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Improving Irrigation Regimes and Plant Spacing to Maximize Rice Grain Yield and Water Productivity

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ABSTRACT

Field experiments were initiated during 2017 and 2018 seasons at the Experimental Farm of Sakha Research Station, Kafr El-Sheikh, Egypt to explore the effects of different irrigation regimes and plant spacing on growth, grain yield and water productivity of Giza 179 rice cultivar. The experiments were laid out in a strip-plot design with three replications. Three irrigation treatments namely, continuous flooding (CF), irrigation every 6 (6D) and 9 days (9D) were located in the horizontal plots. However, the vertical plots were occupied by four plant spacing i.e. 15 x 20, 20 x 20, 25 x 20 and 30 x 20 cm. The main results revealed growth, grain yield and it components were significantly increased at CF and 6D compared to 9D treatment. The close spacing (15 x 20 or 20 x 20 cm) registered higher values of growth and grain yield than of wider one (30 x 20 cm). The density response gradually increased with prolonging irrigation from CF to 6D and recorded the maximum response to narrow spacing 9D treatment. CF recorded the highest amount of water usage, while the lowest amount was received by 9D treatment. Irrigation every 6 days gave similar grain yield to CF with less amount of water and gave reasonable water productivity. Generally, it could be concluded that, under the same conditions, using irrigation every 6 days with the close spacing (15 x 20 or 20 x 20 cm) leads to high values of growth, grain yield, and water productivity for Giza 179 cultivar.

Keywords: Rice, irrigation regimes, plant spacing, water productivity, grain yield.

INTRODUCTION

More than half of the world's populations depend on rice (*Oryza sativa* L.) as their main food. Almost 115 nations in the world grow rice as it comes the second after wheat in a global agricultural product (Badawi *et al*., 2002). In Egypt, rice is an essential crop for Egyptian farmers. The dominant practice in rice production is flooded irrigation, which consumes large amounts of water as being approximately 18 % of the total water resources (Busari *et al.*, 2019).

Considering the scarcity of freshwater, the economic management of water has become essential. Attempts are underway to reduce the huge volume of irrigation water required for rice crop production. Intermittent irrigation or irrigation intervals for rice crops instead of flooding aim to save water (Ali *et al.*, 2005). It has been reported that the application of water 1-6 days after the disappearance of ponding water saved 25 to 50% of irrigation water as compared to the continuous submergence of fields without any adverse effect on rice yield El-Refaee (2012). In Egypt, increase intervals between irrigation, wherever, the rice field is allowed to dry for a few days in between irrigation events draining in which the field is allowed to dry for six to eight days. Awad (2001) found that the grain yields were not affected by irrigation intervals, ranging from four to eight days. Belder *et al.* (2002) reported that water productivity in alternately submerged and non-submerged regimes was higher than in the continuously submerged regime.

Controlling plant spacing is one of the best practices being developed for rice production in Egypt. The skills of transplanting, plant spacing, and water management are necessary to be applied by farmers to enhance rice yields production, within the same space of planting. Plant spacing has a significant role in increasing rice grain yield. Optimum plant density ensures proper plant growth. When the plant density exceeds the optimal level, there is sever competition among plants for the sunlight or for nutrients. Therefore, the plant growth slows down and the grain yield decreases (Mancosu *et al*., 2015). Farmers need to employ methods to save quantities of water in rice production; benefiting from new varieties that consume less water. These water-saving techniques, when combined with appropriate spacing, can greatly improve rice production (Bouman *et al*., 2005).

The objective of the present study was to evaluate the effect of irrigation regime and plant spacing on plant growth, grain yield and water productivity of Giza 179 rice cultivar.

MATERIALS AND METHODS

Experimental site:

The present experiment was conducted at the Experimental Farm of Sakha Research Station, Agricultural Research Center, Kafr El-Sheikh, Egypt during the 2017 and 2018 seasons. The study aimed to explore the effect of different irrigation regimes and plant spacing on grain yield characteristics associated with optimum grain yield and water-saving irrigation of Giza 179 rice cultivar (duration about 120 days). The average meteorological data (from May to September) of the experimental sites were 32.8 and 31.7^{0}C for maximum temperature, 17.3 and 23.5 ^{0}C for minimum temperature, 82.1 and 81.4 % for relative humidity, 6.8 and 6.5 mm/day for pan evaporation in

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2017and 2018 seasons, respectively. All experiments were preceded by a barley crop (*Hordum spp.*). The results of mechanical and chemical soil properties are presented in Table 1.

Table 1. Mechanical and chemical analysis of the experiments soil

Soil analysis		2017	2018
Soil texture (%)		clayed	clayed
pH		8.05	8.20
EC(ds m^{-1})		2.00	2.05
Organic matter %		1.65	1.50
Available NH_4	mg kg^{-1}	13.50	12.60
Available NO_3	mg kg^{-1}	10.00	11.80
Available P	mg kg^{-1}	14.00	12.00
Available K	mg kg^{-1}	366	350
Available Zn	mg kg^{-1}	0.8	0.9

Experimental Design and Land Preparation

The experiment was laid out in a strip-plot design with three replications. Three irrigation treatments namely, continuous flooding (CF), irrigation every 6 days (6D) and 9 days (9D), were put in the horizontal plots, with 5-7 cm water head at the time of water addition. The vertical plots were occupied by four levels of plant spacing i.e. 15 x 20, 20 x 20, 25 x 20 and 30 x 20 cm among rows and hills. The recommended dose of nitrogen fertilizer (165 kg N/ha in form of urea 46 % N) was applied in two splits (2/3 as a basal and 1/3 as a top dressing at panicle initiation). Seeds of Giza 179 rice cultivar, at the rate of 120 kg ha^{-1}, were soaked in sufficient water for 24 hours and incubated for another 48 hours to enhance germination. The nursery was well ploughed and leveled. Nitrogen, phosphorus (P_2O_5) and zinc (Zn So_4), as well as all other cultural practices were applied as recommended to the nursery. For permanent field phosphorus fertilizer at the rate of 35.5 kg P_2O_5 ha^{-1} was basally applied to the soil during the land preparation. The potassium fertilizer was added, at the rate of 57 kg K_2O ha^{-1}, as a basal dose and incorporated into dry soil. The experiment was sown on the 13th and 15th of May in the first and second seasons of the study, respectively. All plots, with an area of 30 m^2 (5 x 6 m) each, were transplanted with three to four (thirty days old) seedlings at distance among hills and rows according to plant spacing treatments. To avoid lateral irrigation water movement and more water control, each main plot was lightly separated by two-meter wide ditches. Water pump, provided with a calibrated water meter, was used for all water measurements.

Data recording

At the booting stage (after 75 days from sowing) plants of five hills were randomly taken from each plot to estimate dry matter production. Leaves of three hills were randomly taken to determine the leaf area of plant samples and they were measured by Portable Area Meter (Model LI–3000A), then leaf area index (LAI) was estimated. Prior to harvest, plant height was estimated and total number of panicles of ten random hills were counted and then converted into numbers/m^2. Ten random panicles were collected from each plot to estimate panicle length, total number of grains/panicle, unfilled grain percentage, panicle weight and 1000-grain weight. Grain and straw yields were randomly measured from an area of 12 m^2 (3 x 4 m) and grain yield was adjusted to 14 % moisture content. Water productivity (WP) was calculated as the weight of grains per unit of irrigation received during crop growth (kg grain / m^3 water input).

Statistical Analysis

Data collected were statistically analyzed using the analysis of variance technique according to Gomez and Gomez (1984). Duncan's Multiple Range Test was used to compare the treatment means (Duncan 1957). All statistical analyses were accomplished using analysis of variance technique by means of "COSTAT" statistical software package.

RESULTS AND DISCUSSION

1-Growth attributes:

Data in Table 2 revealed that LAI and dry matter production at the booting stage as well as plant height at harvest stage of Giza 179 rice cultivar were higher in continuous flooding (CF) and irrigation every six days (6D) than in nine days (9D) treatment in both seasons. Prolonging irrigation intervals from CF up to 9D treatment apparently decreased LAI, DM and plant height. Continuous flooding and irrigation every 6 days recorded the highest values of LAI and DM with no significant difference between CF and 6 days irrigation interval for LAI in both season and DM in the first season. Continuous flooding increased plant height due to the full excretion of panicles with normal cell division and elongation. Prolonged irrigation interval during early stages affected cumulative water stress in tiller development and cell elongation, resulting in a reduction in LAI, DM and plant height. Such reduction in LAI with increased irrigation intervals could be attributed to the shortage in plant height, number of tiller and total leaf area due to death of the lower leaves and plant growth, in general, as affected by water stress. These results are in agreement with those obtained by Uddin *et al*. (2010), El-Refaee *et al.* (2012), El-Saka (2013), Ashouri (2014), Ghazy (2015) and Ibrahim *et al.* (2017).

The close spacing (15 x 20 cm) recorded maximum values of leaf area index, dry matter and plant height as compared to wider spacing (30 × 20 cm). This might be due to more competition for interception and utilization of solar radiation under higher number of plant population in close spacing than the wider one. The results are in accordance with the findings of El-Refaee *et al*. (2012) and Ghazy (2015).

Table 2. Leaf area index (LAI), dray matter and plant height of Giza 179 rice cultivar as affected by irrigation intervals and plant spacing in 2017 and 2018 seasons.

Treatment	LAI		Dray matter (g/m²)		Plant height (cm)	
	2017	2018	2017	2018	2017	2018
Irrigation regime (I):						
CF	5.98a	6.16a	1142.5a	1187.9a	99.8a	101.3a
6D	5.75a	5.91a	1110.4a	1135.4b	97.1b	98.6b
9D	4.23b	4.70b	838.0b	885.0c	88.0c	89.5c
F. test	**	**	**	**	**	**
Plant spacing (cm) (S):						
15 x 20	6.29a	6.60a	1100.5a	1063.6a	96.8a	98.3a
20 x 20	5.91b	6.21b	1089.9a	1052.9a	95.4b	96.9b
25 x 20	5.00c	5.31c	1057.8b	1016.5b	94.4c	95.9c
30 x 20	4.09d	4.24d	1029.5c	988.2c	93.3d	94.8d
F .test	**	**	**	**	**	**
Interaction						
I X S	*	**	**	**	*	*

NS= Not Significant. **, * Highly significant and significant at 0.01 and 0.05 levels, respectively.
Means of each factor designated by the same letter are not significantly different at 5% level according to Duncan's Multiple Range Test. CF = continuous flooding, 6D= irrigation every 6 days and 9D= irrigation every 9 days

Data in Fig.1 showed that the combination of irrigation as CF with the narrow spacing of 15 x 20 and 20 x 25 cm produced the highest values of LAI and dry matter production at booting stage as well as plant height at harvest stage, followed by irrigation every six days with the same spacing. Meanwhile, the minimum values were recorded by irrigation every nine days with the spacing of 30 x20 cm in both seasons. Under prolonging irrigation (6D and 9D) the close spacing recorded higher plant height and leaf area index than wider spacing (30 × 30 cm). The results are in accordance with the findings of El-Refaee *et al*. (2012) and Ghazy (2015).

2- Yield attributes:

The data in Table 3 indicated that, in both seasons, the CF treatment significantly registered the maximum values of the number of panicles m², total number of grains/panicle and panicle length without significant difference with 6D treatment, except for unfilled grains percentage which respects to the highest value under CF irrigation in the second season. On the other hand, 9D irrigation treatment gave the minimum values of all the above-mentioned traits. The increased number of panicles under submerged treatment may be attributed to the essential role of water and nutrients for producing new tillers which led to an increase in the number of tillers bearing panicles and total number of grains/ panicles, while water stress reduced the number of plants within unit area due to the death of tillers caused by drought stress. These findings are in agreement with those obtained by El-Refaee (2012), El-Saka (2013), Ashouri (2014) Ghazy (2015), and Alhassan *et al*. (2017).

Among the plant spacing, the narrow spacing of 15 x 20 cm followed by plant spacing 20x 20 cm significantly exhibited the highest values of a number of panicles/m² and unfilled grain percentage, which were mainly due to higher plant population and more number of hills, in spite of lower number tillers per hill (Table 3). Meanwhile, a wider space of 30 x 20 cm recorded the maximum values of the total number of grains/ panicles and panicle length in both seasons. Studies have demonstrated that plant spacing influences plant physiological activities via intra-specific competition (Oad *et al*., 2001; Uddin, 2010; Sen, 2014; Ghazy, 2015 and Munyithya *et al*., 2017).

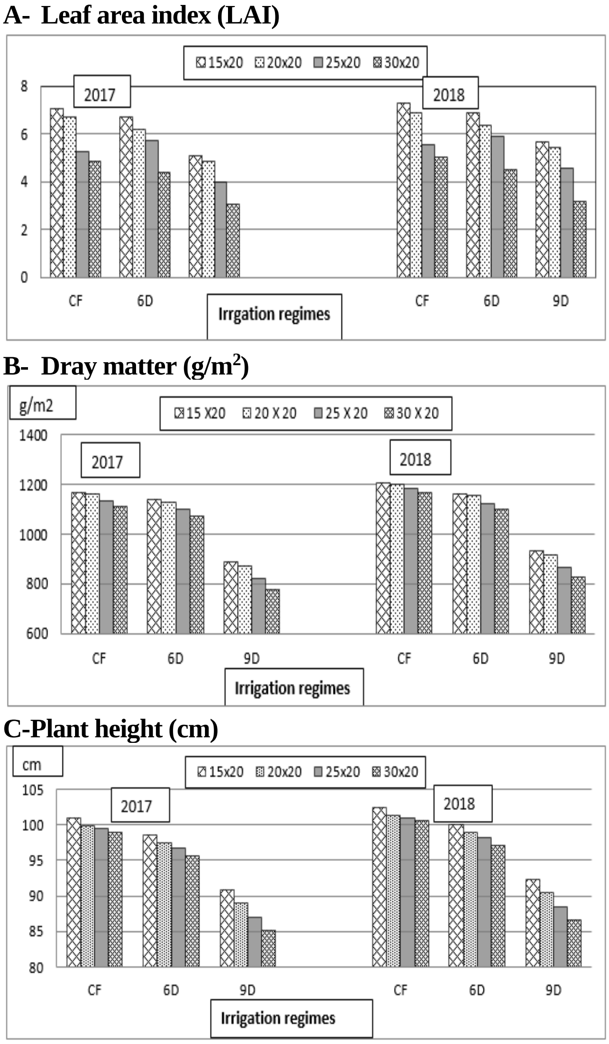

Fig .1. Leaf area index (A), dry matter production (B) and plant height (C) of Giza 179 rice cultivar as influenced by irrigation intervals and plant spacing in 2017 and 2018 seasons.

NS= Not Significant. **, * Highly significant and significant at 0.01 and 0.05 levels, respectively .
Means of each factor designated by the same letter are not significantly different at 5% level according to Duncan's (CF = continuous flooding, 6D= irrigation every 6 days and 9D= irrigation every 9 days).

Table 3. Number of panicles, total number of grains/ panicle, unfilled grain (%) and panicle length of Giza 179 rice cultivar as affected by irrigation intervals and plant spacing in 2017 and 2018 seasons.

Treatment	No. of panicles /m^2		Total number of grains/ panicle		Unfilled grain (%)		Panicle length (cm)	
	2017	2018	2017	2018	2017	2018	2017	2018
Irrigation regime (I)								
CF	531.1a	556.5a	150.3a	155.1a	6.48a	6.10a	23.7a	24.2a
6D	515.5a	537.4a	144.2a	148.0a	6.32a	4.98b	22.0ab	23.5a
9D	406.2b	415.0b	105.0b	104.5b	5.35b	4.51c	20.2b	20.9b
F .test	**	**	**	**	**	**	*	**
Plant spacing (cm) (S)								
15 x 20	522.3a	536.2a	121.1c	120.2d	6.30a	6.77a	21.0b	21.5c
20 x 20	492.0ab	525.6a	131.3b	132.1c	6.14ab	5.51b	21.5b	22.6b
25 x 20	474.1b	489.2b	137.8a	142.0b	5.96bc	4.70c	22.2ab	23.3ab
30 x 20	448.7c	460.9c	142.4a	149.1a	5.80c	3.81d	23.1a	24.06a
F .test	**	**	**	**	**	**	*	**
Interaction								
I x S	*	**	NS	*	**	NS	NS	NS

NS= Not Significant. **, * Highly significant and significant at 0.01 and 0.05 levels, respectively.
Means of each factor designated by the same letter are not significantly different at 5% level according to Duncan's Multiple Range Test.
CF = continuous flooding, 6D= irrigation every 6 days and 9D= irrigation every 9 days

The effect of the interaction between irrigation regimes and plant spacing had a significant effect on the number of panicles m^{-2} (Table 4). Data showed that the highest value of a number of panicles m^{-2} was produced under irrigation as CF with the plant spacing of 15 x 20 cm. However, the lowest number of panicles m^{-2} was produced with irrigation every 9 days at the spacing of 30 x 20 cm, in 2017 and 2018 seasons, respectively. The results are in accordance with the findings of El-Refaee *et al*. (2012), Sen (2014) and Ghazy (2015).

Table 4. Number of panicles, total number of grains/ panicle and unfilled grains (%) of Giza 179 rice cultivar rice as influenced by the interaction between irrigation regimes and plant spacing.

Treatment	Irrigation regime					
	2017			2018		
Number of panicles m^{-2}						
Plant spacing (cm)	Cont. flooding	Irrigation every 6 days	Irrigation every 9 days	Cont. flooding	Irrigation every 6 days	Irrigation every 9 days
15 x 20	560.8a	538.3ab	467.6de	579.8a	565.9ab	463.0f
20 x 20	528.6abc	516.8bc	430.5e	574.2a	556.7bc	446.0g
25 x 20	525.8abc	512.5bc	384.0f	544.7c	526.7d	396.1h
30 x 20	509.1bcd	494.4cd	342.6f	527.2d	500.3e	355.1i
F .test		*			**	
Total number of grains/ panicle (2018)				Unfilled grains (%) (2017)		
15 x 20	141.9d	132.7e	86.1i	6.61a	6.56ab	5.74f
20 x 20	153.3bc	154.4d	97.0g	6.51abc	6.38cd	5.53g
25 x 20	159.7ab	153.5c	115.7h	6.44bc	6.22de	5.24h
30 x 20	164.9a	160.4a	122.1f	6.36cd	6.13e	4.91i
F .test		*			**	

****, * Highly significant and significant at 0.01 and 0.05 levels, respectively.**
Means of each factor designated by the same letter are not significantly different at 5% level according to Duncan's Multiple Range Test.

The interaction between irrigation intervals and plant spacing had a significant effect on the total number of grains/ panicles in 2018 season and unfilled grains percentage in 2017 season (Table 4). The highest value was produced under CF irrigation with the plant spacing of 30 x 20 cm. However, the lowest total number of grains/ panicles was produced with irrigation every 9 days at the spacing of 15 x 20 cm, in 2018 season. Meanwhile, the highest value of unfilled grains percentage was produced under CF irrigation with the plant spacing of 15 x 20 cm. However, the lowest number of unfilled grains percentage was produced with irrigation every 9 days at the spacing of 30 x 20 cm, in 2017 season.

The effect of interactions among the two factors was not significant on total number of grains/ panicles in the 2017 seasons, unfilled grain (%) in the 2018 season and panicle length in the 2017 and 2018 seasons respectively.

As for irrigation intervals, their effect was significant on panicle weight, 1000-grain weight, grain yield and straw yields in both seasons (Table 5). Prolonging irrigation intervals up to 9 days induced significant reduction in the abovementioned traits in 2017 and 2018 seasons. Interestingly the coupled irrigation intervals of continuous flooding (CF) and 6 days had the same level of significance on the previously mentioned traits. The total number of grains/ panicles and grain yield while water stress reduced the number of plants within the unit area due to the death of tillers caused by drought stress. These findings are in an agreement with those obtained by El-Refaee (2012), El-Saka (2013), Ghazy (2015) and Ibrahim *et al*. (2017). The current results indicated that exposing rice plant to drought caused a significant reduction in grain yield, this held true since all yield components were hampered by such conditions in the terms of prolonging irrigation interval up to 9 days. The unavailability of water inhibits the production and transport of dry matter content in the different plant organs besides reducing the number of panicles m^{-2} and the total number of grains/ panicles. All this is reflected on the grain yield. Similar findings were reported by El-Refaee *et al*. 2012, Ghazy (2015) and Alhassan *et al*. (2017).

Table 5 . Panicle weight, 1000 grain weight, grain and straw yields of Giza 179 rice cultivar as affected by irrigation intervals and plant spacing in 2017 and 2018 seasons

Treatment	Panicle weight (g)		1000-grain weight (g)		Grain yield (t/ha)		Straw yield (t/ha)	
	2017	2018	2017	2018	2017	2018	2017	2018
Irrigation regime (I):								
CF	3.49a	3.83a	26.73a	26.37a	11.36a	11.33a	14.23a	14.00a
6D	3.38a	3.59a	26.43a	25.85a	10.90a	11.06a	14.19a	13.53b
9D	2.48b	2.39b	25.86b	24.80b	8.76b	8.82b	11.93b	11.41c
F .test	**	**	**	*	**	**	**	**
Plant spacing (cm) (S):								
15 x 20	2.73c	3.06c	25.35d	24.13c	10.77a	10.85a	13.93a	13.41a
20 x 20	3.05b	3.19bc	26.11c	25.34b	10.51a	10.58ab	13.72ab	13.14a
25 x 20	3.29a	3.3b	26.67b	26.31a	10.24ab	10.25bc	13.39bc	12.87ab
30 x 20	3.38a	3.51a	27.23	26.91a	9.85b	9.91c	13.03c	12.50b
F .test	**	**	**	**	*	**	**	**
Interaction								
I x S	NS	NS	NS	NS	**	*	*	**

CF, 6D and 9D = Continuous flooding, irrigation every 6 and 9 days, respectively.
****, * Highly significant and significant at the 0.01 and the 0.05 levels, respectively. NS= Not Significant.**
Means of each factor designated by the same letter are not significantly different at 5% level according to Duncan's Multiple Range Test

With respect to plant spacing effect, data analysis variance indicated that significant differences were developed by plant spacing for panicle weight,1000-grain weight, grain and straw yield in both seasons. Wider spacing of 30 x 20 cm significantly exhibited the highest values of panicle weight 1000-grain weights. Meanwhile, a narrow spacing of 15 x 20 cm produced the highest values of grain yield and straw yield followed by plant spacing 20 x 20 cm without significant differences between them in both seasons (Table 5). The findings agree with those reported by Ram *et al*. (2014). Physiological competition within the hill is an integral part of the physical environment and the competition by neighbors often accentuates, both factors contribute to the determination of yield. Studies have demonstrated that plant spacing influences plant physiological activities via intra-specific competition (Moro *et al*., 2016; Munyithya *et al*., 2017). The optimum plant population coupled with better yield parameters, in leaf senescence delaying resulted from more pre- heading, current photosynthesis and higher assimilation rate might be a possible cause of higher grain yield with closer spacing than wider spacing. The present findings are in good conformity with the results of Yoshida (1981), Singh *et al.* (2012) and Bhowmik *et al*. (2012).

The effect of the interaction between irrigation intervals and plant spacing had a significant effect on grain and straw yields in both seasons (Table 6). Close spacing of 15 x 20 cm produced the maximum grain yields under all irrigation intervals.

Table 6. Panicle weight, grain and Straw yields of Giza 179 rice cultivar as influenced by the interaction between the study factors.

Treatment	Irrigation regime					
	2017			2018		
Plant spacing	Cont. flooding	Irrigation every 6 days	Irrigation every 9 days	Cont. flooding	Irrigation every 6 days	Irrigation every 9 days
Grain yield (t/ha)						
15 x 20	11.47a	11.12ab	9.72d	11.50a	11.33ab	9.72d
20 x 20	11.40a	11.07ab	9.07e	11.48a	11.23abc	9.04e
25 x 20	11.37a	10.88bc	8.46f	11.20abc	10.92bc	8.64e
30 x 20	11.22ab	10.53c	7.80g	11.13abc	10.74c	7.85f
F .test		**			*	
Straw yield (t/ha)						
15 x 20	14.55ab	14.43ab	12.80d	14.16a	13.78abc	12.38e
20 x 20	14.61a	14.41abc	12.15e	14.06ab	13.66bc	11.70f
25 x 20	14.34a	14.03bc	11.80e	14.00ab	13.51cd	11.11g
30 x 20	14.21abc	13.88c	10.98f	13.88abc	13.17d	10.46h
F .test		*			**	

**** Highly significant and significant at 0.01 and 0.05 levels, respectively. NS= Not Significant.**
Means of each factor designated by the same letter are not significantly different at 5% level according to Duncan's Multiple Range Test.

Data showed, also that the highest values of grain yields were produced under CF with a plant spacing of 15 x 20 cm, which was statistically under the same irrigation level with other spacing. Meanwhile, the highest values of grain yields under irrigation every 6 days were produced with the plant spacing of 15 x 20 cm without significant differences with those obtained by 20 x 20 cm. However, the lowest means of grain and straw yields were produced with irrigation every 9 days at the spacing of 30 x 20 cm in both seasons. The response of rice plants to varying plant spacing is similar under CF. However, it significantly responded to close spacing with increased irrigation intervals. Under prolonging irrigation interval, water stress decreased the number of panicles m^{-2}. So, high plant density was much needed to obtain a considerable grain yield El-Refaee *et al*. 2012 and Ghazy (2015).

4- Density response:

Regarding density response, the highest grain yields were obtained by the closest spacing of 15 x 20 cm and 20 x 20 cm (Table 7). Over both seasons, under CF, grain yield was increased by 315, 265 and 115 kg/ha. The density response, gradually, increased with prolonging irrigation from CF to 6D as the grain yield was increased to be 589, 517 and 264 kg/ha. However, grain yield recorded high responses to narrow spacing with increased irrigation interval to 9D, where, grain yield was increased by 1896, 1229 and 727 kg/ha, at the spacings of 15 x 20, 20 x 20 and 25 x 20 cm, respectively. Such results showed that the increased density response percentage was associated with increased grain yield response to plant density. The density response percentage gradually increased with prolonging irrigation from CF to 6D and recorded the maximum response (24.21%) to narrow spacing (15x20 cm) with increased irrigation interval to 9D (Table 7). Our findings are in good conformity with the results of El-Refaee *et al.* (2012).

Table 7. Grain yield and density response of Giza 179 rice cultivar under different irrigation intervals.

Treatment		Grain yield (kg/ha)			Density response (increase in kg/ha)			Density response (% increase)		
I's	Spacing (cm)	2017	2018	Mean	2017	2018	Mean	2017	2018	Mean
CF	15 x 20	11470	11503	11487	253	376	315	2.26	3.38	2.82
	20 x 20	11397	11477	11437	180	350	265	1.60	3.15	2.38
	25 x 20	11370	11203	11287	153	76	115	1.36	0.68	1.02
	30 x 20	11217	11127	11127	-	-	-	-	-	-
6D	15 x 20	11117	11330	11224	590	587	589	5.60	5.46	5.53
	20 x 20	11070	11233	11152	543	490	517	5.16	4.56	4.86
	25 x 20	10880	10917	10899	353	174	264	3.35	1.62	2.49
	30 x 20	10527	10743	10635	-	-	-	-	-	-
9D	15 x 20	9723	9720	9722	1923	1867	1896	24.65	23.77	24.21
	20 x 20	9067	9043	9055	1267	1190	1229	12.24	15.15	13.70
	25 x 20	8463	8643	8553	663	790	727	10.13	10.06	10.10
	30 x 20	7800	7853	7827	-	-	-	-	-	-

CF, 6D and 9D = Continuous flooding, irrigation every 6 and 9 days, respectively.

5- Water relations:

Comparing the different treatments of irrigation, it was observed that increasing irrigation intervals from continuous flooding up to 6 and 9 days tended to decrease the amount of water used (Table 8). The result revealed that CF received the highest amounts of total applied water throughout the season (14033.8 and 14011.6 m^3/ha) followed by 6D irrigation intervals treatment (13033.4 and 13000 m^3/ha), while, the lowest amounts were received by irrigation as 9D treatment (9946.5 and 9782.3 m^3/ha) in 2017 and 2018 seasons, respectively. There were no large variations in the amounts of irrigation water input due to the stable conditions; namely, temperature, relative humidity and evaporation rates in both seasons. The amount of water-saving percentage was found to be 7.12 and 7.21 % when rice plants were irrigated every 6 days, at the same time the water-saving percentage under prolonged irrigation interval of 9 days was 29.12 and 30.18 % compared to CF treatment in 2017 and 2018 seasons, respectively.

Table 8. Total water used, water saved and water productivity (WP) as affected by irrigation intervals during the 2017 and 2018 seasons.

0	Total water use (m^3ha^{-1})			Water saved (%)			WP (kg m^{-3})		
	2017	2018	Mean	2017	2018	Mean	2017	2018	Mean
CF	14033.8	14011.6	14022.7	-	-	-	0.810	0.808	0.809
6D	13033.4	13000	13016.7	7.12	7.21	7.16	0.836	0.850	0.843
9D	9946.5	9782.3	9864.4	29.12	30.18	29.65	0.881	0.901	0.891

CF, 6D and 9D = Continuous flooding, irrigation every 6 and 9 days, respectively.

Among different irrigation regimes treatments of six and nine days recorded the highest value of water productivity followed by 6 days irrigation intervals. Moreover, irrigation at nine days was considered the best WP, followed by the six days treatment in both seasons. The high values of WP, in 9D and 6D treatments, were caused by the extremely high grain yield and low water inputs in those treatments as compared to continuous flooding treatment. These results are in line with the findings of El-Refaee (2012), El-Saka (2013), Ghazy (2015) and Ibrahim *et al.* (2017).

Regarding the effect of rice plant spacing on WP, it was data observed that WP, over irrigation regimes, ranged from 0.797 to 0.808 kg m^{-3} with 30 x 20 cm and from 0.883 to 0.896 kg m^{-3} with 15 x 20 cm in both seasons, respectively, (Table 9). Under all irrigation regimes, the narrow spacing of 15 x 20 cm followed by 20 x 20 cm treatment recorded higher WP than the wider treatment 30 x 20 cm. High WP with narrow spacing was associated with high grain yield. The mean WP could be increased to reach its maximum values under 6D treatment with a narrow spacing of 15 x 20 cm (0.853 and 0.872 kg/m^3), followed by the spacing of 20 x 20 cm (0.849 and 0.864 kg/m^3). Also, the maximum values of WP under 9D were recorded by the spacing of 15 x 20 cm (0.978 and 0.994 kg/m^3), followed by the spacing of 20 x 20 cm (0.912 and 0.924 kg/m^3), in the two respective seasons.

Table 9. Water productivity (kg/m^3) as affected by irrigation intervals and plant spacing in the 2017 and 2018 seasons.

Season	Spacing (cm)	Irrigation interval			
		Continuous flooding	Irrigation every 6 days	Irrigation every 9 days	Mean
2017	15x20	0.817	0.853	0.978	0.883
	20x20	0.812	0.849	0.912	0.858
	25x20	0.810	0.835	0.851	0.832
	30x20	0.799	0.808	0.784	0.797
2018	15x20	0.821	0.872	0.994	0.896
	20x20	0.819	0.864	0.924	0.869
	25x20	0.800	0.840	0.884	0.841
	30x20	0.794	0.826	0.803	0.808

From the water productivity point of view and from the results, generally, irrigation every six days gave a similar grain yield as that of continuous flooding for both seasons, with high water productivity. So, in the case of the shortage of irrigation water, it could be recommended to be using the irrigation every 6 days and narrow spacing 15 x 20 or 20 x 20cm for the highest grain yield and acceptable water productivity of Giza 179 rice.

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تحسين نظم الري ومسافات الزراعة لتعظيم محصول الحبوب وإنتاجية المياه في الأرز

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تعتبر نظم الري ومسافات الزراعة من العمليات الزراعية التي لها تأثيرات كبيرة على نمو وتطور والإنتاج النهائي لمحصول الأرز. لذا، أجريت هذه الدراسة خلال موسمي 2017 و2018 م في المزرعة البحثية لمحطة البحوث الزراعية بسخا - كفر الشيخ – جمهورية مصر العربية بهدف دراسة تأثير نظم الري وزيادة كثافة النباتات على خصائص المحصول، والمرتبطة بالإنتاجية المثلى للحبوب وتوفير مياه الري لصنف الأرز جيزة 179. استخدم تصميم الشرائح المتعامدة في ثلاث مكررات بحيث احتوت الشرائح الأفقية على ثلاث معاملات للري هي الغمر المستمر طوال الموسم والري كل ستة أيام والري كل تسعة أيام في حين احتوت الشرائح الرأسية على أربع مسافات للزراعة بين النباتات وهي 15 x 20, 20 x 20, 25 x 20 و30 x 20 سم بين السطور والجور. وتوضح النتائج أن دليل مساحة الورقة والوزن الجاف وارتفاع النباتات وعدد الداليات /م^2 وعدد الحبوب الممتلئة/الدالية ووزن الدالية ووزن الألف حبة ومحصول الحبوب ومحصول القش قد زادت معنويا عند الري بالغمر المستمر والري ستة أيام بالمقارنة مع الري كل تسعة أيام. وقد أظهرت مسافات الزراعة الضيقة (20x15 و 20x20 سم) قيمًا أعلى لصفات النمو ومحصول الحبوب عن مسافات الزراعة الواسعة (30 x 20 سم). وقد زادت الاستجابة للكثافة النباتية تدريجيا مع زيادة فترات الري من الغمر المستمر وحتى الري كل ستة أيام، وقد سُجلت أقصى استجابة لمسافات الزراعة الضيقة مع زيادة فترة الري الى تسعة أيام. استهلكت معامله الغمر المستمر اكبر كميات من مياه الري بينما استهلكت معامله الري كل تسعة يوم اقل الكميات واعطت معاملة الري كل ستة ايام محصول متقارب لمحصول الحبوب لمعامله الغمر المستمر مع كميه مياه اقل وسجلت معاملة الري كل تسعة أيام زيادة في انتاجيه وحدة المياه في كلا الموسمين. بصفة عامة، وتحت نفس الظروف المماثلة للتجربة توصى الدراسة أن استخدام الري كل ستة أيام مع المسافة الضيقة للنباتات (15x 20 و20 x 20 سم) يؤدي إلى زيادة في خصائص النمو ومحصول الحبوب وإنتاجية وحدة المياه لصنف الأرز جيزة 179.