Development of a low-cost drip irrigation system for low-income farmers

Animashaun, I. M.*, Shuaib, S. A., Jimoh, W., Gbadebo, A. J.
Department of Agricultural & Bioresources Engineering, Federal University of Technology, Minna, Nigeria
*ai.iyanda@futminna.edu.ng

Abstract

Recently, the use of drip irrigation system is becoming more popular among many commercial farmers in Nigeria and the West Africa at large due to the reduced level of the available fresh water resulting from factors such as climate change and increase in population. However, the drip irrigation system is associated with high initial and maintenance cost, a limiting factor to low-income farmers. To this end, this project was aimed at developing low-cost drip irrigation system. To achieve this, drip irrigation system was designed and constructed to have high efficiency at low cost. The design was site-specific and consideration was given to the emitter spacing and emitter flow rates. The construction was done exclusively from cheap and locally available materials (such as T – Joint, Control Valve, PVC Pipe (1/2, 3/4 inches), Hose Pipe, PVC gum, Elbow connector, Union connector, T – Connector, Nail, Sieve, 25 liters Jerry-Can), integrating the medical infusion set as emitter. The evaluation of the developed system was done by catching water discharged by emitter containers into shallow container and measured after a minute. The result of the evaluation showed that the minimum, maximum and average discharged were 7010 mL/hr (7.01l/hr), 7560 mL/hr (7.6l/hr) and 7280 mL/hr respectively. The obtained measurements were all within the 5% deviation below and above the mean value suggesting that the system will be efficient for water and fertilizer application. Hence, construction of drip irrigation system of high efficiency and low cost was achieved. It is recommended that the performance evaluation of the system be done with crops.

Keywords: Drip irrigation, emitter discharge, infiltration, Nigeria

1. Introduction

Water is one of the most important commodities that is directly or indirectly needed by man for survival. The growth of the economy, industry and particularly agriculture depends largely on the quality and quantity of the available water (Tirupathi *et al.*, 2018). The importance of water suggests why the main challenges facing man across the world today from food insecurity to regional conflicts are associated with it (Oguntunde, 2022). Of all the sectors, agriculture accounts for 70% of the total freshwater withdrawal and 80% of consumptive water use (Shiru *et al.*, 2018; Duhrkoop *et al*., 2009). Though the percentage of water withdrawal varies greatly across the globe, Africa takes the lead in water withdrawal for agricultural purposes. This implies the high reliance of the agricultural sector in Africa on rainfall, the principal source of the freshwater.

Variability and change in climate variables – rainfall and temperature - are great threats to every nation, particularly the developing ones not only because of their reliance on rainfall but also their low coping strategies (Animashaun e*t al*., 2023). The effects of climate variability and change are

likely to manifest through a reduction in rainfall amount. Small-scale farmers have been experiencing a declining output in crop yield due to erratic rainfall patterns and non-uniform water requirements in all the growth stages (Animashaun e*t al*., 2020). The negative consequence of this will be enormous for the agricultural sector which uses about 88% of available water in Africa as against the 50% reported for Europe (Nwachukwu et al., 2019). The downward trend in freshwater availability has necessitated the need to improve the way water is used as rainfed agriculture that is mostly practised is a subject of climate that continues to vary greatly in recent times. Judicious water usage has the benefit of ensuring water is available to farmers throughout the season to ensure food security.

Irrigation water is supplied to supplement the water available from rainfall, soil moisture and the capillary rise of groundwater and to meet the water use and water requirement of crops and hence improve yield and production (Asenso, 2011). When water becomes scarce or its distribution does not coincide with demand peaks, it is then necessary to supply it artificially. The different types of alternative water application methods such as sprinkler and drip irrigation may contribute substantially in making the best use of the scarce available water for crop production (Duhrkoop *et al*., 2009). Irrigation systems are selected, designed and operated to supply the irrigation water requirements of each crop on the farm while controlling deep percolation, runoff, evaporation and operation losses, to establish a sustainable production process.

To mitigate against the forecasted future water reduction, a system with optimum use of water with less dependency on the characteristics of climate, soil and crop and most importantly, the economic status of the farmers worth considering. In recent time, attention has been focused on methods of conserving the little available water for maximum yield. Drip is a better irrigation system and is suitable in water-scarce regions as it has the ability to reduce the impact of drought and climate change on yield, and prevent surface and groundwater contamination by fertilizer leaching. More so, it has been judged to be a better system for poverty and rural-urban migration reduction. Drip irrigation limits the supply of water for consumptive use of the plant by keeping the minimum soil moisture equal to the field capacity, thereby saving water, fertilizer and energy and preventing waste that arises from runoff, leaching and evaporation. Also, the system helps in controlling nutrients and moisture and enables high yield (Punmia and Pande, 2005). Drip irrigation requires little water compared to other irrigation methods as only about 40-80 litres per day are needed per 100-200 plants (Infornet –Biovision 2010). The small amount of water reduces weed growth and limits the leaching of plant nutrients down the soil. It also allows for the efficient application of organic fertilizer to the plants (Infornet –Biovision 2010).

Recently, a number of researchers have advocated for the replacement of traditional irrigation methods with automated ones. Some have advanced it with the use of the Internet of thing (IoT) (e.g., Kumar and Ravi, 2016; Nandhini *et al.*, 2017). They argued for the use of the smart system as it helps to save time, and power and at the same increase productivity. However, the incorporation of the Internet of a thing into the system has not increased its acceptance rate among the majority of the farmers. The reason could be as a result of high importation and initial installation costs, high cost of maintenance, lack of technical knowledge as well and scarcity of technical personnel that can help maintain or repair the system. Hence, there is a need for the

development of a drip irrigation system that can help obtain similar result of high farm yield with less water and power usage using readily available materials that will help make the system affordable to all.

A number of crops complete their growth within the period of rainy season while it takes some a whole year to ready for harvest. The non-availability of water throughout the year round has limited the cultivation of sugar as it is mostly planted near the river. This is due to its water requirement as sugarcane consumes about 2500 L of water per kg of sugarcane produced (Saini and Singh, 2007). Such a volume of water is not available in all spaces. Hence, a need for a simple and water-saving design that makes it possible to continue watering the plant when the rain stops. Sugarcane is a wide-space crop and as such drip irrigation will help to boost its yield with good quality providing sufficient moisture and avoiding wastage of water, as about 40% of water is saved (Madhu Bindu *et al.*, 2015). The aim of this project is to develop a low-cost drip irrigation system using readily available materials.

2.Materials and Methods

2.1 The Study Area

The study was conducted at the Department of Agricultural and Bioresource Engineering, Federal University of Technology, Minna, Nigeria. Minna has a tropical climatic condition with two seasons namely; dry and wet (rainy) seasons. The wet season starts in April and ends in October while the dry season begins in November and ends in March. The area receives an average annual rainfall of 1208 mm (Animashaun *et al.*, 2020). The selected area has a dimension of 10 m x 15 m. The topography of the area is flat with a gentle slope.

2.2 Materials

The study made use of materials that are affordable to many of the local farmers for construction and a simple approach that can allow for replicability was adopted. The materials used comprise of T-joint, Emitter, Control Valve, PVC Pipe (1/2, 3/4 inches), Hose Pipe, PVC gum, Elbow connector, Union connector, T – Connector, Sieve, Reservoir (Jerrycan). PVC material was preferred for the system due to its ability to withstand saline irrigation water and resistance to chemical fertilizers (Edoga and Edoga, 2006). The system was designed for sugarcane

2.3 Field/Laboratory soil test

In order to achieve high efficiency, a drip irrigation system is expected to suit the condition of a particular site for which it is designed. Hence, some soil analyses were carried out. Soil samples were randomly taken from three (3) different locations within the site using soil auger and the samples were taken to the laboratory for analysis. The soil textural class, soil moisture, soil pH and infiltration rate were determined using Bouyoucos Hydrometer method, moisture meter, pH meter and double-ring infiltrometer method respectively (Animashaun *et al.*, 2015; Zakari *et al.*, 2013). The sample was weighed using an electric weighing scale and then oven-dried at 105^{o}C and reweighed again. Thereafter, soil bulk density was computed using the equation 1 below;

$$P_b = \frac{M_d}{V_c} \quad (1)$$

Where;

P_b is the soil bulk density in g/cm^3, M_d is the mass of oven dried soil in g and V_c is the volume of the core cutter in cm^3.

The porosity was computed using the equation 2 below

$$\eta = \frac{M_{sat} - M_d}{V_c} \times 100\% \quad (2)$$

where; η is the porosity in percentage, M_{sat} is the mass of saturated soil in g, M_d is the mass of oven dried soil in g, and V_c *is* the volume of the core cutter in cm^3.

2.4 Design consideration

In the design of the drip irrigation system, the following parameters were considered:

a) **System area:** The area to be irrigated was divided into several zones for more efficient use of filtering and water reservoirs.
b) **Soil type:** The soil type was also considered in the design of the system.
c) **Crop:** The maximum duration of operation required for the system is a form of the crop to be irrigated. This system was designed to irrigate sugarcane and as well as pepper.
d) **Filter:** It is a vital part of a drip irrigation system that prevents the blockage of pipes and emitters.
e) **Emitters:** Emitters otherwise known as drippers are provided at regular intervals on the laterals to allow water to emit at very low rates usually in trickles. The pressure and size of the opening determine the amount of water dripping out of each emitter in a unit time. Dripline selection involves consideration of emitter spacing, dripline diameter and wall thickness, and emitter flow rates.

2.4 Design Calculation and Analysis

2.4.1 Determination of Consumptive water use of sugarcane

The Calculation of consumptive water use of sugarcane was done using the methods described in equation 3 below. Most of the formular used can be found in Egharevba (2009)

$$ETp = R_f[(0.45T + 8)(520 - R^{1.32})/100] \text{ mm/day.} \quad (3)$$

Where, ET_P is the Consumptive water use of crop. R_f is the ratio of the monthly to annual radiation, T is Temperature and R is the mean monthly relative humidity. Using the above equation, the mean monthly temperature, radiation and relative humidity for dry season is given in the Table 1

Table 1: Table of Monthly Mean of Temperature, Radiation and Relative Humidity

Month	Mean Monthly Temperature (^{0}C)	Mean Monthly Radiation (MJm-2day -1)	Mean Monthly Relative Humidity (%)
November	27.35	8.9	39.08
December	27.27	7.1	33.7
January	29.37	7.3	30.00
February	32.83	7.7	28.08
March	37.08	6.8	42.75

But crop water requirement is given by

$$ET_C = K_C * ET_P \quad (4)$$

Where K_C is crop coefficient, the K_C value for sugarcane was taken as 0.7

R_f for each are calculated below:

$$R_f = \frac{Monthly\ radiation}{Annual\ radiation} \quad (5)$$

$R_{f\ (Nov)} = 8.9/80.9 = 0.110$

Therefore, ET_P of November was computed as:

ET_P (Nov) = 0.11[(0.45×27.35+ 8) (520 – 39.08$^{1.32}$)/100]

ET_P (Nov) = 8.79 mm/day.

But November has 30 days, therefore

$ET_{P\ (Nov)}$ = 8.79×30 = 263.84 mm/month.

Using the procedure, ET_P for other months were also computed

Seasonal consumptive use

Seasonal consumptive use is the sum of the water required by the crop for the season. This is given by:

ET_c (seasonal) = ET_c (Nov) + ET_c (Dec) + ET_c (Jan) + ET_c(Feb)+ ET_c (Mar)

ET_c (seasonal) = 184.69 + 161.01 + 178.55 + 185.89 +170.01 = 880.15 mm

2.5 Design of drip system

2.5.1 Main line discharge

Pipe 1

D = 0.02m; L = 12m;

$$Q = VA \quad (6)$$

where Q is the discharge, V is velocity of water flow into the pipe and A = Area of the pipe

$$A = \frac{\pi d^2}{4} \quad (7)$$

$$A = \frac{\pi (0.02)^2}{4}$$

A = 3.142×10^{-4} m^2

Velocity at which water enters into the pipe (V)= $\sqrt{2gh}$ (8)

h = height = 0.5m

V = 3.13m/s

Hence, Q = 9.83 × 10^{-4}m^3/s (or = 9.83 × 10^{-7} l/s)

2.5.2 Emitter discharge (Ed)

$$Ed = \frac{total\ discharge}{total\ number\ of\ emitter} \tag{9}$$

$$Ed = \frac{9.83 \times 10^{-7}}{198}$$

Ed = $4.96 \times 10^{-9}\ l/s$

Various losses by friction are calculated as follows using the Williams Hazen's equation.

$$Hm = 15.27\left(\frac{Q^{1.852}}{D^{4.871}}\right) \times L \tag{10}$$

Where: Hm is Energy drop by friction at the main; Q is the total discharge in the pipe (l/s), L = Length of the pipe (m), D = Diameter of the pipe (m)

2.5.3 Performance criteria for system flow

Three widely-used parameters for measuring emitter discharge uniformity (i.e., Flow variation; Q_{var}, Uniformity coefficient; *UC,* and Coefficient of Variation; *CV*) as well as distribution uniformity were computed

(a) Flow variation

Emitter flow variation Q_{var} was calculated using the equation:

Flow variation, $Q_{var} = \frac{100 \times (Q_{max} - Q_{min})}{Q_{max}}$ (11)

Where: Q_{max} = maximum emitter (drip hole) flow rate

Q_{min}= minimum emitter (drip hole) flow rate

(b) Uniformity coefficient

Uniformity coefficient (*UC)* was computed using the equation 4 below (**Asenso**, 2011)

$$UC = 100 \times \left[1 - \left(\frac{\frac{1}{n}\sum_{i=1}^{n}|qi - \bar{q}|}{\bar{q}}\right)\right] \tag{12}$$

Where: q = discharge, $\bar{q}$ is the mean of discharge, n is the number of emitters evaluated.

(c) Coefficient of Variation

Variation coefficient, $CV = \frac{S}{\bar{q}}$ (13)

where: s = standard deviation of (drip flow) emitter flow rate

(d) Distribution uniformity

Uniformity coefficient, $DU = \frac{\bar{q}_{25}}{\bar{q}}$ (14)

Where: q_{25}= the lowest quarter of mean value of emitter flow rate

2.6 Design Layout Description

The drip system consists of an overhead tank (Jerry-can) of 30ltrs at an elevation of 0.5m connected at a right-angle 90º to the mainline of ½ inches diameter pipe via elbow connector. The mainline was in turn connected to the lateral line via the T-joint at 180º on both sides. The lateral lines are the line that carries water to the field, which was connected at a right angle (90º) to the drip line (which is smaller in diameter), using T-joint. The reduction in the diameter of the drip pipe increases the flow pressure. Holes were made on the drip lines using a hot nail at the required crop spacing of 1m. The field was then divided into 5 plots based on different days for irrigation scheduling.

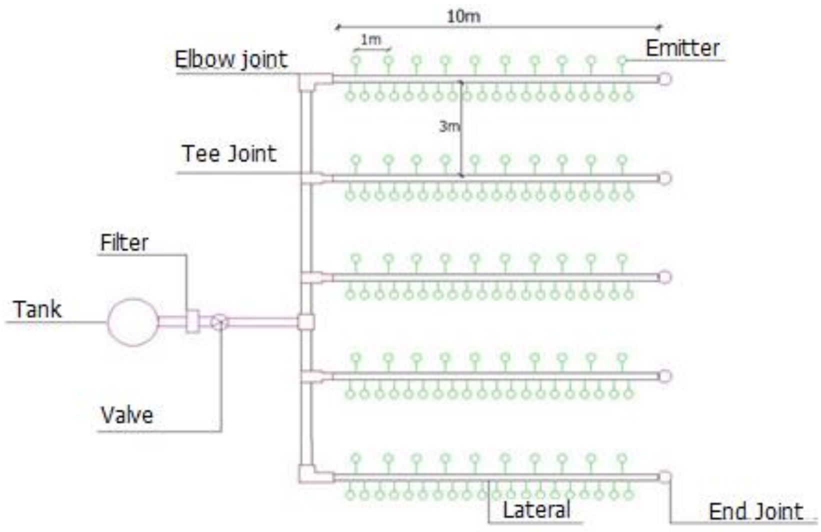

Figure 1.0: Layout of Drip irrigation system.

2.7 Construction and evaluation of the system

A 15 m PVC pipe length was cut into five equal sizes and these serve as inter-row to row on sub-main. A hacksaw was used to cut the PVC pipe. The ¾ inch of hose pipe used was measured and cut at intervals of 10 m each into 5 pieces which serve as the laterals, the hose pipe was later measured at intervals of 1m to locate the accurate interval of fixing infusion set (emitter). The marked area on the hose pipe was bore using hot material to fix the infusion set to the hose pipe with the use of PVC gum to prevent water wastage.

Figure 2a: Fitting of the emitters

Figure 2b: Connection of adaptor to Jerry-Can

For the evaluation of the system, the method described by Prince (2016) was adopted. To determine the water delivery of the system, a catch-can test was used. Water was supplied into the Jerry-Can from a nearby borehole using a bucket. The water flows out of the Jerry-Can by gravity passing through a filter as the first chamber, then to the gate valve. The valve was opened to allow the passage of water. One valve controlling five laterals each was then opened to allow the water into the sub-mains and then to the laterals. The emitters located at 1m from one another started to discharge at a uniform rate. While the system was running, shallow containers were used to catch water delivered by nine drippers located at the highest, lowest and middle points of the slope. The water caught in a minute for each dripper was measured by sucking it into a syringe and the reading taken in millilitres per minute (mL/min) was converted into millilitres per hour (mL/hr). The readings taken from the nine containers were compared. Prince (2016) asserted that good measurement should not be more than 5% below or above the average reading or 10% of the difference between the highest and lowest drippers. To check if the highest value is within 10% of the lowest, the lowest measurement is multiplied by 1.1. And the highest measurement was also multiplied by 0.9 to see if the lowest measurement is within 10%. The front view and side view of the system layout are shown in Figure 2.

Plate 5: The side view of the drip system

Plate 6: The front view of system

3. Results and Discussion

The result of the physicochemical parameter of the soil is shown in Table 2. The result showed that the soil has particle distribution (75% of sand, 9% of silt and 16% of clay) that qualifies it to be classified as sandy loam based on texture classification. The soil moisture content and pH were 12.5% and 7.1 respectively. The average infiltration rate was 60.06 mm/hr which indicates that water will infiltrate into the soil to the depth of 60.06 mm in an hour. The soil bulk density was found to be 1.23 g/cm^3. The porosity value indicated that 38.1% of the total volume of applied water will pass through the soil.

Table 2: Physicochemical parameters of soil in the study area

S/N	Test	Mean Value
1	Soil classification	Sandy loam (Sand 75%, Silt 9% and Clay 16%)
2	Moisture content	12.5%
3	pH	7.1
4	Infiltration rate	60.06 mm/hr
5	Soil bulk density	1.23 g/cm^3
6	Porosity	38.1%

Table 3 shows the summary of performance criteria for the system flow calculated for the growing period of sugarcane, which was used to determine the irrigation interval. Also, the values of the emitter discharge, flow variation, uniformity coefficient, coefficient of variation and distribution uniformity obtained were 4.96×10^{-9} *l/s*, 46.2%, 81.56%, 21.02% and 67.43% respectively.

Table 3: Performance Criteria for System Flow

S/N	Parameters	Value
1	Emitter discharge	$4.96 \times 10^{-9} l/s$
2	Flow variation	46.2%
3	Uniformity coefficient	81.56%
4	Coefficient of variation	21.02%
5	Distribution uniformity	67.43%

Dripper 1 to 9 has a discharge rate that ranges from 7210 mL/hr (7.2l/hr) to 7160 mL/hr (7.16l/hr) as shown in Table 4. Comparing the highest value to the lowest measurement and the lowest to the highest indicated that the system was able to distribute water evenly. Dripper 4 has the least discharge while the highest value was measured at dripper 6. The average measurement for all the discharge was 7280 mL/hr with a 5% deviation of 6916 and 8372 mL/hr below and above the

mean value. This suggests the system will be efficient for water and fertilizer application as mentioned by Prince (2016).

Table 4: Testing of the design drip system

S/N	Measurement (mL/hr)	Comparison with low and high values (mL/hr)
1	7110	
2	7330	
3	7190	
4	**7040**	7010*1.1=7710
5	7210	
6	**7560**	7560*0.9=6804
7	7280	
8	7450	
9	7350	
Average Values	7280*0.95	6,916
	7280*1.15	8372

4. Conclusion

The construction of a drip irrigation system was carried out using minimum and low-cost materials. The project was designed for sugarcane in sandy loam soil. Though sugarcane was considered during the design, it can be used for other crops particularly those with similar crop water requirements. This simple design would allow for the use of drip irrigation system by many low-income farmers and helps save water and power and as well encourage off-season farming.

References

Animashaun, I. M., Oguntunde, P. G., Akinwumiju, A. S., and Olubanjo, O. O. (2020): Rainfall Analysis over Niger Central Hydrological Area, Nigeria: Variability, Trend and Change-point detection, Scientific African https://doi.org/10.1016/j.sciaf.2020.e00419

Animashaun, I. M. Oguntunde, P.G., Olubanjo, O.O., Akinwumiju, A.S. (2023) Assessment of climate change impacts on the hydrological response of a watershed in the savanna region of sub-Saharan Africa Theoretical and Applied Climatology https://doi.org/10.1007/s00704-023-04372-w

Animashaun I. M., Otache M. Y., Yusuf S. T., Busari M. B., Aliyu M., Yahaya M. J. (2015): Phytoremediation of Agricultural Soils polluted with Nickel and Chromium Using Fluted Pumpkin Plant (*Telfairia Occidentalis*). 1st International Engineering Conference pp 360-366

Asenso, E., (2011). Design and Evaluation of a Simple PVC Drip Irrigation System Usin*g Akposoe* Maize Variety as a Test Crop. Soil Sci. Soc. Am. J. 66, 16–18.

Duhrkoop, A., Saathoff, F. and Dede, C., (2009). Material Investigation for an efficient auto regulative subsurface irrigation method with permeable pipes. Institute for Environmental Engineering, Rostock University, Germany. http://www.tropentag.de/2009/abstracts/full/257.pdf Accessed on 15/10/2010.

Edoga R. N. and Edoga, M.O. (2006) Design of drip irrigation set for small vegetable gardens, 2006. Page 137.

Egharevba, N. A. (Ed.). (2009). Irrigation and Drainage Engineering: Principles, Design and Practices. Nigeria: Jos University Press.

Infonet-Biovision (Editor) (2010): Water for Irrigation retrieved at https://infonet-biovision.org/EnvironmentalHealth/water-irrigation

Kumar M. K. and Ravi, K. S. (2017). Automation of Irrigation System based on Wi-Fi Technology and IOT. *Indian Journal of Science and Technology*, 9(17), 1-5, DOI:10.17485/ijst/2016/v9i17/93048

Madhu Bindu, G. S., Vijay Kumar, M., Suresh, K and Chiranjeevi, K (2015) Performance of Sugarcane Under Different Plant Spacings and Irrigation Methods Annals of Plant and Soil Research 17 (Special Issue): 66-68

Nandhini, R. Poovizhi, S., Jose, P., Ranjitha, R. and Anila, S. (2017). Arduino based smart irrigation system using IoT", *3rd National Conference on Intelligent Information and Computing Technologies (IICT '17)*, pp. 1-5,

Nwachukwu, C. P., Orakwe, L. C. and Okoye, N. M. (2019) Development and Evaluation of a Drip Irrigation System in Southeastern Nigeria *Journal of Engineering Research and Reports*

Oguntunde, P. G. (2022) The Water Paradox: naturally abundant but scarcely available. 145th Inaugural lecture of the Federal University of Technology, Akure, Nigeria. 20th December, 2022

Prince, R. (2016). Measuring delivery of drip irrigation systems Agriculture and food. Retrieved at https://www.agric.wa.gov.au/strawberries/measuring-delivery-drip-irrigation-systems

Punmia, B. C., & Pande, B. B. (Eds.). (2005). Irrigation and Water Power Engineering. New Delhi, India: Laxmi Publications (P) Ltd, 22 Golden House, Daryaganj.

Saini, S. K. and Singh, D. (2007) Management of irrigation water in sugarcane. In Sugarcane Planting Techniques and Crop Management (eds Yadav, R. L. and Yadav, D. V.), Indian Institute of Sugarcane Research, Lucknow, pp. 57–61.

Shiru, M. S., Shahid, S., Alias, N. and Chung, E. S (2018) Trend Analysis of Droughts during Crop Growing Seasons of Nigeria Sustainability 2018, 10, 871; doi:10.3390/su10030871

Tirupathi, C., Shashidhar, T., Srinivasan, R. (2018) Analysis of rainfall extremes and water yield of Krishn River basin under future climate scenarios Journal of Hydrology: Regional Studies 19, 287–306

Zakari, M. D., Tadda, M. A., Maina, M. M., Abubakar, M. S., and Lawan, I. (2013). Design, Construction and Installation of Localized Drip Irrigation System. African Journal of Engineering Reseach and Development. Vol. 6, NO. 1. Devon Science Publication, Nsukka, Enugu State- Nigeria. Pp.39-47