J. of Plant Production, Mansoura Univ., Vol 11 (1): 7 - 16, 2020

Journal of Plant Production

Journal homepage: www.jpp.mans.edu.eg
Available online at: www. jpp.journals.ekb.eg

Soil Nutrients Availability, Rice Productivity and Water Saving under Deficit Irrigation Conditions

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ABSTRACT

Two field experiments were carried out at Rice Research and Training Center, Sakha, Kafr El-Sheikh, Egypt during 2018 and 2019 cropping seasons. Experiments aimed to determine the impacts of different deficit irrigation treatments on the available soil nutrients, N, P, K and Zn uptakes, rice yield and water use efficiency. The field experiments were laid out in a strip-plot design with four replications. The horizontal plots were devoted to the four irrigation treatments: continuous submergence (W1), intermittent irrigation at 6-day intervals (W2), intermittent irrigation at 9-day intervals (W3) and intermittent irrigation at 12-day intervals (W4), while vertical plots were occupied by the three rice genotypes, namely Giza 177, Giza 179 and GZ10154. Intermittent irrigation at 6-days intervals (W2) treatment, recorded the highest available NH_4^+-N, NO_3^--N and K concentrations in the soil. The highest values of available-N and available-P concentrations in the soil were obtained with (W1) while (W4) recorded the lowest values. The N, P, K and Zn uptakes were significantly affected by the prolonged irrigation intervals. Rice yield and its attributes decreased significantly as irrigation intervals increased up to 12-day (W4) in both seasons. The highest values of plant height, number of panicles m^{-2}, panicle weight (g), 1000-grain weight (g), number of filled grains $panicle^{-1}$, grain and straw yields were obtained with (W1) followed by (W2) treatment, except panicle length and number of unfilled grains $panicle^{-1}$ in both seasons. Water saved (%) ranged from 8.90% to 26.46% and from 17.47% to 27.25% in 2018 and 2019 seasons, respectively.

Keywords: Rice cultivars, water management, available nutrients, nutrients uptake

INTRODUCTION

Rice grows in soils with moisture regimes that range from the submerged lowland to the water deficient upland and with nutrient transformation processes that vary with the moisture regimes. Several physical, chemical, and biochemical changes that accompany submergence or deficit irrigation are important in determining the soil suitability for rice production (Bouman and Tuong 2001). Therefore, it is important to understand the unique nutrients availability under continuous submergence and deficit irrigation management in order to manage soil, fertilizer, moisture regimes and to sustain rice production (Farooq *et al*. 2009).

Water is essential for growth and development of rice plants. However, continuous flooding results in a large amount of unproductive water outflows through evaporation, seepage, and percolation Alberto *et al*. (2011). Growing evidence indicates that continuous flooding is unnecessary for rice to achieve high yields, however, is based on short-term trials. Long-term field water conditions would produce profound changes in soil properties, which may further affect soil water conservation and crop yield. Water is crucial for growth and productivity of rice as it influences the availability of nutrients through its ability to solubilise nutrients making it easy for plants to absorb them from the soil as plants can only take up mineral nutrients dissolved in soil solution (Depar *et al*. 2011). Also, water can lead to loss of nutrients from soil through its influence on erosion and leaching if not managed properly. Reducing the amounts of water use for rice production is still controversial since there are critical issues associated with yield loss. Soil moisture content above field capacity may reduce rice grain yield by 20-25% as compared to continually flooded treatments. Rice is most sensitive to water stress during the reproductive stage. Water shortage at this growth stage can cause yield loss by lowering sterility (Fageria *et al*. 2007). Water deficit during the vegetative stage can reduce plant height, tillers number, leaf area and grain yields if plants do not have adequate time to recover before flowering (Hartinee *et al*. 2010). The duration of moisture stress is more important than the plant growth stage at which the stress occurs. Intermittent drying or keeping soils saturated during the growing season at either vegetative or reproductive phase lowers rice yields significantly in most tropical rice fields. However, in some parts of China, Japan, and Korea, intermittent wetting and drying cycle during rice growing season governs with rice yields, because organic and inorganic toxins accumulated from the decomposition under low soil temperature at early growing season is diminished. Short aeration periods at the end of the tillering stage can improve rice yields if followed by flooding (Depar *et al*. 2011).

Deficit irrigation is an optimization strategy to reduce water use and increase water use efficiency (WUE) in many parts of the world (Eissa *et al*. 2010). The water resources in Egypt are limited to the share of Egypt in the flow of the Nile

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DOI: 10.21608/jpp.2020.77983

River by 55.5 billion m^3, the deep groundwater in the deserts and small amounts of rainfall in the northern coastal area. Meanwhile, water demand is continually increasing due to population growth and industrial development.

Egypt has pioneered various water-saving irrigation technologies to achieve more water-efficient irrigation for rice. One of the most commonly practiced water-saving irrigations is deficit irrigation practice. In this method, soil is dried out to some degree in between irrigation intervals (Mao *et al*. 2000). Deficit irrigation cycles in the rice field for some periods of time significantly increases plant growth (Bouman and Tuong 2001). This is attributed to the reduction of the toxic elements and some toxic intermediate organic acids (that occurs during decomposition of plant residue), and increases the availability of some nutrients resulting from the mineralization of organic N during this period. The uptakes of P, K, Zn, and Fe were greater in continuously flooded treatment, whereas uptake of S was higher in alternately flooded and drained treatment. El-Refaee (1997) observed that dry matter, leaf area index, crop growth rate and relative growth rate were significantly affected by prolonged irrigation. Also, day to heading increased with increasing irrigation intervals. Continuous flooding followed by irrigation every 6-days gave highest rice grain yield as well as highest grain quality. Awad (2001) reported that plant height, panicle length, No. of panicles/m^2, and yield decreased significantly with increasing irrigation intervals. El Refaee (2006) reported that water withholding of 12 day throughout the rice growing season, significantly reduced the dry weight, length of panicle, No. of tillers/m^2 and yield.

Deficit irrigation practice have been reported to save water compared with continuous flooding in rice cultivation. Furthermore, it is not known how deficit irrigation modifies nutrient use efficiencies and if it requires different N-fertilizer management compared with continuous flooding practice. Understanding the effects of deficit irrigation on nutrient-use efficiency of rice is essential for improving soil fertility and increasing rice productivity. Therefore, the aims of this research were to quantify the influence of various deficit irrigations treatments on available soil nutrients, nutrients uptakes (N, P, K and Zn), yield and water use efficiency.

MATERIALS AND METHODS

Two field experiments were conducted at Rice Research and Training Centre, located at Kafr EL Sheikh Governorate (31 08° N Latitude and 30 58° longitude) during 2018 and 2019 seasons to study the impact of irrigation intervals on rice yield, nutrient uptake and soil chemical properties as well as water productivity of three rice cultivars. The air temperature (°C), relative humidity (RH, %), and evaporation (mm day^{-1}) during the growing seasons are presented in Table (1). The soil sample was collected at 0-0.2m. The soil sample was air-dried, ground and passed through 2-mm sieve. Soil samples were analysed for some physical and chemical characteristics such as electrical conductivity (EC,) pH, organic matter (OM) and texture as outlined by Page *et al.* (1982). The physio-chemical characteristics of the soil are shown in Table (2).

Table 1. Average monthly relative humidity (RH, %), temperature (°C), and Pan evaporation (mm day^{-1}) recorded during the 2018 and 2019 rice growing seasons.

Month	Relative humidity (%)		Temperature (°c)		Pan Evaporation (mm day^{-1})	
	2018	2019	2018	2019	2018	2019
May	44.1	44.6	26.7	26.9	6.40	6.60
June	50.9	51.2	28.5	28.9	6.70	6.80
July	53.6	53.9	28.4	28.8	6.10	6.30
Aug.	59.9	58.9	30.2	30.8	5.10	5.40
Sep.	56.2	56.9	27.5	27.9	3.15	3.10

Table 2. The physical and chemical characteristics of soil during 2018 and 2019 growing seasons.

Soil properties	Growing season	
	2018	2019
Clay (%)	55.1	56.4
Silt (%)	32.4	31.3
Sand (%)	12.7	12.3
Organic matter (%)	1.65	1.70
Total-N %	0.05	0.06
NH_4^+-N (mg kg^{-1})	19.0	20.3
NO_3^--N (mg kg^{-1})	15.0	18.3
Available-P (mg kg^{-1})	13.0	15.5
Total- K (%)	1.01	1.04
pH	8.30	8.20
EC (dS m^{-1})	2.01	2.30

EC = Electrical conductivity.

Experimental design

Field experiment was carried out in a strip-plot design using four replications. The horizontal plots were devoted to the four irrigation treatments (with 6 cm water head throughout the flooding time). The irrigation regimes were: continuous submergence (W1), intermittent irrigation at 6-day intervals (W2), intermittent irrigation at 9-day intervals (W3) and intermittent irrigation at 12-day intervals (W4) were located in the horizontal plots with 6 cm water head. Meanwhile the vertical plots were occupied by three rice varieties cultivars, namely Giza 177, Giza 179 and promising line GZ 10154. The horizontal plots were surrounded by deep ditches to prevent any lateral movement of irrigation. Seeds of the rice cultivars @ of 144 kg ha^{-1}, was soaked in water for 24 h, then incubated for 48 h. Pre-germinated seed was sown on May 15th and May18th in 2018 and 2019 seasons. The permanent field was identified and well prepared. P-fertilizer was added @ 36 kg P_2O_5 ha^{-1} as superphosphate (15.5% P_2O_5) as soil basal application just before transplanting. Nitrogen-fertilizer was applied in two splits (2/3 before transplanting and 1/3 at 30 DAT). Thirty-day old seedlings of each variety was individually pulled out and transferred from nursery to the permanent field and manually transplanted at the space of 20x20 cm. Water pump was used to irrigate the experiment and the amount of water applied throughout the experiment was measured. Water Use Efficiency (WUE) was calculated as follows:

$$\textbf{WUE} = \frac{\textbf{Grain yield (kg)}}{\textbf{Water applied (m}^3\textbf{)}}$$

Water saving was obtained with reference to the irrigation water and calculated as the difference in irrigation under the two irrigation regimes divided by the irrigation water applied under the continuous submergence regime.

Assessment of agronomic parameters

At harvesting, 5 hills were selected from each plot to measure plant height (cm) and No. of panicles/ hill. Ten panicles were selected randomly from each plot to measure length of panicle, No. of filled grains/ panicle, No. of unfilled grains/panicle and 1000-grain weight. After harvesting, biological yield and rice grain yield was estimated from a 5 m2 area from each plot, and grain yield was adjusted to 14% moisture content and calculated as ton t ha^{-1}.

Plant tissue analysis

Rice grain and straw samples were dried, ground and sieved by using 0.5 mm sieve. The fine powder was digested by the $HClO_4$ - H_2O_2 acids as described by Chapman and Partt (1965) and the digests were analysed for nitrogen, phosphorus, potassium and zinc contents and the uptakes of these nutrients were estimated.

Soil samples and analysis

Soil samples were collected from each plot 60 day after transplanting and at harvesting. The soil samples were homogenized and frozen directly after collection to prevent microbial activity. Then samples were immediately extracted to determine the nutrient concentration. Available NH_4^+ and NO_3^- contents of the soil was determined according to the method of Chapman and Partt (1965) while available P, K, and Zn concentration were determined according to Page *et al.* (1982). The analysis of the samples was conducted in cooperation with Soils and Water department, Faculty of Agric., Tanta Univ., Egypt.

Statistical analysis

Data collected were computed into Microsoft Excel Spread sheet and then subjected to the analysis of variance using the GenStat Statistical Software Package. Least significant difference at 5% probability level was used to compare the means of treatments.

RESULTS AND DISCUSSION

Available soil nutrients

Table 3, Figures 3a and 3b, present the concentrations of available NH_4^+ in the soil at 60 day after transplanting (DAT) and harvesting under different deficit irrigation. The available NH_4^+ concentrations in the soil 60 day ranged from 31.8 to 66.4 mg kg^{-1} and from 35.9 to 56.9 mg kg^{-1} in 2018 and 2019, respectively. In general, the highest values of available NH_4^+-N concentrations in the soil was observed 60 DAT then decreased at harvesting. This result may be attributed due to the absorption of rice plants and the N lost by different ways. The findings are in line with those founded by Doberman and Fairhruse (2000) and Gewaily (2006). Data indicated that under (W2), recorded the highest available NH_4^+-N concentrations in the soil.

Table 3, Figures 4a and 4b present the concentration of available NO_3^- -N in the soil as affected by rice cultivars under different irrigation intervals. Data show that the highest values of available NO_3^- concentrations in the soil were found with (W2) and the lowest concentrations were recorded with the (W1) in 2018 and 2019. The increase in available NO_3^-N concentration in the soil may be attributed to the higher amount of oxygen under prolonged irrigation intervals (W2, W3 and W4) which leads to more nitrification taking place and therefore, producing higher amounts of NO_3^--N. The highest available NO_3^--N concentrations in the soil were obtained 60 DAT, then decreased slightly at harvesting. The decreased in available NO_3^--N concentrations in the soil is mainly due to the improved aeration in the soil layers after harvesting and therefore nitrification process take place. These results are in agreement with those obtained by Gewaily (2006). Generally a depletion in available NH_4-N and NO_3^--N concentrations occurred with the advent of plant growth, this is probably attributed to the plant uptake and subsequent they are lost through nitrification- denitrification process due to the upper aerobic layer over an anaerobic layer in a flooded soil, NH_3 volatilization and the leaching process (Singh *et al.* 2001). When irrigation interval increased, more available nutrients are required by plants, this is mainly due to wetting and drying cycles, the losses of N increased significantly, so that more N is applied to compensate the losses and meet the plant requirements.

Table 3. Means of available soil NH_4^+-N, NO_3^--N, P, K and Zn (mg kg^{-1}) concentrations as influenced by irrigation intervals at 60 day after transplanting and harvesting during 2018 and 2019 seasons.

Irrigation Intervals	NH_4^+-N				NO_3^--N				Available – P				Available – K				Available – Zn			
	60 DAT		Harvesting		60 DAT		Harvesting		60 DAT		Harvesting		60 DAT		Harvesting		60 DAT		Harvesting	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Irrigation(W)																				
W_1	44.7	46.7	23.7	25.4	11.6	12.5	11.0	13.2	40.9	50.2	20.2	23.5	351.1	361.2	300.5	320.2	0.593	0.590	0.585	0.510
W_2	66.4	56.3	23.8	27.3	39.0	45.6	22.2	25.2	35.2	39.6	17.3	19.8	381.0	385.5	355.9	365.3	0.624	0.612	0.585	0.550
W3	42.7	45.4	21.4	23.3	15.7	20.5	11.5	15.2	35.1	37.2	16.4	18.6	371.2	380.2	343.4	345.6	0.633	0.664	0.590	0.570
W4	31.8	35.9	17.6	19.4	12.0	16.5	13.6	14.9	30.2	33.2	13.4	15.6	343.7	348.2	355.9	377.2	0.710	0.699	0.665	0.599
LSD 0.05	14.7	4.55	1.76	1.88	11.8	13.5	0.87	3.10	6.70	6.90	2.99	3.55	5.67	6.65	13.94	18.1	0.362	0.214	0.107	0.11
Varieties (V)																				
Giza 177	43.4	45.6	21.0	24.1	19.1	21.1	13.2	15.5	33.2	35.6	15.6	17.9	388.1	399.1	336.2	341.2	0.652	0.545	0.662	0.578
Giza 179	51.4	56.3	22.0	25.2	20.7	22.2	15.7	17.8	37.8	39.2	19.1	21.5	372.8	388.2	340.2	350.2	0.625	0.632	0.609	0.620
GZ 10154	44.6	48.2	21.9	23.2	19.0	21.1	14.8	16.7	35.0	37.2	15.9	18.2	344.8	365.2	339.7	345..3	0.575	0.614	0.591	0.587
LSD 0.05	5.70	3.55	0.872	1.51	0.81	0.09	0.89	2.01	4.83	3.01	3.07	4.21	5.65	4.89	2.12	3.14	0.031	0.022	0.073	0.064
W x V	*	*	*	*	NS	NS	*	*	*	*	*	*	*	*	*	*	*	*	*	*

W1: continuous submergence; W2: intermittent irrigation at 6-day intervals; W3: intermittent irrigation at 9-day intervals;
W4: intermittent irrigation at 12-day intervals; DAT= day after transplanting; NS=not significant; * significant at 0.05 level.

Available-P soil concentrations 60 DAT and harvesting used by the three rice varieties under different irrigation intervals are presented in Table 3, Figures 5a and 5b. Regardless of the irrigation intervals, data indicated that the higher available-P concentrations in the soil were recorded 60 DAT, while the lowest values were observed at harvesting in the two growing seasons. The decreases in the available-P concentrations may be attributed to P fixation on organic and clay (Ponnamperuma, 1972). Phosphorus concentration was higher under continuous submergence (W1) than other treatments. The increases in P concentration due to continuous submergence is attributed mainly to the reduction of Fe, Mn concentrations, which increase the P solubility (Doberman and Fairhruse, 2000). The increase in the available soil-P concentrations under continuous submergence conditions might be due to reduction of insoluble ferric phosphate to more soluble ferrous phosphate. Increase in increasing the solubility of P is associated with the decrease in soil pH caused by accumulation of CO_2 in soil (Zhang *et al*. 2004).

Table 3, Figure 6a and Figure 6b present the concentration of available-K in the soil as affected by rice cultivars under different irrigation intervals. The results showed that, the available-K in the soil increased at 60 DAT, then declined to the lower values at harvesting in the two seasons. At 60 DAT, the available-K values in the soil varied from 343.7 to 381.0 mg kg^{-1} in 2018 and 2019, respectively, while at harvesting, the values ranged from 300.5 to 355.9 mg kg^{-1} and from 320.2 to 377.2 mg kg^{-1} in 2018 and 2019, respectively. The highest concentration of available-K in the soil were recorded with (W2) compared with (W1) treatment. Belder *et al*. (2004), reported that the available K in the soil decreased in continuous submergence. This result is mainly attributed to the K leaching loss.

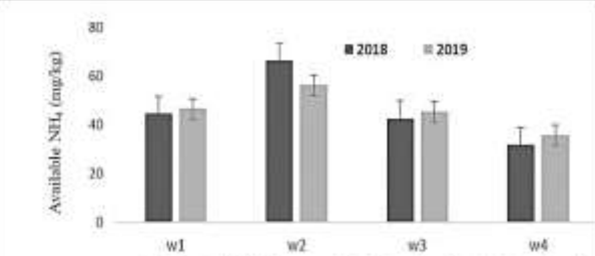

Fig. 3a: Availble NH_4 content 60 DAT as affected by inrigation intervals. Vertical bars represent error.

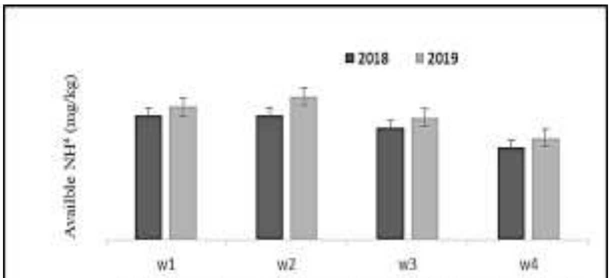

Fig. 3b: Effect of irrigation intervals on NH_4 concentration at harvesting. Vertical bars represent error.

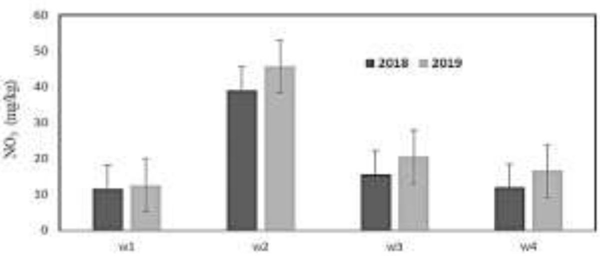

Fig. 4a: Effect of irrigation intervals on avialble soil NO_3 content 60 DAT. Vertical bars represent error.

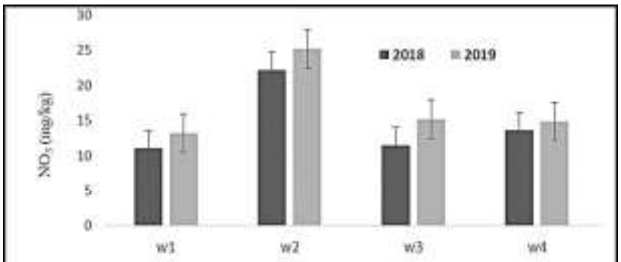

Fig. 4b: Effect irigation intervals on avialble soil NO_3 content at harvesting. Vertical bars represent error.

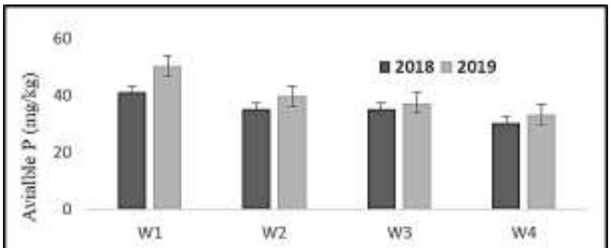

Fig. 5a: Effect of irrigation intervals on avilable P in the soil at 60 DAT. Vertical bars represent error.

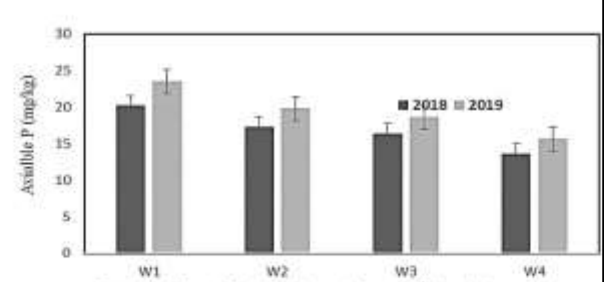

Fig. 5b: Effect of irrigation intervals on avialble soil P at harvesting. Vertical bars represent error.

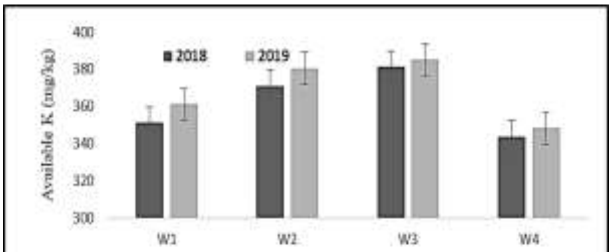

Fig. 6a: Effect of irrigation intervals on avialble soil K content at 60 DAT. Vertical bars represent error.

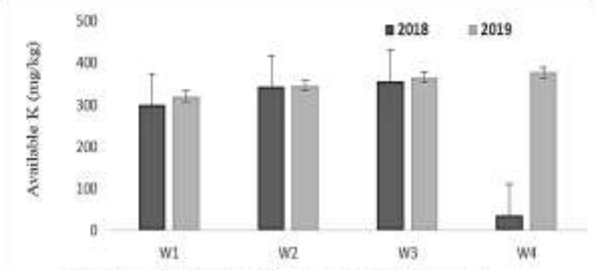

Fig. 6b: Effect of irrigation intervals on availble soil K at harvesting. Vertical bars represent error.

Available Zn concentrations values 60 DAT and harvesting as influenced by W1, W2, W3 and W4 are shown in Table 3 and illustrated in Figures 7a and 7b. The data clarified that the highest values of available Zn (0.710 mg kg^{-1}, 0.699 mg kg^{-1} 60 DAT) and (0.665 mg kg^{-1}, 0.599 mg kg^{-1} at harvesting) were obtained with (W4), and the lowest mean values of available Zn concentrations in soil were obtained with (W1) in both seasons. This may be due to the improving effect of aeration in the soil layers under intermittent irrigation at 12-day (W4), and therefore increase availability of Zn. Das and Mandal (1986) indicated that available Zn concentrations were higher in saturated soil than in continuous submergence. Ntanos and Koutroubas (2002) reported that under continuous submergence, the availability of Zn in soil is adversely affected by continuous submergence due to the increased production of CO_2 and S ions, which may cause Zn precipitation. Under continuous submergence, Zn availability is decreased because of the reduction in its solubility (Dobermann and Fairhurst 2000). Zhang *et al.* (2004) found that the concentration of Zn in the soil solution generally decreases after continuous submergence.

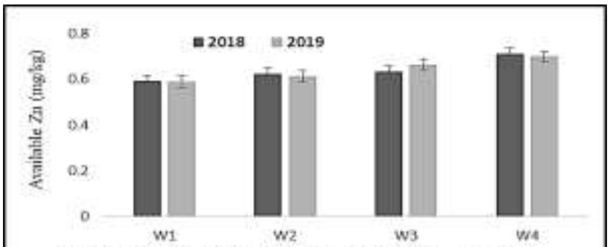

Fig. 7a: Effect of irrigation intervals on avialble Zn in the soil at 60 DAT. Vertical bars represent error.

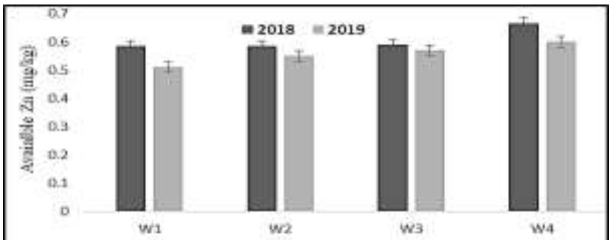

Fig. 7b: Effect of irrigation intervals on the availble Zn in soil at harvesting. Vertical bars represent error.

Nutrients uptakes

Uptake of N (kg ha^{-1}) by rice grain and straw as affected by irrigation intervals were presented in Table 4 and Figure 8. The results showed that the N uptake values were significantly affected by irrigation intervals in 2018 and 2019 seasons. The maximum values of N uptake in grain (125.1 kg ha^{-1} in 2018 and 130.1 kg ha^{-1} in 2019) recorded in (W1), while the minimum values were obtained with (W4). The data indicated that, with prolonged irrigation intervals, N uptake was significantly decreased. This mainly attributed to that with prolonged irrigation, expose rice plant to water deficit consequently and therefore less uptake relative to continuous submergence. The outcome results are in line with those reported by Pandey *et al.* (2006) and Havlin *et al.* (2007).

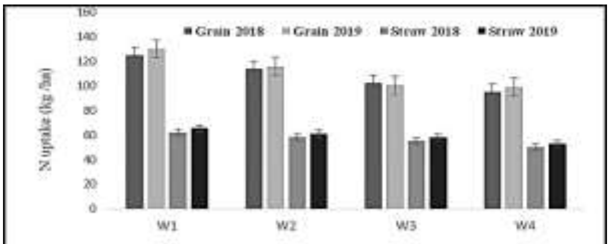

Fig. 8: Effect of irrigation intervals on N uptake during 2018 and 2019. Vertical bars represent error bars. Vertical bars represent error.

Uptake of P (kg ha^{-1}) by rice grain and straw as affected by irrigation intervals treatments were shown in Table 4 and Figure 9. The analysis of variance indicated that the P uptake values were significantly affected by irrigation intervals. The mean P uptake values by the grain ranged from 13.7 to 20.18 kg ha^{-1} and from 14.8 to 22.1 kg ha^{-1} in 2018 and 2019, respectively. The maximum values of P-uptake in grain were obtained with (W1), while the minimum values were obtained with (W4) in the two seasons. The reduced uptake under deficit irrigation is attributed to lower dry matter accumulation and reduced soil P-availability significantly.

The data indicated that the K uptake values were significantly affected by irrigation intervals (Table 4 and Figure 10). Data revealed that there was a progressive and consistent decline in K uptake by prolonging off period up intermittent irrigation at 12 day in both seasons. At harvest time, the average mean values of K-uptake by rice grain was 27.1, 29.1 kg ha^{-1} for (W1) treatment compared with 17.4, 19.4 kg ha^{-1} for (W4) treatment in 2018 and 2019, respectively. This is mainly due to continuous submergence (W1), rice plants produced the highest dry matter production. Sorour *et al.* (1998) reported that K-uptake by straw and grain significantly decreased as irrigation intervals increased from 3 to 12 day.

Data show that irrigation intervals had significant effect on Zn-uptake by rice grain and straw (Table 4 and Figure 11). Continuous submergence (W1), recorded the lowest Zn-uptake by rice while, the highest Zn-uptake was obtained with (W4) in both seasons. Zinc uptake by rice plant was inhibited by higher P fertilizer application (Gaber 2000). In general, the differences in Zn- uptake are attributed to greater water deficit stress during the rice growth stages. In contrast, concentrations Zn was affected by irrigation intervals, differences in uptake are attributed to lower dry matter production (Pandey *et al.* 2006; Zaman *et al.* 2018). The availability of soil moisture plays a key role in mineralization, solubilization, availability and uptakes of nutrient determines the rice growth and grain yield. However, flooding of soil increases the availability of nutrients like P, N, K, S, Fe, Mn and Mo, but reduces the availability of Zn, Cu and B (Havlin *et al.* 2007). Tavakkoli and Oweis (2004) reported that the total uptakes of N, P, K, Ca, Mg, Mn, Zn, Fe and S was higher under flooded conditions compared to non-flooded condition, due to higher availability of these nutrients.

Table 4. Nitrogen, P, K and Zn uptakes (kg ha^{-1}) by rice varieties as influenced by irrigation intervals.

Irrigation Intervals	N (kg ha^{-1})				P (kg ha^{-1})				K (kg ha^{-1})				Zn (kg ha^{-1})			
	Grain		Straw		Grain		Straw		Grain		Straw		Grain		Straw	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Irrigation (W)																
W_1	125.1	130.1	62.4	65.7	20.8	22.1	241.3	248.3	27.1	29.1	258.3	266.1	0.149	0.155	0.150	0.160
W_2	113.9	115.8	58.5	61.4	17.5	19.5	238.9	241.3	24.3	27.3	240.9	250.2	0.169	0.165	0.165	0.170
W3	102.9	100.6	55.4	58.3	17.4	18.4	228.9	230.1	24.0	26.1	240.4	238.6	0.210	0.221	0.167	0.185
W4	95.40	99.40	50.1	53.2	13.7	14.8	220.9	210.2	17.4	19.4	242.5	240.6	0.388	0.410	0.388	0.420
LSD 0.05	2.24	3.01	1.76	2.90	0.88	0.91	13.4	11.2	2.09	2.01	4.39	4.72	0.011	0.15	0.026	0.022
Varieties (V)																
Giza 177	109.5	111.2	56.8	62.3	17.2	19.2	233.5	238.2	22.6	24.6	248.7	255.1	0.217	0.225	0.217	0.240
Giza 179	111.9	110.3	58.9	60.1	19.4	20.4	242.5	245.1	24.5	26.5	243.3	250.3	0.251	0.267	0.251	0.260
GZ 10154	106.7	108.3	54.2	59.3	15.4	17.3	221.6	225.6	22.5	24.1	244.5	245.1	0.220	0.232	0.220	0.255
LSD 0.05	0.74	0.51	0.86	0.90	0.48	0.70	5.12	4.95	1.48	1.28	5.25	4.81	0.008	0.11	0.016	0.022
W x V	*	*	NS	NS	*	*	NS	NS	*	*	NS	NS	*	*	NS	NS

W1: continuous submergence; W2: intermittent irrigation at 6-day intervals; W3: intermittent irrigation at 9-day intervals; W4: intermittent irrigation at 12-day intervals. NS=not significant; * significant at 0.05 level.

Based on the results of the previous studies, the increase uptakes of N, P, and K in rice plants may be due to increase soil moisture. As soil moisture content increased, solubility and mobility of N, P and K are increased (Othman-Sanaa *et al*. 2005; Ibrahim and Kandil, 2007; Eissa and Ahmed, 2016). Deficit irrigation has negative effect on the uptakes of N, P, and K by rice plants (Pascale *et al*. 2001; Hafiz *et al*. 2016; Karandish and Shahnazari, 2016).

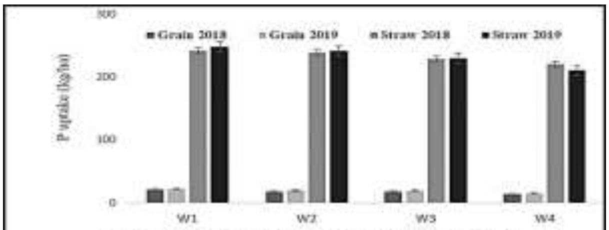

Fig. 9: Effect of irrigation intervals on P uptake. Vertical bars represent error bars. Vertical bars represent error.

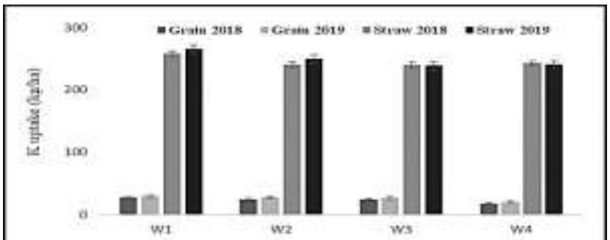

Fig. 10: Effect on irrigation intervals on K uptake during 2018 and 2019. Vertical bars represent error bars.

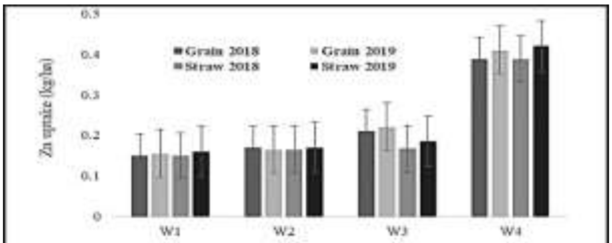

Fig. 11: Effect of irrigation intervals on Zn uptake. Vertical bars represent error.

Grain yield and its attributes

Rice yield and its attributes were significantly influenced by deficit irrigation (Tables 5 and 6). Rice yield and its attributes decreased significantly as irrigation intervals increased at 12-days (W4) treatment in 2018 and 2019 seasons. The maximum values of yield traits (plant height, No. of panicles per m^{-2}, weight of panicle, 1000-grain weight, No. of filled grains/panicle, yield of grain and straw) were recorded with (W1) followed by (W2) except the length of panicle and No. of unfilled grains in 2018 and 2019 seasons. The results are in line with those reported by El-Refaee *et al*. (2006), Gewaily et *al*. (2011) and Gewaily *et al*. (2019). Such increment in yield attributes under non stress condition as in continuous submergence (W1) could be due to the available water which enhanced the biological and physiological processes which increase the production and translocation of the dry matter content from source to sink which result in more tillers, panicles, grain filling and weight, therefore leads to an increase in rice grain yield. The interaction between rice variety and irrigation intervals had no significant effect on length of panicle and No. of unfilled grains. Gagandeep and Gandhi (2015) reported that vegetative growth of rice is significantly influenced by the type of varieties. Plants under (W1) treatment produced the highest dry matter accumulation compared to the other irrigation interval treatments in both seasons and it may be attributed to the absence of water stress on the plants since water was continuously kept above the soil surface throughout the plant cycle. Akram *et al*. (2013) reported a higher reduction in rice grain yield when there was no water stress at panicle initiation stage than at flowing stage. The difference between these findings may be due to the degree of the water stress, soil type and the varieties. The results indicated that, practicing deficit irrigation (intermittent irrigation at 6-day, 9-day and 12-day) treatments throughout the plant cycle reduces grain yield significantly due to the reduced soil moisture. However, Sun *et al*. (2012), Liu *et al*. (2013) and Chu *et al*. (2015) observed a higher grain yield under deficit irrigation than continuous submergence treatments. Moreover, Dong *et al*. (2012) and Howell *et al*. (2015) reported a similar grain yield between deficit irrigation and continuous submerged treatments. The discrepancies in these findings may be due to the fact that deficit irrigation varies in terms of frequency and duration of drying periods and the type of soil.

Rice variety has a significant effect on No. of panicles m^{-2} and grain yield and it may be attributed to the genetic constitution of the varieties studied. Garba *et al*. (2013); Getachew and Birhan, (2015) reported that rice grain yield and its components were significantly influenced by the varieties. Giza 179 variety produced the highest grain yield may be due to its higher No. of panicles m^{-2}, and No. of filled grains compared to other varieties

The interaction between irrigation intervals and rice varieties on yield attributes are presented in Table (7). There was a significant interaction between irrigation intervals and varieties on plant height in 2018 and 2019 seasons. The tallest plants (101cm and 100.3 cm) were those of Giza 177 under (W1) treatment. Number of panicle/m^2 was significantly affected by the interaction between irrigation intervals and varieties. The highest No. of panicle/m^2 (578.3 and 562.7) were produced by Giza 179 under (W1) in 2018 and 2019, respectively. The highest panicle weight (3.33 g in 2018) and (3.653 g in 2019) was obtained with Giza 177 under (W2). The higher No. of filled grains/panicle (151.3 and 155.3) in in 2018 and 2019 were obtained with Giza 179 under (W1) treatment. The highest 1000-grain weight (29.20 g and 29.47 g) were achieved by Giza 177 under (W1) in 2018 and 2019 seasons. Data indicated that there was a significant interaction between irrigation intervals and varieties on grain yield in both seasons. The highest grain yields (11.08 t ha^{-1} and 10.85t ha^{-1}) were produced by Giza 179 and under (W1), followed (W2) in 2018 and 2019 seasons. However, the lowest grain yields (5.98 t ha^{-1} and 6.19 t ha^{-1}) were obtained with Giza 179 under (W2) in 2018 and 2019 seasons (Table 7). This is may be due to that Giza 179 is more sensitive to water stress than the other two rice varieties. Significant difference was observed among the tested rice varieties in respect of agronomical traits in both seasons. The variation among the rice varieties in agronomic traits may be due to the genetic background differences (Gagandeep and Gandhi 2015).

Table 5. Means of plant height (cm), No. tillers m^2, panicle length (cm), panicle weigh (g), No. of filled grains/panicle and No. of unfilled grains/panicle of some rice varieties as influence by irrigation intervals during 2018 and 2019 seasons.

Irrigation Intervals	Plant height (cm)		No. of panicle/m^2		Panicle length (cm)		Panicle weight (g)		No. of filled grains/ panicle		No. of unfilled grains /panicle	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Irrigation (W)												
W_1	99.29	99.37	546.1	541.8	17.96	20.96	3.08	3.56	136.9	141.7	7.67	8.37
W_2	90.98	91.73	511.6	509.2	19.09	20.66	3.25	3.42	129.1	136.8	8.22	8.29
W3	79.98	82.19	420.6	436.3	20.13	19.23	2.93	2.96	119.4	121.3	5.20	6.23
W4	77.09	75.67	351.6	373.7	20.94	18.27	2.60	2.56	101.5	90.40	4.98	6.02
LSD 0.05	2.79	0.74	27.46	30.67	1.80	0.40	0.66	0.089	13.8	11.33	1.66	0.54
Varieties (V)												
Giza 177	86.73	86.9	404.1	424.3	18.90	19.21	2.55	2.90	106.4	107.0	5.61	6.95
Giza 179	86.58	85.91	491.3	495.4	19.28	19.43	3.16	3.21	137.8	138.4	7.51	8.58
GZ 10154	87.18	89.28	477.0	476.1	20.41	20.69	3.19	3.25	121.0	122.3	6.43	6.15
LSD 0.05	NS	0.56	19.25	20.47	1.18	0.64	0.41	0.17	6.82	14.31	1.30	1.02
W x V	*	*	*	*	NS	NS	*	*	*	*	NS	NS

W1: continuous submergence; W2: intermittent irrigation at 6-day intervals; W3: intermittent irrigation at 9-day intervals; W4: intermittent irrigation at 12-day intervals. NS=not significant; * significant at 0.05 level.

Table 6. Mean of 1000-grain weight (g), grain yield (t ha^{-1}), straw yield (t ha^{-1}) and harvest index of some rice varieties as influenced by irrigation intervals during 2018 and 2019 seasons.

Irrigation Intervals	1000-grain weight (g)		Grain yield(t ha^{-1})		Straw yield(t ha^{-1})		Harvest index	
	2018	2019	2018	2019	2018	2019	2018	2019
Irrigation (W)								
W_1	28.11	28.36	10.49	10.61	13.17	12.67	0.456	0.456
W_2	27.47	27.87	9.84	10.14	11.88	11.82	0.461	0.461
W3	26.80	26.97	7.79	8.080	10.41	10.00	0.446	0..443
W4	25.91	25.93	7.04	6.760	9.011	8.480	0.443	0.444
LSD 0.05	0.520	0.190	0.620	0.580	0.860	0.940	0.043	0.043
Varieties (V)								
Giza 177	28.08	28.31	7.91	8.27	10.98	10.47	0.439	0.439
Giza 179	25.39	25.57	9.46	9.35	11.37	10.99	0.459	0.459
GZ 10154	27.75	27.97	8.99	9.07	11.01	10.78	0.456	0.456
LSD 0.05	0.510	0.500	0.370	0.330	0.390	0.290	0.043	0.044
W x V	*	*	*	*	*	*	*	*

W1: continuous submergence; W2: intermittent irrigation at 6-day intervals; W3: intermittent irrigation at 9-day intervals; W4: intermittent irrigation at 12-day intervals. * Significant at 0.05 level.

Table 7. Weight of 1000-grain weight (g), grain yield (t ha^{-1}), straw yield (t ha-1) and harvest index as affected by interaction between irrigation regimes and rice varieties.

Irrigation Intervals	1000-grain weight (g)						Grain yield (t ha^{-1})					
	2018			2019			2018			2019		
	Giza 177	Giza 179	GZ1054	Giza 177	Giza 179	GZ1054	Giza 177	Giza 179	GZ1054	Giza 177	Giza 179	GZ1054
W1	29.03	26.10	29.20	29.47	26.27	29.33	9.72	11.08	10.66	10.15	10.85	10.81
W2	28.60	25.43	28.37	29.13	25.877	28.60	9.10	10.05	10.05	9.60	10.49	10.32
W3	27.77	25.37	27.27	28.03	25.37	27.50	6.85	8.61	7.89	7.12	8.98	8.150
W4	26.90	24.67	26.17	26.60	24.77	26.43	5.98	7.77	7.38	6.19	7.09	7.010
LSD 0.05		0.446			0.506			0.972			0.346	
	Straw yield (t ha^{-1})						Harvest index					
	2018			2019			2018			2019		
	Giza 177	Giza 179	GZ1054	Giza 177	Giza 179	GZ1054	Giza 177	Giza 179	GZ1054	Giza 177	Giza 179	GZ1054
W1	13.33	13.25	12.92	12.53	12.78	12.70	0.448	0.459	0.460	0.448	0.459	0.460
W2	12.02	11.73	11.84	11.46	12.10	11.90	0.458	0.464	0.464	0.456	0.464	0.464
W3	9.780	11.10	10.36	9.660	10.33	10.02	0.424	0.465	0.448	0.424	0.465	0.448
W4	8.770	9.370	8.900	8.220	8.730	8.490	0.429	0.449	0.453	0.429	0.449	0.434
LSD 0.05		0.992			0.987			0.044			0.019	

W1: continuous submergence; W2: intermittent irrigation at 6-day intervals; W3: intermittent irrigation at 9-day intervals; W4: intermittent irrigation at 12-day intervals.

Water consumed and productivity

Total amounts of irrigation water used throughout the 2018 and 2019 seasons, water saved (%), yield reduction (%) and water use efficiency (kg m^{-3}) are presented in Table (8). The results indicated that the total amounts of irrigation water used for land preparation of the nursery, raising seedling (about 30 day), preparation of permanent field and 15 days after transplanting before irrigation treatments starting were 4280 m^3 ha^{-1} and 4400 m^3 ha^{-1} in 2018 and 2019 seasons, respectively. There were no large variations in the amounts of added water due to the stable temperature, relative humidity and evaporation as presented in Table (1). However, El Refaee (2002) reported that the average amount of water needed before irrigation treatments application was 4449 m^3 ha^{-1}. There was variation in the amounts of irrigation water used in the two seasons due to the differences in the tile drainage system in the experimental sites. Regarding the yield reduction (%) and water saved (%) with compared to (W1) treatment are listed in (Table 8). The results indicated that the water saved (%) ranged from 8.90% to 26.46% and from 17.47% to 27.25% in 2018 and 2019 seasons, respectively. Irrigation every 12-day reduced the water inputs compared with (W1), but the yield reduction (%) decreased significantly in the 2018 and 2019 seasons. Yield reduction (%) of Giza 177 was higher than that of Giza 179 and GZ 10154 in both seasons. This means that, Giza 177 were tolerant to deficit irrigation. The WUE values for W1, W2, W3 and W4 were 0.729, 0.743, 0.657 and 0.666 kg m^{-3} in the first season and 0.737, 0.774, 0.682 and 0.640 kg m^{-3} in the second season. The means of WUE values for Giza 177, Giza 179 and GZ10154, respectively were 0.629, 0.750 and 0.718 kg m^{-3} in 2018 season and 0.656, 0.746 and 0.723 kg m^{-3} in 2019 season. The results indicated that yield and WUE values, decreased significantly as prolonged irrigation increased. This may be attributed to the marked decreased in irrigation water inputs among the treatments.

Table 8. Water consumed (m^3 ha^{-1}), water saved (%), yield reduction (%) and water used efficiency (kg m^{-3}) in 2018 and 2019 cropping seasons.

Season	Irrigation Intervals	Total Water Used (m^3 ha^{-1})	Water Saved (%)	Yield Reduction (%)				Water Use Efficiency (kg m^{-3})			
				Giza 177	Giza 179	GZ 1054	Mean	Giza 177	Giza 179	GZ 1054	Mean
2018	W1	14380	-	-	-	-	-	0.676	0.771	0.741	0.729
	W2	13100	8.90	6.38	9.30	5.72	7.13	0.695	0.767	0.768	0.743
	W3	11850	17.59	29.53	22.29	25.99	25.94	0.578	0.727	0.666	0.657
	W4	10575	26.46	38.48	29.87	30.77	33.04	0.565	0.735	0.698	0.666
Mean		12461	17.65	24.79	20.49	20.83	-	0.629	0.750	0.718	-
2019	W1	14310	-	-	-	-		0.706	0.755	0.752	0.737
	W2	13000	19.15	5.42	3.32	4.53	4.42	0.733	0.801	0.788	0.774
	W3	11810	17.47	29.85	17.24	24.61	23.90	0.601	0.758	0.688	0.682
	W4	10410	27.25	39.02	34.65	35.15	36.27	0.585	0.670	0.663	0.640
Mean		12382	17.95	24.76	18.40	21.43	-	0.656	0.746	0.723	-

W1: continuous submergence; W2: intermittent irrigation at 6-day intervals; W3: intermittent irrigation at 9-day intervals; W4: intermittent irrigation at 12-day intervals.

CONCLUSION

Continuous submergence increased the uptakes of N, P and K, but reduced Zn-uptake significantly. The intermittent irrigation at 6-days intervals produced grain yield at par with the treatment of continuous submergence with 7.13% and 4.42% reduction in grain yield and maintenance nutrients availability in both seasons. Further, deficit irrigation treatments reduced significantly yield, WUE, N, P, and K uptakes. Due to the increasing fertilizer costs that farmers facing nowadays, along with the irrigation water shortage in Egypt, that are increasingly occurring, it makes sense to switch from continuous submergence to intermittent irrigation at 6-day, which can reduce the amounts of water consumed, maintain soil fertility and sustain rice production. More research on deficit irrigation practices, with different rice varieties and different rice growing seasons are needed. Moreover, appropriate water management should be studied systematically to know what schedule of water application will give best results under different soil and climatic conditions. Such studies should examine also the relationships among root systems, nutrients uptakes and rice yield. The study concluded that good management irrigation water and rationalizing the use of chemical fertilizers and soil nutrients availability have to be considered for the sake of saving irrigation water and to sustain rice production.

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العناصر الميسرة بالتربة وانتاجية الارز وتوفيرالمياه تحت ظروف نقص مياه الري

عادل محمد غنيم

مركز البحوث والتدريب في الارز– معهد بحوث المحاصيل الحقلية – مركز البحوث الزراعية, مصر.

أجريت تجربتين حقليتين بمزرعة مركز البحوث والتدريب في الارز- سخا - كفر الشيخ في موسمي 2018 و2019 لدراسة تاثير نقص مياه الري علي تيسر العناصر الغذائية وإمتصاص العناصرومحصول الارز وكفاءة استخدام المياه. أجريت التجربتين باستخدام تصميم الشرائح المتعامدة في أربعة مكررات. حيث وضعت معاملات المياه في القطع الافقية وهي: الغمر المستمر,الري المتقطع كل ٦ ايام, الري المتقطع كل ٩ ايام و الري المتقطع كل ١٢ يوم, بينما وضعت اصناف الارز جيزة ١٧٧, جيزة ١٧٩ والسلالة ١٠١٥٤ في القطع العمودية. الري المتقطع كل ٦ ايام سجل أعلي قيم لتيسرالامونيوم, النترات والبوتاسيوم بالتربة. تركيز النيتروجين والفوسفور الميسر كان أعلي في الري المستمر بينما الري المتقطع كل ١٢ يوم كان اقل. تأثر النيتروجين والفوسفور والبوتاسيوم معنويا بتطويل الري. قل محصول الارز ومكوناته معنويا بفترات الري حتي الري المتقطع كل ١٢ يوم في الموسمين. اعلي قيم لطول النبات,عدد السنابل للمتر المربع, وزن السنبلة, عدد الحبوب الممتلئة للسنبلة, محصول الحبوب ومحصول القش كان في معاملة الري المستمر ثم الري المتقطع كل ٦ ايام ما عدا عدد الحبوب الفارغة في الموسمين. تراوحت نسبة توفير المياه من ٨.٩٠% الي ٢٦.٤٦% ومن 17.47% الي 27.25% في موسمي 2018 و2019 علي التوالي.