DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF A DRIP IRRIGATION SYSTEM

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ABSTRACT

A gravitational drip irrigation system was designed and constructed using available materials; and tested for the use of small-scale farmers. The system has 4 laterals each 4m long, with each of the laterals having pressure-compensating emitters. This was evaluated based on its efficiency. Tests show that discharge per lateral is 8 l/hr and each of the emitters can deliver 2.1 l/hr with an operating head of 0.97 m. The crop water requirement was based on the evapotranspiration rate for Ibadan climatic zone that was given as 5 mm/day. Water conveyance efficiency was 99%; Application efficiency approximates to 94.5% while overall system efficiency was 94.05 %. These results corroborate with Jess (2001) who put the overall efficiency of drip irrigation system at 90 % and above. The total cost of ownership was estimated at ₦ 10,030 while the total operating and maintenance cost was ₦ 308, as at February 2004. The efficiency of the system coupled with the cost of installation, maintenance and repair show that it is cost effective and viable.

Key words: Design, Drip, Efficiency, and Irrigation.

1. INTRODUCTION

One of the developmental challenges of the new millennium is how to achieve a cost effective irrigation practice and management method. The world population is expected to reach 9 billion by the year 2050, but by then, almost all the crop production will occur in the developing countries, many of which the research by Johan (2001) has established will be situated in the tropical environment where water is a primary constraint in social and economic development. Accordingly, it has been estimated that some 55% of the world population will be facing water scarcity by the year 2025 (Keller et. al. 2000). The primary reason for this is the large volume of water would be needed to sustain human diet.

Irrigation may be total or supplemental. Microsoft (2002) listed four main methods as used today to irrigate field: Flood, Furrow, Sprinkler, and Drip (trickle) irrigation systems. Sub-classes of furrow and flood irrigation systems are basin, border, and corrugation systems (Larry, 1998). Drip irrigation delivers small but frequent amount of water to the root area of the crop. Larry, (1998); Jess (2001); and Microsoft (2002); classify drip irrigation as the most efficient method of irrigation which ensures a minimum loss of water through evaporation and percolation into the ground. A drip irrigation system essentially consists of a main line, sub main, lateral, and emitters. The ancillary components include a valve, pressure regulator, filters, pressure gauge, fertilizer application component, backflow stopper, and end cap (Michael, 1998). The ratio of volume of water actually utilized by plant to the volume of water applied to the field is the irrigation efficiency (Larry, 1998). Upton (1997) ranged the field irrigation efficiency between 25% and 95%. With only 20% of the world cropland currently under irrigation, it has contributed almost 40% of the world food production (Johan, 2001). This fact alone as Upton (1997) has presumed, serves to emphases the importance of irrigation as a means of increasing agricultural productivity.

Research shows that irrigation is practised on about 20% of the world cropland, and is claimed to contribute almost 40% of the world food. However, Johan (2001) stressed that in poor developing countries irrigated agriculture generally accounts for less than 5% of cropland, and 70% of the developed and developing countries generally depend on rain fed agriculture for food production. The reason for this especially in developing countries is lack of initial capital or the rather too expensive initial cost. Thus, there is the need to present a simple and efficient irrigation method- with greater economy for water use without undermining crop production output. Hence the objectives of this study were: to design and construct gravitational drip irrigation system; evaluate the system; and estimate the cost of installation of the system.

2. METHODOLOGY

Climatic data or reference crop evapotranspiration (ET_o) data was retrieved from the CropWat for Windows Programme of the FAO (1992), which uses the Penman-Monteith method for calculating ET_o used in crop water requirements and irrigation scheduling calculations (Table 1). The station, Ibadan is located on latitude 7.26^{0}N and longitude 3.54^{0}E; at 228m above mean sea level. Long-term average climatic data (1973-2002) for Ibadan was obtained from IITA weather station and these climatic data (rainfall, humidity, temperature, wind speed, solar radiation, and sunshine hours) were imputed into the CropWat

Programme for verification and validation of the ET_0 model.

Soil texture analysis had been carried out by Ohioma (2000), revealing the sand, clay and silt percent to be 68, 24and 8 respectively. Actual soil type was found from the USDA textural triangle to be ***sandy clay loam*** soil with high final infiltration rate 3-8 cm/hr.

Table 1: Climate and Evapotranspiration data for Ibadan.

17/12/2003 CropWat 4 Windows Ver 4.3

Climate and ETo (grass) Data

Data Source: D:\CROP\CLIMATE\IBADAN.PEN

Country : Nigeria **Station : Ibadan**

Altitude: 228 meter(s) above M.S.L.

Latitude: 7.26 Deg. (North) **Longitude: 3.54 Deg. (East)**

Month	MaxTemp (deg.C)	MiniTemp (deg.C)	Humidity (%)	Wind Spd. (Km/d)	SunShine (Hours)	Solar Rad. (MJ/m2/d)	ETo (mm/d)
January	32.8	20.6	70.0	104.0	6.5	17.6	4.09
February	34.1	21.3	68.0	104.0	6.9	19.2	4.56
March	34.3	22.5	72.0	86.0	6.3	19.1	4.48
April	33.5	22.5	72.0	69.0	6.0	18.7	4.26
May	31.5	22.1	76.0	69.0	6.1	18.3	3.98
June	29.7	21.6	79.0	69.0	5.1	16.4	3.50
July	27.8	21.0	81.0	43.0	3.0	13.5	2.82
August	27.7	21.0	81.0	69.0	2.3	12.8	2.82
September	29.2	21.0	79.0	69.0	3.0	13.9	3.11
October	30.3	20.8	77.0	69.0	5.3	17.0	3.61
November	31.8	21.0	74.0	86.0	6.8	18.2	3.94
December	32.3	20.6	72.0	86.0	6.8	17.6	3.86
Average	31.3	21.3	75.1	76.9	5.3	16.9	3.75

Pen-Mon equation was used in ETo calculations with the following values for Angstrom's Coefficients:

A = 0.25 b = 0.5

Source: FAO (1992).

3. THE DESIGN

PEAK EVAPOTRANSPIRATION RATE FOR CROPS UNDER DRIP IRRIGATION: Schwab et. al. (1993) gave the following water use rate for drip irrigation design.

$$ET_{pk} = ET_o \times P / 85 \quad \text{.........(1)}$$

Where; ET_{pk} = Peak evapotranspiration rate for February (mm/day) = 5 mm/day (Table 1)

P = Percentage of the total area shaded by the crop (%). Assuming a vegetable plant shaded 80% of the area, the peak evapotranspiration rate is 4 mm/day.

VOLUME OF WATER PER PLANT: According to Schwab et. al. (1993) can be expressed as

$$\text{Volume of water / plant} = \frac{ET_t \times \text{area / crop}}{Eu} \quad (2)$$

Where; Eu (emission uniformity at 2-2.5% slope range and uniform steep topography= 87.5% (ASAE, 1985)
Area / crop = 1m × 1m; ET_{pk} = 4 mm/day = 4 / 1000 = 0.004 m^3/day=4 l/day
Therefore the volume of water required per plant is 4 l/day.

EMITTER DISCHARGE: The rate at which an emitter will discharge water depends on the hours of operation. Assuming the irrigation system would be operated for 2½ hrs. Then emitter discharge per plant will be 4.9/2½ = 2½ l/hr. This implies that the lateral would deliver 4 × 2 l/hr = 8 l/hr (4 emitters on a lateral) and the mainline would deliver 4 × 8 l/ hr = 32 l/ hr (since three are 4 laterals on the mainline).

EMITTER SELECTION: This depends on the crop to be irrigated, filtration requirement and particularly on grower's preference. The various emitters include; line source, point source, bubbler and micro sprinkler emitters. The point source emitter was chosen for this design because it is well suited to vegetable crops.
The point source emitter that was available is the point source pressure compensating emitter, which is equipped with an independent pressure compensating mechanism that ensures even distribution regardless of the difficult topographic situation and varying water pressure. It has a coefficient of variation of 0.03. The pressure at which the lateral would operate so that the emitter could deliver the specified amount of water (2 l/hr) was obtained from the manufacturer's chart and the value was 0.96 meters

DESIGN OF THE LATERAL AND MAINLINE: The pressure variation in the lateral is normally kept within the range of the emission uniformity. (ASAE, 1985)

$$Eu = 100\left(1.0 - \frac{1.27\,Cv}{n}\right)\frac{q_m}{q_a} \quad \text{............ (3)}$$

Where; Eu = Assigned value of the uniformity of emitter discharge rates of the system is .875; n = number of emitters per plant (1) ; C_v = manufacturers coefficient of variation (0.03); q_m = minimum emitter discharge rate for the minimum pressure in the system (l/hr); and q_a = design emitter discharge rate (l/hr)
From (3.0); q_m / q_a= 0.91. The AutoCAD design layout of the drip Irrigation is shown in Fig. 1

FRICTIONAL LOSS CALCULATION IN THE LATERAL: The frictional loss in the lateral was calculated by using the Darcy-Weisbach equation, which is written in the form

$$H_L = \frac{(K)(C)(L)(Q^m)}{D^{2m+n}} \quad (4)$$

Where; K = frictional factor that depends on pipe material; L = length of pipe (m)
Q = flow rate (l/min); D = diameter of pipe (mm); C, m, n = are constants.
The value of K can be determined from the formula

$$K = 0.811\,(f/g). \quad (5)$$

Where; f = the frictional factor; g = acceleration due to gravity
The value of f is also estimated from its relation to the Reynolds number thus;
$f = 64 / N_R$ (6)
for N_R < 2000 (the flow is laminar); $f = 0.32\,N_R^{-0.25}$
for N_R between 2,000 and 10,000 (the flow is turbulent) but

$$N_R = \frac{(\rho)(D)(v)}{(K_0)(\mu)} \quad (7)$$

Where; N_R = Reynolds number (dimensionless); = ρ density of water (g/cm³); v = average velocity (cm/s);
μ = Viscosity of fluid (N-s/m²); K_0 = constant i.e. 10 for ρ in g/cm³.
Barb losses due to emitters protruding through the pipe wall to obstruct flow must also be included in the losses due to head. These losses are read from a graph of equivalent pipe length in meters for various sizes of barbs and inside diameter of lateral (James, 1993). With 16mm diameter pipe (assumed), the head loss can be calculated thus;
Let P ρ = 1 g/cm³, D = 1.6cm, Q = 8/3600 (l/s), μ =1.002 × 10^{-3} at 20°c, K_0 = 10
Velocity (V) = Q/A; Where; A = area of pipe ($\pi D^2/4$);
V =1.11 cm/s; N_R =177.2
Since N_R is < 2,000, then the flow is laminar hence; f = 0.36 and K = 0.03.
Correcting for barb losses, equivalent length (L) = 4 + (number of emission device) × C_L
Where; C_L =0.36 ft = 0.11m
L =4+ 4 × 0.11 =4.44m
H_L = 6.24 × 10^{-4}.
The result of the head loss for other pipe diameter and cost per meter length of lateral is shown in Table 2
The 16 mm pipe was chosen specifically due to cost so that it can be tested for pressure variation. The pressure variation within the lateral can be

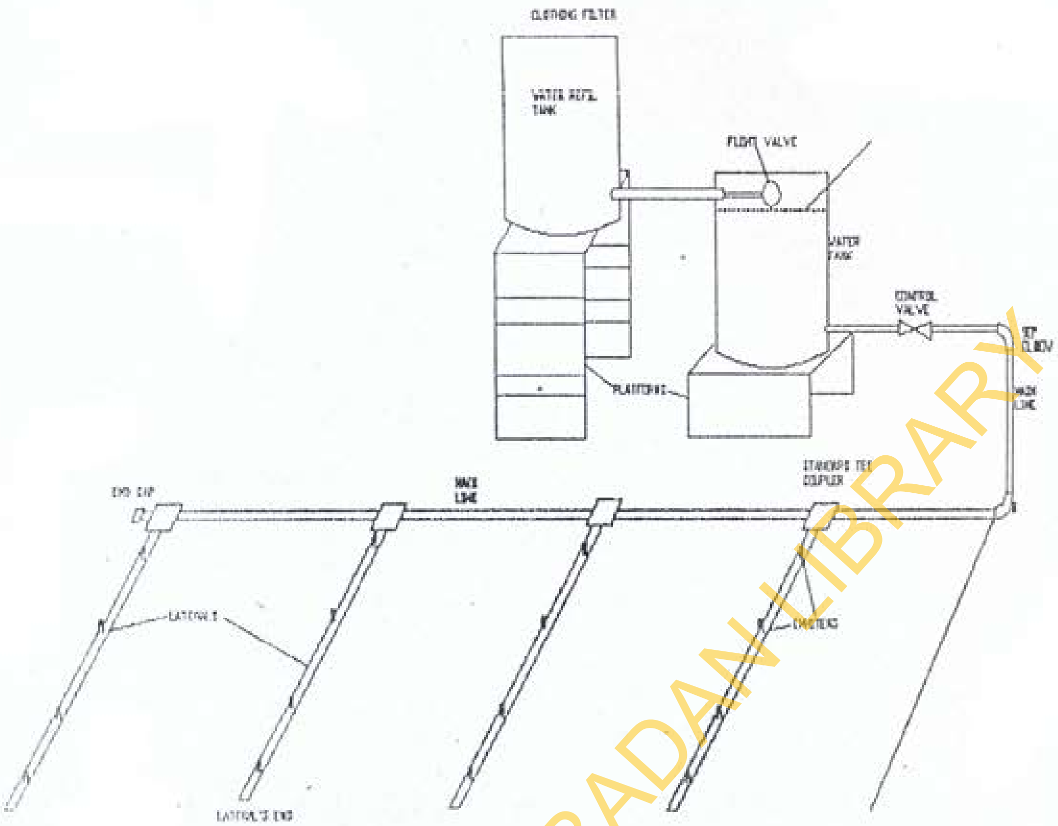

Fig. 1. Gravitational Drip Irrigation System

Table 2: Calculated Head Loss and Cost of the lateral pipes

Pipe diameter (mm)	16	18	20
Frictional loss (m)	6.24×10^{-4}	3.84×10^{-4}	2.44×10^{-4}
Cost/ m length of lateral	N 400	N 480	N520

can be calculated thus;
Pressure variation in pipe = $P_u - P_d$; and $P_u - k (h_l \pm \nabla z)$. Where; P_u, P_d = pressure at upstream and downstream positions respectively; h_l = energy loss in pipe between upstream and downstream (m); ∇z = elevation difference between upstream and downstream (m); k = constant (k = 9.81 for P_u, and P_d in kPa)
But $h_l = f \times H_L + M_l$
Where; f = constant depending on the method used to estimate H_L = 0.469 (Source: James 1993).
M_l = minor losses through fittings (it is zero since there is no fittings along the pipe line)
Therefore $h_l = (0.469 \times 6.24 \times 10^{-4}) + 0 = 2.93 \times 10^{-4}$
P_d = 9.42 (kPa) – 9.81 (m/s²) × 2.93 × 10^{-4}(m) = 9.417 kPa

Pressure variation = (9.42 – 9.417) =0. 003 kpa
But 5% of the operating pressure is 5 / 100 × 3.42 = 0.47 kpa
Therefore, pressure difference in the 16mm lateral pipe diameter is within the recommended range because it is not up to 5% of the lateral operating pressure (James, 1993). Therefore the lateral design is o.k.

FRICTIONAL LOSS CALCULATION IN THE MAIN LINE: Similar procedure was used in the calculation of frictional loss in the lateral pipes. Pressure variation was calculated to be 0.002 kPa, but 10% of pressure in the mainline is 0.9422. Hence the pressure deference in this case is very small i.e. not up to 10 % of the pressure in the mainline (James, 1993). Therefore the mainline design is acceptable.

PRESSURE AT THE INLET TO THE MAIN:
The value of this pressure is found thus
Pressure at inlet to the main = operating pressure of the lateral (see section 4.5) + frictional loss in the lateral + frictional loss in the main line + elevation difference between the junction with the main and the farthest lateral (it is assumed to be zero in this case). Schwab et al (1993).
Pressure at inlet to the main = 0.96 + 0.000624 + 0.00038 = 0.961m
Applying the steady flow energy equation we have Pressure at outlet to the main to be 0.969 m. Calculated value is 0.008 meters above the required main supply pressure, this is negligible. Hence design is o.k.

4. RESULTS DISCUSSION

The overall performance of this irrigation scheme is obtained using the equation suggested by Larry (1998), presented below:

$$E_s = (E_r/100 \times E_c/100 \times E_a/100) \qquad (8.0)$$

Where, E_s = overall system efficiency; E_r = reservoir storage efficiency; E_c = conveyance efficiency; E_a = application efficiency.
Water conveyance efficiency was 99%, while the reservoir storage efficitncy was 100% (no leakage of containers used as reservoirs). Application efficiency approximated to 94.5% while overall system efficiency was 94.05%. This result corroborates with Jess (2001) who put the overall efficiency of drip irrigation system at 90% and above.

Neglecting water, labour and energy costs, the ownership and operating cost include the following: Reservoir, Emitters, Pipes (lateral + main), Gate valve (1), Ball valve (1), Elbow joint (2), Adhesive, Standard tee joint, and Clothing filter (0.91 m). The total cost of ownership was estimated at ₦10,030 while the total operating and maintenance cost was ₦ 308 as at February 2004

The discharge per emitter of 2L/h for the designed 4 x 4 m² area of land shows that there is tendency for pressure fluctuations especially for larger hectares of land except for a larger reservoir storage tank. However, a 50 x 50 m² area of land will still be covered with the capacity of the tank used here without any appreciable effect on the pressure.

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