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CROP WATER PRODUCTIVITY OPTIMIZATION FOR RICE CULTIVATION UNDER DRIP IRRIGATION SYSTEM

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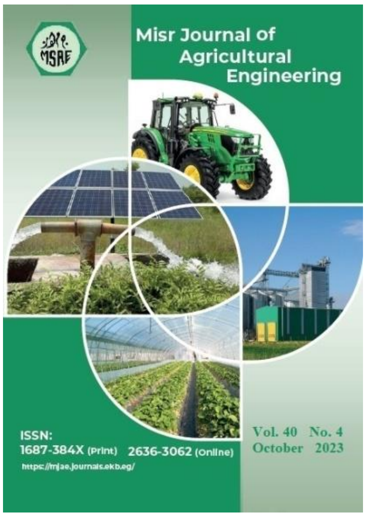

Keywords:
Micro irrigation; Water use efficiency; Heavy soil.

ABSTRACT

Recently, micro irrigation technology has started to be applied in irrigation of field crops in some of old lands of Egypt. Rice (Oryza sativa, L.) is the most important crop for Egyptian food security in spite of its traditional methods of irrigation which needs large quantities of water to flood paddy field during different growth stages. Therefore, to optimize crop water productivity, this work aims to assess the effect of some drip irrigation parameters on yield and crop water productivity of drip irrigated paddy rice under clay soil conditions.

Field experiment was conducted to evaluate the effect of drip irrigation emitters discharge treatments (2, 4 and 8 lh^{-1}) and emitters spacing treatments (30 and 50 cm), on soil moisture and salt distribution, plant growth parameters, yield and its components and crop water productivity of drought-resistant rice varieties (Oraby3). The obtained results indicated that, the highest values of grain yield of paddy (12.54 $ton.ha^{-1}$) and crop water productivity (1.66 kg $grain.m^{-3}$ of water) were obtained from same treatment (D_{4-30}) of 4 lh^{-1} emitters discharge at 30 cm spacing between emitters on lateral lines, while highest rice straw yield (16.06 and 16.73 $ton.ha^{-1}$) was obtained from both (D_{8-30}) and (D_{8-50}),which is means that this high straw yield comes from the treatments of higher discharge 8 lh^{-1} at both 30 and 50 cm spacing. So, introducing appropriate drip irrigation system to irrigate rice crop in old land can save water and maximize crop yield and crop water productivity.

1. INTRODUCTION

With proven fresh water resources available, where the Egyptian water share from the main water source of River Nile is limited by 55.5 x 109 $m^3 year^{-1}$ which is not enough to meet the demand of all sectors. About 80-85% of the Egyptian water supply is used in agricultural sector. So, the necessity to rationalize the use of irrigation water becomes a must according to **Darwesh et al. (2016).** The continuous increase of the population and the continuation of this increase will lead to a decrease in the per capita share of water and this may lead to water scarcity. Therefore, it was necessary to think about how to maximize the efficiency of water use by crops to increase production and to cope with the horizontal expansion where the increase in the cultivated areas of crops. Rice (*Oryza sativa*, L.) represents a major staple food for the Egypt's population. Many investigators studied also the water requirements of rice at continuous flooding in the whole season. Rice normally needs (under traditional methods in Egypt) a water application of about 2000 mm, an amount that is much higher than other crops (**Mostafa and Fujimoto, 2014**). Using the cultivation of drought rice varieties under drip irrigation in the desert lands led to save about 59% of consumed water compared with traditional rice varieties (**Abdel-Ghany, 2020**). The saved water can be used to cultivate drought rice for the sake of an increase in production that estimated with 8.9 $ton.ha^{-1}$. Soman et al. Under drip irrigation, rice hybrids gave grain yield varied between 5.93 to 11.61 $ton.ha^{-1}$ which was 7.34 to 29.90% higher than that under flood irrigation (**Soman et al., 2018**).The drip irrigation in dry-seeded rice resulted in higher grain yield (7.34-8.01 $ton.ha^{-1}$) than flood irrigation (6.63–7.60 $ton.ha^{-1}$), with water savings of more than 40% (**Sharda et al., 2017**).

The aim of this work was to study the effect of drip irrigation emitters characteristics (water discharge and spacing between emitters) on soil moisture distribution and salt accumulated patterns, as well as on growth parameters, yield components and crop water productivity (CWP) for drip irrigated rice crop (*Oryza sativa*, L.) under clay soil conditions.

2. MATERIALS AND METHODS

1. Site Description

To achieve the objectives of this study, field experiments were conducted at the Experimental Farm of Faculty of Agriculture, Benha University at Moshtohor – Qalyubia Governorate, Egypt, during the two successive summer seasons of 2020 and 2021. This location represents clay soil conditions of the Nile Delta region. Field preparation and practices performed according to the traditional local management. Thirty days old drought resistant rice (Oraby3) seedlings were transplanted on flat soil surface at the hills (2 plants) distance of 20 x 20 cm to give the rate of (25 $hills.m^{-2}$) in all treatments. Fertilization program and weed control was carried out as recommended from Ministry of Agriculture and Land Reclamation (MALR). The growing season for rice extends from May to end of September. The dominant soil of the experimental site was clay textured throughout the profile (1.62% coarse sand, 21.12% fine sand, 28.05% silt and 49.24% clay). The field capacity, wilting point and electrical conductivity values were 36%, 17.25% and 0.66 $dS.m^{-1}$, respectively.

2. Experimental design and layout

The applied statistical design of the experiments used was split-split plot with three replicates, where two treatments of emitters spacing on drip irrigation lateral lines (30 and 50 cm) were assigned as main plots and three emitter discharges of (2, 4, and 8 lh^{-1}) were in sup-main plots (Figs 1 and 2).

PVC main and sup main pipe lines of 75 mm diameter were used to convey water to the manifolds, which distribute irrigation, water to the laterals (drip lines) in each treatment. Each treatment covered by five PE lateral line of 16 mm diameter with built-in emitters, where:

Treatment D_{2-30} consisted as laterals of 2 lh^{-1} built in emitters at 30 cm spacing between emitters,
Treatment D_{4-30} consisted as laterals of 4 lh^{-1} built in emitters at 30 cm spacing between emitters,
Treatment D_{8-30} consisted as laterals of 8 lh^{-1} built in emitters at 30 cm spacing between emitters,
Treatment D_{2-50} consisted as laterals of 2 lh^{-1} built in emitters at 30 cm spacing between emitters,

Treatment $D_{4\text{-}50}$ consisted as laterals of 4 lh^{-1} built in emitters at 50 cm spacing between emitters, and

Treatment $D_{8\text{-}50}$ consisted as laterals of 8 lh^{-1} built in emitters at 50 cm spacing between emitters. The distance between laterals was constant (60cm).

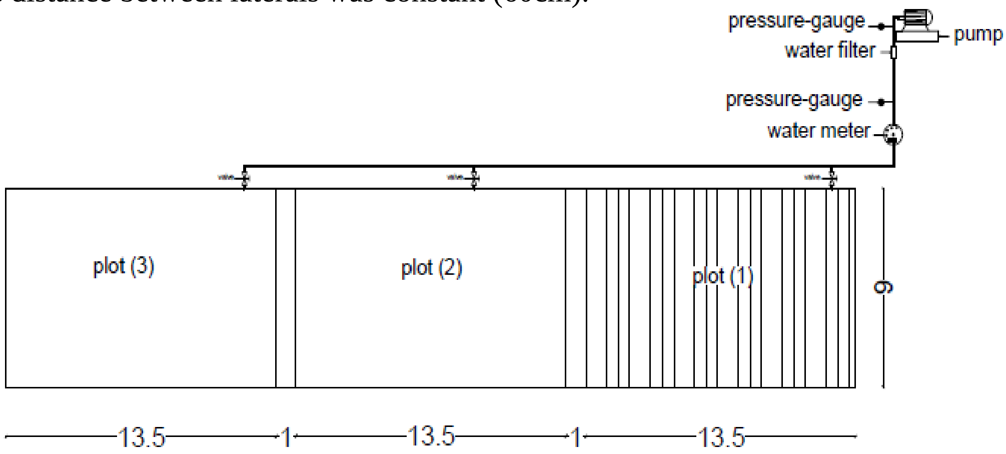

Fig. 1: Experimental irrigation system layout

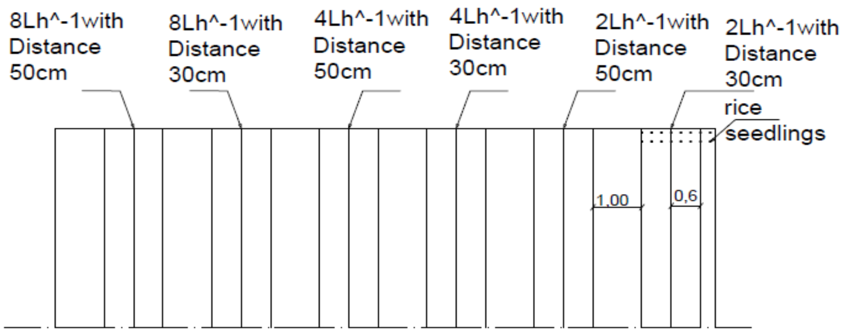

Fig. 2: Details of plot (1)

3. Rice crop growth and yield components measurements

Ten plants were selected randomly after flowering from each treatment for measuring plant height, (cm) – flag leaf area (cm^2) - panicle length (cm) - number of panicles /hill. At harvest, 1000-grain weight- grain yield - straw yield- biological yield-harvest index (%).

4. Rice irrigation water requirement

The amount of irrigation water for rice crop was applied by flow meter after being calculated according to the weekly published data from MALR, and then applied to the equation as follows (**Vermeiren and Jobling, 1980**):

$$\boldsymbol{IW} = \frac{(\boldsymbol{ETo} \times \boldsymbol{Kc} \times \mathbf{II})}{\boldsymbol{Ea}\,(\mathbf{1} - \boldsymbol{LR})} \times \mathbf{10}$$

Where: (IW = Irrigation water applied, m^3/ha/irrigation, ET_0 = Reference evapotranspiration (mm/day), Kc = Crop coefficient, **II**= Irrigation intervals, day, Ea = Irrigation efficiency of drip irrigation system (%) and LR = Leaching requirement = 10% of the total amount of water, m^3/ha/irrigation).

5. Crop water productivity (CWP)

It was calculated using the following equation (**Michael, 1978**):

$$CWP\ of\ rice\ grain\ yield = \frac{Total\ rice\ grain\ yield\ (kg)}{Total\ irrigation\ water\ applied\ (m^3)}$$

3. RESULTS AND DISCUSSIONS

1. Soil moisture distribution under drip irrigation

Fig. 3 shows soil moisture distribution pattern at vegetative stage for three emitter discharge treatments 2, 4 and 8 lh^{-1} and two treatments of emitter spacing on lateral 30 and 50 cm. The results of soil moisture content under D_{2-30} treatment indicated that the average moisture content directly below the emitter were 36.35% in soil layers through 0-60 cm depths, and this value decreased with the horizontal direction away from the emitter until it reached 22.6% for the same soil layers but at a horizontal distance of 60 cm away from the emitter.

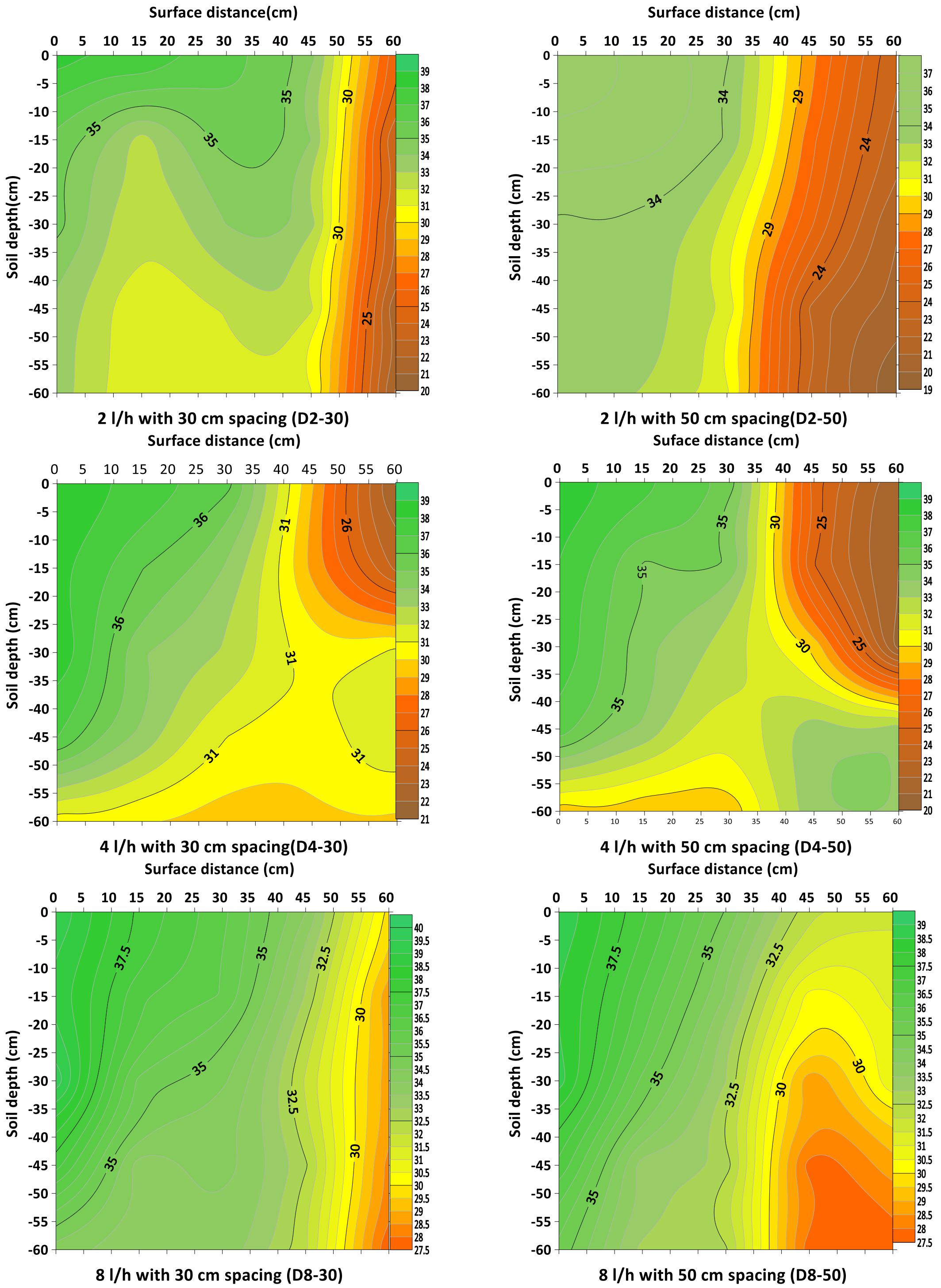

Fig.3: Effect of emitter discharges and emitters spacing on soil moisture distribution (%) after 24 hours from irrigation

While under treatment of D_{2-50} the average values of soil moisture content reached 34.73% in soil layers of 0-60 cm depths directly below the emitter, but it decreased to reach 21.34% at 60 cm horizontal distance far from the emitter. Whereas the soil moisture content under the treatments of D_{4-30} and D_{4-50} did not approximately differ since in soil layers through (0-60) cm depth the average values directly below the emitter were 36.71 and 36.1%, respectively, and for the same soil layers, the average values of moisture content at 60 cm horizontal distance from the emitter were 27.14% and 26.01%, respectively.

The treatments of D_{8-30} and D_{8-50} achieved the highest values of soil moisture content compared to the D_{2-30}, D_{2-50}, D_{4-30} and D_{4-50} treatments, where the average values of soil moisture content directly below the emitter under D_{8-30} and D_{8-50} reached 37.90% and 37.67%, respectively, while at 60 cm horizontal distance far from the emitter, the average soil moisture content were 30.07 and 28.1% for the treatment of D_{8-30} and D_{8-50}, respectively. Therefore, it could be concluded that as the emitter discharge increased the soil moisture distribution horizontally increased, and as the spacing between emitters increases, soil moisture content may be slightly decreases with horizontal distance away from emitter. These findings agree with **Rafie and El-Boraie (2017)**.

2. Salt Distribution Patterns

Results in (Fig. 4) represent distribution patterns of salt concentration (EC in dSm^{-1}) throughout the root zone depths from 0 to 60 cm and from the point source of dripper to 60 cm horizontally. These patterns indicated that salt concentration increased at the end of cropping season under lower emitter discharge treatments as well as under larger spacing between emitters especially at first radial distance from emitters throughout the wetted patterns. These patterns indicated that salt concentration increased at the end of cropping season compared with that measured at the beginning of season. The average values of salt accumulated in the soil through root zone of rice from the beginning to the end of season under the treatments of D_{2-30}, D_{2-50}, D_{4-30}, D_{4-50}, D_{8-30} and D_{8-50} were 0.62, 0.65, 0.61, 0.61, 0.58 and 0.59 dSm^{-1}, respectively. Also, it could be observed that less salt accumulation occurred in the treatments of higher emitter's discharge, which is due to the more leaching expected under treatments of 4 and 8 lh^{-1} dripper discharge. This result also reported by **Rafie and El-Boraie (2017).**

3. Effect of emitters spacing on rice plant growth parameters, yield components and crop water productivity

Results in Table 1 show that the highest values for all measured growth parameters were under treatment of 30 cm dripper spacing on lateral lines, which reached 111.1cm plant height, 27.47 cm^2 flag leave area, number of panicles per bed 37.85, and 24.49 cm for length of panicle. While all the corresponding values were lower under treatments of 50 cm dripper spacing which may due to the reduction in water availability in the root zone compared with 30 cm spacing treatments as indicated previously from moisture distribution patterns. The results agree with **Venkatesan et al. (2005) and Parthasarathi et al. (2013)**.

Results in a Table 2 show that the highest values for all yield components were found under the treatment of 30 cm spacing between emitters on the lateral lines with 60 cm fixed spacing between laterals. Comparing this values under 30 cm emitter spacing with that values under 50 cm spacing could be resulted in 3.36% increasing number of grains, 4.4% increase in 1000 grain weight, 18.9% increase in grain yield, 7% increase in straw yield, 12.6% increase in biological yield, 12.6% increase in Harvest index and 19% increase in crop water productivity. This may be attributed to the reduction effect of the larger emitter spacing (50 cm) in water availability to root zone of rice, causing root biomass to be reduced, and consequently less yield and yield components. These results agree with **Venkatesan et al. (2005) and Parthasarathi et al. (2013).**

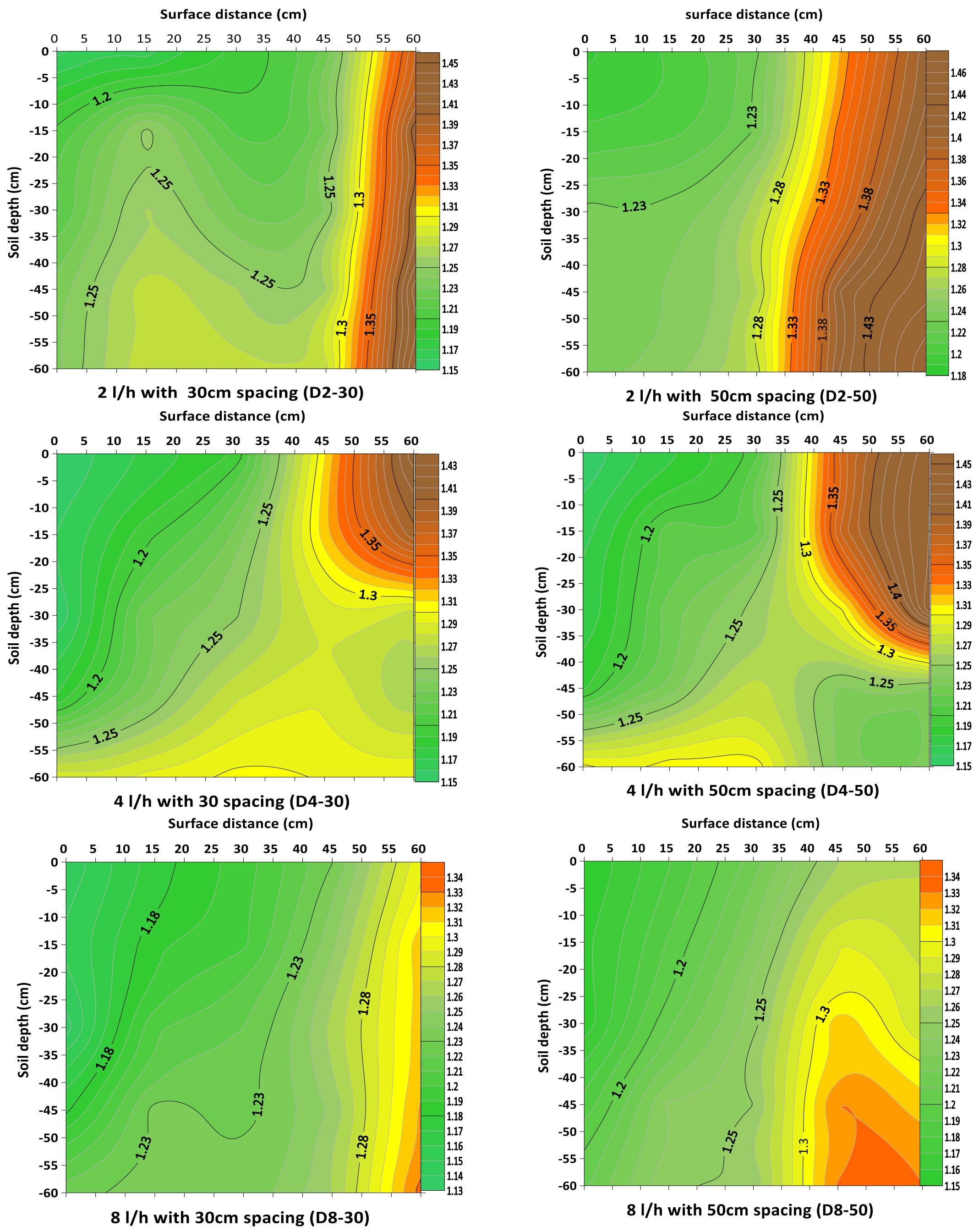

Fig.4: Effect of emitter discharges and spacing's on salt distribution (dsm^{-1}) of soil at the end of season

Table 1: Effect of irrigation emitters spacing on rice plant growth parameters

Distance	Plant height (cm)	Flag leave area(cm^2)	N. of panicles per bed	Length of panicle (cm)
30 cm	111.1[a]	27.47 [a]	37.85 [a]	24.49 [a]
50 cm	103.9 [b]	26.24 [b]	34.33 [b]	23.13 [b]
LSD (P ≤0.05)	1.263	0.6604	2.842	0.3795

4. Effect of irrigation emitters discharge on rice plant growth parameters, yield components and crop water productivity

The highest values of plant height and flag leave area were 112.5 cm and 28.26 cm^2 under discharge of 8 lh^{-1}, while the lowest values were under discharge 2 lh^{-1} for two measurements (plant height and flag leave area), and also there were no significant effects under the three discharges for the other growth parameters, length of panicle, which ranged from 24.33 cm to 23.58 cm as shown in Table 3.

Table 4 shown that the highest value of grain numbers (126.5 per panicle) under discharge 2 lh^{-1}, while the lowest value was 93.17 per panicle under both discharges 4 and 8 lh^{-1}. There were no significant differences under three discharges for grain yield and 1000 grain weight measurements. Whereas straw yield and biological yield values reached 15.987 and 26.608 $ton.ha^{-1}$, respectively, as the highest value under discharge 8 lh^{-1}. Harvest index under 2 and 4 lh^{-1} were 47.65 and 48.32%, respectively, as the highest values. There were no significant differences under three discharges for crop water productivity. Perhaps the explanation for the lack of significant differences between the three treatments was due to the provision of appropriate soil moisture content resulting from raising the overlap between the wetted areas of the short spacing between both lateral lines and emitters under clay soil conditions.

Table 2: Effect of irrigation emitters spacing on rice yield, yield components and crop water productivity

Distance	Number of grain per panicle	1000 grain weight (g)	Grain yield ($ton.ha^{-1}$)	Straw yield ($ton.ha^{-1}$)	Biological yield ($ton.ha^{-1}$)	Harvest index (%)	CWP ($kg.m^{-3}$)
30cm	115.9[a]	22.56[a]	12.03[a]	13.85[a]	25.88[a]	46.74[a]	1.618[a]
50cm	112.0[b]	21.55[b]	9.75[b]	12.82[b]	22.57[b]	43.87[b]	1.310[b]
LSD (P ≤0.05)	0.5843	0.064	0.6348	0.3897	0.7833	2.629	0.02

Table 3: Effect of irrigation emitters' discharges on rice plant growth parameters

Discharge	Plant height (cm)	Flag leave area(cm^2)	Number of panicle per bed	Length of panicle (cm)
2 lh^{-1}	104.1[c]	25.14[c]	35.44[b]	24.33[a]
4 lh^{-1}	106.0[b]	27.16[b]	37.33[a]	23.52[a]
8 lh^{-1}	112.5[a]	28.26[a]	35.50[b]	23.58[a]
LSD (P ≤0.05)	1.812	0.7775	1.765	0.9069

Table 4: Effect of irrigation emitter's discharge on rice yield, yield components and crop water

Discharge	Numbers of grain per panicle	1000 grain weight (g)	Grain yield ($ton.ha^{-1}$)	Straw yield ($ton.ha^{-1}$)	Biological yield ($ton.ha^{-1}$)	Harvest index (%)	CWP (kgm^{-3})
2 lh^{-1}	126.5[a]	22.11[a]	11.064[a]	12.335[b]	23.399[b]	47.65[a]	1.502[a]
4 lh^{-1}	93.17[c]	21.93[a]	10.99[a]	11.644[b]	22.634[b]	48.32[a]	1.468[ab]
8 lh^{-1}	122.2[b]	22.13[a]	10.621[a]	15.987[a]	26.608[a]	39.94[b]	1.422[b]
LSD (P ≤0.05)	2.390	0.5242	0.8218	1.138	1.532	3.297	0.0595

5. Effect of the interaction between irrigation emitters spacing and emitters discharge on rice plant growth parameters, yield components and crop water productivity

The results in Table 5 show that the highest values of both plant height and flag leave area were 115.7 cm and 28.33 cm^2 were obtained under D_{8-30} and D_{8-50} treatments respectively, while the lowest values were 100.5cm and 23.08 cm^2, obtained under D_{4-50} and D_{2-50} respectively. The highest number of panicles for the interaction among all treatments was 38.87 and 38.67 per bed under D_{2-30} and $D_{4-30,}$ respectively. However, the lowest value was 32 per bed under D_{2-50}. The highest value of length of panicle was 25.83 cm under D_{2-30}.

In general, it could be concluded that increasing emitter discharge can slightly improve rice growth parameters especially under shorter spacing between emitters on the lateral lines, these results agree with **Abdel-Ghany (2020).**

Table 5: Effect of the interaction between irrigation drippers spacing and drippers discharges on rice plant growth parameters.

Distance		Plant height (cm)	Flag leave area (cm^2)	Number of panicle per bed	Length of panicle (cm)
30 cm	**2 lh^{-1}**	106.3[c]	27.20[bc]	38.87[a]	25.83[a]
	4 lh^{-1}	111.5[b]	27.02[c]	38.67[a]	24.23[b]
	8 lh^{-1}	115.7[a]	28.18[ab]	36.00[b]	23.40[bc]
50 cm	**2 lh^{-1}**	102.0[d]	23.08[d]	32.00[c]	22.83[c]
	4 lh^{-1}	100.5[d]	27.30[abc]	36.00[b]	22.80[c]
	8 lh^{-1}	109.4[b]	28.33[a]	35.00[b]	23.77[bc]
LSD (P ≤0.05)		2.562	1.099	2.496	1.283

Table 6 shows the interaction effect of different emitter spacing’s and emitter discharges on rice crop yield and yield components as well as water use efficiency. The data in the table indicated that the highest value of grain number was 131 per panicle under D_{2-30} and the lowest value was 90 per panicle under D_{4-50}. While ,the highest 1000 grain weights was 23.47 obtained from D_{4-30} and the lowest was 20.4 g from D_{4-50} .

The effect of the interaction between the emitters spacing and emitters discharges with the fixed distance 60 cm between the laterals lines indicated that there were a significant effect for emitters spacing on yield and its components more than the emitters discharge effect. So, the highest grain yield and crop water productivity values were given from D_{2-30}, D_{4-30} and D_{8-30}, treatments. There were no significant differences between the three treatments, but the D_{4-30} treatment was achieved the highest value of grain yield as it, reached to 12.54 ton.ha^{-1}. On the other hand, using emitters of 8 lh^{-1} at larger distances between dripper, D_{8-50} treatment, achieved the highest value of straw production (16.87 ton.ha^{-1}), this rice straw yield results reflected on the biological yield results as both showed similar trend. Harvest index and crop water productivity values showed that highest values were 51.92% and 1.66 Kg.m^{-3} under D_{4-30} treatment, these results agree with **Abd El-Rahman, (2009) and Atta, (2005).**

Table 6: The interaction between irrigation emitters spacing and emitters' discharges on rice plant yield, yield components and crop water productivity

Distance		N. of grain per panicle	1000 grain weight (g)	Grain yield (ton.ha^{-1})	Straw yield (ton.ha^{-1})	Biological yield (ton.ha^{-1})	Harvest index (%)	CWP (kg.m^{-3})
30 cm	2 lh^{-1}	131.0^{a}	21.33^{b}	12.16^{a}	14.70^{b}	26.86^{a}	45.30^{b}	1.660^{a}
	4 lh^{-1}	96.33^{d}	23.47^{a}	12.54^{a}	11.62^{c}	24.16^{b}	51.92^{a}	1.657^{a}
	8 lh^{-1}	120.3^{c}	22.90^{a}	11.39^{a}	15.10^{b}	26.49^{a}	43.02^{b}	1.537^{b}
50 cm	2 lh^{-1}	122.0^{bc}	22.89^{a}	9.965^{b}	9.968^{d}	19.93^{c}	50.01^{a}	1.343^{c}
	4 lh^{-1}	90.00^{e}	20.40^{c}	9.441^{b}	11.68^{c}	21.21^{c}	44.72^{b}	1.280^{c}
	8 lh^{-1}	124.0^{b}	21.36^{b}	9.853^{b}	16.87^{a}	26.72^{a}	36.87^{c}	1.307^{c}
LSD ($P \leq 0.05$)		3.380	0.7413	1.251	1.609	2.131	4.662	0.084

Finally, the interaction results indicated that, the highest values of grain yield of paddy (12.54 ton.ha^{-1}) and crop water productivity (1.66 kg grain.m^{-3} of water) were obtained from same treatment of 4 lh^{-1}emitters discharge at 30 cm spacing between emitters on lateral lines (D_{4-30}), while highest rice straw yield (15.99 and 16.66 ton.ha^{-1}) was obtained from both (D_{8-30}) and (D_{8-50}) which is means that this high straw yield comes from the treatments of higher discharge 8 lh^{-1} at both 30 and 50 cm spacing. These straw results may attribute to the increase in plant height and flag leaf area under these two treatments of higher emitters discharge 8 lh^{-1}as shown in Table 5.

4. CONCLUSION

From this work, it could be concluded that the drip irrigation of rice in the old lands, saves approximately 40 to 50% of the irrigation water compared to traditional flood irrigation which is known from many studies, including this study. According to the results of this study and under its conditions, it is recommended to use emitters of 4 lh^{-1}, commonly used in the Egyptian market due to its good distribution of water horizontally and its less exposure to clogging compared to with a discharge of 2 lh^{-1}, and it is preferable that the emitters or drippers should be placed at distances of 30 cm between the emitters on the line, because this treatment (D_{4-30}) gave an increase in rice grain yield approximately 3.1 tons of grain rice, representing 33% increase in yield more than that of treatment (D_{4-50}). Which was reflected also in maximizing the crop water productivity, as it was 1.66 kg grains/m^3 of water for treatment 4 lh^{-1} at distances of 30 cm, with an increase of about 30% over its counterpart (1.28 kg/m^3) under emitters spacing of 50 cm.

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تحسين الإنتاجية المائية المحصولية لزراعة الأرز تحت نظام الري بالتنقيط

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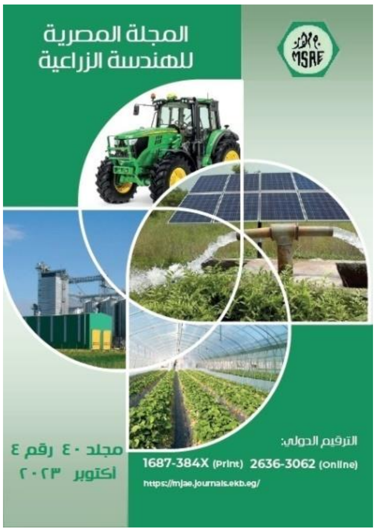

الكلمات المفتاحية:
الرى الدقيق؛ كفاءة استخدام المياه؛ التربة الثقيله.

الملخص العربى

فى ظل محدودية المصادر المائية، فضلا عن الزيادة السكانية الضاغطة على خطط التنمية الزراعية لتوفير الأمن الغذائى فى مصر، بدأ تطبيق تقنية الري الدقيق في ري المحاصيل الحقلية في بعض الأراضي القديمة في مصر. يعتبر الأرز (*Oryza sativa*, L) من أهم المحاصيل للأمن الغذائي المصري على الرغم من الاستهلاك العالى للمياه نتيجة استخدام أساليب الري التقليدية لرى حقول الأرز خلال مراحل النمو المختلفة. لذلك ، لتحسين الإنتاج والإنتاجية المائية ، يهدف هذا البحث إلى تقييم تأثير بعض معايير الري بالتنقيط على المحصول وإنتاجية المياه للأرز المروى بالتنقيط تحت ظروف التربة الطينية.

أجريت تجربة حقلية لتقييم تأثير التصرفات المختلفة للري بالتنقيط (٢، ٤، ٨ لتر/ساعة) والمسافات بين النقاطات (٣٠ و ٥٠ سم)، على رطوبة التربة وتوزيع الأملاح، ومعاملات نمو النبات، والمحصول ومكوناته. وإنتاجية المياه للمحاصيل من أصناف الأرز المقاومة للجفاف (عرابي ٣). أشارت النتائج المتحصل عليها إلى أن أعلى قيم لمحصول الحبوب من الأرز (١٢,٥٤ طن/هكتار) وإنتاجية المياه للمحصول (١,٦٦ كجم/م[٣]) تم الحصول عليها من نفس المعاملة (D_{4-30})٤ لتر/ساعة على مسافة ٣٠ سم بين النقاطات على الخطوط الجانبية، بينما تم الحصول على أعلى محصول لقش الأرز (١٦,٠٦ و ١٦,٧٣ طن/فدان) من كلا (D_{8-30}) و (D_{8-50})، مما يعني أن هذا المحصول العالي من القش يأتي من التصرفات العاليه ٨ لتر/ساعة على مسافة ٣٠ و ٥٠ سم. لذلك، فإن إدخال نظام الري بالتنقيط المناسب لري محصول الأرز في الأراضي القديمة يمكن أن يوفر المياه ويزيد من الانتاج وإنتاجية المياه.