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Hydraulic performance analysis of subsurface drip irrigation for turf grass within different types of driplines

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ABSTRACT

This study was carried out during the months from March to August 2021, in the Gemmeiza Research Station, Gharbeiah Governorate, Egypt. Where the goal of the research was to determine study Hydraulic performance analysis of subsurface drip irrigation for turf-grass within different types of driplines water consumption and maximizes the efficiency of the water productivity in clay soils. The ratio of water retained in the root zone to that applied was used to calculate application efficiency. The paspalum10 turf-grass was selected for its suitability to the conditions of the experiment, to evaluate the effect of deficit irrigation, depths of drip lines, and different types of drip lines on the landscape under subsurface drip irrigation system. The study included three variables, three types of drip lines irrigation hoses (leaky pipe porous, GR, and T-Tape) respectively, laterals were buried at three depths 15, 30 and 45cm, the treatments consisted of three Irrigation systems, full irrigation 100% and deficit irrigation (85 and 70%) of crop water requirement. The results indicated that, the performance of the irrigation system was good. The best of moisture content distribution in the soil of at an application of 85 and 70% for all types of drippers at depths of 15, and 30cm, throughout the turfgrass growth, which affected the increase in the average weight of the turfgrass and the efficiency of water use. The maximum average yield of cutting weight (857 g/m^2) in the month when application 100% of the water requirement with GR drip line at 15 cm burial depth was greater than 3.85 and 7.47% compared to leaky pipe porous, and T-Tape respectively. The highest percentage of water application efficiency (EA) where it was 91 and 88% at application level of 85 and 70% deficit irrigation of the water requirement with 15 depth GR drip line. While the lowest percentage was 72% with 100% level irrigation at 45cm depth and T-Tape drip line. The results showed that the highest value of water productivity was 1.66 and 1.5 kg/m^3 at 85 and 70% level irrigation respectively at 15cm burial G.R dripper, while the lowest value of water use efficiency (WUE) was 0.70 kg/m^3 at 45cm depth with 100% level irrigation with T-Tape dripper. The results obtained from this study showed that it is possible to save 15 and 30% of the amount of water used to irrigate landscape by using a subsurface drip irrigation system with the deficit irrigation by 85, and 70% with GR drip line at 15cm depth, The result was very close when using 85, and 70% deficit irrigation, with GR drip line at burial depth of 15cm without any noticeable effect on drip performance, moisture content, distribution efficiency and water productivity.

1. Introduction

Egypt is located within the dry desert belt, where the river Nile has played, a long time ago the amount of

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Nile water, which is available for Egypt, is about 55.5 thousand million cubic meters per year. However, according to the enormous increase in population, the quota of this water per person became in 2018 is about 564 m^3 / year. The agricultural sector consumes about 85 % of the Nile water each year, with water losses upon it's conveying from the High Dam until reaching the field estimated as 35% i.e. about 19.4 thousand million cubic meters /year. Also, about 2 thousand million cubic meters of Nile water are lost by evaporation, in addition to 2.8 thousand million cubic meters that are lost through transpiration by the weeds (FAO, 2018). Baiamonte (2018) stated that micro irrigation systems saves water by allowing water to drip Slowly to the roots plants, either onto the soil surface or directly near the root zone, through a network of valves, pipes, tubing, and emitters. It is done through narrow tubes that deliver water directly to the base of the plant. Griffiths and Lecler (2001) evaluated the irrigation systems (sprinkler and subsurface drip) performance and found the coefficient of uniformity and distribution uniformity range from 66 to 84% and from 59 to 78% under sprinkler irrigation, while under subsurface irrigation distribution and coefficient of uniformity values range from 33 to 94% and from 53 to 98% (Tobias, et al.,2020). Stewart and Howell (2003) said that Irrigation uniformity is a statistical measure of how evenly applied water is dispersed across the field, whereas application efficiency relates to how much water is available to plants in the root zone relative to how much is provided to plants. Sultan, et al. (2013) told that management of water in irrigation system can be save 42% from irrigation water under sprinkler irrigation system comparing with surface irrigation systems this mean that we can increase the area of landscape with 42% area. And achieves water saving in case of using modern irrigation technique of grass spray compare with traditional methods of irrigation which highly have water loss. Huang (2006) said that there are two classifications for turf grasses relating to climatic conditions, cool season grasses which adapted to temperate and sub-arctic climates, and warm season grass adapted to tropical and subtropical areas. Awady et al. (2003) summarized that water determination saving means depend on four measures: Engineering factors affecting the Distribution Uniformity (DU), Landscape factor that depend on the turf species and condition, Cultural practices and water management taking into account the turf density, and Microclimatic conditions.

The objectives of this study were as follows:

1. Evaluating the performance of subsurface drip irrigation system (SSDI) within different lateral types (GR, T- Tape and Leaky Pipe).
2. Study the effect of different application levels of irrigation water on the yield of turf-grass, and the Irrigation Water Productivity (IWP).
3. Determining the optimal depth of the drip line and studying its effect on moisture distribution in the soil.

2. Materials and methods

2.1. Laboratory experiments

Laboratory experiments for drip irrigation were carried out at the National Irrigation Laboratory of Agricultural Engineering Research Institute (AEnRI), ARC, Dokki, Giza. The drippers were tested and calibrated under five different operating pressures (50 - 75 – 100 -125- 150) KPa.

2.2. Experimental site description

This study was carried out from March to August 2021, at a private farm, in the Gemmeiza Research Station, Gharbeiah Governorate, Egypt. (latitude 31° N, and longitude 31.09° E). The source of irrigation water was domestic water with total salinity of 46.6 ppm and ph 7.37. The tested grass variety was paspalum10. Physical characteristics of the sampled soil before planting were determined according to Klute (1986); Page et al. (1982) respectively, and the results of these determinations are presented in Table 1.

Table 1
Soil physical analysis of experimental site.

Depth (cm)	Particle size distribution %			Texture class	Bulk density (g/cm^3)	Field capacity (%)	Wilting Point (%)	Available Soil water (%)	Readily available water (%)
	Clay (%)	Sand (%)	Silt (%)						
0-15	49.07	16.73	34.20	Clay	1.24	45.53	21.31	24.22	33.42
15-30	52.27	12.31	34.42	Clay	1.44	44.58	20.97	23.61	32.77
30-45	53.92	9.70	36.38	Clay	1.47	42.99	19.75	24.46	31.98
45-60	51.60	11.56	36.84	Clay	1.49	40.86	19.03	21.83	29.94

2.3. System installation and experimental treatments

The experimental layouts are shown in Fig. 1. The experimental consists of three treatments of soil depth (15, 30 and, 45cm), and three treatments of irrigation levels, 100 %, 85%, and 70%) of the total irrigation water requirements. The sub main plot is three drip lateral types (leaky pipe porous (I_1), GR (I_2), and T-Tape (I_3)) while the main plot was soil depth treatments were (15, 30 and 45cm). Irrigation water is applied according to the daily reference evapotranspiration (ET_o) which calculated by Penman–Monteith method (Allen et al., 1998). Subsurface laterals were placed in trenches prepared by hand at depth 15, 30, and 45cm below soil surface, The distance between the drippers along the line is 30 cm in both laterals G.R and T- tab. Rice straw and sand were used as the soil conditioners, which were placed 5 cm above and below the drip lines in all treatments as shown in Fig.1.

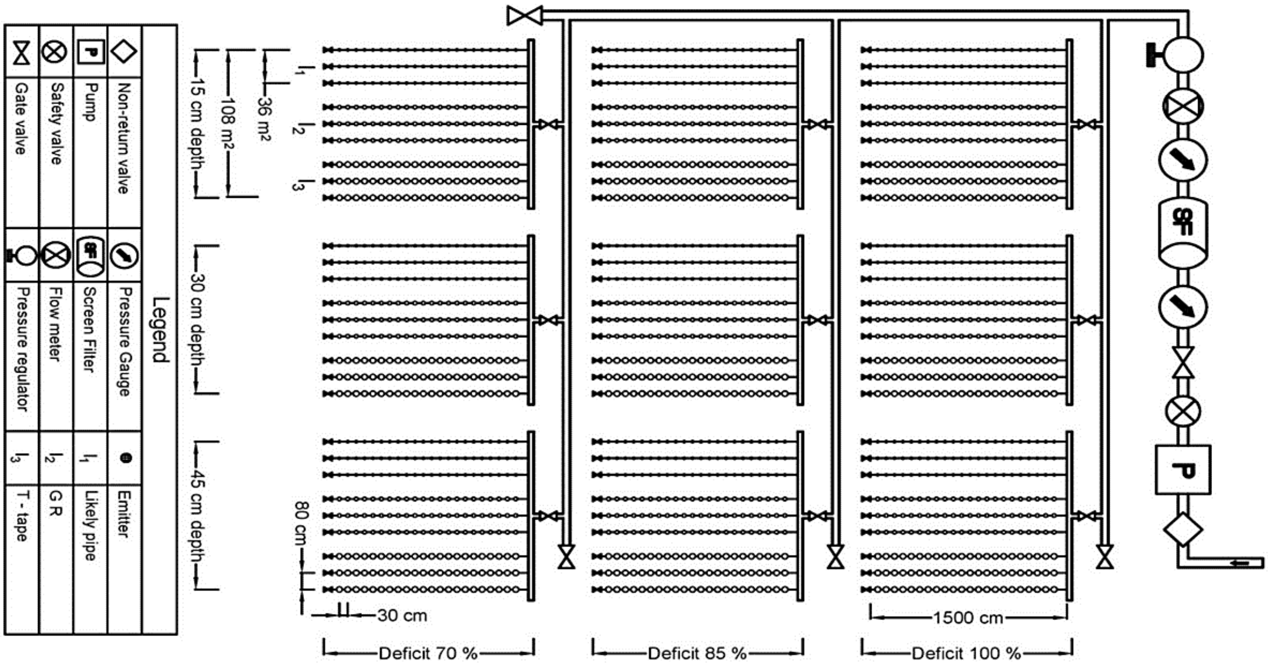

Fig.1. The layout of the experimental field irrigation treatments and replicates.

2.4. Turf-grasses

Paspalum10 (paspalum vaginatum) was cultivated in the experimental field to study the effect of the different treatments mentioned above.

2.5. Coefficient of discharge variation and emission uniformity of drip laterals

The uniformity of water application was determined from the dripper outflow collected in cans for an estimated duration. The water application uniformity was calculated from the statistical distribution of dripper flow rates in terms of coefficient of variation (CV) and emission uniformity (EU) using equation 1 and 2 (keller and karmeli,1975) as follows:

$$CV = \frac{s}{q_a} \quad \dots [1]$$

$$EU = 100\left(1.0 - 1.27\frac{CV}{\sqrt{\grave{N}p}}\right)\frac{q_a}{q_n} \quad \dots [2]$$

where:

CV: Manufacturer's coefficient of emitter variation,

S: Standard deviation of emitter flow rates at a reference pressure head, and

q_a: Mean flow rate of emitter at that reference pressure head (l/h).

N'p: The number of emitters per plant

q_n: The minimum discharge rate (l/h).

Five micro-irrigation uniformity classifications, ranging from excellent to unacceptable, recognized by the American Society of Agricultural Engineers (ASAE, 2000) were used to evaluate SDI systems as shown in Table 2.

2.6. Evapotranspiration

The estimation of evapotranspiration for turf grass was determined by the crop coefficient-reference evapotranspiration procedure. Reference evapotranspiration (ET_o) was computed for a hypothetical reference crop according to the FAO methodology (Allen et al., 1998) and is then multiplied by an empirical crop coefficient (Kc) to produce an estimate of crop evapotranspiration (ET_c), as in Eq. 3.

$$ET_c = K_c \times ET_o \quad \dots [3]$$

Table 2
Hydraulic characteristic of the drip irrigation system.

Characteristics	Drip types		
	Leaky pipe	T-tape	GR
Wall thickness (mm)	2.00	0.30	1.00
Tape inner diameter (mm)	16.00	16.00	16.00
Pressure compensating	No	No	No
Dripper discharge (L/h) in linear meter	8	13.33	13.33
Spacing between two drippers (cm)	Porous	30.00	30.00
Exponent (x)	0.70	0.50	0.51
CV % at 1 bar (100 kPa)	Average	Excellent	Excellent
EU %	89	**96**	98

Accordingly, the ET_o is calculated using the FAO Penman–Monteith method, which uses all parameters that govern energy exchange and corresponding latent heat flux (evapotranspiration) from uniform expanses of vegetation. Most of the parameters are measured or can be calculated from weather conditions. It requires daily, weekly and monthly meteorological data including air temperature, humidity, sunshine duration and wind speed.

The FAO Penman–Monteith equation used for 24-h calculations of ET_o and using daily or monthly mean data can be simplified (Allen et al., 1998) as in Eq. 4.

2.7. Determination of water application time

The water application time was calculated as in the following equation:

$$T_i = \frac{ET_c \times A}{q} \quad \dots [4]$$

where:

T_i: is the irrigation time (min),
ET_c: is the plant evapotranspiration (mm/period irri.),
A: is the dripper service area (m^2) and
q: is dripper flow rate (m^3/min).

2.8. Water application efficiency (WAE)

The application efficiency is defined as the ratio of water required in the root zone to the total amount of water applied (Jamrey. et al., 2018). Water application efficiency expresses the percentage of irrigation water contributing to root zone requirement. It indicates how well the irrigation system can deliver and apply water to the crop root zone. Burt et al. (1992); ASAE (2000) considers only the fraction of applied water stored in the root zone and potentially available for evapotranspiration:

$$WAE = \frac{\text{Average depth of water stored in the root zone}}{\text{Average depth of irrigation water applied}} \times 100 \quad \dots [5]$$

An accurate estimation of the evaporation close to the site being irrigated is an extremely valuable irrigation management aid (Connellan, 1999). Deficit irrigation is an optimizing strategy under which plants are deliberately allowed to sustain some degree of water deficit, the aim of it is to increase water use efficiency by reducing irrigation adequacy, and it recognized when use limited or high cost (English, et al., 2002).

2.9. Water Productivity, and Irrigation Water Productivity

Water use efficiency in (kg/m^3) and irrigation water use efficiency in (kg/m^3) was calculated using the following formula according to Ertek et al. (2006).

$$W.P. = \frac{(Y)\ \text{yield}}{(ET_C)\ \text{total applied rate}} \quad \dots [6]$$

$$I.W.P. = \frac{(Y)\ \text{yield}}{(I_r)} \quad \dots [7]$$

where:

W.P.: is the water productivity (kg/m^3),
Yield: is the total yield (kg/fed),
ET_C: is the total applied rate,
I.W.P.: is the irrigation water productivity (kg/m^3), and
I_r: is the amount of irrigation water applied (m^3)

2.10. Distribution efficiency

The application uniformity along water stream was expressed by Christiansen uniformity coefficient (Cu) The uniformity coefficient was computed according to James (1988).

$$Cu = \left[1 - \frac{\sum |X_i - \bar{X}|}{n\bar{X}}\right] \times 100 \quad \dots [8]$$

where:

Cu: is the Christiansen uniformity coefficient (%),
X_i: is the depth of water stored at point I,
$\bar{X}$: is the average depth of water stored along the furrow during the irrigation, and
n: is the number of observations.

3. Results and discussions

3.1. *Evaluation of drippers performance in the laboratory*

The Hydraulic characteristics of drippers and classifications, the flow rate for drippers, Parameters, and Variations in both Emission uniformity (EU) and Manufacturing coefficient of variation (CV %) for the different types of drippers are shown in Table 3.

3.2. *The relation between application efficiency and dripline depth*

In Figs. 2, 3, and 4 the results indicated that by increasing drip line depth from 15 to 45cm decreased application efficiency of different treatments, where the maximum value of application efficiency without losing amounts of water were (91%, 88% and 86%) and (88%, 85% and 83%) at deficit irrigation 85% and 70%, at depth of 15cm with (G.R, leaky-pipe and T-Tape) drip lines treatment, respectively, while the minimum value of application efficiency were (84%, 81% and 80%) at 100% full irrigation at depth of 15cm with (G.R, leaky-pipe, and T-Tape) drip lines treatment, respectively. This is consistent with the findings in other studies e.g., Irmak et al. (2011).

3.3. *Effect of drip line depth and irrigation levels on the weight of cutting grass*

The effect of drip line depth on the weight of cutting grass Figs. 5, 6, and 7 showed the relationship between weight cutting turf-grass by (g/m^2) under different drip line depths for drip line type's treatments. Where the maximum weight of cutting grass was recorded (857.0g/m^2) in treatment G.R dripper at 15cm with irrigation level 100%, the increments were 3.85% and 7.47% compared with treatments Leaky-pipe dripper at 15cm with irrigation level 100%, and T-Tape dripper at 15cm with irrigation level 100%, respectively., The average weight of cutting grass in treatment G.R dripper at 15cm with irrigation level 85%, was 808.0 g/m^2 with increments of 2% and 8.91% compared with treatments Leaky-pipe dripper at 15cm with irrigation level 85%, and T-Tape dripper at 15cm with irrigation level 85%, respectively. While average the weight of cutting grass in treatment G.R dripper at 15cm with irrigation level 70%, was 698.0 g/m^2, with increments of 2.43%, and 10.74% compared with treatments Leaky-pipe dripper at 15cm with irrigation level 70%, and T-Tape dripper at 15cm with irrigation level 70%, respectively. The result showed that the higher yield drip line depth of 15.0cm. obtain higher yields. While the minimum values were at 45cm depth in all treatments. Meanwhile, The Effect of irrigation levels on the weight of cutting grass was the maximum with applying 100% of irrigation water requirement in all treatments, compared with 85% and 70% deficit of irrigation water requirement in all treatments. Hiekal (2009); Shock and Feibert (2000) reported Similar results.

3.4. *Irrigation Water Productivity (I.W.P)*

The average values of IWUE are shown in Figs. 8, 9 and 10 Treatment at drip line depth of 15cm gave the highest average value (1.76, 1.63, and 1.5 kg/m^3) and (1.5, 1.48, and 1.36 kg/m^3) for (I_2, $I_3$and I_1) at 85 and 70% deficit irrigation, respectively. The average values obtained with 85% and 70% deficit irrigation were higher than those with 100% (full irrigation) at all the applied irrigation water levels. Thus, saving 15.0 and 30.0% of irrigation water by burying the drip line at 15.0 cm depth had significantly affected the mean values of IWUE under the experiment conditions. Meanwhile, the 100% (full irrigation), gave the lowest average value (1.20 kg/m^3) of IWUE, these results agree with that obtained by Ahmed at al. (2019); Sultan et al. (2013); Hosam (2009) who observed similar findings results that gave the highest IWUE with deficit irrigation.

Table 3
The Hydraulic characteristics of drippers:

Hydraulic characteristics		Leaky-pipe	T-Tape	GR
Flow rate (l/h)	Normal	8	4	4
Manufactures coefficient of variation (CV%) at (1 bar)	Value	7	3	1
	ASAE standard	Average	Excellent	Excellent
Parameters	Emitter discharge exponent (x)	0.7	0.5	0.5
	Flow coefficient (k)	6.97	3.88	4.09
Flow regime		Mostly turbulent flow	Fully turbulent flow	Fully turbulent flow
Emission uniformity (Eu%)	Value	98	96	98
	ASAE standard	Excellent	Excellent	Excellent

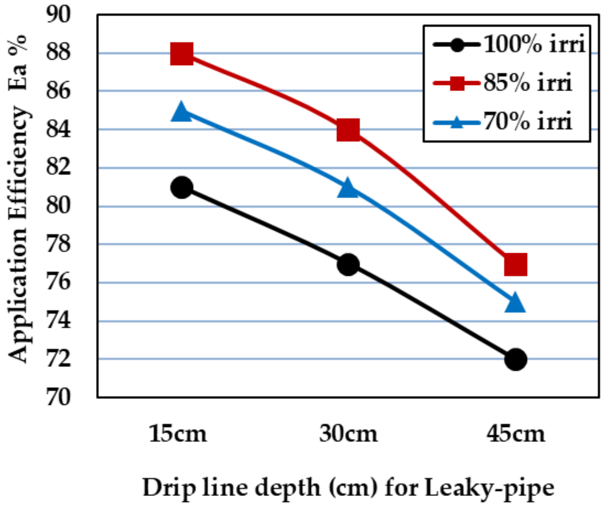

Fig. 2. Application Efficiency (Ea %) for all irrigation levels and different depths for leaky-pipe.

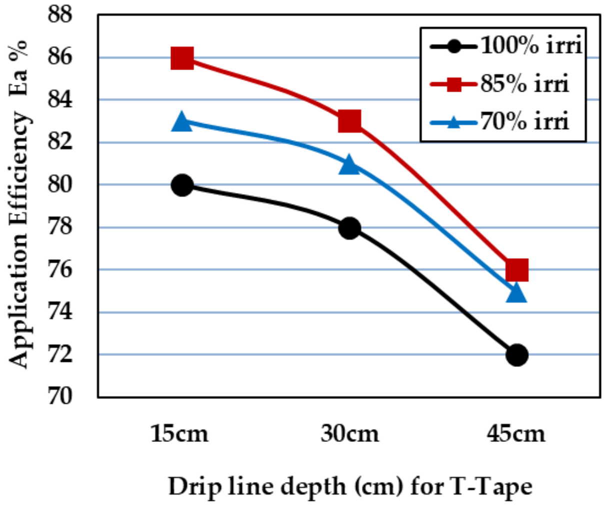

Fig. 3. Application Efficiency (Ea %) for all irrigation levels and different depths for T-Tape.

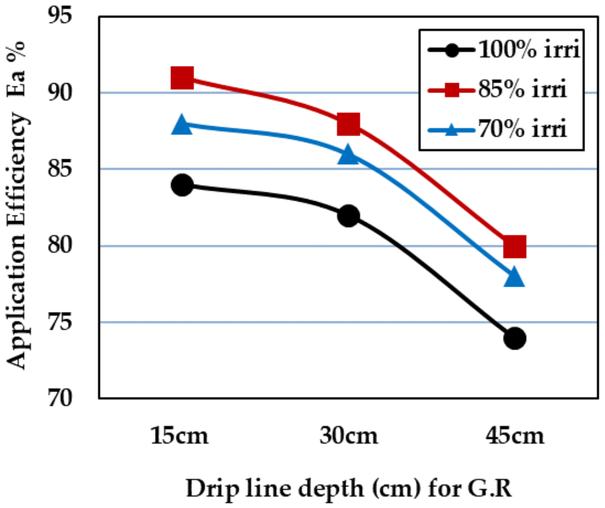

Fig. 4. Application Efficiency (Ea %) for all irrigation levels and different depths for G.R.

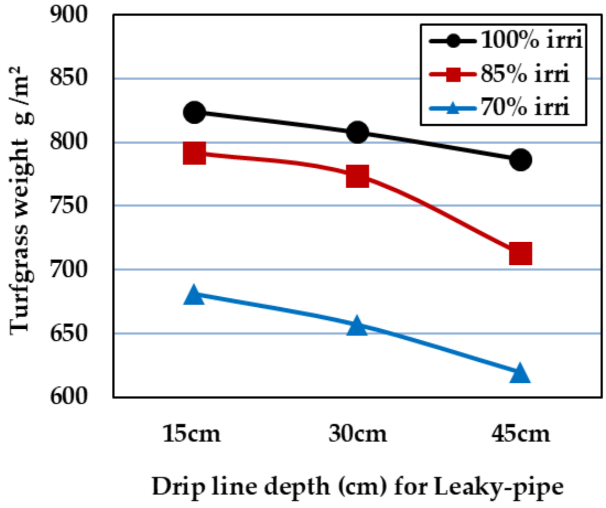

Fig. 5. Turf-grass weight g/m² for all irrigation levels and different Drip line depth for Leaky-pipe.

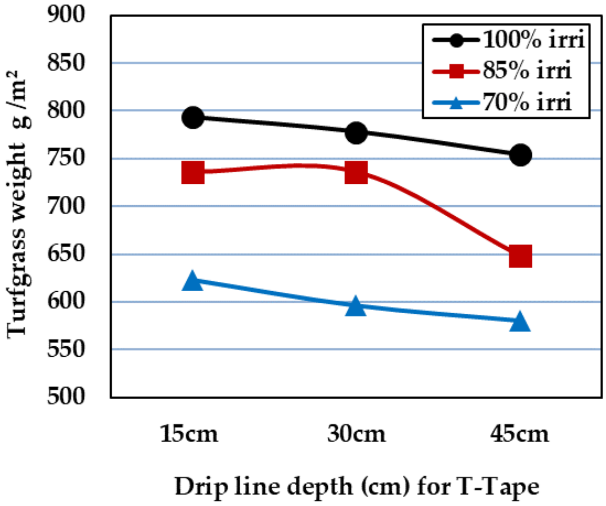

Fig. 6. Turf-grass weight g/m² for all irrigation levels and different Drip line depth for T-Tape.

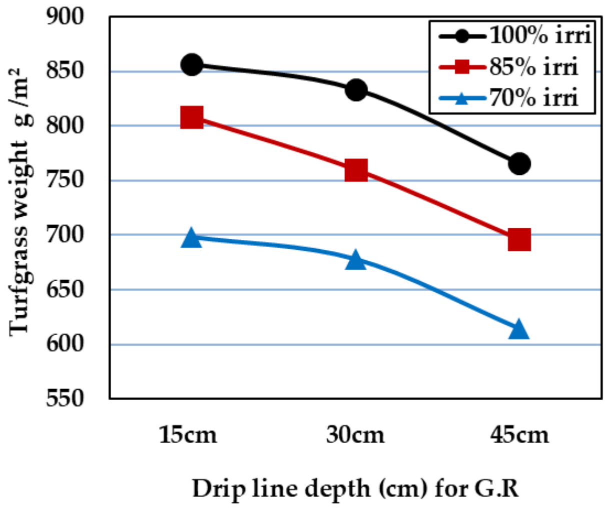

Fig. 7. Turf-grass weight g/m² for all irrigation levels and different Drip line depth for G.R.

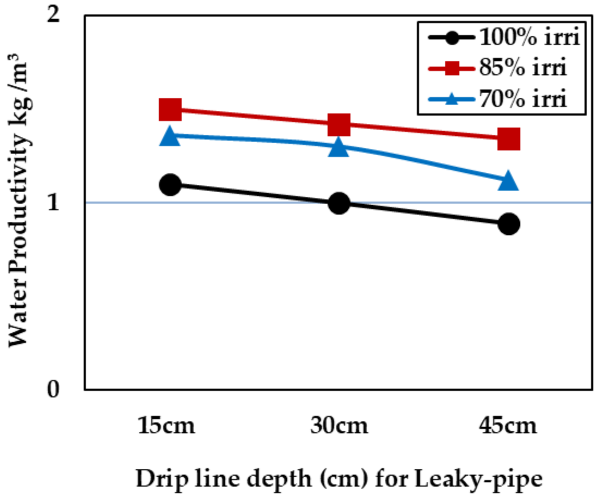

Fig. 8. Water productivity under for all irrigation levels and different drip line depth for Leaky-pipe.

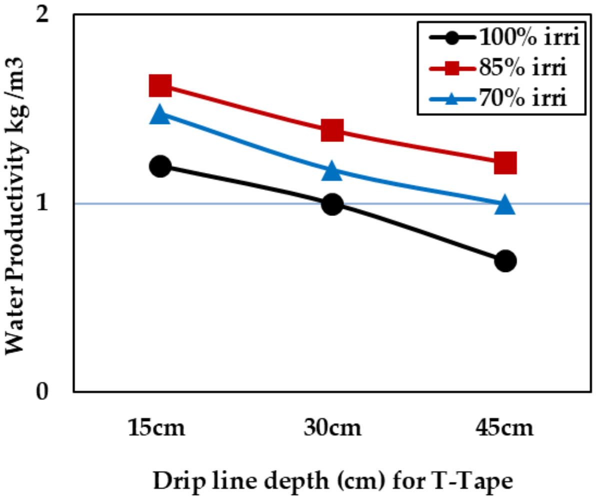

Fig. 9. Water productivity under for all irrigation levels and different drip line depth for T-Tape.

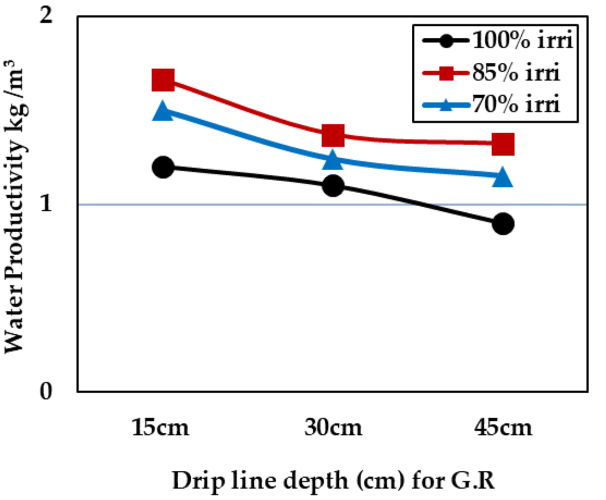

Fig. 10. Water productivity under for all irrigation levels and different drip line depth for G.R.

3.5. Water Distribution efficiency (Cu %)

Figs. 11, 12, and 13 Showed that the greatest values of distribution efficiency were about 95 and 93% at 80 and 70% deficit irrigation for depth 15cm, respectively, with drip line types G.R treatment, While the lowest value of distribution efficiency was about 79% at 100% irrigation for depth 15cm with drip line type of T-Tape. These results agree with that obtained by Hosam et al. (2009).

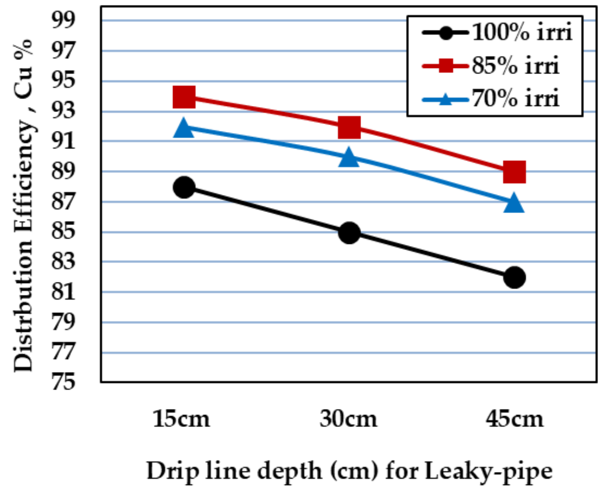

Fig. 11. Distribution Efficiency under for all irrigation levels and different Drip line depth for Leaky-pipe.

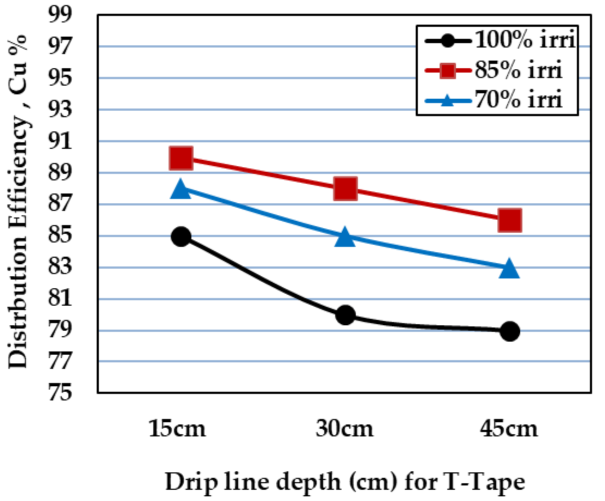

Fig. 12. Distribution Efficiency under for all irrigation levels and different Drip line depth for T-Tape.

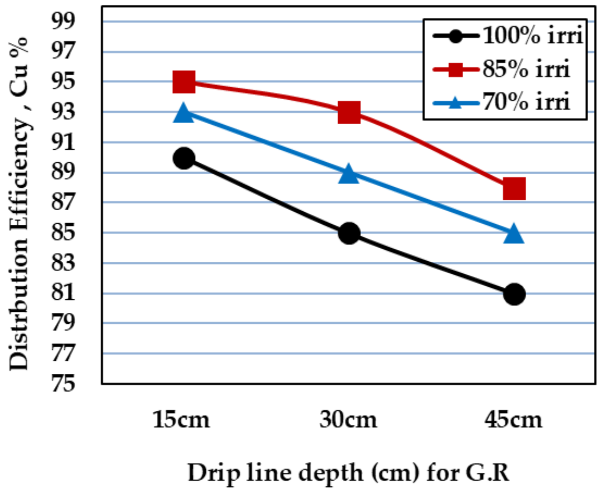

Fig. 13. Distribution Efficiency under for all irrigation levels and different Drip line depth for G.R.

4. Conclusions

Using the GR drip type with a depth of 15cm in the clay lands gave the best results, while the lowest results were with the T-Tape drip type in all treatments. Excluding a depth of 45cm with a subsurface drip irrigation system, which gave very bad results with all treatments. It is recommended to use a deficit irrigation level of 85 and 70%, as it is possible to save 15 and 30% of the irrigation water requirement respectively, in the subsurface drip irrigation system without any noticeable effect on the performance of the drippers.

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تحليل الأداء الهيدروليكي للري بالتنقيط تحت السطحي للنجيل باستخدام أنواع مختلفة من خطوط التنقيط

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الملخص العربي

أجريت هذه الدراسة خلال الفترة من مارس الي أغسطس ٢٠٢١م بمحطة البحوث الزراعية بالجميزة محافظة الغربية، مصر. والهدف من البحث هو تحليل الآداء الهيدروليكي للري بالتنقيط تحت السطحي للنجيل باستخدام أنواع مختلفة من خطوط التنقيط في التربة الطينية. تم اختيار نجيل صنف Paspalum 10 لملائمته ظروف التجربة وتم استخدام نظام الري بالتنقيط تحت السطحي. كانت متغيرات الدراسة ثلاثة أنواع من خراطيم الري ذاتية التنقيط مصنوعة من مادة البولي إيثيلين PE ذات قطر داخلي ١٦ مم هي: T-Tape - GR - leaky pipe porous ذات تصرفات ١٣,٣ و ١٣,٣ و 8 لتر/متر طول على التوالي. وكانت المسافة بين النقاطات ٣٠سم والمسافة بين خطوط التنقيط ٨٠ سم وطول خط التنقيط ١٥متر وتم دفنها على ثلاثة أعماق مختلفة ١٥ و ٣٠ و ٤٥ سم لدراسة تأثير عمق الدفن على كفاءة الإضافة ووزن القص للنجيل وتم استخدام ثلاث مستويات مختلفة لمياه الري كنسبة من

الاحتياجات المائية للمحصول وهي ١٠٠٪، والري الناقص بنسبة ٨٥٪ و ٧٠٪. ولقد صممت التجربة حيث تتمثل في ٢٧ معاملة منها معاملات رئيسية متمثلة في نسب الري الثلاثة من الاحتياج المائي، ومعاملات فرعية تتمثل في نوع النقاط وعمق الدفن، واعتبرت معاملة الاضافة بنسبة ١٠٠٪ من الاحتياج المائي على عمق دفن ١٥سم لكلا من T-Tape و leaky pipe porous و GR. وقد تم دراسة كل من كفاءة الإضافة (Ea) وتأثير أعماق الدفن ونسب الري على الإنتاجية وكذلك إنتاجية وحدة مياه الري (IWUS) حيث أظهرت النتائج المتحصل عليها ما يلي:

- أعلى معدل لوزن القص ٨٥٧ جم/م٢ عند معدل إضافة ١٠٠٪ من الاحتياج المائي مع النقاط G.R وعمق دفن ١٥سم بزيادة ٣,٨٥٪ و٧,٤٧٪ مقارنة بالنقاط leaky pipe porous و T-Tape على التوالي.
- أعلى كفاءة إضافة للماء عند مستوى إضافة ٨٥٪ و ٧٠٪ كانت ٩١,٨٨ % و ٨٨ % على التوالي مع النقاط G.R على عمق دفن ١٥سم.
- أعلى متوسط لإنتاجية وحدة مياه الري عند مستوى اضافة ٨٥٪ و ٧٠٪ من الاحتياج المائي كانت ١,٦٦ , ١,٥ كجم/م٣ على التوالي مع النقاط GR وعمق دفن ١٥سم بنسبة إضافة ١٠٠٪ من الاحتياج المائي.
- يمكن توفير من ١٥ % - ٣٠٪ من كمية المياه المستخدمة لري المسطحات الخضراء باستخدام نظام الري بالتنقيط تحت السطحي مع استخدام الري الناقص بنسبة ٨٥٪ و ٧٠٪ مع خط التنقيط GR على عمق ١٥ سم، حيث كانت النتيجة قريبة جدًا مقارنة باستخدام الري الكامل بنسبة ١٠٠٪، مع خط التنقيط GR على عمق ١٥ سم وذلك بدون أي تأثير ملحوظ على آداء النقاطات والمحتوى الرطوبي وكفاءة التوزيع وكفاءة استخدام المياه.

توصي الدراسة باستبعاد عمق الدفن ٤٥ سم ونوع النقاط t-tape لحصولهم على أقل النتائج في جميع المعاملات على الإطلاق.