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Comparing the Relationship of Different Drip Irrigation Uniformity Parameters with Crop Yield

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ABSTRACT

Drip irrigation system has the ability to apply water over the field uniformly. Uniformity of drip irrigation can be measured through many parameters. Uniformity is one of the procedures which should be considered in drip irrigation design and management to gain the maximum possible crop yield. The objective of this study was to investigate the effect of some uniformity parameters including Christiansen's uniformity coefficient (UC), distribution uniformity (DU), Manufacturing coefficient of variation (CV_f), and emission uniformity (EU) on crop yield and water productivity, in addition to evaluate the strength of the relationship between each of studied uniformity parameter and crop yield. Four operating pressure heads 5, 10, 15, and 20m were used to operate the irrigation system to make the required change in drip irrigation system uniformity level. The study included two crops which were lettuce and turnip. Results indicated that increasing drip irrigation system uniformity will lead to increase crop yield and water productivity of both crops. Values of correlation coefficient (r) were less than 0.5 for all uniformity parameters when correlated to crop yield. This indicated that uniformity might not be the most important factor representing the quantity of crop yield though its importance. According to the values of the (r) resulted from the relationship between each uniformity parameter and crop yield; EU had the strongest effect on crop yield. The study recommended modeling the relationship between drip irrigation uniformity and crop yield basing on EU.

Keywords: Crop Yield , Drip irrigation, Parameters, Relationship, Uniformity, Yield.

INTRODUCTION

Irrigation systems should be well managed to achieve the purposes of saving water and energy with keeping the possibility of reaching the maximum possible crop yield. Drip irrigation system is characterized by applying irrigation water in slow flow rates directly in the root zone. This feature makes drip irrigation one of the most saving irrigation systems for water and energy. Drip irrigation system is able to save irrigation water which leads to expand water use efficiency (Aujla *et al*., 2007; Ibragimov *et al*., 2007). Drip irrigation is also characterized by applying water uniformly and precisely at a high irrigation frequency if compared to both sprinkler and furrow irrigation (Hanson and May, 2007). It is expected in drip irrigation system that all emitters discharge equal amounts of water, but a difference in flow rates between two identical emitters may appear due to pressure change along laterals and sensitivity of emitters to this change (Mizyed and Kruse, 2008). Management of drip irrigation system should consider operation at acceptable levels of uniformity. Reaching these levels requires selecting suitable emitters in addition to investigating the suitable operating pressure. Emitters are the largest contributors to pressure losses in a drip irrigation system (Shamshery and Winter, 2018). Many studies on drip irrigation system revealed that the higher uniformity level leads to higher crop production obtained (Zhao *et al*., 2012; Abd El-Hady *et al.*, 2015) , higher water productivity (Wang *et al.*, 2018; . Narayanamoorthy, 2016), efficient chemical use (Narda and Chawla 2002; Kumari and Kaushal, 2014), better energy use (El-Nemr, 2013; Ozkan *et al.*, 2004), higher net profits (Lopez-Mata *et al.*, 2010), and lower water losses especially deep percolation (Wang *et al.*, 2014). Due to this, many studies have introduced different techniques to reach best hydraulic performance for drip irrigation system whether by using pressure compensating emitters like the study of Sokol *et al.*,2019 or using closed water circuits (Abo-Kora *et al.*, 2019). The relationship between uniformity parameters and expected crop yield included Christiansen's uniformity coefficient (Sepaskhah and Ghahraman 2004; Wang *et al*., 2017), statistical uniformity (Bralts *et al*., 1981) and distribution uniformity (Santos, 1996). It is important to understand the meaning of each uniformity parameter and what it does describe in the system's hydraulic performance. It is also important to develop mathematical models to describe the relationship between uniformity parameters and crop production like the models developed by (letey *et al*., 1984; Mantovani *et al*., 1995; Li and Kawano, 1996; and Lopez-Mata *et al.*, 2010). In order to obtain a successful model, the strength of the relationship between uniformity and crop yield should be investigated for each uniformity parameter individually. This will help in selecting the most appropriate parameter for describing the relationship between uniformity and crop yield, on which the mathematical model for the description is expected to be developed and improved. The objectives of this study are as follows:- 1- investigate the effect of some uniformity parameters including Christiansen's uniformity coefficient (UC), distribution uniformity (DU), Manufacturing coefficient of variation (CV), and emission

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uniformity (EU) on crop yield and water productivity. 2- Evaluate the strength of the relationship between each of studied uniformity parameter and crop yield to recommend one of them for modeling purpose.

MATERIALS AND METHODS

Agronomic practices

The experiment included two crops which were turnip (Hybrid California) and lettuce (Romaine). Experiment location was 31.41º N, 31.75º E in Kafrelbatikh city, Damietta governorate, Egypt. Physical properties of the soil and soil texture are listed in Table (1).

Table 1 Physical properties of experiment soil

Depth, cm	Particle size distribution, %			Texture	Field capacity, %	Wilting point, %
	Clay	Silt	Sand			
0-15	18.50	1.50	80.00	Sandy loam	19.48	9.06
15-30	19.13	2.52	78.35	Sandy loam	17.05	8.79
30-45	15.93	1.99	82.08	Sandy loam	16.69	7.05
45-60	17.05	2.01	80.94	Sandy loam	18.29	7.44

Lettuce planting started at 23/10/2019 using 1 month aged seedlings; while turnip planting started at 31/10/2019 by adding 3 seeds/ pore then thinned to one plant after germination. Soil was ploughed with 7 shares chisel plough before planting two times after adding organic manure with a rate of 25m^3.ha^{-1}; in addition to 350 kg.ha^{-1} ammonia sulfate and 150 kg.ha^{-1} potassium sulfate. The soil surface was leveled to be completely horizontal with no slope. Turnip was fertilized during growing season with 240 kg.ha^{-1} ammonia nitrate after germination and another batch of the same fertilizer with a rate of 120 kg. ha^{-1} after three weeks of the first one. Two equal batches of 480 kg.ha^{-1} of ammonia sulfate and 120 kg. ha $^{-1}$ of potassium sulfate were used for lettuce crop; the first batch was after seedling and the other one was added after four weeks from the first batch.

Variables

Irrigation network was operated using four operating pressure heads namely 5, 10, 15, and 20 m of water. Choosing these highly varied operating pressures; was to apply the expected variation in the levels of uniformity parameters as it is the most affecting factor in the hydraulic performance of drip irrigation systems (Hezarjaribi *et al.*, 2008). At the same time they are considered suitable for drip irrigation system.

Irrigation network layout

Irrigation network layout is shown in Fig. 1. A 5 cm inner diameter PVC manifold was used to feed 16mm inner diameter polyethylene laterals with built-in emitters. The network was divided into four parts; each of them works at a certain operating head and consisted of 6 laterals. Treatments were separated by control valves to control the flow and operating pressure. Three laterals for both turnip and lettuce crops were used to act the replicates of crop yield at each treatment. Pressure gauges were fitted after each control valve to assure the value of operating head. T-shaped valves were fitted in the inlet of laterals to enable ending irrigation process at desired time for each treatment separately. Laterals were 20m length, 1.5m spacing, and 0.5m spacing of emitters. Separation distance between each part of the experiment was 3m. Water pumping process was carried out using 3.73 kW (5 hp) gasoline pump.

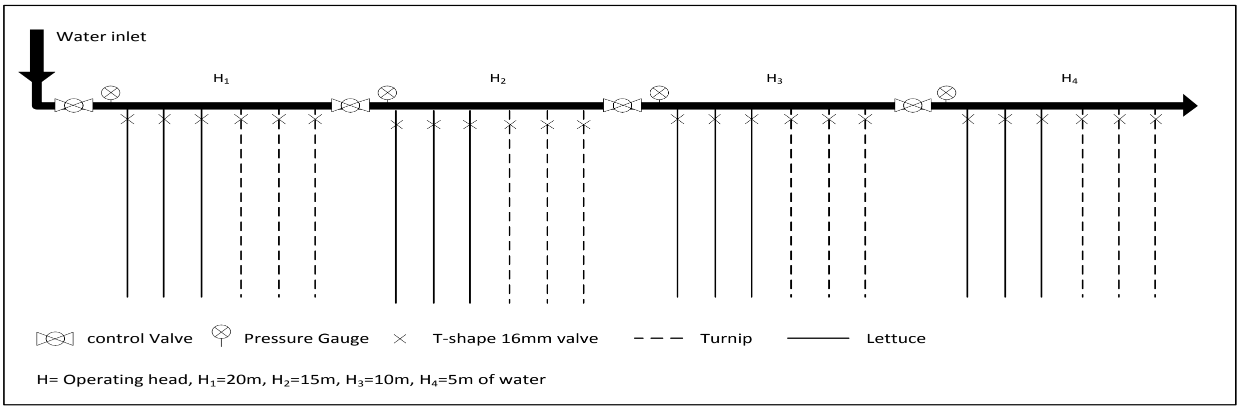

Fig. 1. Drip irrigation network layout

Measurements

Irrigation system uniformity parameters

Relationship between operating pressure head and emitter flow rate was obtained and described according to Equation 1.

$$q = kH^x \quad (1)$$

Where:-

q= emitter flow rate, l.h^{-1}; H= Operating head, m and x= emitter exponent; and k= A derived constant from the equation.

This equation will describe the type of flow inside emitter and how its flow rate is sensitive to the change in operating pressure. Curve expert v1.3 computer application program was used to obtain the previously mentioned formula of the experimental condition.

Uniformity parameters

Measurement of drip irrigation system uniformity included uniformity coefficient (UC), distribution uniformity (DU), field manufacturing coefficient of variation (CV_f), and emission uniformity (EU).

Measurement of these parameters was based on collecting water volume of 20 emitters along lateral. A 100 ml cans were put under each selected emitter at once for two minutes time period. Emitters' flow rates were calculated by dividing the collected volume by operation time. The degree of emitter flow variation is expressed by UC as defined by the following equation (Christiansen, 1942):-

$$UC = 1 - 100\left(\frac{\sum_{i=1}^{i=n}|q_i - q^{`}|}{q^{`}.n}\right) \quad ....2$$

Where: -

n = number of observed emitter, $q^{`}$ = average of emitters flow rates , $l.h^{-1}$.

DU is a measure of how uniformly water is applied to the irrigated area. DU was calculated using the following equation (Kruse, 1978): -

$$DU = 100\frac{q_{lq}^{'}}{q^{'}} \quad ....3$$

Where: -

$q^{'}_{iq}$ =mean of lowest one-fourth of emitter flow rates, $l.h^{-1}$.

Emitters' manufacturing coefficient of variation was measured in the field (CV_f); it was calculated as follows (Keller and Karmeli, 1974):-

$$CV_f = 100\frac{S_q}{q^{'}} \quad ....4$$

Where:- S_q = standard deviation of emitters flow rate.

EU indicates how uniform does the system apply water to the field. It is a critical prerequisite for system design and reaching high application efficiency. EU was calculated using Equation 5 (Karmeli and keller, 1975):

$$EU = 100\left(1 - \frac{1.27CV}{N_p^{0.5}}\right)\frac{q_{\min}}{q^{'}} \quad ....5$$

Where:-

q_{min} = minimum discharge rate, $l.h^{-1}$, N_p = number of emitters per plant and it was 2 according to lateral design.

Amount of applied water

Crop water requirements for the two crops were calculated according to (FAO, 1998) basing on climate data obtained from Damietta meteorological station (31.25º N and 31.49º E) for the years 2017 and 2018. Cropwat 8.0 software was used to calculate reference evapotranspiration (ET_o) during the experiment time period. The Crop coefficient values were 0.35, 1.2, and 0.70 for turnip and 0.7, 1.0, and 0.95 for lettuce for the crop development, mid-season, and late-season growing periods respectively (FAO, 1998). Leaching requirements (LR) were calculated according to electric conductivity (EC) of both irrigation water (EC_{iw}); and drainage water (EC_{dw}) as shown in Equation 6:-

$$LR = 100\frac{EC_{iw}}{EC_{dw}} \quad ....6$$

Resulted percentage was 17.8% which was added to crop water requirement in order to calculate net irrigation requirement.

Crop yield and water productivity (WP)

Harvesting of turnip and lettuce started after reaching acceptable marketing specifications. lettuce harvesting started at 16/12/2019 while harvesting of turnip was at 22/12/2019. The yield was weighed on three digits accuracy scale. Turnip weight was for the whole plant including green canopy. Average of the three replicates was used to express the yield produced from each treatment. Water productivity (WP) was calculated according to Rodrigues and Pereira (2009) as follows:-

$$WP = \frac{Y}{W_{app}} \quad ....7$$

Where: Y=Crop yield $kg.ha^{-1}$, W_{app}= amount of applied water $m^3.ha^{-1}$.

Strength of the relationship between uniformity parameters and crop yield

Correlation coefficient (r) was used to describe how strong the relationship between each of uniformity parameters and crop yield is. Correlation coefficient value was calculated according to Pearson's equation which was mentioned by Rodgers and Nicewander (1988):

$$r = \frac{n(\sum uy) - (\sum u)(\sum y)}{\sqrt{[n\sum u^2 - (\sum u)^2][n\sum y^2 - (\sum y)^2]}} \quad ....8$$

Where u= Uniformity parameter value, %. Y= Crop yield, $Mg.ha^{-1}$.

RESULTS AND DISCUSSION

The relationship between operating pressure, m and emitters average flow rate ($l.h^{-1}$) was described in Fig. 2. Emitter exponent value shown in Equation 9 points out that the used emitter is a laminar flow emitter which means it is not considered a pressure compensating emitter.

$$q = 1.05H^{0.66} \quad ....9$$

Standard Error (SE)=1.72%

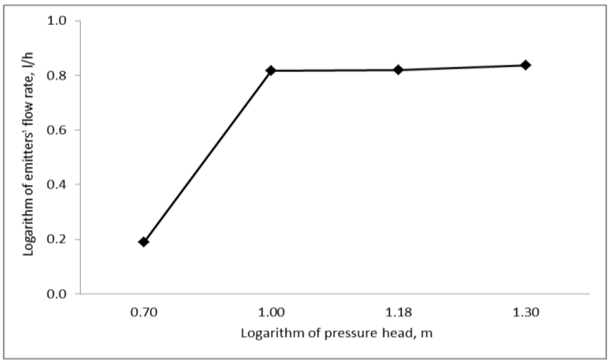

Fig. 2. Relationship between operating pressure and emitter flow rate

Uniformity parameters

Values of uniformity parameters listed in Table (2) showed that increasing operating pressure from 5 to 15 m; led to increase the drip irrigation system uniformity parameters. At 20m head values of UC, DU, and EU were less than the obtained values at 15m head but still higher than the values of 5 and 10m head. CV_f value at the 20m was higher than both the values at 15m and 10m.

Table 2. Uniformity parameters values

Head, m	Average flow rate, $l.h^{-1}$	UC, %	DU, %	CV_f, %	EU, %
20	6.87	90.27	84.16	12.38	66.94
15	6.59	91.46	87.53	11.25	68.09
10	6.55	85.95	79.85	11.45	46.21
5	1.55	48.14	41.01	18.16	7.17

The relationship between operating pressure head and system uniformity tends to be proportional till 15m operating head; but these trend has changed at 20m head which showed lower uniformity compared to 15m head. This change may be due to the change of flow type inside the emitters which made the 15m head more suitable for operating the used emitters than 20m head.

Crop yield

Crop yield values have followed the uniformity trend of drip irrigation system. The more uniformity of the irrigation system, the more yield obtained. Greatest crop yield was at 15 m operating pressure with values of 8.97 $Mg.ha^{-1}$ and 14.79 $Mg.ha^{-1}$ for both lettuce and turnip, respectively. The highest values of uniformity parameters were reached at the same operating head. Crop yield was reducing starting from the 20 m operating head, followed by 10 and 5m, respectively as shown in Table (3).

Table 3. Crop yield of lettuce and turnip, Mg. ha^{-1} under different operating heads

Head, m	lettuce	turnip
20	7.95	12.77
15	8.97	14.79
10	6.73	9.89
5	5.75	8.15

Water productivity

Amount of applied water was 2837.12 m^3. ha^{-1} and 2721.28 m^3. ha^{-1} for lettuce and turnip crops, respectively. Table (4) shows water productivity of lettuce and turnip crops under different operating head.

Table 4. Water productivity, kg.m^{-3} for both lettuce and turnip under different operating pressure heads

Head, m	lettuce	turnip
20	2.80	4.69
15	3.16	5.43
10	2.37	3.63
5	2.03	2.99

The greatest water productivity of lettuce crop was 3.16 kg.m^{-3} at 15m head; which showed highest uniformity. At the same operating head; water productivity of turnip reached its greatest value 5.43 kg.m^{-3}. It was noticed that there was a proportional relationship between irrigation system uniformity and water productivity as a result of the increase in crop yield.

Correlation coefficient

Referring to the values of correlation coefficient (r) listed in Table (5); EU has the greatest effect on crop yield followed by DU, UC, and CV_f, respectively for both crops. The negative value (r) for CV_f is due to the reverse relationship between the value of CV_f and crop yield.

Table 5. Evaluation of the effect of each uniformity parameter on crop yield based on correlation coefficient (r) value.

Parameter	lettuce	turnip
UC	0.18	0.18
DU	0.21	0.20
CV_f	-0.16	-0.15
EU	0.43	0.42

These results points out the importance of EU as a uniformity parameter on the design and management of drip irrigation system to obtain maximum possible crop yield. According to this result in case of developing a model to describe the relationship between drip irrigation system uniformity and crop yield; it is recommended to be based on EU. Low values of r which tends to zero value direction more than the value 1 direction for all parameters; reflect that uniformity was not the only factor affected the crop yield. This result was mentioned by Ayars *et al*., 1991; Mateos, 1997; Bordovsky and Porter, 2008; and Zhao *et al.*, 2012 who indicated that uniformity of drip irrigation system does not have a significant effect on crop yield as expected. On the other hand many studies also indicated a significant role for drip irrigation uniformity in increasing crop yield (Jiusheng, 1998, López-Mata *et al.*, 2010, and Guan *et al*,. 2013). In general drip irrigation uniformity has an impact on crop yield but the measurement and description of this role will vary from a study to another according to the experiment conditions.

CONCLUSION

This study has been taken place to investigate the effect of drip irrigation system uniformity on crop yield and water productivity and to study how strong the relationship between some uniformity parameters and crop yield is. Results indicated that the crop yield of lettuce and turnip has a proportional relationship with drip irrigation system uniformity. This was reflected on water productivity which followed the same trend of increase with the increase in drip irrigation system uniformity. Correlation coefficient (r) value has been calculated basing on uniformity parameter as independent variable and crop yield as dependent variable. Values of (r) indicated that uniformity may not be the most effective factor in the value of crop yield though its importance. EU had the strongest effect on crop yield if compared to (UC), (DU), and (CV_f). In case of developing a model to describe the relationship between crop yield and drip irrigation system uniformity; it is recommended to use deign emission uniformity (EU) as it had the highest effect on crop yield according to this study results.

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مقارنة علاقة مؤشرات مختلفة لانتظامية الرى بالتنقيط بإنتاجية المحصول

معتز كمال النمر و أحمد جلال عامر
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تعتبر الانتظامية من أهم العوامل الواجب مراعاتها عند تصميم وادارة الرى بالتنقيط لما لها من ارتباط مباشر بالمحصول الناتج. تهدف الدراسة الى تتبع أثر التغير في مستويات مؤشرات الانتظامية على انتاجية المحصول وانتاجية المياه بالإضافة الى تقييم قوة العلاقة بين كل مؤشر من تلك المؤشرات على حده وكمية المحصول الناتج لبيان أكثرها تأثيراً. أجريت الدراسة على نظام الرى بالتنقيط بتربة رملية- لوميه على محصولى الخس واللفت. شملت الدراسة تشغيل نظام الرى بالتنقيط بأربعة ضواغط هى ٥، ١٠، ١٥، ٢٠م. شملت مؤشرات الانتظامية تحت الدراسة كل من معامل الانتظامية، انتظامية التوزيع، معامل اختلاف التصنيع المقاس حقلياً، بالإضافة لانتظامية التنقيط. حقق الضاغط ١٥م أعلى انتظامية لنظام الرى مقارنة بباقي ضواغط التشغيل تحت الدراسة. أظهرت النتائج أن هناك علاقة طردية بين انتظامية الرى وكمية المحصول الناتج لكل من نباتى الخس واللفت وتحقق نفس الأمر بالنسبة لإنتاجية المياه. أظهرت قيم معامل الارتباط أن الانتظامية قد لا تكون هى العامل الأكثر تأثيراً في تحديد كمية المحصول الناتج بالرغم من أهميتها. انتظامية التنقيط كانت هى أكثر المؤشرات أثرا في كمية المحصول الناتج سواء لمحصول الخس أو اللفت. أوصت الدراسة بمراعات مؤشرات الانتظامية في عملية الصميم وادارة نظام الرى بالتنقيط للحصول على أعظم انتاج ممكن للمحصول وكذلك أكبر قيمة من انتاجية المياه مع استخدام انتظامية التنقيط في عمل النماذج الخاصة بوصف العلاقة بين الانتظامية وانتاج المحصول.