Production of drip irrigated squash (*Cucurbita Pepo*, L.) under different levels of irrigation and uniformity

Moataz Kamal Elnemr[1*], Adel Helal Elmetwalli [2]

(1.Department of Agricultural Engineering, Faculty of Agriculture, Damietta University, Damietta El-Gadeeda, Egypt.34517; 2. Department of Agricultural Engineering, Faculty of Agriculture, Tanta University, Tanta, Egypt. 31111)

Abstract: This study aimed to get the most possible benefit of using deficit irrigation to maximize water productivity of squash, besides investigating the ability of drip irrigation uniformity to reduce the expected negative effect of deficit irrigation on squash crop yield production (*Cucurbita pepo* - Hybrid Revera). Three levels of irrigation uniformity (*UL*) based on the value of uniformity coefficient (UC) namely excellent (E), very good (VG), and unacceptable (UA) were examined with three irrigation levels (*IL*) based on crop evapotranspiration (ET_c) which were full irrigation (FI) or 100% ET_c; in addition to two deficit irrigation levels 90% ET_c (DI_{90}), and 80% ET_c (DI_{80}). Results showed that both *ULs* and *ILs* had significant effect on squash production. There was significant reduction in crop yield values due to the decrease in irrigation water at all uniformity levels. The greatest values of water productivity (WP) for all *ULs* were obtained at FI followed by DI_{80} and the least was DI_{90}. The profits of water volume unit showed that the greatest values were for E level. FI recorded the greatest profits under all *ULs*. Increasing uniformity level led to increase crop production but it could not prevent the significant reduction in squash crop related to deficit irrigation. The study recommended to manage drip irrigation uniformity and irrigation water separately as the high levels of uniformity could not prevent the effect of water shortage regarding the decrease of crop yield, WP, and water unit profits.

Keywords: Deficit irrigation, Drip irrigation, Production, Squash, Uniformity, Water productivity, Yield.

Citation: Elnemr M. K., A. H. Elmetwalli. 2021. Production of drip irrigated squash (*Cucurbita Pepo*, L.) under different levels of irrigation and uniformity. Agricultural Engineering International: CIGR Journal, 23(1): 68-74.

1 Introduction

Scarcity of water around the world is increasing. Water is the main critical input in agricultural activities, which are necessary to assure the needs of human life. Agriculture withdraws about 70 percent of global fresh water resources and this percentage may reach 95 percent in some developing countries (Steduto et al., 2012). Based on these statistics, it is no longer luxury to use all available and possible methods, tools, and technologies to save water and maximize the efficiency of its use. The water use in agriculture is mainly related to irrigation practices. It is necessary to develop strategies that keep the quality and quantity of crop production while saving irrigation water (Nangare et al., 2016). Deficit irrigation can be an acceptable technic to save irrigation water and increase water use efficiency when water is limited. Tejero et al. (2011) concluded in his study undertaken in Spain in a citrus orchard, that deficit irrigation strategies have the potential to improve water use efficiency. The studies made by Mele (2019), Abdelkhalik et al. (2020), Mattar et

Received date: 2019-12-26 **Accepted date:** 2020-04-04

[*]**Corresponding author: Moataz K. Elnemr,** Associate Professor, Department of Agricultural Engineering, Damietta University, Damietta El-Gadeeda City, Damietta Governorate 34517. Egypt. Tel:+201550066948. Email: moknemr@agr.du.edu.eg.

al. (2020), Çolak et al. (2018), Al-Omrana et al. (2005), and Romero et al. (2004); proved that deficit irrigation led to increase water use efficiency despite the reduction in crop production if compared to full irrigation. Drip irrigation system is able to save irrigation water by a percentage of 25% if compared to furrow irrigation (Aujla et al., 2007) which leads to expand water use efficiency (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 (Gil et al., 2008). Studies on drip irrigation system revealed that the higher uniformity level (UL) led to obtain higher crop production (Solomon 1984, Abd El-Hady et al., 2015) in addition to efficient chemical use (Narda and Chawla, 2002), higher net profits (Lopez Mata et al., 2010), and lower water losses specially deep percolation (Wang et al., 2014). Bordovsky and Porter (2008) and Li et al. (2012) indicated that for arid and semi-arid areas, drip irrigation system uniformity had no significant effect on soil moisture distribution in the soil as well as crop yield. They concluded that the lower levels of uniformity coefficient, which may be not recommended by current standards, could be used. Deficit irrigation, which is expected to reduce crop yield, has no impediments to be applied with high irrigation ULs in irrigation management strategy. From this point we should start to investigate the effect of using deficit irrigation strategy with different levels of drip irrigation system uniformity. This investigation is supposed to clarify whether the recommended levels of uniformity can reduce the negative effect of deficit irrigation on crop production beside the non-recommended levels of uniformity to state the significance of such combination on crop production and water use efficiency. Squash is a popular vegetable for Egyptian consumers and considered an important economic crop (Refaei et al., 2003). Squash as a vegetable crop is preferred to grow under drip irrigation system, as it is the most efficient irrigation system to use scarce water resources to produce vegetables (Locascio, 2005). In addition to investigate the ability of high levels of drip irrigation system uniformity to reduce the expected negative effect of deficit irrigation on crop production compared to non-recommended levels, the objective of this study is to get the most possible benefit of using deficit irrigation to maximize water productivity of squash.

2 Material and methods

2.1 Agronomic practices

The field experiment location was 31.41º N, 31.75º E in Kafrelbatikh city, Damietta governorate, Egypt. The sandy loam soil for growing squash crop (*Cucurbita pepo* - Hybrid Revera) was specified 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

Seeds planting started at 2/7/2019. Before planting, 48 $m^3.ha^{-1}$ of organic manure was added to the soil surface and mixed with the soil during ploughing operation. The surface of the soil was leveled using a scraper hitched to a 60 hp tractor. Effect of soil slope was neglected due to the natural leveling of the experimental area and the proposed short lateral lengths (20m).Seeds were added with a rate of three seeds/pore then thinned to one plant/pore after germination. Fertilization during growing stages included adding Ammonium sulphate, Potassium sulfate, and Super phosphate with rates of 240, 240, 360 $kg.ha^{-1}$ by hand near plants after two weeks of cultivation and before irrigation process. After one week of the previous fertilization process, Urea was added before irrigation with a rate of 120 kg.ha^{-1}. After flowering, an amout of Calcium nitrate with 180 kg. ha^{-1} rate was added.

2.2 Experiment layout and design

The experiment included two variables. First variable was uniformity level (*UL)* which had three levels of drip irrigation uniformity namely Excellent (E), very good (VG), and Unacceptable (UA). Second variable was the irrigation level *(IL)*, which consisted of three irrigation levels of crop evapotranspiration (ET_c) which were 100% ET_c or full irrigation (FI), in addition to two deficit irrigation (DI) levels namely 90, 80% ET_c. The statistical design of the experiment was split plot design. *UL* was the main plot while irrigation level (IL) was the sub-main plot. Each treatment had three replicates. Statistical analysis was performed using Cropstat7 software in addition to mean comparison test using Mstat software.

Figure 1 showed the layout of drip irrigation network. A 63mm inner diameter PVC manifold was used to feed 16mm inner diameter Polyethylene laterals with built-in emitters. The network was divided into three parts; each part acted a level of uniformity. These parts were separated by control ball valves to control the flow and pressure in each of them. T-shaped valves 16mm inner diameter were fitted in the laterals to enable ending irrigation process at desired time for each treatment separately. A pressure gauge with 2m accuracy was fitted on the manifold to monitor the pressure head. Laterals were 20m length, 1.5m spacing, and 0.5m space between emitters. Separation distance between each part of the experiment was 3m.

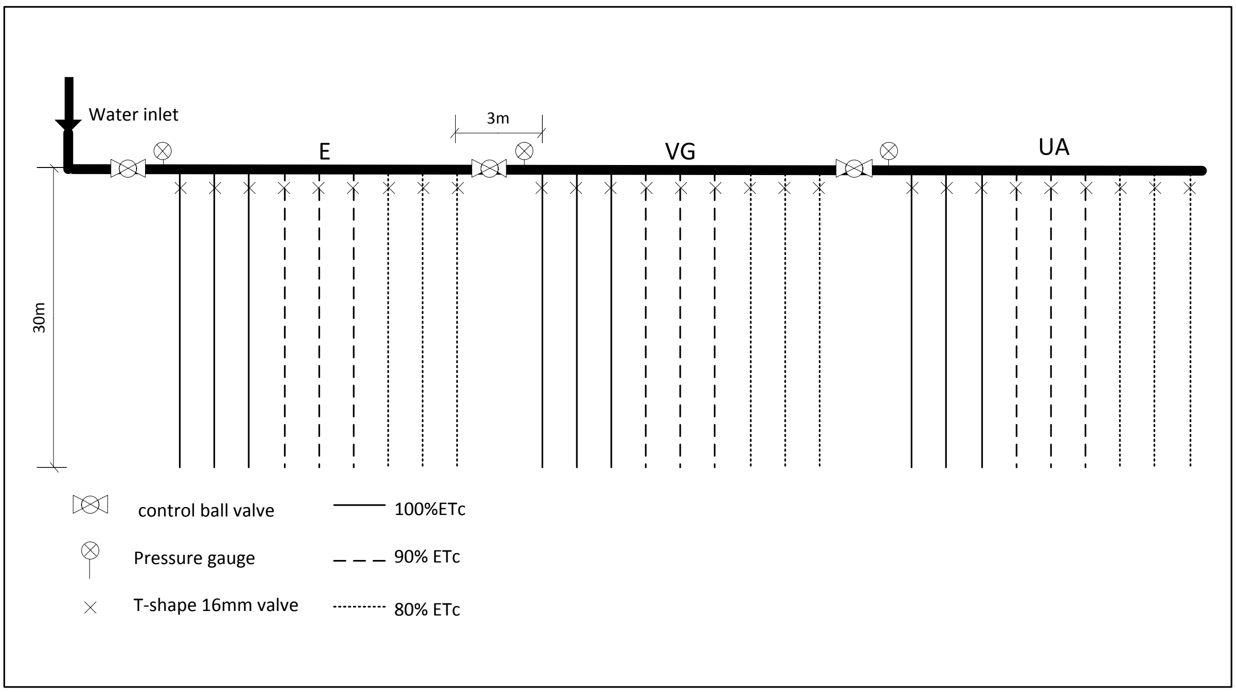

Figure 1 Schematic diagram for the drip irrigation network

2.2.1 Levels of uniformity

In order to reach the required levels of uniformity, uniformity coefficient (UC) was used to evaluate the hydraulic performance of the drip irrigation system. UC is used to describe how uniform water was applied by the system on soil surface. Four operating pressure heads were used with the drip irrigation system to determine the variation in UC values. These heads were 20, 15, 10, and 5 m of water. The high variation in heads values was assumed to assure the required variation in UC values which described uniformity level. Twenty emitters along the lateral were used on UC calculations. The volume of water from the twenty emitters was collected at once for two minutes in a 100mL can under each emitter. Dividing the values of water volume by time has resulted emitters flow rates. UC was calculated using the spreadsheet developed by (El-Nemr, 2012). Table 2 showed the obtained values of UC and their evaluation according to ASAE (1997).

Table 2 UC values and evaluation

Head (m)	Average flow rate (l/h)	UC (%)	Evaluation
20	6.87	90.27	Excellent
15	6.59	91.46	Excellent
10	6.55	85.95	Very good
5	1.55	48.14	Unacceptable

2.2.2 Crop water requirement

Crop water requirements were calculated referring to (Allen et al., 1998) based on the climate data obtained from Damietta meteorological station (31.25º N, 31.49º E) which covered the experimental area 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 0.5, 0.95, and 0.75 for the initial, crop development, mid-season, and late-season growing periods (Allen et al., 1998). Crop evapotranspiration (ET_c) was calculated according to the following Equation (1):

$$ET_c=ET_o.K_c \quad (1)$$

Where, ET_o is reference evapotranspiration, mm d^{-1}, K_c is crop coefficient.

2.3 Harvesting and crop yield

Fruit picking started when fruits reached the suitable commercial size which is 5-7 cm diameter and/or 12-17 cm length (Tecson, 2001). End of growing season was at 11/9/2019 by a total 72 days growing season. Digital balance with three digits accuracy was used to find the weight of the fruits. The average of three replicates for each treatment expressed the total production of the treatment.

2.4 Water productivity

Water productivity (WP) was used to describe the squash crop productivity per volumetric unit of irrigation water. WP was calculated according to Rodrigues and Pereira (2009) as follows:

$$WP=\frac{Y}{AW} \quad (2)$$

Where, Y is Squash productivity, kg.ha^{-1}, AW= Amount of applied water m^3ha^{-1}.

2.5 Profits

Gross revenue of squash crop was calculated referring to the method followed by Abdelkhalik et al., (2020) to determine the gained profits of each unit of water volume. The price of selling squash from the farm was based on the Egyptian market data during the experiment time period. Price of selling squash was 3.25 Egyptian pound (EGP) per kilogram. The official conversion price during the experiment time period for US dollar was 16.32 EGP.

3 Results and discussion

3.1 Crop yield

Statistical analysis shown in Table 3, illustrated that there was a highly significant effect for both *UL* and *IL* on squash production. There was no interaction between the two variables. The non-significance of the interaction between the two variables was considered as an index that each of the two variables did not affect the other or independent of the other factor. This mean *UL* could not really compensate the effect of the reduction in applied irrigation water.

Table 3 Variance analysis of the effect of uniformity level and deficit irrigation on squash production

Source of variance	DF	Sum of squares	Mean squares	F ratio
Replicates	2	72.563	36.282	23.58**
UL	2	38.319	19.159	12.45**
IL	2	97.623	48.811	31.72**
ULXIL	4	4.463	0.116	0.08ns
Residuals	16	24.621	1.539	
Total (corrected)	26	233.589	8.984	

Note: ** means P<0.001, ns means not significant at 5% level.

The greatest crop production was 21.90 Mg.ha^{-1} for the treatment UL_EFI while the least production was observed for the treatment $UL_{UA}DI_{80}$ with 14.50 Mg.ha^{-1}. Values listed in Table 4, showed that under each *UL*, deficiency in irrigation water caused a decrease in crop production. There was a significant difference between crop production at FI level and the other two levels of deficit irrigation for all *UL*s. There was no significant difference between treatments UL_EFI and $UL_{VG}FI$. The decrease of applied water from 100% to 80% of ET_c led to decrease crop production by 29.66%, 29.17%, and 28.83% of the least production for the E, VG, and UA uniformity levels respectively. Mean comparison of productivity values showed that UA level caused significant reduction in squash production at full irrigation treatments. This disagreed with the recommendations of (Bordovsky and Porter, 2008) and Zhao et al. (2012) about the possibility of using non-recommended levels of uniformity with drip irrigation. On the other hand, the obtained results were in agreement with López-Mata et al. (2010) and Solomon, (1984). As the UA level is not recommended by standrds, it is recommended to keep the drip irrigation system working with E or VG levels to keep the production in highest possible level.

Table 4 Squash crop yield (Mg ha^{-1}) and mean comparison at different levels of uniformity and deficit irrigation

E			VG			UA		
FI	DI_{90}	DI_{80}	FI	DI_{90}	DI_{80}	FI	DI_{90}	DI_{80}
21.90A	18.83B	16.89BCD	21.30A	18.45BC	16.49CDE	18.68B	16.19DE	14.50E

Note: Least Significant Difference at 5% level was 2.147. Different letters on the same line indicated significant differences.

3.1.1 Water productivity

Amounts of applied water for the diffierent levels of irrigation were 3873.5, 3486.15, 3098.8 $m^3.ha^{-1}$ for FI, DI_{90}, and DI_{80} respectively. Data listed in Table 5 showed the values of WP of squash under the experiment treatments. The greatest value of WP was obtained at the treatment UL_EFI while the minimum value was for $UL_{UA}DI_{90}$ treatment. For all *UL*s the value of WP at FI was the maximum followed by DI_{80} and DI_{90}, respectively. It was obvious that increasing UL would be reflected on higher WP.

Table 5 Water productivity (kg.m^{-3}) at different levels of uniformity and irrigation

E			VG			UA		
FI	**DI_{90}**	**DI_{80}**	**FI**	**DI_{90}**	**DI_{80}**	**FI**	**DI_{90}**	**DI_{80}**
5.65	5.40	5.45	5.50	5.29	5.32	4.82	4.64	4.68

Table 6 showed the reduction of WP due to deficit irrigation under each uniformity level as a percentage of the maximum WP value at each *UL*. The results showed that WP values had the greatest reduction due to DI whether from 100% to 90% or from 100 to 80 % ET_c at E uniformity level followed by VG, while the minimum value was at UA.

Table 6 Percentage of WP reduction due to DI referring to maximum WP at each UL.

Reduction in irrigation water	E (%)	VG (%)	UA (%)
100-90 (10% ET_C)	4.42	3.81	3.73
100-80 (20% ETc)	3.54	3.27	2.9

Treatments with lower amounts of applied water could not cause an increase in WP if compared with FI. This may be due to the high sensitivity of squash for water deficit, which caused the increase in crop production at FI under all *UL*s. The increase in WP values for DI_{80} treatments if compared with DI_{90} at all *UL*s was in agreement with the results obtained by Al-Ghobari and Dwidar (2018) in their study on tomato production for surface drip irrigation. The higher WP at DI_{80} if compared to DI_{90} at different UL was due to the less amount of applied water beside the non-significant difference between the crop production values for these two DI levels under all uniformity levels. In order to obtain the maximum benefit of deficit irrigation to increase water productivity of squash, we may need to apply the use of another irrigation technic like subsurface drip irrigation and/or mulching to reduce water loss. This irrigation technic may be reflected on keeping the reduction in crop productivity in non-significant variation range specially in highly water sensitive crops like squash.

3.1.2 Profits

Data listed in Table 7 showed the profits of squash crop production per cubic meter of applied water.

Table 7 Effect of uniformity and irrigation levels on the profits of squash crop per cubic meter of water.

E			VG			UA		
FI	**DI_{90}**	**DI_{80}**	**FI**	**DI_{90}**	**DI_{80}**	**FI**	**DI_{90}**	**DI_{80}**
1.13	1.08	1.09	1.10	1.06	1.06	0.96	0.93	0.94

Increase in *UL* would lead to increase the profits. The highest profits was 1.13 US dollar per cubic meter of water at the UL_EFI treatment while the lowest one was 0.93 13 0.93 13 U.S.dollar per cubic meter of water at $UL_{UA}DI_{90}$. DI_{80} was slightly higher than the profits of DI_{90} with E and UA uniformity levels. The previously mentioned levels of DI showed equal profits at VG level. This was due to the non-significant difference in crop production for DI_{90} and

DI_{80} at all *UL*s, which was combined, with less amounts of applied water for the DI_{80}.

The increase in crop profits for FI treatments with E level of uniformity was 2.65%, and 17.7% of the profits of the VG and UA levels respectively. The DI_{90} under E level also showed an increase by 1.87% and 16.13% of profits of VG and UA uniformity levels. The same trend of increase in profits for the E level was observed at DI_{80}. Operation of drip irrigation system with E level would increase crop production by 2.83% and 15.96% of the profits obtained at VG and UA levels for the same irrigation level. The results revealed that deficit irrigation would not cause the increase in profits of water unit and it was important to keep drip irrigation uniformity in recommended levels to obtain higher profits.

3 Conclusion

The present study aimed to investigate the ability of drip irrigation uniformity to reduce the expected effect of deficit irrigation on reducing squash crop production (*Cucurbita pepo* - Hybrid Revera). Results showed that *IL* and *UL* had a significant effect on crop production but there was no interaction between the two variables. Using UA level of uniformity led to significant decrease in crop production. In addition, deficit irrigation water led to significant decrease in crop production at all ULs. Reduction of applied water could not achieve higher WP. The greatest values of WP were with FI for all *UL*s and the greatest WP was observed for the treatment UL_EFI. The profits of water volume unit showed that the greatest values were for E level. FI recorded the greatest profits under all ULs. The non-significant difference between crop production values of DI_{90} and DI_{80}, led to increase the profits of DI_{80} compared with DI_{90} at E and UA levels while they were equal at VG level. Increasing uniformity led to increase crop production but it could not prevent the significant reduction in squash crop related to deficit irrigation. It was recommended to avoid unacceptaible drip irrigation uniformity level in order to obtain the most possible crop production, WP, and profits. Deficit irrigation may be required some times specially in arid areas but should be regulated to obtain the best possible WP. It is important when planning the management strategy of a drip irrigation system to consider both *UL* and *IL* specially deficit irrigation (if required) separately as uniformity could not compensate the negative effect of water shortage on squash crop.

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