Hydraulic Performance of Drip Irrigation System in a Sloped Greenhouse and Effects on Cucumber (*Cucumis sativus, L.*) Yield and Water Productivity

Hisham M. Mohammed, Alwaleed M. Hassan, Mohammed E. Hassan and Zulfa N. Hassan

Faculty of Agricultural Science, University of Gezira, Sudan

ABSTRACT

This study was conducted to study the effects of land slope on hydraulic performance and water productivity of cucumber under drip irrigation system in greenhouse. The greenhouse under study was divided into two sections and were identified simply as Sec A and Sec B. Sec A has its flow uphill while Sec B flow downhill. The hydraulic performance parameters like average emitter discharge (q), discharge variation (Q_{var}), coefficient of variation (Cv%), water application uniformity (AU%), uniformity coefficient (CU%), uniformity coefficient (DU%) and statistical uniformity (Us%)Plant parameters such as plant height (cm), stem diameter (mm), yield (ton/ha) and water productivity (kg/m^3) were determined. There were a significant differences (P≤0.05) on all the hydraulic performance parameters. The recorded discharge rate along the lateral was 0.38 and 0.64 l/h for section (A) and section (B), respectively. Q_{var} % for section (A) classified as unacceptable while section (B) was acceptable. Cv% for section (B) was found to be less than 20 % (Good) while in section (A) were more than 20 % (unacceptable). Section (A) recorded the lowest values 50, 60, 30 and 50% while section (B) recorded the highest values 80, 82, 69 and 78% for AU%, CU%, DU% and Us%, respectively. Section (A) values classified as unacceptable, unacceptable, poor and unacceptable while section (B) was fair, good, acceptable and acceptable for AU%, CU%, DU% and Us%, respectively. The analysis showed that there were no significant differences between section (A) and section (B) on plant height but there were a significant differences (P≤0.05) on stem diameter (mm), yield and water productivity. The highest yield value of 3.78 ton/ha was observed at section (B) and the lowest 1.89 ton/ha was observed in section (A), these low yield is due to Due to the difficulty of water distribution or the irregularity of water distribution. The highest water productivity value of 38 kg/m^3 was observed at section (B) and the lowest 29.3 kg/m^3 in section (A).This study recommended that good leveling is the best practices in greenhouse because it leads to good hydraulic performance and high yield.

Keywords: hydraulic performance, drip, emitter, uniformity, field slope.

1. Introduction

There is an urgent got to increase water productivity and water application efficiency thanks to the continues increase in population, increase in demand for vegetables and increased pressure ashore available for agriculture including the over welming effect of global climate change (Raphael *et.al.,* 2018). Drip irrigation is taken into account because the most effective irrigation system, but there's proof from literature that this technique also can be in-efficient, as a results of water quality, mismanagement and maintenance problems (Koegelenberg *et al.,* 2003). Drip irrigation system is supposed to use to use precise amount of water near the plant with a specific degree of uniformity. The uniformity describes how evenly an irrigation system distributes water over a field. it's considered one among the important features for selection, design, and management of the irrigation system (Mirjat, *et al.,* 2010). Irrigation uniformity is that the most vital reason for evaluation of the irrigation system performance and is suffering from the sector topography, hydraulic design of drip system also as level of partial or complete clogging (Smajstrla *et al.,* 2015| and Zhu *et al.,* 2009). Poor uniformity of water application leads to portions of drip irrigation systems receiving little or no water discharges resulting

Corresponding Author: Hisham M. Mohammed, Faculty of Agricultural Science, University of Gezira, Sudan**.**
Email: hishsmmosa20@gmail.com

in poor crop yields as seen by Kabutha *et al.* (2000). Drip irrigation has not yet been used on an outsized scale for crop production within the Sudan. However it's utilized in green houses and privately owned small farms and gardens. (Abdalla, 2003). With drip irrigation system, water use efficiency is maximized because there's even less evaporation or runoff. Raina *et al.,* (1998) reported the water use efficiency was higher under drip irrigation as compared with surface irrigation. Dawood and Hamod, (1985) found water use efficiency for trickle irrigated lima beans to be twice as high as that for furrow and sprinkler irrigated lima beans. Also, Sammis (1980) reported higher water use efficiency for trickle and subsurface irrigation as compared to sprinkler and furrow irrigated for potatoes. Salvin *et al.* (2000) observed the water use efficiency was considerably higher in drip than basin irrigation. Narayanamoorthy (2003) reported water use efficiency up to 90% in drip irrigation against the efficiency of 30-40% under furrow method. Muralikrish nasamy *et al.* (2006) reported that prime water use efficiency was related to drip irrigation compared with surface irrigation. Ella *et al.,* (2009), when studying the uniformity of water distribution during a low-cost drip irrigation system with different slopes and hydraulic loads, verified that uniformity decreased because the slopes increased. Uneven fields and unlined irrigation channels cause the loss of an enormous amount of irrigation water (Gill, 1994). Rickman (2002) found a robust correlation between the levelness of the land and crop yield. Ml Jat *et al.* (2015) reported that water management by proper irrigation scheduling together with better crop management techniques (i.e., laser-assisted precision land leveling, conservation-agriculture-based management practices) are potential options for saving of water and increasing water productivity (WP). Several researchers have reported that irrigation application efficiency on unleveled fields is reduced by up to 30% to 50% as compared to an attainable level of 60% to 80%. Land leveling is important for enhancing the utilization efficiency of water, fertilizer, nutrients, and improving the crop stand and yields. Volume and wetted soil surface and moisture onion shape depends on various factors including soil texture and layering, soil homogeneity, dripper flow, primary moisture of soil, consumption water, and land slope.

2. Materials and Methods

2.1 Study area

Experiments were carried out during the season of 2020/21 at the Mohamed Obaid Al Mubarak Laboratory Greenhouse. University of Gezira, Gezira State, Sudan. It lies north of Wad Medani town, Lat. 14° 06` N, Long. 33° 38` E and altitude of 405 masl. The total greenhouse area was 324 m² and its maximum height was 3 m.

2.2 Cultural practices

The experimental Cucumber crop (Hemis variety) was planted on 17/11/2020 and the crop was removed on 15/03/2021, so the duration of the growing cycle was 120 days. The plant spacing was 30 cm. The experiment was laid out in a RCBD with four replicates. The main objective of this work was to study the effects of land slope on hydraulic performance and water use efficiency of cucumber under drip irrigation system in greenhouse.

2.3 Data collection

The performance parameters evaluated include: average discharge (Q_{avg}), discharge variation (Q_{var}%), coefficient of manufacture variation (C_V%), water application uniformity (AU%), coefficient uniformity (CU%), distribution uniformity (DU%) and statistical uniformity (Us%).The crop parameters including: plant height, stem diameter and yield (ton/ha) were also evaluated.

2.3.1 Discharge measurement

The evaluation was carried out according to ASAE, 1997. These procedures are based on taking measurements of emitter discharge along selected drip lines on a sub-main. Three positions were tested on each drip lines which is 18 m long each: one located on the first emitter point close to the inlet, one at the middle far end, and one in the end positions. The greenhouse under study was divided into two sections and were identified simply as Sec A and Sec B. Sec A has its flow uphill while Sec B flow downhill. Average discharge rate was measured using graduated measuring cylinder, catch cans and stopwatch. The model was lifted to work for 10 minutes, and then the collected water in catch cans

measured. The test was repeated three times to get the average volume in liter. The average volume divided by time, to obtain the discharge (q) l/hr (Eq. 1).

$$q = V/t \quad \text{................(1)}$$

Where:
q = Discharge (L/h)
V = Volume collected (ml)
t = Time taken (hours)

2.3.2 Discharge variation (Q_{var})
Flow variation is also a design parameter to evaluate a trickle lateral design. The defining equation for flow variation is:

$$q_{var} = (q_{max} - q_{min})/q_{max} \quad \text{................(2)}$$

Where:
q_{var} = Flow variation
q_{max} = maximum emitter discharge rate in system (l/h)
q_{min} = the lowest emitter discharge rate in system (l/h)
General criteria for Q_{var} values are 10% or less (desirable) and 10 to 20% acceptable and greater than 25%, not acceptable (Guguloth, 2016).

2.3.3 Coefficient of manufacture variation (C_V %)
The C_V can be calculated, using the following formula (Burt and Styles, 2007).

$$CV\% = Sq/qavg \quad \text{................(3)}$$

Keller and Bliesner (1990) represented localized irrigation sub-units classification according to coefficient of variations as presented in Table (1).

Table 1: Classification of coefficient of variation

Coefficient of variation, Cv	Classification
> 0.4	Unacceptable
0.4 – 0.3	Low
0.3 – 0.2	Acceptable
0.2 – 0.1	Very good
< 0.1	Excellent

2.3.4 Application uniformity (AU)
Equation (4) was used to calculate water application uniformity (AU), where it depends on the uniformity of water discharge. This equation also gives information on how water distributed efficiently in the field (Jusoh *et al.,* 2020).

$$AU = (1.0 - Cv) \times 100 \quad \text{................(4)}$$

Water application uniformity obtained was compared with the general criteria for uniformity value as depicted in Table 2.

2.3.5 Uniformity coefficient (CU %)
One of the widely used CU is Christiansen uniformity coefficient. Uniformity coefficients of emitters were tested using the Christiansens formula (1942). It gives the information that how efficiently water is distributed in the field.

$$CU = 100 - (80*Sd/Vavg) \quad \text{................(5)}$$

Where:
CU = Uniformity coefficient (%),
Sd = Standard deviation of observations,
Vavg = Average volume collected.

The coefficient of uniformities and classifications is presented by (ASABE standards EP458, 1999) in Table 3.

Table 2: Percentage of application uniformity (AU%) and its corresponding classification

AU (%)	Classification
< 60	Unacceptable
70-65	Poor
80-75	Fair
90-85	Good
100-95	Excellent

Table 3: Classification/standards of uniformity coefficient

Uniformity coefficient, CU (%)	Classification
Above 90%	Excellent
90 – 80%	Good
80 – 70%	Fair
70 – 60%	Poor
Below 60%	Unacceptable

2.3.6 Distribution uniformity (DU) or Emitter flow uniformity

Distribution uniformity (DU) was computed according to Keller and Karmeli (1974):

$$DU\ (\%) = (qavg25\%/\ )*100 \dots\dots\dots\dots\dots\dots (6)$$

Where:
Qavg 25% = mean of the lowest 0.25 of emitter discharge.
q = average emitter flow rate (L/h).

According to Merriam and Keller (1978), the classifications of distribution uniformities are expressed in Table 4.

Table 4: Classifications of emission uniformity

Eu (%)	Classification Merriam and Keller (1978)
<70%	Poor
70 – 80%	Acceptable
80 – 86%	Good
86 – 90 %	Good
90 – 94%	Excellent
>94%	Excellent

2.3.7 Statistical uniformity (Us %)

Statistical uniformity between the emitters is determined by Eq. (7) (Bralts and Kesner 1983).

$$Us= 100\ (1 – Sq/\bar{q}\ ) \dots\dots\dots\dots\dots\dots.\dots\dots.(7)$$

Where:
Us= statistical uniformity (%)
Vq = overall change in emitters discharge
Sq = standard deviation of emitters discharge (l/h)

Statistical uniformity is evaluated according to ASAE (2003) based on the classification criterion presented in Table 5.

Table 5: System classification according to statistical uniformity values

Us (%)	Classification
<60	Un acceptable
60 – 70	Poor
70 – 80	Acceptable
80 – 90	Good
>90	Excellent

2.3.8 Plant parameters

The data collected consisted of the following parameters: Plant height (cm) and stem diameter (mm).

2.3.9 Yield (ton/ha)

Crop yield was estimated by weighing the weight of Cucumber during harvesting day and the total amount of water consumed was evaluated by continuous monitoring of flow rate meter reading weekly.

2.3.10 Water productivity (ton/m³)

WP is defined as ratio between amount of crop produced and the amount of water involved in crop production system (Ali and Talukder, 2008).

WP= Yield (ton)/ Applied water (m³) …………………………………………………………………(8)

2.4. Statistical analysis

Analysis of variance appropriate for complete randomized block design was applied by using Statistics 8 programme.

3. Results and Discussions

3.1. Discharge (l/h)

Discharge (l/h) of section (A) and section (B) show the difference within the emitters along and between the laterals as affected by the slope of the lateral. . There have been highly significant differences (P≤0.01) in discharge (l/h) among sections. From this figure it's seen that section (A) and section (B) the discharge had a special trend. The flow rate along the lateral length ranged between (0.054 to 0.612 l/h) and (0.306 to 0.858 l/h) for section (A) and B, respectively. The variation is attributed to extend operational head along the land slope and reduce in emission uphill since the sub main line is found midway of the screen house and a part of the water flow downhill section (B) and uphill section (A). The discharge increases from the middle line of the greenhouse which is at a distance of 18 m downhill and reduces uphill. this is often purely a topographically induced occurrence and agrees with the findings of Jiang and Kang, (2010). For the sloping system, a degree of the most important flows at the top of the last line was explained by the gradual increase of the pressure that happens until the top of the pipe. In contrast with Raphael *et al.,* 2018 who found that the mean emitter discharge for section 1 and section 2 weren't significantly different at confidence level of 95% (P≤0.05). Also, Mofoke *et al.* (2004) stated that the overall variability in discharge might be attributed to major and minor losses occurring at the delivery pipe joints and fittings right from the availability tank to the emitters.

3.2. Discharge variation (Qvar%)

Average discharge variation (Qvar) was significantly (P≤0.05) influenced by greenhouse land slope (Table 1). Section (B) emitter's had significantly lower Qvar than section (A). the overall criteria Qvar values are ≤10%, desirable; 10-20%, acceptable; and > 20% isn't acceptable. the general performance description for discharge variation (Qvar) was acceptable for section (A) and unacceptable for Section (B). Manisha and Tripathi (2015) stated that the discharge flow of emitter is increased when the rise of the pressure and therefore the coefficient of variation is increased when the pressure is decreased means the pressure directly affected the discharge rate of emitter. James, (1993) reported that

the emitter discharge variation mainly depends on pressure differences due to difference operational head. Other significant factors affecting emitter discharge include water temperature, quality with which the emitter is manufactured.
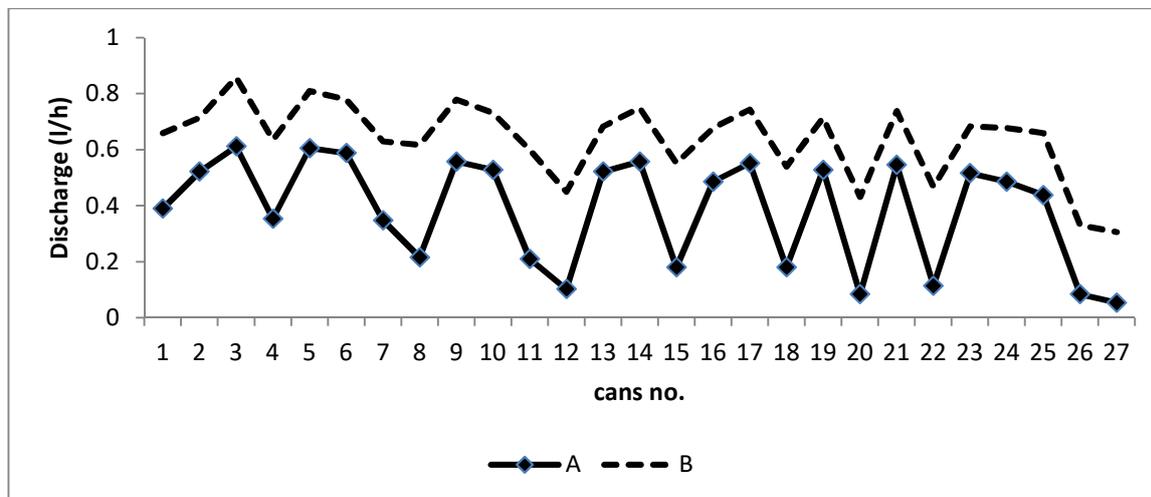

Fig. 1: Discharge (l/h) of the section (A) and section (B)

3.3. Coefficient of variation (C_V %)

The coefficient of variation was significantly ($P \leq 0.05$) suffering from greenhouse slope Table (1). For section (B) the coefficient of variation was found to be but 20 % (Good) while, section A were found to be quite 20 % (unacceptable). On the opposite hand, section A recorded highest values of coefficient of variation (CV %), while section B revealed rock bottom one (Table 1). The low Cv% indicate an honest performance of the system throughout the cropping season. The typical values of CV% for section B emitters were generally low and consistent with American Society of Agricultural Engineering (ASAE) recommended classification of coefficient of worldwide variation in discharge; these values are below the 20% threshold as „good". The differences within the values of Cv are often attributed to the direction of flow which was downhill for section B and uphill for section A. Al-Ghobari, (2007) stated that ASAE to classify emitters supported the worth of coefficient of variation. consistent with this classification, the emitters vary within the values of Cv, and range from 0.2 with good quality to 0. 5 with an unacceptable quality, which can end in high discharge variations from emitters.

Table 1: Effect of land slope on discharge variation coefficient of variation

Section	Q_{var} %	Classification	Cv%	Classification
Section A	55.9 a	Unacceptable	0.50 a	Unacceptable
Section B	17.8 b	Acceptable	0.20 b	Good
C.V%	2.54		3.77	
SE±	4.75		0.042	
Sig. l	**		*	

3.4. Application uniformity (AU%)

Application uniformity was significantly ($P \leq 0.05$) suffering from greenhouse slope (Table 2). The very best application uniformity value of 80 % (Fair) was observed at section (B) and therefore the lowest uniformity coefficient value of 59.9 (Unacceptable) was observed at section (A). Water application uniformity (AU%) express how evenly the uniformity of water is cover the irrigated area used. Application uniformity between section (A) and (B) was found to be 50 attempt to 80 %, respectively. These contributed to unacceptable classification of on top of things for section (A) and fair for section (B). Similar result obtained by Ali and Talukder (2008) who tested the performance of a drip irrigation system and located that average uniformity for drip irrigation system under the greenhouse was 80%. Also, Asif *et al.* (2015) reported that application uniformity was counting on the manufacturing variation in emitters and pressure variation within the system thanks to pipe friction and elevation changes.

3.5. Uniformity coefficient (CU %)

Uniformity coefficient was significantly (P≤0.05) suffering from greenhouse slope (Table 2). the very best uniformity coefficient value of 82.4 % (good) was observed at section (B) and therefore the lowest uniformity coefficient value of 59.9 (Unacceptable) was observed at section (A). The differences within the values of cabinets are often attributed to the direction of flow which was downhill for sec B and uphill for section (A). These results were in line with those obtained by Raphael *et al.* (2018). Also, with Ella *et al.,* (2009), when studying the uniformity of water distribution during a low-cost drip irrigation system with different slopes and hydraulic loads, verified that uniformity decreased because the slopes increased. Also, Alamin (2017) reported that the kinds of emitters and operating pressures have a transparent effect on the performance of drip irrigation system. Charles (2004) reported that approximately 45% of the non-uniformity was thanks to pressure differences, 52% was thanks to "other causes", 1% thanks to unequal. On the other hand, Shareef *et al.,* (2016) found that the emitter type and water quality are the most factors affecting the hydraulic performance of drip irrigation systems.

Table 2: Effect of land slope on application uniformity and uniformity coefficient

Section	AU%	Classification	CU%	Classification
Section A	50 b	Unacceptable	59.9 b	Unacceptable
Section B	80 a	Fair	82.4 a	Good
C.V%	3.81		6.71	
SE±	1.43		3.27	
Sig. l	**		*	

3.6. Distribution uniformity (DU %)

Distribution uniformity was significantly (P≤0.05) suffering from greenhouse slope (Table 3). The very best distribution uniformity value of 69 % (Acceptable) was observed at section (B) and therefore the lowest distribution uniformity value of 29.7% (Poor) was observed in section (A). Consistent with the classification of irrigation system performance by ASAE, a cabinet rating of 90 - 95% is taken into account excellent and therefore the system would only require regular maintenance, while a distribution uniformity of 85% or greater is taken into account excellent. The reduced uniformity coefficient is thanks to high variation in flow rates. The results also agreed with the results obtained by Al-Ghobari, (2007) who reported that the causes of non-uniformity and low efficiency might be associated with some factors like, pressure variation within the system, in correct system design and emitter discharge variation. Charles (2004) and Zellman, (2016) reported that the evidence of the diminished DU is either pressure losses or variations, but more likely, would be the partial plugging of emitters by silt and clay, algae or chemical precipitates. Raphael *et al.,* (2018) reported that emission uniformity decreases slightly up the slope. This result was in line with Ella *et al.,* (2009) who reported that the coefficient of uniformity (CU%) and therefore the distribution uniformity (DU%) generally increase with increasing heads and reduce with increasing slope uphill. Zhang and Hui (2018) found that water distribution and throw radius were measured for the Rainbird LF1200 sprinkler on various slopes. The water distribution curve is roughly "heart-shape" on slope, and therefore the water has the trend of that specialize in the upslope with the rise of the slope. Throw radius decreases for upslope and increases for down slope because the slope increases.

3.7. Statistical uniformity (Us %)

The statistical uniformity was significantly (P≤ 0.05) suffering from the greenhouse slope Table (3). It shows the statistical uniformity for section (A) and for section (B). It falls within the unacceptable and acceptable range, respectively, as specified by Michael, (1978). Zamaniyan (2014) reported that performance of drip irrigation systems in Iran is low and poor, the typical statistical uniformity values in several sites were 61.3. Most frequent problems detected were: inadequate working pressure and emitters clogging. Also, the differences within the values of Us are often attributed to the direction of flow which was downhill for section (B) and uphill for section (A). These results were below with those obtained by Ali *et al.* (2014) in Pakistan it's between 82.8 to 100%.

Table 3: Effect of land slope on distribution and statistical uniformity

Section	DU%	Classification	Us%	Classification
Section A	29.7 b	Poor	49.8 b	Unacceptable
Section B	69 a	Acceptable	78 a	Acceptable
C.V%	9.21		8.88	
SE±	4.71		4.13	
Sig. l	**		**	

3.8. Plant height (cm) and stem diameter (mm)

Table (4) shows the plant height (cm) and stem diameter (mm) for the all treatments under test. The analysis of data showed that there were no significant differences between section (A) and section (B) on plant height but there were a significant differences (P≤0.05) on stem diameter (mm) section (B) gave the highest values of stem diameter in mm.

3.9. Yield (ton/ha)

Yield (ton/ha) was significantly (P≤0.05) affected by greenhouse land slope (Table 4). The highest yield (ton/ha) value of 3.78 was observed at section (B) and the lowest yield value of 1.89 was observed in section (A). These low yield is due to shortage of water (slope variation). Zellman, (2016) reported that drip system distribution uniformity describes the ability of an irrigation system to apply water evenly to each cucumber. If an irrigation system has poor uniformity, some cucumbers do not receive enough water, while other cucumber will get too much with the excess water percolating below the cucumber's root zone and is lost along with any fertilizer or chemical in the water. In order to adequately irrigate all cucumber s in a field with an irrigation system that has poor uniformity, excess water must be applied. This is wasteful of water, energy, fertilizers and money. Water stress depends on both the uniformity of the irrigation system and the gross depth of water applied. The amount of irrigation water that fully satisfies the irrigation requirements is the so-called Required Depth (Recaa, *et al.,* 2018).

3.10. Water productivity (kg/m³)

Water productivity (kg/m^3) was significantly (P≤0.05) affected by greenhouse land slope (Table 4). The highest water productivity value of 38 (kg/m^3) was observed at section (B) and the lowest water productivity value of 29.3 (kg/m^3) was observed in section (A). This wide water productivity range shows the importance of management and operation in water productivity improvement in greenhouses. Similar result obtained by ElMamoun *et al.* (2019) who found that water productivity of cucumber under different greenhouse covers ranged between 15.8 to 21.3 kg/m^3. Also, Najafipour, (2020) found that cucumber water productivities in greenhouses ranged from 9. 23 to 22. 44 Kg/m^3.

Table 4: Effect of land slope on plant hieght, stem diameter, yield and water productivity

Section	Plant height (cm)	Stem diameter (mm)	Yield (ton/ha)	WP (kg/m³)
Section A	265 a	6.64 b	1.89 b	29.3 b
Section B	266 a	7.55 a	3.78 a	38 a
C.V%	3.42	14.83	5.30	4.37
SE±	3.27	0.65	1.23	1.43
Sig. l	N.S	*	**	**

4. Conclusions and Recommendations

The values of the hydraulic performance of drip irrigation system under the slope, including: discharge variation, coefficient of manufacture variation, water application uniformity, coefficient uniformity, distribution uniformity, and statistical uniformity were quite good for section (B) and found to be within the acceptable range but in section (A) all values were below an acceptable range. Also, the yield was high on section (B).

From the results obtained and conclusions drawn from this study the following recommendations can be made: Good leveling is the best practice in greenhouse because it leads to good hydraulic performance and high yield.

References

Abdalla, N.A., 2003. Drip Irrigation System Performance A CASE STUDY- Oumdom Farm. Unpublished M.Sc. thesis, Dept. of Agric. Engineering, Faculty of Agriculture, University of Khartoum.

Acar, B., F.C. Yavuz and R. Topak, 2011. Research on Drip Irrigation System Performance under Greenhouse Conditions. Bulletin UASVM Agriculture, 68(1): 21-27

Al-Ghobari, H.M., 2007. Field evaluation of drip irrigation systems in Saudi Arabia WIT Transactions on Ecology and the Environment, Vol 103, © 2007 WIT Press Water Resources Management, IV- 583- 592.

Ali, A., G.D. Khan and F. Akbar, 2014. Performance Assessment of Existing Drips Irrigation Systems' Parameters (Uniformity, Efficiency and Adequacy Degree Installed In Selected Sites of Peshawar Valley. Innovative Systems Design and Engineering. ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online).Vol.5, No.4.

Ali, M.H. and M.S.U. Talukder, 2008. Increasing water productivity in crop production A synthesis. Agricultural Water Management, 95: 1201-1213.

American Society of Agricultural Engineers (ASAE) Engineering Practice Standard EP 458: Evaluation of Micro Irrigation Systems, St. Joseph, Michigan., USA 1997

ASAE, 2003. Field evaluation of micro irrigation systems. EP458. American Society of Agricultural Engineers, St. Joseph, 760−765.

Asif, M., C. Islam-ul-haq, A.G. Mangrio, N. Mustafa and B. Iqbal, 2015. Analysis of application uniformity and pressure variation of microtube emitter of trickle irrigation system. Net Journal of Agricultural Science, 3(1): 14–22.

Bralts, V.F. and C.D. Kesner, 1983. Drip irrigation field uniformity estimation. Transactions of the ASAE, 26(5):1369- 1374.

Burt, C.M. and S.W. Styles, 2007. Drip and Micro Irrigation Design and Management for Trees, Vines, and Field Crops. Practice plus Theory. 4th Edition. ISBN 978-0-9643634-4-1. 396.

Charles, M.B., 2004. Irrigation and Drainage Systems 18: 275–297, 2004. Kluwer Academic Publishers. Printed in the Netherlands. Rapid field evaluation of drip and micro spray distribution uniformity.

Dawood, S.A. and S.N. Hamod, 1985. A comparison of on farm irrigation systems. Drip/ Trickle irrigation in Action, Proc. of the Third Int, Drip/Trickle Congress, 540-545. Fresna, Calf.

Elamin, A.W.M., A.M. Abd Eldaiam, N.A. Abdalla, and M.E. Hussain, 2017. "Hydraulic performance of drip irrigation system under different emitter types, and operating pressures using treated wastewater at Khartoum state", International Journal of Development and Sustainability, 6(9): 1086-1095.

Ella, V.B., M.R. Reyes, and R. Yoder, 2009Effect of hydraulic head and slope on water distribution uniformity of a low-cost drip irrigation system. *Applied Engineering in Agriculture, 25*(3): 349-356. https://doi.org/10.13031/2013.26885

ElMamoun, A.A., A.B. Adam, S.K. Abbouda, Sahar Gaafar Ahmed, N.I. Mourad and O.A. Mohamed, 2019. Water productivity of cucumber under different covers of greenhouses using drip irrigation system Agricultural Science, 9(5) PRINT ISSN No 2249 - 555X

Gill, M.A., 1994. On-farm water management: A historical overview. In Water and Community: An Assessment of On-Farm Water Management Programme, Inayatullah C (ed). SDPI, Islamabad, Pakistan, 24–39.

Guguloth, P., 2016. Hydraulic performance evaluation of drip irrigation system for cabbage (Brassica oleracea L). M.Sc Thesis. Professor Jaya Shankar Telangana State Agricultural University.

James, L.G., 1993. Principles of farm irrigation systems design. Krieger Publishing Company, Malarbar, Florida, USA.

Jiang, S. and Y. Kang, 2010. Evaluation of Micro-irrigation Uniformity on Laterals Considering Field Slopes. J. Irrig. Drain Eng. 136: 429-434.

Jusoh M.F., A. Nurhayatie, M.F Abdul Muttalib and A. Katimon, 2020. Performance Evaluation of Drip Irrigation System and Water Productivity (WP) of Rock Melon Grown inside Netted Rain House Shelter. 2nd International Conference on Tropical Resources and Sustainable Sciences.IOP Conf. Series: Earth and Environmental Science 549 (2020) 012094

Kabutha, C., H. Blank, and B. van Koppen, 2000. Drip irrigation kits for small-holder farmers in Kenya: experience and way forward. In: 6th international microirrigation congress, South Africa. 22–27 .

Keller, J. and R.D. Bliesner, 1990. Sprinkle and trickle irrigation.Van Nostrand Reinhold, New York. 427-602.

Keller, J. and D. Karmeli, 1974. Trickle irrigation design parameters. Transaction of the ASAE. 7.678-684.

Koegelenberg, F.H., F.B. Reinders, A.S. van Niekerk, R. van Niekerk and W.J. Uys, 2003. Performance of surface drip irrigation systems under field conditions. ARC-institute for agricultural engineering.Water Research Commission, 2003. WRC Report No.1036/1/02. ISBN No. 1-86845-973-X.

Jat M.L., S. Yadvinder, G. Gerard, H.S. Sidhu, P.A. Jeetendra, S. Clare, and G. Bruno, 2015. Laser-Assisted Precision Land Leveling Impacts in Irrigated Intensive Production Systems of South Asia. https://www.researchgate.net/publication/281004835

Manisha, J.S. and M.P. Tripathi, 2015. Studies on hydraulic performance of drip irrigation system under different operating pressure. International Journal of Applied Engineering and Technology ISSN: 2277-212X (Online). An Open Access, Online International Journal Available at http://www.cibtech.org/jet.htm 2015 Vol. 5 (2). pp. 58-63.

Merriam, J.L. and J. Keller, 1978. Farm irrigation system evaluation: A guide for management. Logan: Agricultural and irrigation engineering department, Utah State University, 120 – 130.

Michael, A.M., 1978. Irrigation: Theory and practices. Vikas publishing house. PVT. LT. New Delhi, India.

Mirjat, M.S., M.U. Mirjat and F.A. Chandio, 2010. Water distribution pattern, discharge uniformity and application efficiency of locally made emitters used in a trickle subunit. Pakistan Journal of Agricultural. Agriculture Engineering. Veterinary. Sciences, 26 (1): 1-15.

Mofoke, A.L.E., J.K. Adewumi, O.J. Mudiare, and A.A. Ramahan, 2004. Design, construction and evaluation of an affordable continuous – flow drip irrigation system. Journal of Applied Irrigation Science, 39(2): 253-269.

Muralikrishnasamy, V., Krishnasamy, K., and Sakthivel, 2006. Drip irrigation and fertigation in Chillies (Capsicum Annuum). 7th International micro irrigation congress. Kuala Lumpur.

Najafipour, R., E.H. Ramezani , and B. Nazari, 2020. Determination of Water Productivity and Greenhouse Cucumber Water Requirement in Qazvin. Journal of Water and Soil (Agricultural Sciences and Technology) January-February, 33(6) 811-822.

Narayanamoorthy, A., 2003. Averting water crisis by drip method of irrigation: A study of two water intensive crops. Indian Journal of Agricultural Economics, 58(3): 427-437.

Phocaides. A., 2007. Handbook on pressurized irrigation techniques. Second Edition. Food and Agriculture Organization of the United Nations, Rome, 2007

Raina, A.N., B.C. Thakur, and A.R. Bhournal, 1998. Effect of drip irrigation and plastic Mulch on yield, water use efficiency and benefit cost ratio of pea cultivation. Journal of Indian Society of Soil Science, 46(4): 562-567.

Raphael, O.D., M.F. Amodu, D.A. Okunade, O.O. Elemile and A.A. Gbadamosi, 2018. Field Evaluation of Gravity-Fed Surface Drip Irrigation Systems in a Sloped Greenhouse, International Journal of Civil Engineering and Technology (IJCIET) 9(10): 536–548.

Recaa, J.C., J.A. Trillob, J. Sánchezb, and D.V. Martíneza, 2018. Optimization model for on-farm irrigation management of Mediterranean greenhouse crops using desalinated and saline water from different sources. Agricultural Systems, 166: 173-183.

Rickman, J.F., 2002. Manual for Laser Land Leveling, Rice-Wheat Consortium Technical Bulletin Series 5. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

Salvin, S., K. Baruah, and S.K. Bordoloi, 2000. Drip irrigation studies in banana cv. Barjahaji (Musa AAA group, Cavendish sub- group). Crop Res. (Hissar). 20(3): 489-493.

Sammis, T.W., 1980. Comparison of sprinkler, trickle subsurface and furrow Irrigation Methods for row crops. Agronomy Journal, 72: 701-704.

Shareef, T.M.E., B.S. Amir, W.M.E. Ali and B. Zhao, 2016. Hydraulic Performance of Drip Emitters under Different Types of Emitters and Levels of water Salinity. Journal of Agri-Food and Applied Sciences Available online at jaas.blue-ap.org ©2016 JAAS Journal, 4(2): 43-52.

Smajstrla, A.G., B.J. Boman, D.Z. Haman, D.J. Pitts, and F.S. Zazueta, 2015. Field Evaluation of Micro-irrigation Water Application Uniformity. Institute of Food andAgricultural Sciences, University of Florida. UF/IFAS Extension, 2015, AE09400, Bul 265.Gainesville, FL 32611. [5].

Zamaniyan M., R. Fatahi, and S. Boroomand-Nasab. 2014. Field performance evaluation of micro irrigation systems in Iran. Soil and Water Resources, 9: 135–142.

Zellman, P., 2016. Drip irrigation system evaluations: how to measure and use distribution uniformity tests. http://micromaintain.ucanr.edu/emClog/clogInfo/selfEval/surfDrip/

Zhang, L., X. Hui and Ch. Junying, 2018. Effect of terrain slope on water distribution and application uniformity for sprinkler irrigation

Zhu, D.L., T.P. Wu, G.P. Merkley, and J. Jin, 2009. Drip irrigation lateral design procedure based on emission uniformity and field microtopography. Irrig. and Drain. 2009, DOI: 10.1002/ird.518. (3).