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Research Article

Design, Development and Evaluation of a Bucket Drip Irrigation System for Dry Season Vegetable Production in South-Eastern Nigeria

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ABSTRACT

In South-Eastern Nigeria, during the dry season from November to April, vegetables are always in short supply and consequently expensive. Hence, there is a need to design, develop an affordable and simple bucket drip irrigation system that can be used to grow vegetables under limited water supply conditions. Using the estimated consumptive use of the proposed crop okra and the area occupied by the crop stands, the capacity of the bucket as a source of water was computed. The bucket filled with water was placed at a head of 1 m. The water was allowed to flow through emitters located at 30 cm intervals along the lateral lines laid at the land slope of 2%. Two lengths of PVC tubes 11 m long, 1 mm thick and internal diameters 16 mm, Micro-tubes 5 cm long and internal diameter 1.2 mm, were used. The discharge from each emitter was determined through volumetric measurements. The system was then evaluated using the Christiansen's method and the Merriam and Keller's method and assessed using ASAE standards 1996(a) and 1996(b) performance rating. 22 sampled emitters evaluated from the lateral line showed total energy drop of 2.5 x 10^{-5} m, flow variation (FV) of 8%, coefficient of variation (CV) of emitter discharge of 0.02, uniformity coefficient (UC) of 97% and emission uniformity (EU) of 73%. The results show that the system is efficient and can be used by farmers to meet the demands for vegetables in the dry season.

RESEARCH ARTICLE

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- Bucket drip irrigation system,
- Consumptive use,
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- Nigeria

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INTRODUCTION

Water used for crop production is becoming scarce at a faster rate in most of the agro-ecological zones globally. In Nigeria, crop production is the largest user of water in agriculture. Agriculture is growing fast around all main cities in Africa with the upsurge of city population and consequent growing demand for vegetables. There is need to increase Irrigated agriculture quickly in the future in order to cope with this increasing demands. However, water resources are inadequate and irrigation is labor demanding because in many inner-city and cities farming, irrigation water is carried by hand from the well, reservoir or river to the field (Van Leeuwen, 2001). In south-eastern Nigeria, crops are grown mostly during the rainy season when soil moisture is adequate to support crop production. Farmers produce food crops in large quantities during this period but due to lack of storage facilities and short storage life of the crops, they become scarce during the dry season when demand for them usually is very high. The nutritional gap created by the scarcity of vegetables among households during this period can be addressed by developing an affordable and simple irrigation system that farmers can use to grow vegetables and other crops under limited water availability.

Bucket-fed drip irrigation system has the potential to address the problem of water deficit that hampers the cultivation of vegetables by smallholders during the dry season. Vegetables with shallow root systems and some crops like corn respond well to drip irrigation with increased yield and quality of seed or cob (Camp, 1998). This irrigation technology delivers water directly to the crop root zone efficiently, with far less effort and for a minimum cost (Ngigi *et al.*, 2000). In Kenya, the use of bucket drip irrigation systems by smallholders during the dry season has shown that it is possible to produce enough vegetables for their domestic use and even for sale (Lusaka, 1999). It, therefore, has the potential to improve household nutrition and income of small-scale farmers in African (Nyakwara *et al.*, 2000; Winrock, 2000).

The bucket drip irrigation system is a small-scale drip irrigation system that operates at pressure heads of 0.5 to 2 m (0.05-0.2 bar) and with water distribution uniformity of 73 to 84 percent (Ngigi et al., 2000; Keller,2002). It consists of a 20 liter bucket or a 200 liter drum, drip tape, filters, rubber washers, male and female adapters, two supply tubes, barbed fittings and emitters. The drip lines are supplied in lengths of 15 m and the emitters are spaced at planting distances of crops (Ngigi *et al.*, 2000; Opar *et al.*, 2014). In countries like Kenya, the Philippines, Vietnam and Indonesia there are various types or versions of drip kits. These include International Development Enterprises (IDE), Chapin, T-Tape and Waterboys. Researchers in these countries have carried out extensive studies to evaluate and assess the performances of these kits using overall water application uniformity (UC), emission uniformity (EU) and coefficient of variation (CV) of emitter discharge and performance rating of ASAE standards (ASAE, 1996; Ella *et al.*, 2008; Jiang and Kang, 2010; Opar *et al.*, 2014).

At present in Nigeria, low head drip systems are not available for use by small-holder farmers to grow vegetables in the season thereby depriving them of improved nutrition and income during this period. Despite the popularity and acceptance, the technology has gained in other developing countries of the world as a panacea to poverty alleviation and food security, Agricultural Engineers in Nigeria are yet to see the need to develop or adapt existing drip irrigation technologies to suit our environment. Given the scenario, this study was conducted to develop and evaluate an affordable and easy to-operate bucket irrigation system for vegetable production by smallholder farmers.

MATERIALS AND METHODS

The study was conducted at Students Research and Demonstration Farm of Federal College of Land Resources, Owerri located at Oforola, Imo State, Nigeria. The area is located on Latitude 5° 12' N and 6° 38' E, 60 m above mean sea level and about 7 km from Owerri. Mean annual rainfall varies from 2000-2500 mm, mean temperature ranges from 26-28°C and humidity 70-80%. Many smallholder farmers in the area grow vegetables with a hand-held watering system (Obineche and Ahaneku, 2008).

The materials and equipment used for the study include:

1. A 20 liter metallic bucket with a hole at the bottom
2. A simple support
3. Water outlet fitting and filter for keeping sand and silt from blocking the emitters
4. 2 lengths of 16 mm by 11 mm with 1 mm thick plastic tube as laterals
5. 2 mm by 5 cm micro-plastic tubes as emitters
6. Plastic containers to catch water from emitters
7. Stopwatch to record time of water collection from emitters
8. 250 ml graduated cylinders to measure the volume of water collected from emitters 2 inches nail to make perforations at 30 cm intervals on the lateral to receive the emitters.

A timber framework (12 m long) experimental layout was assembled to support the lateral line laid at the land slope 2% as shown in Figure 1, A 20-litre PVC bucket fitted with a faucet used as water source was placed on a wooden stand at a head of 1 m. The water was allowed to flow through the lateral line 11 m long, 1 mm thick and internal diameter of 16 mm and then through drip lines fitted with micro tubes 5 cm long and internal diameter 1.2 mm as emitters. The drip lines were located at 30 cm interval along the lateral line. Catch cans were placed below the emitters to collect the emitter discharges.

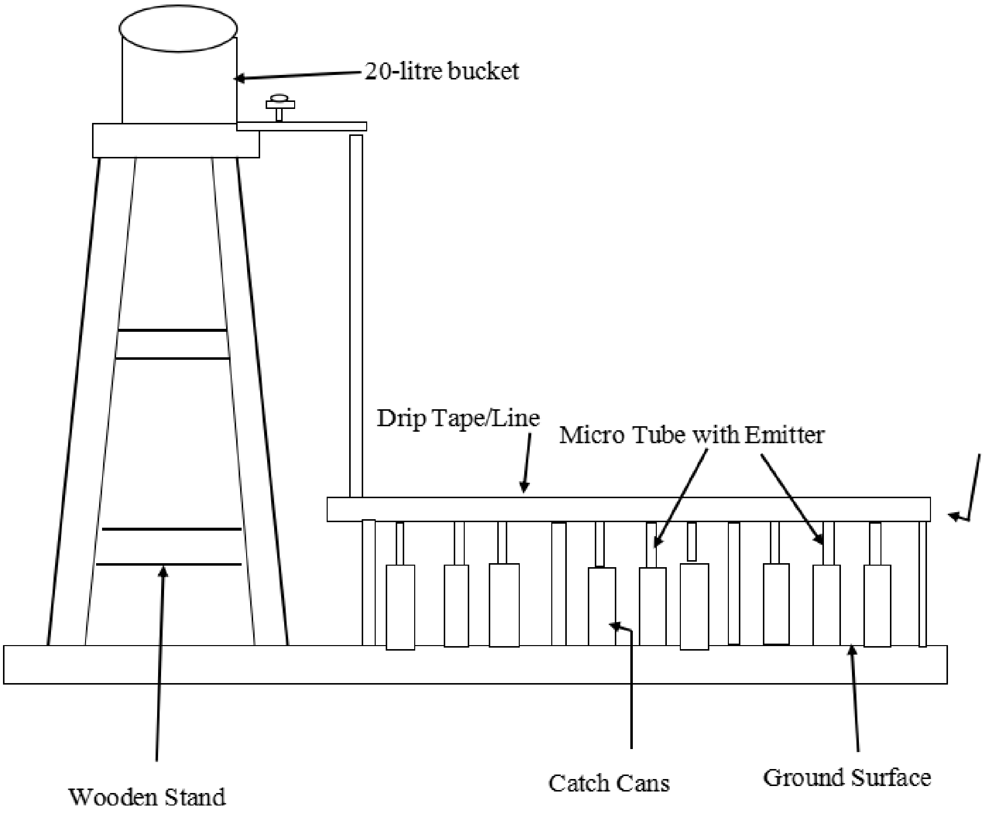

Figure 1. Side view of experimental layout of the drip system.

General Considerations

1. Consumptive use of okra (*Abelmoschus esculentus*) = 6.5 mm d^{-1}
2. Along with the row spacing of okra = 30 cm
3. Inter row spacing = 45 cm
4. No. of crop stands = 22
4. Operating head = 1 m
5. Land slope = 2%

Design Procedure

The crop water requirement of the test crop Okra was calculated using the equation proposed by Allen *et al.* (1998) and applied by Al-Kalifa *et al.* (2013).

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

Where:

ET_c = Crop evapotranspiration [mm d^{-1}]

ET_o = Reference crop evapotranspiration [mm d^{-1}]

K_c = Crop coefficient [dimensionless]

The volume of water applied in liters per plant was calculated by modifying the equation according to Choudhary and Kadam (2006). ET_c was assumed to be equal to the net depth of water in mm required and water applied to plants on daily basis.

The capacity of the bucket was then calculated thus:

$$V_b = ET_c \ x \ A_p \ x \ N_p \quad (2)$$

Where:
V_b = Volume of bucket
ET_c = Crop evapotranspiration
A_p = Area occupied by crop [row spacing x plant spacing]
N_p = Number of stands of the plant.

Length of Drip Lines and Emitter Spacing

The lengths of drip lines were determined from the planting distance of the crop and the distance between the ground surface and bottom of the hung bucket. The emitter spacing was determined from the planting distance of the crop (Okra) which is 30 cm apart.

System's Performance Evaluation

The discharge from each emitter was determined by volumetric measurement and time over which water was collected thus:

$$Q = V/t \quad (3)$$

Where:
Q = Emitter discharge (l s^{-1})
V = Volume of water collected in a graduated cylinder (l)
T = Time taken to collect water (s)

Total Energy Drop

The total energy drop by friction at the lateral was calculated using modified Hazen Williams Equation:

$$D_H = 5.35[Q^{1.852}/D^{4.871}] \ L \quad (4)$$

Where;
D_H = Total energy drop by friction at the end of lateral (m)
Q = Total discharge at the inlet of lateral (l s^{-1})
D = Inside diameter of lateral (cm)
L = Total length of lateral (m)

Emitter Flow Variation

Flow variation of system was calculated using the equation:

$$FV = (q_{max} - q_{min})/q_{max} \quad (5)$$

Where:
FV = Flow variation
q_{max} = Maximum emitter discharge rate in the system (l s^{-1})

q_{min} = Minimum emitter discharge rate in the system (l s^{-1})

Pressure Variation

The pressure variation along the lateral was calculated using the equation below:

$$hvar = h_{max} - h_{min} / h_{max} \quad (6)$$

Where:

h_{var} = Maximum pressure head (m)

h_{max} = Maximum pressure head (m)

h_{min} = Minimum pressure head (m)

Coefficient of Uniformity (UC)

Christiansen (1942), equation was used to calculate the uniformity coefficient of the system thus:

$$UC = [1 - D / q_{avg}] \times 100 \quad (7)$$

Where;

UC = Coefficient of uniformity (%)

D = Average of the absolute values of the deviation from the mean discharge

(l h^{-1}) = $\frac{1}{n\Sigma(qi - qavg)qavg}$ = average of emitter discharge values $(l / s) = \Sigma^{qi}/_{n}$

q_i = Emitter discharges (l s^{-1})

n = Number of observed discharge values

Coefficient of Variation of the Emitter

The coefficient of emitter (5 cm long, 1.2 mm diameter plastic tubes) flow was computed from discharge measurements using the following equation:

$$CV = \frac{(q_1^2 + q_2^2 + q_3 \ldots + q_n^2 - nq_m^2)^{1/2}}{q_m(\text{n} - 1)^{1/2}} \quad (8)$$

Where:

CV = Coefficient of variation of emission device

$q_1, q_2 \ldots q_n$ = Discharge of emission devices (l s^{-1})

q_m = Average discharge of emission devices tested (l s^{-1})

n = Number of emission devices tested

Emission Uniformity (EU)

Emission Uniformity of the system was calculated using the following equation [15];

$$EU = (1 - 1.27 CV) \, 100 q_{min} / q_{avg} \quad (9)$$

Where:
EU = Design emission uniformity (%)
q_{min} = The lowest emitter discharge rate in the system (l s^{-1})
q_{avg} = Average emitter discharge rate (l s^{-1})

RESULTS and DISCUSSION

Table 1 and Figure 2 show emitter discharge rates and their variability along the laterals of the system respectively. The emitter flow rates along the laterals show an only slight variation on the average after every 4 emitters indicating that field crops will receive a nearly equal amount of water from the micro-irrigation system.

Table 1. Average emitter discharge rates along the lateral at the general land slope of 2 % and head of 1 m.

Emitter position	Lateral length (m)	Average emitter discharge (l h^{-1})
1	1.5	1.18
2	1.95	1.18
3	2.40	1.18
4	2.85	1.18
5	3.30	1.16
6	3.75	1.16
7	4.20	1.16
8	4.65	1.16
9	5.10	1.14
10	5.55	1.14
11	6.00	1.14
12	6.45	1.14
13	6.90	1.14
14	7.35	1.12
15	7.80	1.12
16	8.25	1.12
17	8.70	1.12
18	9.15	1.10
19	9.6	1.10
20	10.05	1.08
21	10.50	1.08
22	10.95	1.08

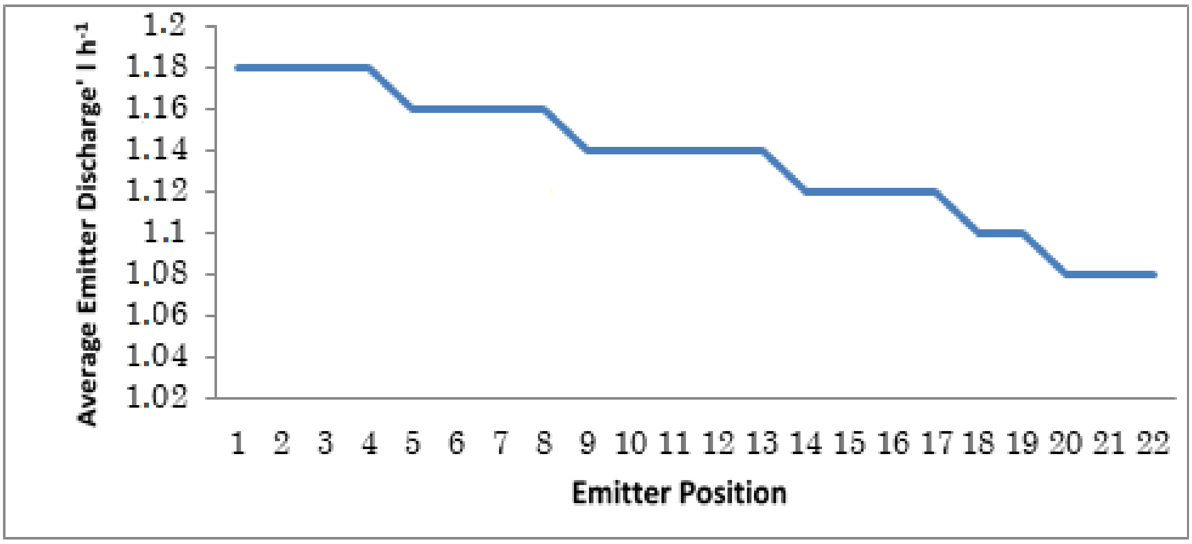

Figure 2. Variation of average emitter discharge rates along the lateral under the general land slope of 2% and a hydrostatic head of 1 m.

Table 2. System's performance parameters.

B_c (l)	Q (l s^{-1})	h_v	D_H (m)	CV (%)	FV (%)	EU (%)	UC (%)
20	0.0025	0.24	0.000025	0.02	8	73	97

B_c is bucket capacity; Q = Average emitter discharge; h_v = pressure variation along the drip line; D_H = Total energy drop; CV = Coefficient of variation; FV = Flow variation; EU = Emission uniformity; UC= Coefficient of uniformity

Table 3. Assessment of indices of performance of the system based on ASAE (1996) standard criterion.

Parameter	Calculated value	Rating
%CV	0.02	Excellent
%FV	8	Good
%EU	73	Fair
%UC	97	Acceptable

Table 2 shows the system's performance parameters. The system's pressure variation of 24% and average emitter discharge of 0.0025 l s^{-1} or 9 l h^{-1} are below standard 40% and within the range of 2 - 10 l h^{-1} respectively recommended by Rajput (1985). The low value of 0.000025 m recorded for the total energy drop of the system accounts for the nearly uniform discharge rates of the emitters. The negligible energy drop was attributed to the smoothness of the wetted surface of the laterals.

Table 3 shows the rating of the system with respect to the values of water distribution uniformities. The coefficient of variation of emitter flow (CV) of 0.02 was considered excellent, which conforms to the report by ASAE EP405.1, (1996) that for line-source emitters, values of CV less than 0.05 are excellent. A 73% EU was considered as fair, which is in conformity with ASAE EP405.1, (1996) report that for most micro-irrigation systems operating with design emission uniformity ranging from 70-80% are classified as fair. The flow variation (FV) of the 16 mm internal diameter PVC lateral line of 11 m at 1 m head was 8%, which confirms the report by ASAE EP409, 1996b that emitter flow variation of less than 10% is generally considered good. An acceptable coefficient of uniformity (UC) of 97% agrees with the report by Bralts *et al.* (1987), that acceptable UC should be greater than 90%.

CONCLUSION

The greatest irrigation choices that have the highest chance to work are those that benefit small holders move to a substantially higher productivity and increased income to manage their irrigation system independently. The values of CV, EU, FV and UC of 0.02, 73%, 8% and 97% respectively obtained when the drip irrigation system was evaluated indicate that the system is generally good and acceptable to irrigate field crops especially vegetables during the dry season. The use of drip/trickle irrigation systems, especially micro systems related to one suggested by Batcher *et al.* (1996) as an alternative of the sprinkler system, would moderate fuel consumption, cost of pumping and labor, as well as save more water for effective irrigation water management usage for dry season vegetable productivity. The above performance rating recommends the system well for promotion by extension providers to ensure enhanced crop production, improved farmers' income and poverty alleviation in different countries of the world.

DECLARATION OF COMPETING INTEREST

The authors declare that there are no conflict of interest

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Donatus Okwudiri Igbojionu: Writing original draft, methodology and investigation.
Christopher Ikechi Obineche: Analysis of figures, validation and review.
Juliet Nnennaya Igbojionu: Compilation and statistical review.

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