

ROOTS DISTRIBUTION UNDER DEFICIT IRRIGATION FOR MAIZE PRODUCTION

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ABSTRACT

Root growth and its distribution is fundamental in explaining crop responses to irrigation systems and determining its appropriate management. An experiment was conducted to study the effect of drip emitters (Em) under full and deficit irrigation on root distribution, yield and water use efficiency (WUE) of maize crop in sandy soil. Four emitter types were used to irrigate the crop by three percentages 100, 80 and 60% of evapotranspiration (ET_c). The emitters discharge and emission uniformity (EU) were evaluated. Under operating pressure of 100 kPa, the emitters Em_1 , Em_2 , Em_3 were classified as excellent EU , while the Em_4 was poor EU . The root distribution increased by increasing emitter EU with low discharge. Also, the distribution root decreased by reducing $ET_c\%$ and increasing the distance from emitter. 60% ET_c concentrated the roots near the emitters, while, 80% ET_c has enough distribution to increase the plant ability to withstand winds. The highest yield was achieved with 100% ET_c and Em_1 , while WUE of both 60% and 80% was approximately the same and greater than WUE of 100% ET_c . It could be recommended that to have the highest yield of maize in sandy soil, a low discharge and excellent EU emitters should be used with adding 100% ET_c . While, adding 80% ET_c is preferred when the priority to water saving.

Keywords: *Root distribution, Emitters, Emission uniformity, Water use efficiency and Evapotranspiration.*

INTRODUCTION

To manage water scarce supplies, deficit irrigation, defined as the application of water below full crop-water requirements (evapotranspiration), is an important tool to achieve the goal of reducing irrigation water use. Although, deficit irrigation is widely practiced over millions of hectares, it has not received the sufficient attention in research (Fererres and Soriano, 2007).

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Microirrigation systems have lower energy requirement, more effective and less expensive than other irrigation systems. It saves water to the extent of 30 to 70% without significantly affecting the crop yield (**Pandey *et al.*, 2003; 2006**). Drip irrigation is also considered as highly efficient system because it allows small but frequent application of water with minimum losses (**Locascio, 2005**). The distance that water spreads horizontally from a drip line and the volume of soil wetted are play an important role in designing of drip irrigation system (**Skaggs *et al.*, 2010**). The water movement and its distribution in the soil depends upon many parameters such as the soil type, emitter discharge, quality of water applied, antecedent moisture content, depth of water table and certain climatic factors too. The rate of applying water in drip irrigation system is an important factor, which governs moisture distribution in soil profile. Soil water movement under drip irrigation will also be affected by a high discharge rate which may cause deep percolation losses whereas very low rate may contribute to evaporation losses (**El-Meseery, 2011**). Emission uniformity is an important parameter to explain the discharge variations along the lateral lines (**Li *et al.*, 2012**). It is essential to understand hydraulic performance of drip irrigation system in relation to soil moisture distribution. Emitter is the critical component of drip irrigation system through which water is delivered precisely to satisfy the crop water requirement. Therefore, the selection of appropriate type of emitters will not only discharges the desired quantity of water but will also render the exact wetting pattern (**Ragheb *et al.*, 2011**). Considering all other factors of production at their optimum level, crop response is defined as a crop yield decreased constantly by decreasing quantity of water applied into the root zone in deficit irrigation (**Amer, 2010**); nevertheless, crop yield is decreased constantly by increasing quantity of water applied in surplus irrigation.

In general, soil water uptake pattern is correlated to root distributions, which have been found to depend mostly on the availability of soil water and type of irrigation system. Characterization of root growth and distribution is fundamental in explaining crop responses to irrigation and in determining appropriate management of irrigation systems, particularly with drip systems since it is widely believed that drip irrigation may limit

the extent of root development (**Mansour *et al.*, 2015**). Information on root growth patterns is crucial to understand cultivar adaptations to deficit irrigation, particularly for drip-irrigated crops, where root systems are more confined than furrow. Crop cultivars differ in root growth adjustments to soil moisture deficit depending upon their interactions with soil type (**Sharma *et al.*, 2018**). The rooting depth and root distribution define the soil volume that plants can potentially explore to extract water and nutrients (**Fan *et al.*, 2016**).

Maize (*Zea mays L.*) is considered one of the most important cereal crops in the world. Therefore, microirrigation systems with low head could be suggested for maize cultivation. Maize yield production and water use efficiency increased with increasing irrigation frequency and rate under drip irrigation system (**El-Hendawy and Schmidhalter, 2010**). A high productivity of corn (4.6 Mg/fed) under drip irrigation in sandy soil was obtained with water use efficiency of 1.92 kg m^{-3} , when applied amount of water is full plant requirement (**El-Meseery, 2003**).

Therefore, the main goal of the present study is to determine the effect of deficit irrigation and emission uniformity (as a function of emitter type) on root distribution and water use efficiency of maize in a sandy soil.

MATERIALS AND METHODS

To achieve the research goals, four different emitters and three water percentages as 100, 80 and 60% of evapotranspiration (ET_c) were applied.

Hydraulic Evaluation

The four emitters (Em) chosen with a same nominal discharge of 4.0 l h^{-1} . An experiment was carried out to calibrate the selected emitters discharge. The emitter flow rate, $q \text{ (l h}^{-1}\text{)}$ was estimated under different operating pressure heads $h_i \text{ (m)}$, according to the following equation (**ASABE, 2008**):

$$q = k h_i^x \quad (1)$$

Where, k is the dimensionless constant of proportionality that characterizes each emitter, x is the dimensionless emitter discharge exponent that is characterized by the flow regime.

The emission uniformity of the emitters was tested by using an experimental schematic layout of drip irrigation system, including 12

similar subunits (three for each emitter). Each subunit consists of three laterals with 30 m length at distance of 0.75 m, and 0.3 m interval between emitters. Each subunit was equipped with a valve and pressure gauge. All subunits were connected to a control station equipped with a pressure gauge water meter and pumped fresh Water from Nile river (figure 1).

The emission uniformity (*EU*) plays an important role in root distribution, yield and water use efficiency. The irrigation unit was tested under different operating pressure (20, 40, 60, 80, 100 and 120 kPa) to determine the emission uniformity (*EU%*), calculated using the following equation (Li *et al.*, 2012):

$$EU = \frac{q_n}{\bar{q}} \times 100 \quad (2)$$

Where, q_n is the average of the lowest quarter emitter flow rates (lh^{-1}) and \bar{q} is the average of all emitters flow rates (lh^{-1}).

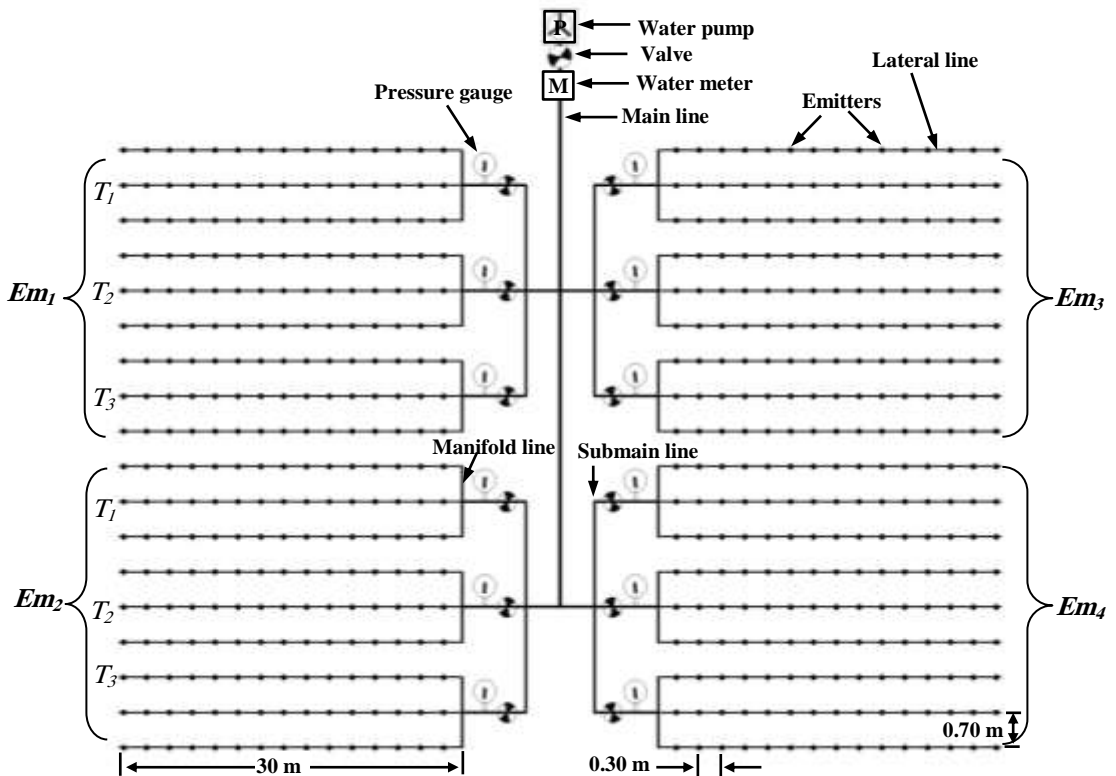


Figure (1): Experimental schematic layout used in the study.

Field Experiment

A field experiment was carried out by planting Maize crop (*Zea mays L.*) during the summer season of 2018 (from 1st May to 18th August) in the Research Farm of Faculty of Agriculture, Ismailia, Egypt. The constructed drip irrigation system (figure 1) was used under operating pressure of 100 kPa to grow one plant at each emitter. This experiment was achieved to examine how root distribution and water use efficiency (*WUE*) could be affected by a changing emitter type and water deficit. The field has a homogeneous sandy soil in the tested depth layers as shown in table (1).

Table (1): Physical characteristics of the experimental field soil.

Soil depth (cm)	Particle size distribution %			Texture Class	<i>DBD</i> (g/cm ³)	<i>FC</i> (%)	<i>PWP</i> (%)	<i>AW</i> (%)
	Sand	Silt	Clay					
0-20	95.20	2.50	2.30	Sand	1.63	8.7	1.7	7.0
20-40	96.67	1.53	1.80	Sand	1.65	8.9	1.8	7.1
40-60	97.02	1.05	1.93	Sand	1.64	8.5	1.8	6.7

DBD: Dry bulk density, *FC*: Field capacity (- 0.1 atm), *PWP*: Permanent wilting point (- 15 atm), and *AW*: Available water.

Irrigation water requirements (*IWR*) of maize through the growing season were calculated based on the determination of crop evapotranspiration (ET_c , mm/day) by the Penman-Monteith equation which recommended by FAO (**Allen et al., 2011**) using CROPWAT software (v. 8.0):

$$ET_c = ET_o \cdot k_c \quad (3)$$

$$IWR = ET_c \cdot A \cdot F \quad (4)$$

Where, ET_o is the reference evapotranspiration (mm/day), k_c is the crop coefficients, *IWR* is amount of applied irrigation water ($\ell/Irri.$), *A* is the plant area (m²) and *F* is the irrigation frequency.

Three irrigation water percentages from requirements as 100, 80 and 60% of evapotranspiration (ET_c) were applied. The water application time for each $ET_c\%$ was calculated from the following equation:

$$I_t = \frac{IWR}{q} \quad (5)$$

Where, I_t is water application time (h) and q is the emitter discharge (ℓh^{-1}).

In order to determine the root density, samples were obtained at the dough growth stage. The samples were collected manually using a soil cylinder has a diameter of 8 cm and a depth of 10 cm with a total volume of 500 cm³. Root samples were taken from centers of 10, 20 and 30 cm distances from emitter through a depth of 60 cm each layer 10 cm increment. Roots were separated and dried in electrical oven at 70 °C. The computer software SURFER program was used to draw the graphs for the root distribution pattern.

To understand how *WUE* could be affected by a changing emitter type and water deficit, it will be necessary to determine how these changes will impact plant growth and water use of the plant. To achieve this understanding requires we examine *WUE*, calculated by the following equation:

$$FWUE(\text{kg m}^{-3}) = \frac{\text{Grain yield (kg fed}^{-1}\text{)}}{\text{Water applied (m}^3 \text{ fed}^{-1}\text{)}} \quad (6)$$

RESULTS AND DISCUSSION

Drip Irrigation Hydraulic Characteristics

The water application rate versus operating pressure relationship plays a vital role in the characterization of emitters. It is one of the key factors in selecting an emitter type and system design. table (2) shows the variation between actual and nominal emitter discharge under operating pressure of 100 kPa with emitter discharge constants (k, x) in equation (1). The field emission uniformity (*EU*) was calculated by equation (2) and the results are shown in table (2) figure (2). Emitters can be classified based on the *EU* values as excellent uniformity (above 90%), good (80 to 90%), fair (70 to 80%), poor (60 to 70%), and unacceptable (below 60%) according to **ASABE EP 458.0 (1999)**. From figure (2), it can be seen that under all operating pressures (20 to 120 kPa), the emitter Em_1 gives the highest emission uniformity with values higher than 90% which classified as excellent. The emitters Em_2 and Em_3 also gives a high emission uniformity with values ranged from 85 to 93% which classified from good to excellent based on the operating pressure (table 2). On the other hand, the emitter Em_4 showed a very low uniformity ranged from 60 to

70% and classified as poor. These results revealed that the *EU* is mainly dependent on the emitter type.

Table (2): Hydraulic characteristics of tested emitters at operating pressure of 100 kPa.

Emitter	Discharge ℓh^{-1}	Constants k	X	<i>EU</i> %	Classification
<i>Em</i> ₁	3.95	0.61	0.38	94.88	Excellent
<i>Em</i> ₂	4.36	2.52	0.12	92.51	Excellent
<i>Em</i> ₃	5.60	1.33	0.32	92.98	Excellent
<i>Em</i> ₄	20.56	2.04	0.50	68.67	Poor

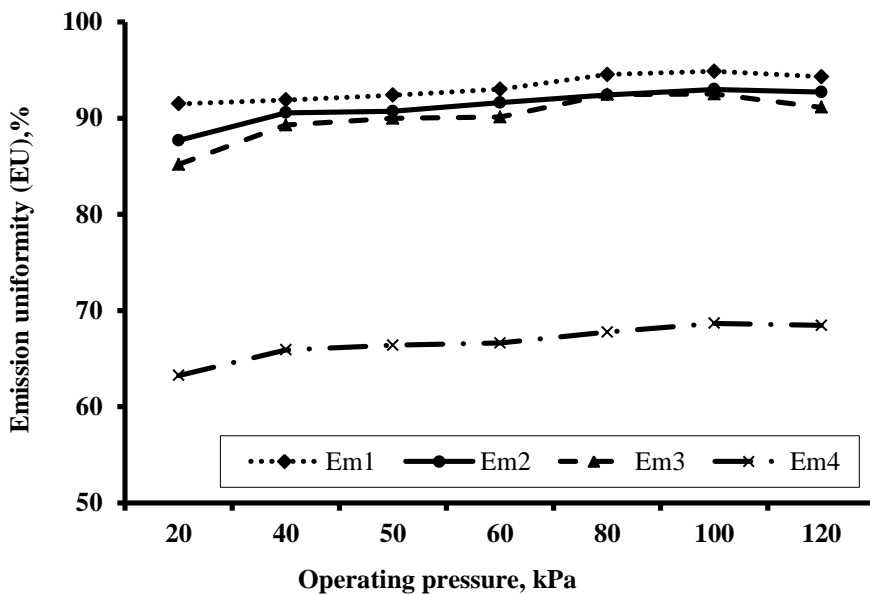


Figure (2): The emission uniformity of tested emitters under different operating pressure.

All emitters reached the highest uniformity by increasing operating pressure up to 100 kPa. While, uniformity decreased with further increasing in operating pressure to 120 kPa as shown in (Figure 2). Therefore, the field experiment was carried out under the operating pressure of 100 kPa. It is noticeable that, the emission uniformity of drip emitters increased by reducing their flow rate.

Roots Distribution and Density

Effect of applied water as a percentage from evapotranspiration ($ET_c\%$) on the root distribution was summarized in table (3) and presented graphically in figure (3). At all tested ET_c , the root density percentage ($R_d\%$) increased proportionally by decreasing the soil depth and the horizontal distance (H_d) from emitter. For instance, the location adjacent the emitter at 0 to 10 cm horizontally in depth from 0 to 60 cm has the highest root density ranged from 56.95 to 78.33%.

Table (3): Root distribution of maize in horizontal distance (H_d , cm) from emitters (Em) under different crop evapotranspiration percentage ($ET_c\%$).

Emitter		Em_1		Em_2		Em_3		Em_4	
$ET_c\%$	H_d , cm	Int. g/500 cm ³	Den. %	Int. g/500 cm ³	Den. %	Int. g/500 cm ³	Den. %	Int. g/500 cm ³	Den. %
100	0-10	2.33	66.01	2.16	63.34	1.59	58.03	1.68	56.95
	10-20	0.90	25.50	0.90	26.39	0.69	25.18	0.69	23.39
	20-30	0.30	8.50	0.35	10.26	0.46	16.79	0.58	19.66
	Total	3.53	100	3.41	100	2.74	100	2.95	100
80	0-10	1.81	69.35	1.65	63.46	1.27	60.48	1.22	59.22
	10-20	0.63	24.14	0.65	25.00	0.51	24.29	0.45	21.84
	20-30	0.17	6.51	0.30	11.54	0.32	15.24	0.39	18.93
	Total	2.61	100	2.60	100	2.1	100	2.06	100
60	0-10	1.19	77.78	0.94	78.33	0.71	75.53	0.56	73.68
	10-20	0.34	22.22	0.26	21.67	0.23	24.47	0.2	26.32
	20-30	0.00	0.00	0.00	0.00	0	0.00	0	0.00
	Total	1.53	100	1.20	100	0.94	100	0.76	100

*The values of root intensity and density at each location are the total roots intensity in the tested depth layers from 0 to 60 cm

The highest root distribution was recorded by irrigated the full water requirements (100% ET_c), that supporting plants against the wind in the soil, beside obtaining a high yield. The irrigation by 80% ET_c saving 20% of water requirements and gives a roots distribution in the soil layer from 0 to 40 cm, which is considered enough to support the plant against the wind, proved required water for growing and gives acceptable yield.

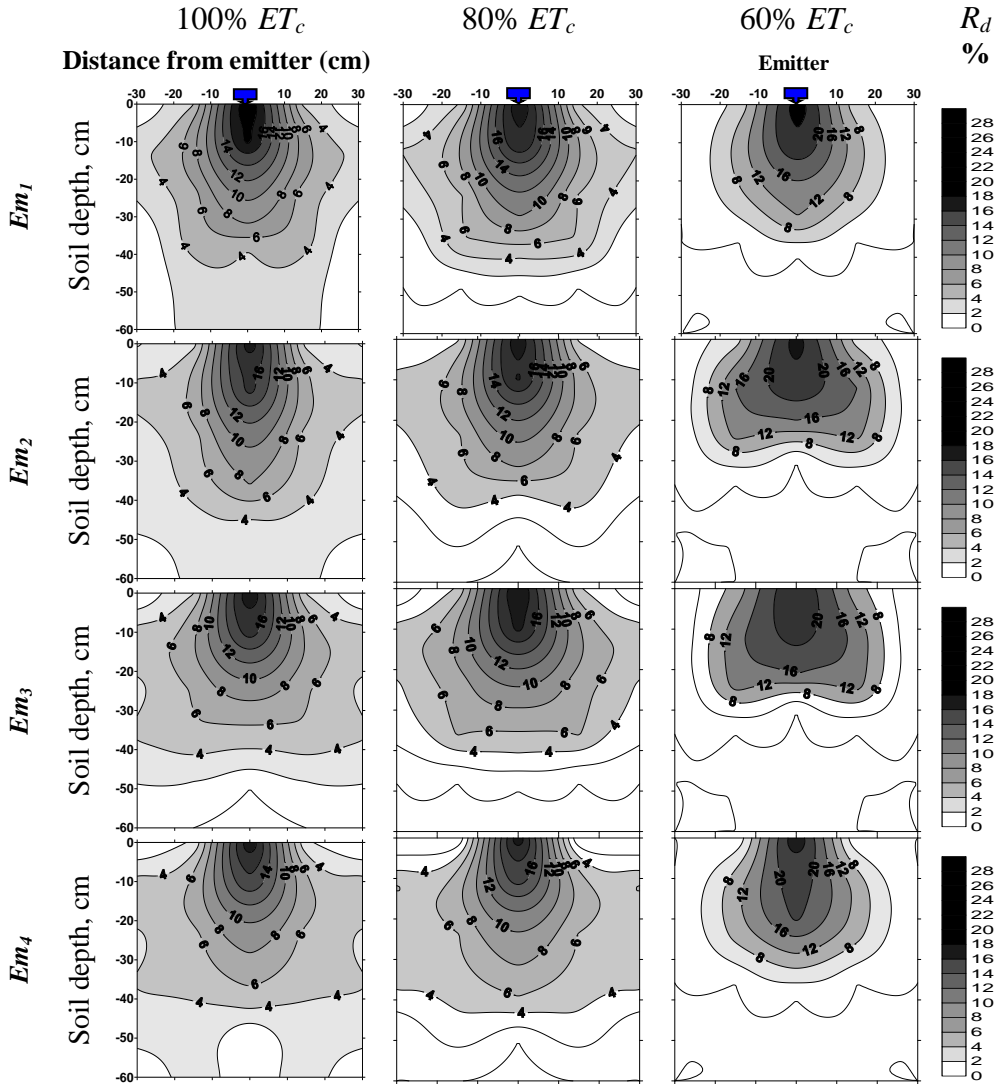


Figure (3): Root distribution pattern of maize plant for different emitters under different water treatments.

Although, 60% ET_c saving 40% of irrigation water, it gives a poor root distribution compared to other irrigation rates (in the soil layer from 0 to 30 cm), which decrease the plant ability to withstand winds. It can be also seen from figure (3) that emitter Em_1 gives the highest uniform distribution patterns for roots under different water treatments. These results due to the high emission uniformity and the low discharge of Em_1 among all tested emitters.

Yield of Maize

In general, it could be noticed that the maize yield decreases by increasing deficit irrigation for all tested emitters as shown in figure (4). For example, the maximum yield of maize is obtained by adding full water requirements to the plant (100% ET_c). The maize production was acceptable by adding 80% ET_c , because the soil water did not expose to a high stress. As, the maize plant is classified as drought sensitive crop, the application of 60% ET_c resulted in a lowest yield.

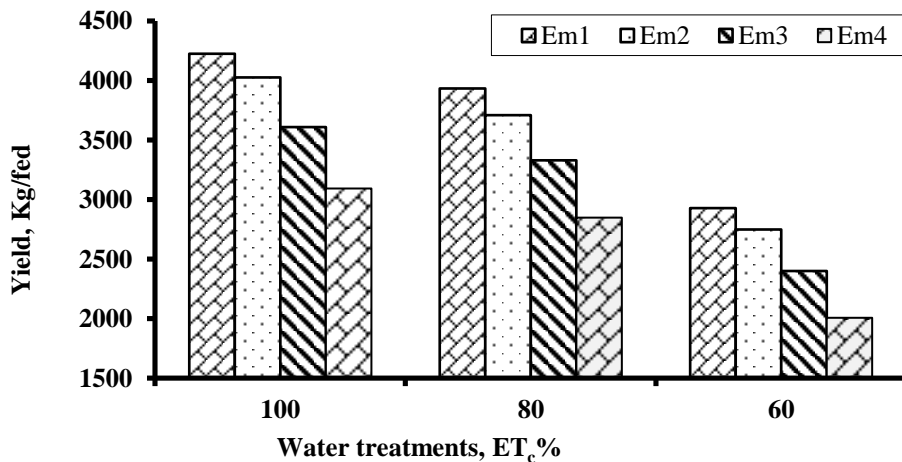


Figure (4): Effect of applied water as ET_c % by drip emitters (Em) on maize yield.

It can be also indicated from figure (4) that under all applied water quantities ET_c %, the emitter Em_1 gives the highest yield. This due to its highest emission and root distribution uniformity. Moreover, the yield of Em_1 decreased only 7% (from 4226 to 3935 kg/fed) by reducing applied water by 20% (80% ET_c) for Em_1 . While, reducing 40% of water (60% ET_c) decreasing the yield to 2930 kg/fed by 31% as shown in Figure (4). Accordingly, 60% ET_c could not be recommended for maize production in sandy soil.

Water Use Efficiency

Water use efficiency (WUE) is a ratio between grain yield and total amount of applied water. The efficient use of applied water as ET_c % was graphically illustrated in figure (5). It can be seen that, WUE was increased by decreasing added ET_c % from 100 to both 80 and 60% for all

emitters. Applying of ET_c 80 and 60% gives a very close values of WUE for each tested emitter except Em_4 showed a clear decrease in its WUE . This due to the poor EU classification of Em_4 . It is clear from the obtained results (figure 5) that the highest value of WUE was achieved for emitter Em_1 at 80% ET_c , which could be recommended for drip irrigated maize in sandy soil.

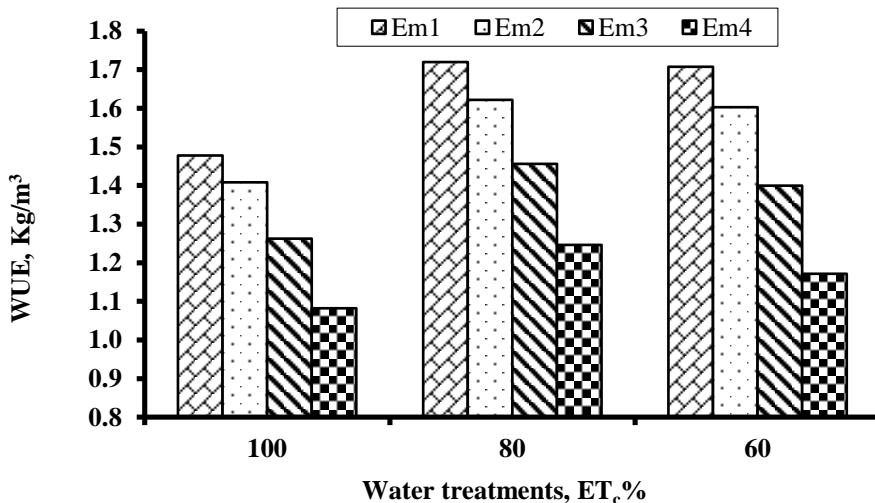


Figure (5): Effect of applied water as ET_c % on water use efficiency for different emitters.

CONCLUSION

The main objective of this research work was to investigate the effect of using different emitter types (Em) under adding water requirement as 100, 80 and 60 % of ET_c on root distribution, maize yield and water use efficiency (WUE) in sandy soil. The results could be summarized as:

- 1- The actual emitter discharge under operating pressure of 100 kPa, was arranged as $Em_1 < Em_2 < Em_3 < Em_4$. The EU of Em_1 , Em_2 and Em_3 were excellent, but Em_4 poor flowed this order $Em_1 > Em_2 > Em_3 > Em_4$.
- 2- The root distribution and yield were increased by increasing ET_c % and EU .
- 3- 60% ET_c concentrated the roots at less than 25 cm horizontally in the upper soil layer, while, 80 % ET_c distributed the roots at more than 30cm horizontally in depth 0 to 40 cm, which increasing a plant ability to withstand winds.

- 4- *WUE* was increased by increasing deficit irrigation. *WUE* was approximately the same by reducing ET_c from 80 to 60% for Em_1 , Em_2 and Em_3 , but it decreased for Em_4 .
- 5- It could be recommended that to have the highest yield of maize in sandy soil, a low discharge and excellent *EU* emitters should be used with adding 100% ET_c . While, adding 80% ET_c is preferred when the priority to water saving.

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الملخص العربي**إنتشار الجذور تحت نقص مياه الري لإنتاج محصول الذرة**أحمد فتحى محمد خضر^١ ، رمضان عبد الحميد الجمل^٢ و محمد أبوزيد رشاد^٣

نمو الجذور ومدى إنتشارها أحد الوسائل الأساسية لتوضيح مدى إستجابة المحصول المزروع لنظم الري المختلفة وتحديد الطرق المناسبة لإدارتها. وقد أجريت تجربة لدراسة منقطات الري (Em) عند الري بكامل الاحتياجات المائية أو بنسب أقل وتأثيرها على كل من إنتشار الجذور، المحصول، وكفاءة استهلاك المياه (WUE) لمحصول الذرة بالتربة الرملية. وعليه تم إستخدام أربعة أنواع من المنقطات لري المحصول بنسب ١٠٠، ٨٠، ٦٠% من الاحتياجات المائية. وكذلك أجريت معايرة للمنقطات وتم تقييم انتظامية تصرف (EU) خطوط المنقطات.

أظهرت النتائج ان تصرف المنقطات الفعلية تحت ضغط ١٠٠ كيلوباسكال اختلف من منقط لأخر ويمكن ترتيبها كالتالي $Em_1 > Em_2 > Em_3 > Em_4$. وصنفت انتظامية التصرف EU لخطوط المنقطات Em_1, Em_2, Em_3 ممتازة بينما كانت ضعيفة للمنقط Em_4 . لوحظ أن إنتشار الجذور زاد بزيادة الانتظامية ومع التصرفات الأقل. كذلك قل الإنتشار بزيادة الابتعاد عن المنقط وبتقليل نسبة كمية المياه المضافة من الاحتياجات المائية ($ET_c\%$) ، حيث وجد أن اضافة نسبة ٦٠% من ET_c ركزت الجذور عند أقل من ٢٥ سم أفقياً في طبقة التربة العلوية، مما يقلل من قدرة النبات على مقاومة الرياح. بينما اضافة نسبة ٨٠% من ET_c أدت لتوزيع الجذور لأبعد من ٣٠ سم أفقياً بعمق يتراوح من ٠ إلى ٤٠ سم، وهو ما يعتبر كافٍ لدعم النبات. بينما تم تحقيق أفضل إنتشار للجذور والمحصول بإضافة ١٠٠% من ET_c مع المنقط Em_1 ، لكن كفاءة استهلاك المياه (WUE) لنسبة ٦٠% و ٨٠% كانت تقريبا متساوية وأعلى من ١٠٠% ET_c . نخلص من هذا البحث انه يمكن التوصية باستخدام منقطات ذات انتظامية ممتازة وتصرف منخفض واطافة ١٠٠% ET_c للحصول على أعلى محصول ذره في التربة الرملية. وكذلك اضافة ٨٠% ET_c تعمل على توفير فى كمية مياه الري وإعطاء محصول مقبول.

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