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PERFORMANCE EVALUATION OF HYDRAULIC PARAMETERS OF A DEVELOPED DRIP IRRIGATION SYSTEM

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Abstract

Experiment was carried out in the department of Agricultural and Bioresources Engineering, during the period of August to October, 2017. The hydraulic performance of a developed drip irrigation system was assessed. The experimental work was conducted on field with irrigated field area of 7 m x 3 m and lateral spacing was 0.35 m. Sixty (60) hospital drip sets (given sets) were used for the experiment as improved emitters. Volumetric method was used to determine application rate (PR) and emitters discharge. The emission uniformity, emitter flow variation, co-efficient of uniformity and co-efficient of variation were determined accordance with the equations described by the American Society of Agricultural Engineering (ASAE). Soil chemical properties were determined accordance with the American Public Health Association (APHA). The findings revealed that the soil in the area is classified as sand clay loam and normal soil. Results indicated that the mean and standard deviation of the emitters were 9.639 L/hr and 0.07 L/hr respectively. There were no emitters clogging. The emitter flow variation was 2.5 % and less than 10 % which was desirable range, while coefficient of variation was 0.07 and less than 0.11 which was marginal. The application rate was 17 mm hr-1 which was within the recommended range of 15 – 25 mm hr-1. The emission uniformity and coefficient of uniformity were 99.4% and 99.2% respectively, which shows that the system was well-designed. This finding indicated that hospital drip sets proved to the high quality. Therefore, it can be used as standard emitter.

Keywords: Coefficient of variation, coefficient of uniformity, drip irrigation system, emitter flow variation, emission uniformity

1.0 INTRODUCTION

Water conservation and food security are being problems facing developing countries and they have been attributed to climate change (Glenn and Marcel, 2012). Besides, water scarcity and lack of water resources management technologies was common challenges facing majority of small scale farmers in most of developing countries like Nigeria. While increasing in competition for water among agricultural, industrial and domestic consumers creating the need for continuous improvements in techniques for judicious use of water in crop production (Glenn and Marcel, 2012). Efficiency in water usage is becoming increasingly important and alternative water application methods such as drip and sprinkler irrigations had been contributed substantially in making the best use of the scarce available water for crop production (Sivanappan, 2002; Namara et al., 2005). As result of negative impact on environment due to common irrigation methods and limited water resources, drip irrigation technology is getting more prominence and acceptability (Sivanappan, 2002).

Drip irrigation also known as trickle irrigation (micro-irrigation) or low-volume irrigation. It is the modern irrigation system that involving the slow application of water and sometimes fertilizer directly into the soil closely to root zone of the crop through of small diameter plastic pipes with built – in outlets called emitters or drippers. It is one of the best economical water application methods that had been used globally, due to high uniformity and water efficient utilization (Narayanamoorthy, 2005). This type of modern technology places greater positive impacts on the yields of cash crops in comparison to the traditional methods of irrigation (Dhawan, 2000, 2002). In addition, it conserves water which is critical during dry season. The others merits of it when compared to traditional (conventional) methods are as follows: It produces no runoff, reduce over-exploitation of groundwater and environmental problems such as waterlogging and salinity (Qureshi et al., 2001; Sivanappan, 2002; Namara et al., 2005)

Performance of drip irrigation system depends on the physical and hydraulic characteristics of the drip tubing (Kumar and Singh, 2007 and Tyson and cutis, 2009). Main feature is that, the uniform distribution of water is possible, which is one of the most important parameters in design, management, and adoption of this system. Proper design drip irrigation system applies nearly equal amount of water to each plant, maintaining uniformity, meets its water requirements, and is economically feasible. Tyson and cutis (2009) highlighted that the distribution uniformity (emission uniformity) of water and operating pressure are major parameters that must be considered in drip irrigation design. Efficiency of drip irrigation system depends on application uniformity which can be evaluated by direct measurement of emitter flow rates (Kumar and Singh, 2007). According to Vance (2004) that uniformity of emission affected by the unit-to-unit variation between emitters which it depends upon the design, the materials and manufacturing processes. The main factors affecting drip irrigation uniformity are manufacturing variations in emitters, pressure regulators, and pressure variations due to elevation changes, friction head losses throughout the pipe network, emitter sensitivity to pressure, irrigation water temperature changes and emitter clogging (ASAE, 1999, Kumar and Singh, 2007). Emitter clogging is one of the factors affecting the performance of the drip irrigation systems and it is caused by physical, chemical and biology such as sediment, bacteria and algae (Wu, 1997). ASAE (1999), Kumar and Singh (2007) and Tyson and cutis (2009) reported that drip irrigation systems depend on the emission uniformity (EU) throughout the system, it measures of the uniformity of emitters discharge from all the emitters, and others parameters are co-efficient of variation (CV), emitter flow variation (Q_{var}), and uniformity co-efficient (CU).

The classifications of hydraulic parameters are presented in Tables 1, 2, 3 and 4 respectively.

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Table 1 Classification of emission uniformity

Emission uniformity (EU)	Interpretation
$\geq$ 90%	Excellent
80 – 90%	Good
70 – 80%	Fair
$\leq$ 70%	Poor

Source: American Society of Agricultural Engineering (ASAE, 1999)

Table 2 Classification of Co-efficient of Variation

Co-efficient of Variation (CV)	Interpretation
$<$ 0.05	Excellent
0.05 – 0.07	Average
0.07 – 0.11	Marginal
0.11 – 0.15	Poor
$>$ 0.15	Unacceptable

Source: American Society of Agricultural Engineering (ASAE, 1999)

Table 3 Classification of Emitter flow Variation (Q_{var})

Emitter flow variation (Q_{var})	Interpretation
$\leq$ 10%	Desirable
10 – 20%	Acceptable
$>$ 25%	Unacceptable

Source: American Society of Agricultural Engineering (ASAE, 1999)

Table 4 Classification of Uniformity Co-efficient (CU)

Uniformity Co-efficient (CU)	Interpretation
$\geq$ 90%	Excellent
80 – 90%	Very good
70 – 80%	Fair
60 – 70%	Poor
$<$ 60%	Unacceptable

Source: American Society of Agricultural Engineering (ASAE, 1999)

Soil properties especially electrical conductivity (EC) and sodium adsorption ratio (SAR) are very essential for proper and effective irrigation operating system. They are the major determinant parameters for evaluation of land suitability for irrigation purposes. Both EC and SAR are commonly used to classify salt-affected soils (Table 5).

Table 5 Classification of salt affected soils

Criteria	Normal	Saline	Sodic	Saline-sodic
EC (Sd/m)	< 4	> 4	< 4	> 4
SAR	< 13	< 13	> 13	> 13

Source: Brady and Weil. 2002

The study was to evaluate the performance of the developed drip irrigation system using improvised emitters under the continuous flow and same operating pressure. Performance evaluation parameters was only based on Emission uniformity (EU) which also known as distribution uniformity (DU), co-efficient of variation (CV), emitter flow variation ($Q_{\_var}$), and uniformity co-efficient (CU).

2.0 MATERIALS AND METHOD

2.1 Study Area

The study was conducted at the department of Agricultural and Bioresources Engineering, Faculty of Engineering, Ikole campus, Federal University Oye Ekiti, Nigeria (latitude 07^{o} 48.439 and longitude 05^{o} 29.869) is slightly sloppy and 2.5 m above sea level.

2.2 Drip Irrigation system Layout

The prototype of drip irrigation system was developed. The experiment was laid in two split plot design and each plot with 6 laterals and field layout of drip irrigation system is presented in Figures 1. The components of the prototype are:

1. A water tank of 250 litres capacity was used to store water
2. The filter was connected to the outlet pipe of water tank
3. The mainline was a pipe of 2.5 m length and 1 inch (2.54 cm) diameter which made from polyvinylchloride (PVC)
4. The lateral lines were made of polyvinylchloride also with 3/4 inch (1.91 cm) diameter, 2.5 m length and 0.35 m laterals spacing.
5. Sixty (60) hospital drip sets (given sets) were used as improved emitters due to availability, simplicity and less cost as compare to others emitters which are scarce. They were fixed on 60 cm spacing along the laterals
6. The three gate valves were used, first valve was connected to the water tank and other two were connected to each sub main pipe respectively.

Measuring cylinders and stopwatch were to measure emitters discharges.

2.3 Experimentation

Six emitters were used as pre-testing and twelve (12) emitters were randomly selected across the laterals for the study. The rationale for the choice of emitters is as follows: The emitters under evaluation were the same topography, operation pressure and laterals. The hydraulic performance of drip irrigation systems was evaluated using Emission uniformity (EU), co-efficient of variation (CV), emitter flow variation ($Q_{\_var}$), and uniformity co-efficient (CU) parameters. The hydraulic evaluation of the continuous-flow drip irrigation system was conducted on August to October, 2017. The irrigated field area (7m x 3m) and lateral spacing was 0.35 m. The gate valve at the exit of the distributary tank was opened full which supplied water to the sub main pipes. The gate valves at the sub mains were opened at 50 % which delivered water to the laterals. Water was allowed to flow about 30 minutes to permit the pre-testing (Figure 1). The total number of emitters is 60. Measuring cylinders were paced under emitters to collect water. The gate valves at the sub main pipes were opened at 50 % which delivered water through the laterals to the emitters. The drops from each emitter were run for 5 minutes. The volumes of water collected at each emitter were recorded. The treatment was replicated three times. Volumetric method was used as perquisite for the determination of the Emitters discharge. The emission uniformity, emitter flow variation, co-efficient of uniformity and co-efficient of variation were determined accordance with the equations described by the American Society of Agricultural Engineering (ASAE, 1999).

Figure 1: Field Layout Gravity Drip Irrigation System

2.4 Soil Parameter Measurements

The required physical and chemical properties of soil were measured at various depths between 0 cm to 120 cm at 30 cm intervals by auger and were taken to the laboratory for the analysis. Soil parameters measured include soil slope, soil depth, textural class, pH, electrical conductivity (EC), potassium, calcium, magnesium and sodium. The soil sampling was done two times for each point. Particle size analysis was carried out by hydrometer method (APHA, 2005). The pH and electrical conductivity of the soil were determined with 10 g of air – dried finely powered soil sample put in a beaker and mixed well with 25ml of distilled water and kept for about half an hour with occasional stirring. The electrode of pH meter and electrical conductivity meter were dipped into the solution and the readings were taken (APHA, 2005). Abney level was used in determination of slope gradient. Textural class was determined with aid of textural triangle (FAO/IISA, 2008). Potassium and sodium were measured using flame photometer while magnesium and calcium were measured using Atomic Absorption Spectrophotometer (APHA, 2005).

2.5 Data Analysis

Data were analysed using descriptive statistics. The following equations were used to evaluate the suitability of soil for irrigation

Calcium Exchange Capacity (CEC)

CEC (meg/kg) = $Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}$ **1**

Sodium Adsorption Ratio (SAR)

$$\text{SAR} = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad \textbf{2}$$

Exchange Sodium Percentage (ESP)

$$\text{ESP (\%)} = \frac{Exchange\ Na^{+}}{Soil\ CEC} \text{ x } 100 \quad \textbf{3}$$

Where,
Na^{+}= Sodium concentration in meg/l
Ca^{2+} = Calcium concentration in meg/l
Mg^{2+} = Magnesium concentration in meg/l
K^{+}= Potassium concentration in meg/l

While the following equations were used to evaluate the performance of drip irrigation systems

Emission Uniformity (EU)

$$\text{EU (\%)} = \frac{100\ Avg\ Q_{Low}}{Q_{Avg}} \quad (ASAE, 1999) \quad \textbf{4}$$

Where,
EU = emission uniformity (%)

$AvgQ_{Low}$ = average rate of discharge of the lowest on fourth of the field data of emitter discharge (L hr^{-1})

Q_{Avg} = average discharge rate of all the emitters checked in the field (L h^{-1})

Co-efficient of Variation (CV)

$$\text{CV} = \left(\frac{SD}{Q}\right) (ASAE, 1999) \quad \textbf{5}$$

Where,
CV = coefficient of variation

SD = standard deviation of emitter discharge (L h^{-1})
Q = average discharge in the same line (L h^{-1})

Emitter Flow Variation (Q_var)

$$(Q_{var}) = 100\,[1- \frac{Q_{min}}{Q_{max}}]\ (ASAE, 1999) \qquad \textbf{6}$$

Where,

Q_{var} = emitter flow variation (%)
Q_{min} = minimum emitter discharge rate in the system (L h^{-1})
Q_{max} = average or design emitter discharge rate (L h^{-1})

Co-efficient of Uniformity (CU)

$$CU = 100\,[1 - \frac{SD}{Q_{avg}}]\ \ (ASAE, 1999) \qquad \textbf{7}$$

CU = Christiansen's uniformity of coefficient of uniformity (%)

SD= sum of average deviation of individual emitter discharge (L h^{-1})

Q_{avg} = average emitter discharge (L h^{-1})

Clogging Emitter Susceptibility (E_Pclog)

$$E_{Pclog} = 100\,[\frac{E_{Nclog}}{E_N}] \qquad \textbf{8}$$

Where,

E_{Pclog} = clogging emitter susceptibility (%)

E_{Nclog} = numbers of clogged emitters

E_T = total number of emitters

Application rate (PR): $\frac{No.\ of\ emitters\ x\ flow\ per\ emitter}{Area\ of\ irrigation}$ **9**

3.0 RESULT AND DISCUSSIONS

The source of water used for the drip irrigation system was borehole.

3.1 Soil Physical And Chemical Properties Of Study Area

The soil in the study area was classified as sand clay loamy with flat slope, moderate soil depth and normal soil (Table 6). All the chemical properties were within the recommended values for irrigation and crop production except cation exchange capacity which below the recommended value (>15) (Table 6). The soil properties evaluated to show the preliminary study of the location which can be used for further study.

Table 6 Physical and Chemical properties of soil in the study area

S/N	Parameters	Value	Critical Value
1	pH	5.6 ± 0.11	5 – 6.5
2	EC (ds/m)	0.22 ± 0.02	0 – 4.0
3	Potassium (mg/l)	1.3 ± 0.22	0 – 6.0
4	Calcium (mg/l)	4.5 ± 0.23	0 – 9.0
5	Sodium (mg/l)	0.6 ± 0.33	0 – 5.0
6	Magnesium (mg/l)	4.1 ± 0.01	0 – 15
7	SAR	0.21 ± 0.01	< 13
8	ESP (%)	4.16 ± 0.21	< 10
9	CEC	13 ± 1.1	> 15
10	Textural class	Sand clay loam	
11	Slope (%)	1	
12	Depth (cm)	110	90 - 112

3.2 The Average Discharges From The Selected Emitters

The average discharges per emitter are presented in Table 6. The minimum and maximum discharges of selected emitters are 9.636 and 9.759 l hr-1 respectively (Table 7). The mean and standard deviation were 9.639 l hr-1 and 0.07 l hr-1 respectively. Relationship between volume and discharge of emitters is presented in Figure 2.

Table 7 Average volume of water drops from the selected emitters

S/N	Selected Emitter	Volume of drop (L)	Run Time (hr)	Discharge (L hr^{-1})	Lateral spacing (m)	Area of Irrigated (m^2)
1	A_1	0.800	0.083	9.639	0.35	0.35
2	B_2	0.810	0.083	9.759	0.35	0.35
3	C_4	0.790	0.083	9.518	0.35	0.35
4	D_3	0.795	0..083	9.578	0.35	0.35
5	E_5	0.805	0.083	9.699	0.35	0.35
6	F_2	0.810	0.083	9.759	0.35	0.35
7	G_4	0.800	0.083	9.639	0.35	0.35
8	H_2	0.795	0.083	9.578	0.35	0.35
9	J_5	0.800	0.083	9.639	0.35	0.35
10	K_4	0.805	0.083	9.699	0.35	0.35
11	L_3	0.800	0.083	9.639	0.35	0.35
12	M_4	0.790	0.083	9.518	0.35	0.35

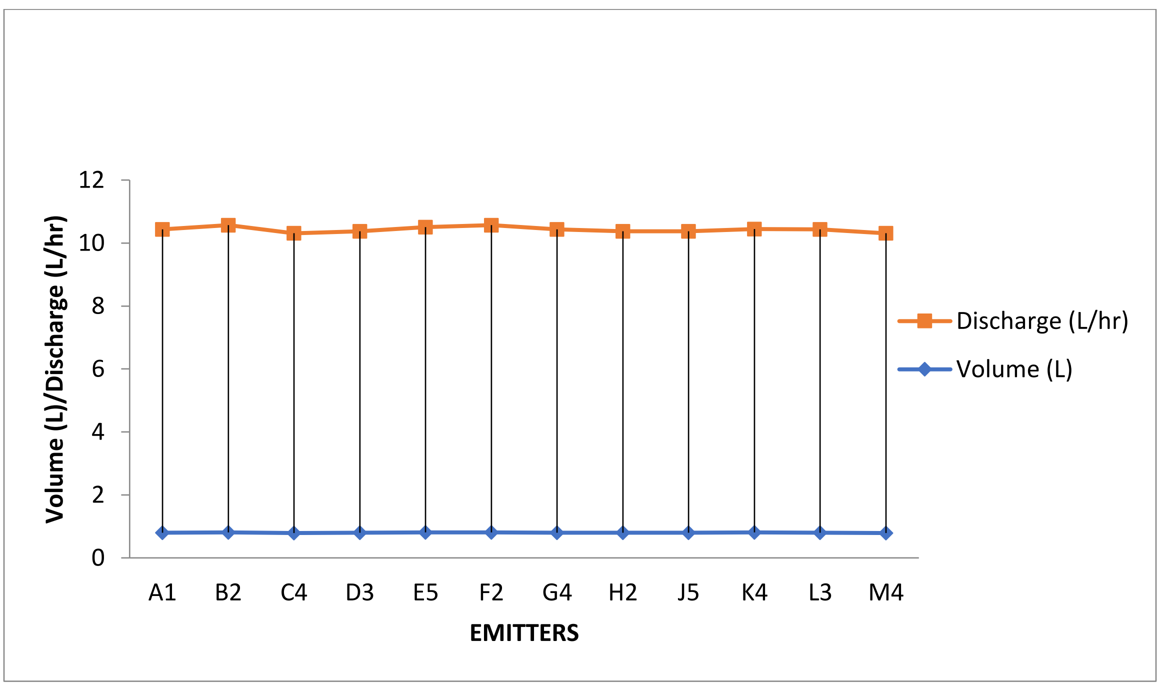

Figure 2 Graphical presentation of volumes (L) and discharge rates (L/hr) of emitters

3.3 Hydraulic Parameters Of Drip Irrigation Systems

The hydraulic performance of continuous flow drip irrigation system was evaluated. The improvised emitters were used with the same operating pressure. The parameters of emission uniformity (EU), emitter flow variation (Q_{var}), co-efficient of uniformity (CU) and co-efficient of variation (CV) were assessed. Emission uniformity is the measure of the uniformity of emitters discharge from the drip irrigation system and is the most important parameter for assessing system performance. While the co-efficient of uniformity describes how evenly an irrigation system distributes water over a field and it is regarded as one of the important features for selection, design and management of the irrigation system. The evaluated values and classification of these parameters are presented in Table 8. The high values of emission uniformity (99.4 %) and coefficient of uniformity (99.2 %) indicated that drip irrigation system was well-designed This finding differs from evaluation made by Mirjat et al, (2010) that emission uniformity and coefficient of uniformity values for randomly selected laterals with smooth emitters averaged 75.4% and 81.7 % respectively. These differences may be attributed to different emitter types, emitter discharge rate, operating pressure, topography and irrigation network. This finding also agreed with others researchers like AL Amound (1995) and Solomon (1983) that high coefficient uniformity at least 85 % and attain an emission uniformity greater than 90 % respectively refers well-designed drip irrigation system. There is no clogging was observed throughout the experiment and application rate (PR) of the emitter was 17 mm hr-1 which within recommended range of 15 – 20 mm hr-1 for nursery and garden vegetables (Haydu et al., 2004, Creswell and Huett, 2006)

Table 8 The Values and Classification of hydraulic parameters of drip irrigation system

S/N	Hydraulic Parameter	Calculated Value	Classification
1	Emission Uniformity (%)	99.4%	Excellent
2	Emitter flow Variation (%)	2.5%	Desirable
3	Coefficient of Uniformity (%)	99.2%	Excellent
4	Coefficient of Variation	0.07	Average

3.0 CONCLUSION

Drip irrigation system and its hydraulic parameters were assessed. There was no emitters clogging were observed throughout the investigation. The emission uniformity and coefficient of uniformity were greater than 90% which was an excellent range. The emitter flow variation was less than 10% which was desirable range, while coefficient of variation was less than 0.11 which was marginal. The application rate was 17 mm hr-1 which was within the recommended range. The soil in the study area was classified as sand clay loam and normal soil. This finding indicated that hospital drip sets proved to the high quality. Therefore, it is recommended as alternative to standard emitter.

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