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EVALUATION OF GRAVITY DRIP IRRIGATION KIT IN A GREENHOUSE

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ABSTRACT

The Research was carried out to evaluate the performance of a gravity drip irrigation kit in a greenhouse. The system consists of a 2m^3 tank mounted 2m above ground, connected to a mainline which is also connected to two sub-mainlines. Each sub-main has six junctions and each junction has two laterals connected to it giving a total of 24 laterals in the system. Measurement of emitters discharges was carried out from six (6) laterals selected one from each of the six junctions. The pressure heads at the designated laterals were measured using a pitot tube from which the operating pressure was calculated. The result of the Research shows an average discharge of the emitter for the system of 857mLh^{-1}. The uniformity coefficient and emitter coefficient of variation for the whole system were found to be 94.87% and 0.07 respectively. The uniformity of the system is classified as Excellent while the emitter coefficient of variation CV, obtained from the study (0.07) for this type of emitter is classified as average. The value of the emitter coefficient (k) and emitter exponent(x) were found to be k=2.54 and x=0.5. The value of the emitter exponent (x=0.5) shows that the flow regime of the emitter is fully turbulent flow. The results of tests show that the emitter discharges were uniformly distributed over all operating pressures. The discharge also increases with operating pressure for all tested emitters.

Keywords*: Drip irrigation, emitter, discharge, and operating pressure*

1.0 INTRODUCTION

The continue increase in population and climatic change impact has continue to put more pressure on limited available water resources, particularly in water-stressed regions of the world. The Population Reference Bureau projected that the world population will rise from 7.8 billion in 2020 to 9.9 billion by 2050 (PRB, 2020: Lawal and Shanono, 2022). This increase in population combined with climatic uncertainties will subsequently reduce the per capita availability of freshwater and may confound the existing problem of water stress in arid and semi-arid region of the worlds.

Agriculture is presently the principal user of the world's water resources. It consumes about 70% of water globally (FAO, 2017; Lawal and Shanono, 2022) and most of this water is used for surface irrigation purposes (Akbari et al., 2018).

Surface irrigation is the conventional and the most commonly adopted irrigation method in which water is applied and distributed over the soil surface by gravity. Surface irrigation is the most dominant irrigation method that is being practiced globally on about 76 % (255,784,630 ha) of the 338,711,000 ha of irrigated cropped area in the world as of 2018 (Lawal and Shanono, 2022). This method of irrigation can lose about 50% of water to conveyance losses, runoff, evaporation and deep percolation (Shanono *et al*., 2020).

Increasing the efficiency of water use for agriculture is necessary in order to secure water for agricultural production, and municipal and industrial purposes. In order to solve the problem of water shortage in agriculture, it is necessary to develop water-saving irrigation. Drip irrigation is a method of applying uniform and precise amounts of water directly to the root zone of the plants as per the requirement, through emitters at frequent intervals over a long period of time, via a pressure pipe network (ICID, 2022). Drip irrigation is the most effective way and its utilization rate can reach up to 90%. Evidence shows that the water-use efficiency increases up to 100 per cent in a properly designed and managed drip irrigation system (INCID, 1994; Luvanda and Indai 2015).

Environmental problems associated with the surface method of irrigation like water-logging and salinity are also completely absent under the drip method of irrigation. The drip method apart from saving irrigation water and increased in water-use efficiency also decreased tillage requirement, ensure higher quality products, increased crop yields and achieve high fertilizer-use efficiency (Namara *et al.*, 2005). However, a pressurized drip irrigation system is capital-intensive and requires expertise and therefore cannot be afforded by an average subsistent farmer.

A gravity drip irrigation system is an irrigation method that consists of an elevated reservoir of about 2 m head above the ground with a pipe connected to the reservoir which supplies water to the drip lines by gravity. The system is simple and effective way to irrigate a small area of cropland and it improves the yield and quality of crops through precise water and fertilizer application. A study conducted by Khanam and Patra (2015) to compare the performance of gravity drip irrigation system with surface irrigation method revealed that gravity drip irrigation system outperformed the surface irrigation method. The results of their study showed that the lowest irrigation water use, highest water use efficiency and water savings and maximum soil water storage was obtained in gravity drip irrigation in comparison with surface irrigation. Maximum plant growth, yield attributes and flower production were also accomplished with gravity drip irrigation system when compared with surface method.

This study is aimed at developing and evaluating a gravity drip irrigation kit which is affordable and easy to maintain by small-scale farmers thereby improving the yield and water use efficiency of their irrigation systems. This will also ensure efficient use of the limited available water resources by the small-scale farmers who cannot afford conventional drip irrigation system because the high initial capital and technical knowledge involved in the operation and maintenance of the system. In addition, the gravity drip irrigation needs to be evaluated based on the local condition of its operation because the efficiency of the system is greatly affected by application uniformity and the successful uniform drip irrigation system depends on the physical and hydraulic characteristics of the drip tubing (Tyson and cutis, 2009; Omofunmi, *et al*, 2019) .

2.0 MATERIAL AND METHODS

2.1 Description of the Study Area

The Research was carried out inside a greenhouse located at National Agricultural Extension and Research Liaison Services' premises, Ahmadu Bello University, Samaru, Zaria. Samaru lies at latitude $11°11'$N and longitude $7°38'E$on an altitude 686m above the mean sea level. The topography of the land is nearly flat with a gentle slope. The area is located within the Northern Guinea Savannah Ecological Zones of Nigeria and rainfall is monsoonal in origin averaging about 1100mm per annum. It starts in May and ends in October with a peak in August. The average humidity of the area is 36.84% during the dry season and 78.5% during the wet season and the average minimum temperature is 15.56°Cand maximum of 38.45℃ as obtained from the meteorological station of the Institute of Agricultural Research, Samaru (Kowal, 1972: Odunze, 1997). The research was conducted from March to April, 2016.

2.2 Experimental Set-up

A set low-cost drip Irrigation kit was laid out inside the greenhouse with an area of $192m^2$. The drip system consists of a 2 m^3 tank mounted 2 m above the ground, connected to a mainline which is also connected to two sub-mainlines of 0.02m diameter each and a length of 7m. Each sub-main has six junctions and each junction has two laterals connected to it giving a total of 24 laterals in the experimental plot. The length of each lateral is 12m, while its diameter is 0.0065m and each lateral has 40 emitters that are 0.3m apart giving a total of 960 emitters for the whole system.

Plate1: A greenhouse with a $2m^3$ overhead tank by the side

Plate 2: Sub mainlines of the system

Plate 3: Interior view of the greenhouse

2.3 Determination of Parameters for Evaluation of Drip Emitters

The following parameters were determined and used for the evaluation of the system. Computations followed the methodology proposed by Keller and Bliesner, 1990 and Kang and Nishiyama, 1996:

1. Average emitter discharge rate (qa)
2. Standard deviation of emitter flow rate (Sq)
3. The variation coefficient of emitter flow (Cv)
4. Uniformity coefficient (UC)
5. Emission uniformity (EU)
6. Distribution uniformity (DU)

2.3.1 Average Emitter Discharge

The Average Emitter Discharge Rate, *qa* (l/h) of a drip irrigation system was determined from equation 1 below:

$$qa = \frac{1}{n}\sum_{i=1}^{n} qi \quad (1)$$

Where *qi* is the flow rate of the emitter *I* (l/h) and *n* is the total number of emitters.

2.3.2 Standard Deviation of Emitter Flow Rate

The standard deviation of the emitter flow rate, *Sq*, for the system was determined by equation 2 as recommended by ASABE, 2008R):

$$Sq = \sqrt{\frac{\sum_{i=1}^{n}(qi-qa)^2}{n-1}} \quad (2)$$

2.3.3 Emitter Flow Variation

The emitter flow variation for the system along the lateral was determined using equation 3, as expressed by (Wu, 1997):

$$q_{var} = \frac{q_{max}-q_{min}}{q_{max}} \times 100 \quad (3)$$

The emitter flow variation is a measure of the degree of uniformity of a drip irrigation system and is a function of hydraulic design, manufacturer's variation, temperature changes and plugging. The emitter flow variation is used to determine irrigation application efficiency and scheduling. The General criteria for emitter flow variation are q_{var} values of 10 per cent or less are considered desirable, 10 to 20 per cent Acceptable and greater than 20 per cent not acceptable. Table 1 shows emitter Flow variation criteria for micro irrigation systems as adopted from Bralts *et al*, 1987; Kumar and Ashoka, 2020)

Table 1: Flow variation criteria for micro irrigation systems as adopted by Bralts et al, 1987; Kumar and Ashoka, 2020

Flow variation $Q_{var} = 100(\frac{Q_{max}-Q_{min}}{Q_{max}})$	
Desirable	$< 10\%$
Acceptable	10-20%
Unacceptable	$> 20\%$

.3.4 Coefficient of Variation of Emitter Flow

The emitter manufacturer's coefficient of variation was determined by equation 4 as recommended by (ASAE, 1997):

$$C_v = \frac{S_q}{q_a} \quad (4)$$

The manufacturer's coefficient variation is a measure of the ratio of the standard deviation of flow to the mean flow for a sample number of emitters in micro-irrigation system. This parameter is used to evaluate the variation in discharge in a sample of new emitters when operated at a constant temperature and near the design operating pressure of the emitter. The value of *CV* can be calculated by measuring the discharge from a sample of new emitters at a fixed inlet pressure; however, it is usually available from the manufacture (ASAE, 1997). The Table 2 shows Classifications of the manufacturer coefficient of variation recommended by ASABE Standards EP405.1, 2008R

Table 2: Micro-Irrigation System Uniformity Classification Based on the Coefficient of Variation

Emitter type	Cv range	Classification
Point-source	< 0.05	Excellent
	0.05 – 0.07	Average
	0.07 – 0.11	Marginal
	0.11 – 0.15	Poor
	>0.15	Un-acceptable
Line-source	< 0.10	Good
	0.10 – 0.20	Average
	>0.20	Marginal to unacceptable

Adopted from ASABE Standards EP405.1, 2008R

2.3.5 Uniformity Coefficient

The uniformity coefficient, Christiansen's UC (%) was determined using equation 5 as represented in ASABE standards:

$$UC = 100[1 - \frac{1}{nqa}\sum_{i=1}^{n} |qa - qi|] \quad (5)$$

The general criteria for an accepting uniformity coefficient UC as recommended by ASABE Standards EP 458, 1999 in a drip irrigation system are given in Table 3.

Table 3: Micro-irrigation system uniformity classification based on uniformity coefficient

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

Adopted from ASABE Standards EP 458, 1999

2.3.6. Emission Uniformity

The Emission uniformity EU (ASABE, 2008R) was determined using equation 6 is expressed as:

$$EU = \left[1.0 - \frac{1.27Cv}{\sqrt{n}}\right] \times \left(\frac{qn}{qa}\right) \quad (6)$$

where: Cv = manufacturer's coefficient of variation, *n* = 1.0 or the number of emitters per plant q_n is the minimum flow rate of the sampling group emitters, q_a = average emitter discharge of all the emitters under consideration *(l/h).*

2.3.7. Distribution Uniformity

Distribution uniformity (DU) was determined by equation 7 expressed as:

$$DU = 100\left(\frac{q_m}{q_a}\right) \quad (7)$$

Where q_m is the average flow rate of the emitters in the lowest quartile.

Distribution uniformity is a measure of the uniformity with which irrigation water is distributed to different areas in the field. Distribution uniformity (DU) applies to all types of irrigation methods (Mohammed *et al,* 2019).

2.4 Determination of Emitter Flow Rate and Pressure Head Relationship

The relationship between flow rate and pressure head for emitters was determined using equation 8 as recommended by (Singh, 2012)

$$q = kp^x \quad (8)$$

q = discharge of emitter, (l/h), p = operating pressure head, (kPa), K = flow coefficient and x = flow exponent

The value of *x* depends on the type of flow regime. to Barua (2019) reported the following: x = 0.5 in fully turbulent flow (non-compensating orifice and nozzle emitters are always fully turbulent), x = 1.0 in laminar flow, 0.5 < x < 1 for unstable flow regime x = 0.0 for fully pressure-compensating

2.5 Data Collection Procedures

Measurement of emitters discharges were carried out from six (6) laterals selected one from each of the six junctions. In each drip tube, ten (10) emitters were randomly selected one from each quarter of the lateral length. A total of 120 emitters were evaluated in the study. Water cans were placed below the tubes to collect water dripping from designated emitters for five minutes. The water collected in each can was measured using a graduated cylinder. Each emitter measurement was replicated three times. The water temperature at the time of measurement was between 27°Cand 31°C using a mercury in glass thermometer. The pressure heads were measured using a pitot tube in the designated laterals from which the operating pressure was calculated. The operating pressure was monitored using the Pitot tube to ensure that the pressure remain constant during each set of measurements. The data collected were analyzed using descriptive statistics. Figure 1 shows the layout of the experimental plot.

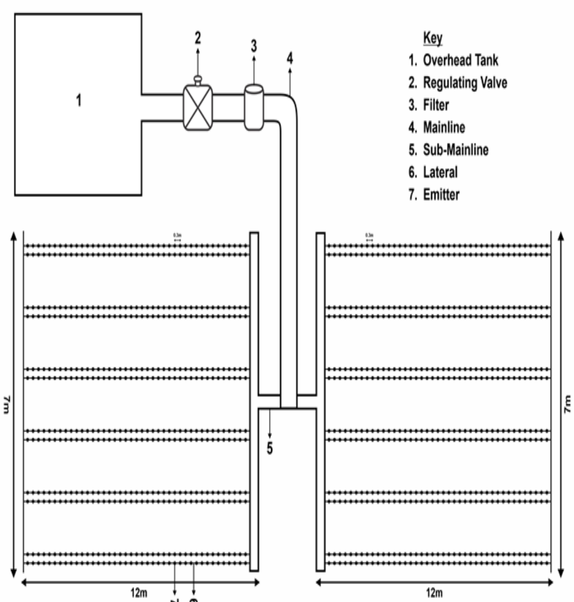

Figure 1: Layout of the experimental plot

3.0 RESULTS AND DISCUSSION

3.1 Pressure-Discharge Relationship

The table 4 shows the average discharge of the emitters and their respective operating pressure along the drip lateral selected for the experiment.

Table 4 Average Discharge of Emitter and their Pressure

Lateral Number	Flow rates, q (ml/hr)	Operating pressure, p (kPa)	Logq, Y (ml/hr)	Logp, X (kPa)
LA_1	897	4.91	2.95	0.69
LA_2	902	6.60	2.96	0.82
LA_3	921	6.90	2.96	0.84
LA_4	931	7.19	2.97	0.86
LA_5	839	6.00	2.92	0.79
LA_6	820	4.91	2.91	0.69
LB_1	858	5.65	2.93	0.75
LB_2	859	5.74	2.93	0.76
LB_3	823	5.56	2.92	0.75
LB_4	865	7.95	2.94	0.90
LB_5	815	5.79	2.91	0.76
LB_6	750	5.30	2.88	0.72

The minimum and maximum discharge of emitters obtained from the study are 750 $ml\ hr^{-1}$ and 931 $ml\ hr^{-1}$ while the minimum and maximum operating pressure are 4.91 kPa and 7.91 kPa respectively. The mean and standard deviation for the emitter discharges are 857 $ml\ hr^{-1}$ 0.060. The results of tests show that the emitter discharges were uniformly distributed over all operating pressure. The discharge also increases with operating pressure for all tested emitters. Figure 1 shows the relationship between the operating pressure and the emitter discharge as expressed in equation 3.1

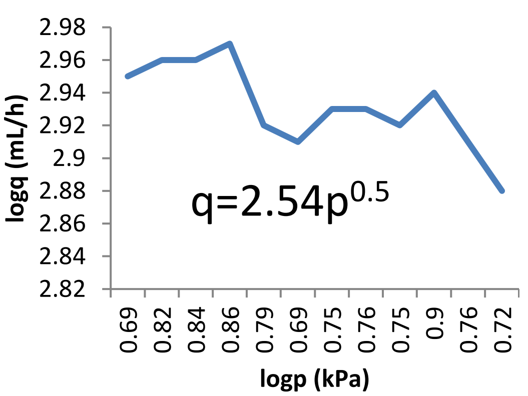

Figure 1: Logarithm of the average emitter discharge and pressure to determine K and x for the pressure compensating emitter model

The figure 1 above shows the relationship between the emitter discharge and the operating pressure of the pipe, which is very important for evaluation of the hydraulic performance of drip irrigation system. The value of the emitter coefficient (k) and emitter exponent(x) were determined from regression analysis based on the logarithm of pressure and discharge of the emitter and were found to be k=2.54 and x=0.5

$$q = 2.54p^{0.5} \quad (9)$$

Where q=emitter flow rate $(ml\ hr^{-1})$ and p=operating pressure(kPa). According to Barua (2019), the value of x for a laminar flow emitter close to 1, the value of x for a turbulent flow emitter is 0.5. The values of x vary from 0 to 1 for wide range of emitters. If x approaches zero, the emitters are classified as fully pressure-compensating. The value of x obtained from this study is 0.5 and therefore the system is classified as turbulent.

3.3 Performance Parameters of the Systems

Table for 4 shows the results of performance parameters obtained from the experiment for all the emitters tested along twelve (12) drip tubes under consideration. The average discharge of the emitter for the system was 857mLh^{-1}. The uniformity coefficient and emission uniformity obtained from the study are 94.87 % and 78.62 % respectively. The uniformity of the system is classified as excellent based on general criteria for an accepting uniformity coefficient as recommended by ASABE Standards EP 458, 1999 in a drip irrigation system presented in the Table 3. The uniformity coefficient obtained from the study agrees with the findings of Omofunmi *et al* (2019) who obtained uniformity coefficient of 99.2 % for their study. The emission uniformity for the system is classified as fair and this is in conformity with the value obtained by Mirjat et al, (2010) of 75.4 %. The emitter coefficient of variation for the system was found to be 0.07 and the system is classified as an average based on ASABE Standards EP405.1, 2008R for Classification of manufacturer coefficient of variation as presented in Table 2. The emitter coefficient of variation (0.07) obtained from the study is in-line with the findings of Ayare and Thokal (2018) who obtained 0.071 as emitter coefficient of variation for the Performance evaluation of gravity fed inline drip irrigation system

The emitter flow variation for the system was found to be 29.5% which is unacceptable according to Bralts et al, 1987criteria for the classification of emitter flow variation for micro irrigation systems as presented in Table 1. The value of emitter flow variation obtained disagrees with the works of Ezekiel *et al,* (2016) whose study recorded 16.54% as average variation of the emitter flow rate of their irrigation system. The high values of emitter flow variation obtained in the study may be attributed to the partial clogging of some emitters and also the pressure variation among the emitters. The problem of clogging could be overcome by regular cleaning of filters and checking the pressure drop across the filters.

4.0 CONCLUSION

The results of study show that the average discharge of the emitter, uniformity coefficient and emission uniformity for the system are 857mLh^{-1}, 94.87% and 78.62% respectively. Other performance parameters evaluated from the study include emitter coefficient of variation and emitter flow variation which were found to be 0.07 and 29.5% respectively.

The result of the study shows that the flow regime of the emitter is fully turbulent. The uniformity of the emitters of the system was found to be excellent while the manufacturer coefficient of variation was found to be average.

The discharges of the emitters show a linear variation with their respective operating pressure and these indicate that the discharge of the emitter is influenced by the operating pressure.

The gravity drip irrigation simple, affordable and easy to maintain and hence, the study recommends and encourages small-scale farmers in water-stressed regions to adopt the system for improve yield and water use efficiency in their irrigation system.

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