتوسع الزراعى فى المناطق الجافة وشبة الجافة وكذلك مصر. لذلك أجريت تجربتان حقليتان خلال الموسمين الزراعيين 2015 و 2016 بمحطة البحوث الزراعية بسخا وذلك لتحسين انتاجية مياه الرى لمحصول الأرز باستخدام فترات رى مختلفة وطرق شتل وكذلك معاملات مكافحة الحشائش. تم استخدام تصميم الشرائح المنشقة ذو ثلاث مكررات، حيث وزعت فترات الرى عشوائياً فى الشرائح الأفقية وتضمنت الرى كل ثلاث أيام (I_1) وكل ستة أيام (I_2) وكل تسعة أيام (I_3)، ووزعت طرق الشتل في الشرائح الرأسية وهى الشتل التقليدى بارض مستوية (M_1) والشتل فى بطن المصاطب (M_2) في حين وزعت معاملات مكافحة الحشائش عشوائياً فى القطع المنشقة الفرعية وهى بينوكسولام 24% (جرانيت) بمعدل 20 جرام مادة فعالة للهكتار (W_1)، بينوكسولام 24% + أورثوسالفوران 50% (كليون) بمعدل 75 جرام مادة فعالة للهكتار (W_2)، ثيوبينكارب 50% (سيترون) بمعدل 1000 جرام مادة فعالة للهكتار متبوعاً بمبيد بينوكسولام 24% بمعدل 20 جرام مادة فعالة للهكتار (W_3) مقارنة بغير المعامل أوكنترول (W_4) والنقاوة اليدوية مرتين (W_5). أوضحت النتائج ان معاملة الرى كل 3 ايام حققت أفضل مكافحة للحشائش واعطت افضل القيم لوزن الارز الجاف وعدد السنابل بالمتر المربع وعدد الحبوب الممتلئة بالسنبلة ووزن الألف حبة ومحصول حبوب الارز. حققت معاملتي الري كل ستة وتسعة أيام توفير في مياه الرى بمقدار 20.7 % و 29.9% مقارنة بالري كل ثلاثة أيام في حين كانت اعلى انتاجية لمياه الرى عند الرى كل 6 ايام مقارنة بمعاملتى الرى كل 3 و 9 ايام . سجلت طريقة الشتل التقليدي أقل وزن رطب وجاف للحشائش بالاضافة لأعلى وزن جاف للأرز، عدد السنابل/م^2، عدد الحبوب الممتلئة/ الدالية، وزن الألف حبة ومحصول الحبوب للأرزمقارنة بالشتل في بطن المصاطب حيث ازداد محصول الحبوب بمقدار 7.1% في الشتل التقليدي عن الشتل في بطن المصاطب خلال موسمى الزراعة. بينما وفرت طريقة الشتل في بطن المصاطب 21.2 % من مياه الري مقارنة بالشتل التقليدي، كما أدت الى زيادة انتاجية المياه بمقدار 18.4% خلال موسمى الزراعة مقارنة بالشتل التقليدي. سجلت معاملة مكافحة الحشائش الثالثة W_3 أقل وزن غض وجاف للحشائش الكلية وأعلى القيم لكل من الوزن الجاف للأرز، عدد السنابل/م^2، عدد الحبوب الممتلئة بالدالية، وزن الألف حبة ومحصول الحبوب للأرز مقارن بباقى معاملات مكافحة الحشائش وأخذت هذة المعاملات الترتيب التنازلى التالي المعاملة الثالثة يليها المعاملة الثانية مساوية للمعاملة الخامسة يليها المعاملة الأولى ثم المعاملة الرابعة (غير المعامل) خلال موسمى الزراعة. الرى كل 6 ايام مع طريقة الشتل التقليدي و اضافة مبيد الحشائش ثيوبينكارب 50% (سيترون) بمعدل 1000 جرام مادة فعالة للهكتار متبوعاً بمبيد بينوكسولام 24% بمعدل 20 جرام مادة فعالة للهكتار كان التفاعل الأفضل للحصول على أعلى محصول حبوب من الأرز. ولكن في حالة نقص الماء فانة يمكن زيادة انتاجية المياه لمحصول الارز عن طريق تطبيق التفاعل الافضل وهو الرى كل 6 ايام والشتل فى بطن المصاطب مع استخدام مبيدات الحشائش ثيوبينكارب 50% (سيترون) بمعدل 1000 جرام مادة فعالة للهكتار متبوعاً بمبيد بينوكسولام 24% بمعدل 20 جرام مادة فعالة للهكتار للحصول على أعلى انتاجية لمياه الري لتكون 0.98 كيلوجرام حبوب لكل متر مكعب من مياه الرى.