



LOW COST CONSTANT – HEAD DRIP IRRIGATION EMITTER FOR CLIMATE CHANGE ADAPTATION IN NIGERIA: ENGINEERING DESIGN AND CALIBRATION

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ABSTRACT

A low cost constant – head emitter for drip irrigation was developed using cheap and readily available materials as a substitute for the imported drip emitters which deter the adoption of drip irrigation in sub – Saharan Africa (SSA). The emitter was calibrated at both laboratory scale and on the field. The drip system comprises of abarrel, sub-main line, lateral lines, tubes and emitters, it can irrigate 140 crop stands and can be extended to 560 stands. The emitters produced a mean discharge and emission uniformity (Eu) of 1.60l/hr. and 74 % respectively; while the calibrated manufacturer's coefficient of variation and distribution uniformity of discharge were 0.098 and 86.3% respectively. The system operates under low pressure (87.9 mbar) and can deliver the daily crop water requirement of a crop like maize in 20 minutes; the overall system performance based on field calibration is generally satisfactory and show potential for improvement when compared with global standards for drip systems. The system's low cost of ₦15, 870 (\$79) gives it an edge over existing locally developed drip systems, the low technology and the use of locally available materials coupled with the water savings will enable famers to adapt to the impact of climate change in sub-Saharan Africa through the production of high value crops in the dry season.

Keywords: Drip Irrigation; Food security, Climate change; Adaptation and Cost

1. INTRODUCTION

The climate change phenomenon has been reported to have severe impact on agricultural production systems, especially in Sub – Saharan Africa (SSA). With the changes in the climate regime, SSA is expected to experience drier climate which will greatly impact the rain fed agricultural production system widely practiced in the region [1]. According to [2], the influence of climate change will also lead to increased variability of freshwater resources which will culminate into surface water scarcity, groundwater

depletion and environmental degradation with consequent effect on food security in the region. The Food and Agricultural Organization of the United Nations reported that almost 1 billion people are undernourished worldwide, particularly in SSA and Asia. In developing countries, even if agricultural production doubles by 2050, one person in twenty still risks being undernourished – equivalent to 370 million hungry people, most of whom will again be in Africa and Asia[3]. Such growth implies that agriculture will remain an engine of growth, vital to

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economic development, environmental services and central to rural poverty reduction.

The above scenario points to the need especially in SSA countries to adopt production systems which will produce more crop yield per drop of water used in order to adapt to the menace of climate change. Drip irrigation has been reported as the most efficient method of irrigating crops; while sprinkler systems are around 75-85% efficient, drip systems typically are 90% or higher [4]. The high efficiency of drip irrigation results from two primary factors, first is that the water infiltrates into the soil before it can evaporate or run off and secondly, because water is only applied to where it is needed (at the plant's roots) rather than sprayed everywhere. The adoption of the drip system in SSA has been hampered by its perceived complexity, high system cost and the low perception of its capability in comparison with the existing irrigation systems.

The adoption of drip irrigation is abysmally low in Nigeria; apart from the total lack of local production of the system, farmers depend too heavily on rain fed systems for their cultivation. The use of surface irrigation and sprinkler systems has however been in practice in the country since 1925; from 1970 – 1990, the country witnessed massive development of surface irrigated schemes [5] without any consideration for the more efficient drip irrigation system. In recent time, a number of research efforts has however been directed at promoting drip irrigation systems for dry season farming in Nigeria [6][7][8], the drip systems used in these studies were imported into the country and not readily available to local farmers for adoption. Concise efforts directed at local design and production of drip systems using locally available materials was pioneered by [9] with the development of a continuous flow drip system using medical infusion sets as emitters; [10] also advanced a simple gravity drip system using polyvinyl chloride pipes with equally spaced holes as line emitters; [11] developed a drip system using micro tubes as emitters, [12] also explored the use of Bamboo pipe and medi-emitters in a simple gravity drip system while [13] presented the possibility of using simple plastic drinking straw as emitters. All these efforts yielded promising results within their operating environment and design objectives, the developed systems however fell below the expectation of low cost and ease of adoption by local farmers for medium and large scale cultivation, their commercial production and economic viability are also cause for concern. These efforts deserve a

great deal of commendation; however, there are still some unexplored possibilities in cheaper and more efficient components for the drip system. The emitter discharge ranges are still showing indications that the existing systems are limited to a small range of crops, and the farmland sizes where they are applicable may be limited to small land holdings. This research was aimed at developing a low cost constant – head drip irrigation emitters using low technology and locally available materials for climate change adaptation in sub – Saharan Africa.

2. MATERIALS AND METHOD

2.1 Materials

The following materials were used for the fabrication of the constant – head emitter: 0.05 m diameter Polyvinyl chloride (PVC) pipe, 0.003 m thick PVC plate, 0.001 m drip orifice, 0.01875 m PVC pipe, 202 litres PVC drum, 0.0125 m PVC pipe, 0.025 m back nut, 0.01875 – 0.0125 m adaptor, 0.0125m coupling, adhesive gum, 0.01875 m valve, 0.01875 m end cap, 0.0125 m end cap, infusion needles, tubes and connectors.

2.2 Design Concept

The concept underlining the design is to develop a drip irrigation system that is cheap to rural farmers using low cost, readily available materials and adopting low technology which will require no special skills and will be adaptable to local environmental conditions in rural areas. The system should also be able to perform the following:

- Apply water to meet peak crop water requirement
- Maintain application and uniformity efficiencies at optimum levels
- Provide an energy and water efficient system to keep initial capital and operating cost as low as possible

2.3 Detailed Engineering Design

Though, drip irrigation systems are best suited for high value vegetable crops, they are adaptable to other type of crops. For the purpose of design, the extra early maize variety (*zea mays spp*) was chosen as the design crop, with a conventional plant spacing of 0.25 m (intra row) by 0.75 m (inter row) with one seed/stand.

2.3.1 Crop Water Requirement:

Crop water requirement (CWR) of plants depends on

many factors viz. temperature, humidity, soil type, wind velocity, growth stage, shade / sun etc. Plants absorb soil moisture and transpire it to the atmosphere during the process of photosynthesis. Water requirement of the plant per day is equivalent to the rate of potential evapotranspiration (PET) per day, the values for reference evapo-transpiration are normally available for particular area at the nearest meteorological observatory.

Using Abeokuta, Nigeria as a design case and considering the fact that CWR depends on growth stage viz. Initial period, crop development, mid-season and late season; each crop stage has its distinct CWR. For the purpose of design, peak CWR was obtained using both CROPWAT® 8.0 software and manual calculation as:

$$CWR = ET_o \times K_c \times K_p \times A \tag{1}$$

In (1), ET_o is reference evapotranspiration, K_c is crop coefficient, K_p is pan coefficient and A is the land area in m^2 . The meteorological data obtained from the Agromet station of the Federal University of Agriculture, Abeokuta reveal that average $Et_o = 4$ mm/day for the critically dry months of December, January, February, March and some parts of April, other months in the year receive sufficient rainfall to sustain crop development; average K_c selected for maize as test crop was 0.84 while selected K_p was 0.7.

Using a crop spacing of $0.25\text{ m} \times 0.75\text{ m} = 0.1875\text{ m}^2$, $CWR_{(maize)}$ (litres/day/plant) = $4 \times 0.84 \times 0.7 \times 0.1875 = 0.441$ Litres/day/plant

For a test plot size of 25 m^2 and a total of 140 maize crop stands,

Total daily water requirement = $0.441 \times 140 = 61.74$ litres/day

2.3.2 Emitter chamber:

Internal diameter = 0.05m; Length of chamber = 0.08m

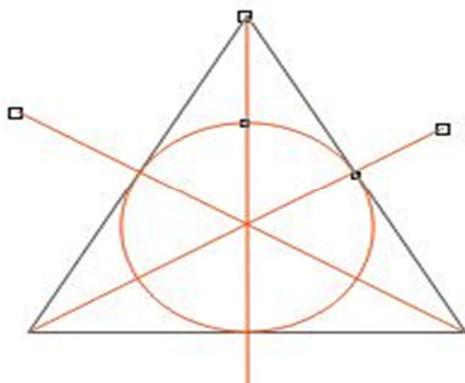


Figure 1a: Geometrical construction of emitter stand

$$\text{Volume of chamber} = \frac{\pi d^2}{4} \times L \tag{2}$$

This yields 157ml. Equation (2) can also be applied for the calculation of the volume for water storage to yield 127ml when $d = 0.045\text{m}$.

Emitter discharge nozzle = 0.001 m internal diameter (ID)

Emitter inlet connector = 0.0055m internal diameter (ID)

2.3.3 Specification of Emitter Stand:

The emitter stand was fabricated from a 0.003 m PVC plate, white in colour and cut to size as detailed in Figure 1. The orthographic projection of the constant-head emitter is also shown in Figure 2;

Specification: $ab = ac = bc = 0.086\text{ m}$

$AB = BC = AC = 0.101\text{ m}$

$$\text{Area of emitter stand, } A = \frac{1}{2}bh \tag{3}$$

This yields $A = 0.00449\text{ m}^2$.

System design for 25 m^2 plot; Lateral Line specification; Lateral pipe size = 0.0125 m internal diameter (ID), Pipe length = 5 m, Lateral pipe spacing on sub-main pipe = 1.5 m, Emitter Spacing on lateral = 0.25 m (for maize), Design plant spacing (intra row x inter row) = 0.25 m x 0.75 m (for single seed/hole), Connecting tube length = 0.375 m and Internal diameter of connecting tube = 0.004m

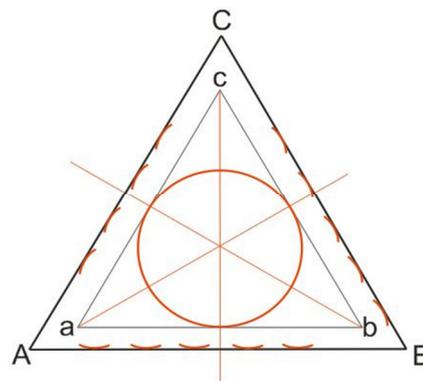
Sub-main line specification:

Sub-main pipe size = 0.1875 m ID, Pipe length = 5m, Operating water pressure = 0.85 m of water = 87.09 mbar.

Design for reservoir:

Drum Height = 0.85 m, ID = 0.56 m, Volume of water = 0.202 m^3 (202 litres), Pressure head at atmospheric condition = 0.85 m of water = 87.09 mbar

Figure 2 shows the schematic diagram and field installation of the low cost drip irrigation system during field calibration and experimentation.



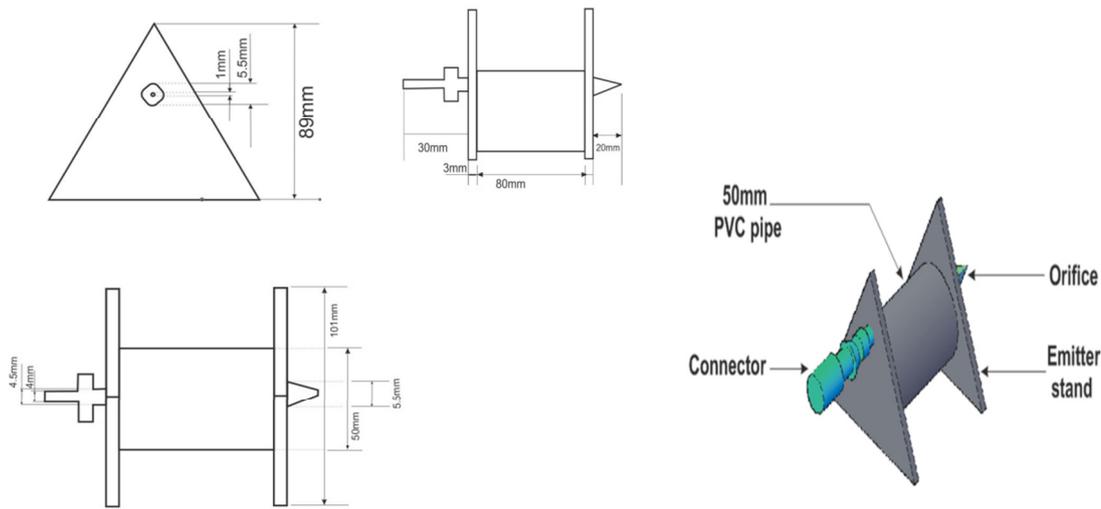


Figure 1b: Orthographic projection and Isometric view of emitter

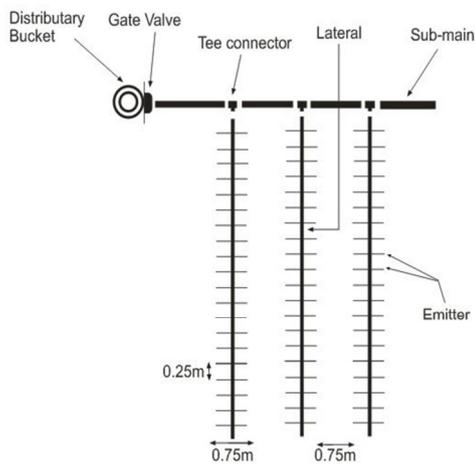


Figure 2: Field layout of low cost drip irrigation system

2.4 System Configuration and Field Layout

The emitters were fabricated using 50 mm OD PVC pipe and 3 mm plastic plate and a drip orifice. The 0.050 m PVC pipes were cut to a length 0.080m, while the plastic plate were cut into a triangular shape of size 0.0101 m x 0.0101 m x0.0101 m to serve as the stand for the emitter and to close the ends of the pipe. The plastic plates were drilled to serve as the inlet (0.004 m ID) and outlet (0.0055 m ID) of the emitter. All joints were fastened together using PVC gum to prevent leakages.

The full system comprises of a 202 litres water barrel as shown in Figure 3, the barrel supplies water to the 0.01875 m PVC sub – mainline; the flow of water from the barrel to the sub – main line is controlled by an 0.01875 m gate valve which supply water into four rows of 0.0125 m PVC lateral lines through reducer tee (0.01875 m – 0.0125 m) installed on the sub – main at a spacing of 150 mm to achieve a plot size of 25 m². A

total of forty emitters were installed on each lateral using a 4 mm ID tube at a spacing 0.020m along the lateral, each lateral was capped with a 0.0125 m PVC end cap.

2.5 Laboratory and field Calibration of Emitter

The emitter was calibrated in the laboratory to ascertain its performance; water was supplied to the emitter at varied elevation (1 m, 0.80 m, 0.60 m, 0.40 m, 0.20 m and 0) using a 75 ml container as water reservoir. Emitter flow rate, Q and length of spray, l were determined at the different elevations at a constant time, t of 120s per experimental run; a total of 36 experimental runs were conducted for both closed and open (gravity) system. Field calibration was also carried out using the field layout in Figure 2; a 25 m² experimental plots in three replicates was used for the field calibration with water supplied by gravity from a 202litres barrel with operating

pressure of 87.09 mbar (0.85 m of water), emitter discharge on the field was evaluated for the 140 installed emitters; data analysis was carried out using SAS® 9.1.3 software for pertinent field performance parameters such as coefficient of variation of emitter discharge, emission uniformity (Eu), distribution uniformity (DU), Christianson's uniformity coefficient (CUC) and Statistical uniformity coefficient (Us) as follows:

Coefficient of variation of emitter discharges, CV calculated as,

$$CV = \frac{Sd_q}{Q_{av}} \quad (5)$$

Where Sd_q and Q_{av} are the standard deviation and average of emitter discharges respectively.

Emission uniformity was calculated from,

$$Eu = 100 \left(1.0 - \frac{1.27Cv}{\sqrt{N_e}} \right) \frac{Q_{min}}{Q_{av}} \quad (6)$$

where, N_e is the number of emitters per plant, Cv = discharge coefficient of variation, Q_{min} is minimum emitter discharge (l/hr.) for minimum pressure in the subunit, while Q_{av} is average emitter discharge, l/hr. for the sub unit

Distribution uniformity, DU calculated as percentages (%) is given as,

$$DU = 100 \left(\frac{Q_{lq}}{Q_{av}} \right) \quad (7)$$

Where Q_{lq} is the average emitter discharge (l/hr.) in the quarter of the field receiving the least water and Q_{av} average emitter discharge in entire field.

Christianson's Uniformity Coefficient, CUC also calculated as a percentage (%) is given as,

$$CUC = 100 \left(1 - \frac{Sd_q}{Q_{av}} \left(\frac{2}{\pi} \right)^{0.5} \right) \quad (8)$$

Where Sd_q and Q_{av} are the standard deviation and average of emitter discharges respectively.

Statistical uniformity coefficient, U_s was calculated as,

$$U_s = 100 \left(1 - \frac{Sd_q}{Q_{av}} \right) \quad (9)$$

Where Sd_q and Q_{av} is the standard deviation and average of emitter discharges respectively

Using maize as a test crop, duration of irrigation using the emitter will be

$$\text{Irrigation time (hrs/day)} = \frac{CWR_{maize}}{WAR} \quad (10)$$

Where CWR is the crop water requirement in litres/day for maize while WAR is the water application rate in litres/hr.

3. RESULTS AND DISCUSSION

The constant - head drip emitter developed for climate change adaptation is presented in Figure 2, the emitter was fabricated using readily available materials that are low cost and can easily be purchased locally. The system layout is also shown in Figure 3.

3.1 Result of Emitter Calibration

The laboratory calibration test carried out on the emitter revealed an optimum performance which was found to be in consonance with existing standards in the design of drip irrigation systems. Figure 4 shows the performance of the emitter when subjected to a closed water system; it specifically shows the relationship between the pressure head of water (elevation) and emitter discharge/length of water spray. The system revealed a positive correlation between elevation and emitter discharge rate ($r^2=0.9434$), this is an indication that operating the system at higher elevation increases the emitter discharge rate; this has direct implications on the type of crops that can be grown using the system, traditionally, drip system are used for the production of high value crops such as vegetables, Tomato, Egg Plant, Onion, Cabbage, Cauli-Flower, Garlic, Watermelon, Cucumber, Lettuce etc. An important observation was that the emitter did not release water when the elevation of the water reservoir was at 20 cm and at datum; this implied that the minimum elevation (pressure head) for water release in a closed system is 40 cm ($Q = 0.77$ l/hr.). The result also showed that the emitter spray length is also directly correlated with reservoir elevation ($r^2=0.955$) with spray length ranging between 11.7 - 28.3 cm for the pressure heads evaluated.

The open system however showed remarkable improvement over the closed system simply because the system was under the force of gravity. Emitter discharge was achieved at 20 cm above datum and even at datum with an average discharge of 1.25 and 0.67 l/hr. respectively. There was a better correlation between reservoir elevation and emitter discharge rate ($r^2=0.9568$) indicating a better performance. Stemming from the foregoing, a gravity system is more appropriate for the fabricated emitter, this is advantageous to the rural farmers because of the elimination of the need for pumping. The gravity system also gave a higher length of spray with a range of 5 - 37.7 cm; this has direct implications for crop spacing and emitter placement on the field.

3.2 Performance Characteristics of Constant – Head Drip Emmitter

The field installation of the developed constant – head emitter is shown in Figure3; the system was installed on a land with predominantly sandy soil and land slope ranging between 2 – 3 %, water filtration was achieved at the inlet of the sub – main line using a cloth mesh of very small opening wound and forced into the inlet pipe, the inlet pipe was also installed at a height of 100 mm above the reservoir bottom to give room for sedimentation of dissolved solids that may be in the irrigation water.

The performance characteristics of the drip system on the field is presented in table 1; result of trials with a test crop (extra early maize) will be presented in the second part of this paper, this is because the uniformity of crop yield within the lateral length is very important in determining system efficiency.

The field test showed an average emitter discharge of 1.6 l/hr. for the 140 emitters installed with a standard deviation of 0.154, the calculated manufacturer's coefficient of variation (C_v) was 0.098 (9.8 %) which revealed that the system performed marginally according to ASAE standards for drip systems (EP405.1). This imply that the system could be further

improved to give higher rating as shown in Table 2; when compared with other locally fabricated drip systems, the constant – head emitter was found to perform better than the one advanced by [13], they reported a C_v of 0.2 which reveal that their drinking straw emitter has a very large variation in discharge which is unacceptable according to ASAE standards ($C_v > 0.15$) (ASAE, 2003); furthermore, the system cost of ₦ 22, 000 (\$105) per 0.1 ha is not realistic owing to the cost of the system components reported. The cost of investment in the barrel kit of the developed constant – head drip system on the other hand for a 25 m² plot size was ₦ 15, 870 (\$79) at a current exchange rate of ₦210 to \$1(US), further evaluation also revealed that the system can be extended to irrigate up to 100 m² by raising the barrel to a height of 1 m above the ground, this will serve 560 maize crop stands. This shows that despite the limitation of marginal C_v , the new system will still perform better. The most important factor militating against the adoption of drip irrigation in SSA has been the capital investment required for system purchase. With this low cost system being advanced, the chances of possible adoption by farmers is higher, however, further research could still make the system cost cheaper.



Figure 3: Installation of low cost drip system on the field and discharge measurement

Table 1: Performance Characteristics of developed Constant – head Drip Emitter

Parameter	Values	Remarks
Mean discharge	1.6 l/hr.	
Standard deviation	0.154	
Discharge Range	1.20 – 1.99 l/hr.	
Coefficient of Variation, CV	0.098 (9.8 %)	ASAE EP405.1 rating – Marginal
Emission Uniformity, E_u	74 %	Acceptable value but could be improved
Distribution Uniformity, DU	86.3 %	Within acceptable limits
Christianson’s Uniformity Coefficient, CUC	71.2 %	Slightly lower than normal, could be improved
Statistical Uniformity Coefficient, U_s	89.5 %	Within acceptable range, best when > 90 %
Irrigation Time (maize crop)	≈ 20 minutes	Time effective system, gives room for other operations
Operating Pressure	87.09 mbar	
Unit cost (25 m ² test plot)	₦15, 870 (\$79)	land size could be increased to 100 m ² if barrel is raised to 1 m above ground

Further evaluation of the constant – head drip system revealed emission uniformity of 74 % which shows satisfactory conformity to standard and also shows the promise of further improvement. [9] reported a Christianson’s uniformity coefficient (CUC) and distribution uniformity (DU) of 92.3% and 89.7% respectively for their continuous flow drip system; the new system being advanced gave a CUC and DU of 71.2% and 86.3% respectively, these values are just slightly lower than acceptable ranges according to ASAE standards. The reasons for these observed lower values are probably due to the non-uniformity of the internal diameter of the drip orifice since they were made manually. This can be improved by using a system of manufacture which will allow for a uniform drill diameter for the orifice.

Table 2: Recommended classification of manufacturer’s coefficient of variation (C_v)

Emitter type	C_v range	Classification
Point source	<0.05	Excellent
	0.05 - 0.07	Average
	0.07 – 0.11	Marginal
	0.11 – 0.15	Poor
	>0.15	Unacceptable
Line source	<0.10	Good
	0.10 – 0.2	Average
	>0.2	Marginal to unacceptable

Source: [14]

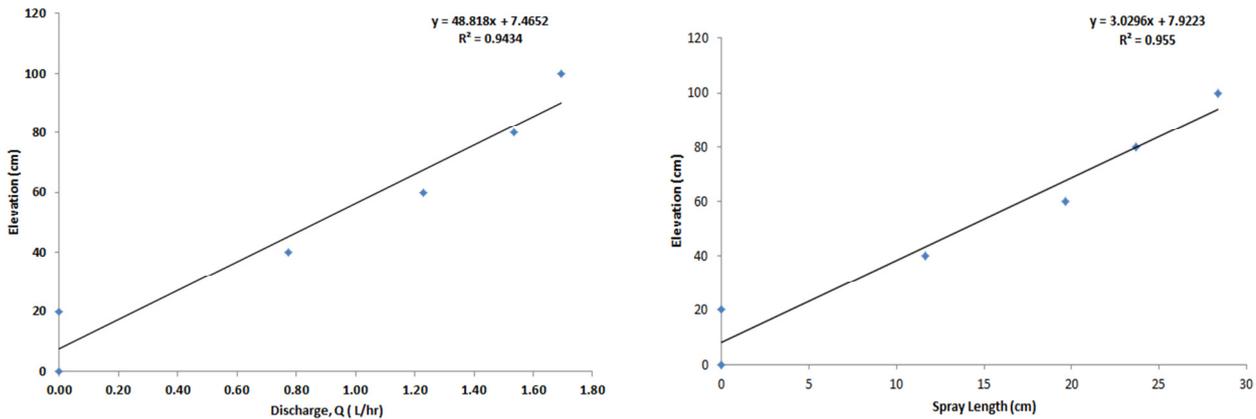
The medi – emitter as used by [12] seems to perform well, but they did not mention the system cost which will determine whether the objective of reduced cost was realized, the reported C_v is not accurate because the values given are ratings for line emitters while their emitter is point source emitter. With the use of appropriate criteria, their drip system can only be adjudged “marginal”. Going by the discharge ranges

obtained from the constant – head emitter, the operating time for the system has been shortened for a test crop like maize in the Abeokuta environ which was used for the design; the 20 minutes obtained for satisfying the peak crop water requirement of maize in the dry season is considered excellent to assist the farmers concentrate on other chores.

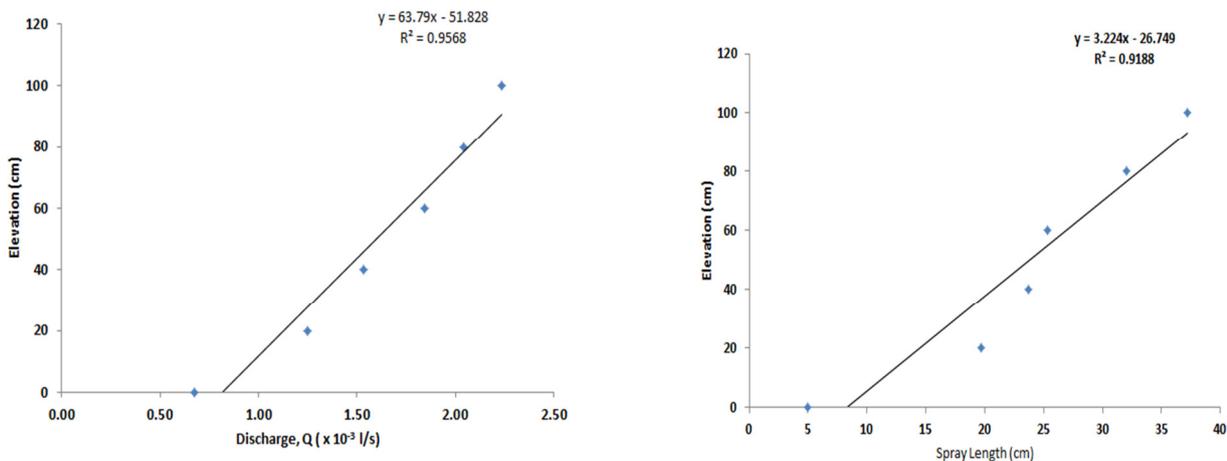
Most drip system has an operating time that ranges from 1 – 24 hours, this takes most of the farmers time especially for systems that delivers water in drops; the constant – head drip emitter delivers water in streams which are sufficiently infiltrated especially in sandy soils where the risk of water ponding does not occur. The new system is configured to deliver water to the crop daily; allowances could be made to adjust the irrigation interval to less frequently such as once in three days, this will require careful design with serious consideration of the water holding capacity of the soil. A notable problem observed with the emitter was surface tension problems at the drip orifice, this was found to occur when the system is unused for three or more days, air traps are created because of the small internal diameter of the orifice; an easy way to break the air trap is insert a simple office pin into the orifice or to increase the operating pressure slightly.

4. CONCLUSION

A low cost constant head emitter was developed for a drip irrigation system for dry season farming using readily available materials and adopting low technology which requires no special skills. The system performed satisfactorily reducing irrigation time to 20 minutes for maize crop; the gravity system will be able to irrigate 140 crop stands with the possibility of extension to accommodate 560 crop stands by simply raising the barrel to an elevation 1 m above the ground.



(a) Closed system



(b) Open system

Figure4: Emitter calibration for pressure head, discharge and length of spray

The system cost was quite low (₦ 5,870 (\$79)) when compared to other existing local designs. The performance characteristics evaluated have yielded encouraging results in comparison with ASAE standards which is widely accepted in global drip irrigation practice.

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