EVALUATION OF THE TECHNICAL PERFORMANCE OF A LOW COST DRIP IRRIGATION SYSTEM FOR SMALLHOLDER FARMERS

BY

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN
PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF
M.PHIL DEGREE IN AGRICULTURAL ENGINEERING

DECEMBER, 2002

DEDICATION

This work is dedicated to Bismark Asare-Larbi

DECLARATION

I hereby wish to declare that, except for references to works of other researchers which have been cited, this work is the result of my own original research under supervision and that this thesis has neither, in whole nor in part, been presented to any other University for the award of a degree.

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ABSTRACT

It is essential that smallholder farmers in developing countries have access to the benefits that modern irrigation technology seeks to offer. However, this has not always been so because of the inability of smallholder farmers in developing countries to adopt this advanced technology due to cost constraints. The objectives of this study were to design and construct a simple low cost drip irrigation system suitable for smallholder farmers, and to evaluate the technical performance characteristics of the system under field conditions. Attempt was also made to compare the technical performance characteristics of the low cost drip irrigation system to that of a commercial drip irrigation system and recommended engineering standards.

The performance parameters evaluated were coefficient of variation of emitter flow, q_{cv}, Emission Uniformity, E_u, Absolute Emission Uniformity, E_{ua}, Statistical Uniformity, U_s, Emitter flow variation, q_{var}, and Application Efficiency, E_a. The q_{cv} and U_s values obtained were 15.12 and 84.90% respectively. These values were reasonable by recommended engineering standards. The q_{var} value of 38.50% obtained is far below the generally accepted standards. However, the application efficiency, E_a, of 94% obtained is considered excellent for such low cost systems. The E_u and E_{ua} values of 76.83 and 73.90% respectively are fair according to generally accepted engineering standards.

In general, the performance characteristics of the low cost drip irrigation system designed and constructed, were below that of the commercial drip irrigation system evaluated. This development does not support the initial hypothesis that the low cost drip irrigation system would have the same technical performance characteristics as that of the commercial drip irrigation system.

From the technical characteristics for the low cost drip irrigation system, it was found that the system had the potential to be improved and could be adopted by smallholder farmers. This will help farmers to realise the benefits of modern irrigation technologies.

ACKNOWLEDGMENTS

I would like to thank the Almighty God for His resources in strength and wisdom to reach this far. To my supervisors, Mr. Mahama Siedu and Dr. Malcolm Josiah, I say a big thank you for your relentless effort in getting this work to a triumphant end. I am also grateful to Dr. R.J. Bani, of The Agricultural Engineering Department, for his suggestions, which I found useful. My special thanks go to Prof. K.B Laryea for suggesting the research area and his advice and encouragement, which I found indispensable.

I am also grateful to the workers of Agricultural Engineering's Workshop for their help during the course of the research. It is my wish to thank you Mary (my wife), who typed part of the manuscript, Bismark (my son), for their patience and deep sense of understanding during the long hours of my absence from home.

Finally, but not the least, to all those who have helped me during the course of the research in one-way or the other, I say AYIKOO! !

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CHAPTER ONE

INTRODUCTION

1.1 Background

A significant challenge facing the irrigation system engineer is the design of irrigation systems to deliver water efficiently. This is because water for irrigation is usually expensive and constitutes one of the most important constraints to increasing food production in our hungry world. So tenuous and delicate is the balance between the demand for water by crops and its supply by precipitation, that even short-term dry spells often reduce production significantly (Hillel, 1980). The growing demand for water resources accentuates the need for improved management of the dwindling water resources to ensure high productivity (Bucks, 1995).

Arable land areas in developing countries are under chronic drought stress (Ahenkorah, 1997). Coupled with this is the very erratic nature of tropical rainfall (Hoogmoed et al. 1990). For example, in West Africa, low precipitation and high temperature increase the difficulty to achieve a sustainable soil/cropping system (FAO, 1995b). As a result, inadequate soil water resulting from long periods of drought spells or low precipitation has negative implications for crop growth and development (Harverkoort and Goudrian, 1994). This suggests that the provision of an irrigation system to deliver water to crops especially during periods of low precipitation and/or long periods of drought spells is very crucial. In particular, if the system of water delivery is to reduce runoff and evaporation losses as in trickle irrigation system, soil moisture usage (water use efficiency) could improve. This will ensure efficient use of water by crops (Bucks and Davis, 1986; Phene et al., 1992).

If Ghana is to become self-sufficient in food and fibre production to meet the demands of the fast growing population, then the predominantly rain-fed agriculture being practiced in the country should be supplemented with irrigation. This is very urgent considering the rainfall variability currently being experienced in the country. Drip irrigation, which involves the release of water through nozzles, allows relatively precise placement of water at the root zone. Losses through evaporation is minimised and weeds growth is reduced since much of the soil surface is dry (Kramer, 1983; Schwab et al., 1993). In addition to conserving water, salinisation and water logging problems are also minimised (Goodland et al., 1984).

The total flow variation of the drip system caused by hydraulics and manufacturing (Bralts et al., 1981) can be investigated for emission uniformity for water application. The flow conditions in the submains and the laterals of a drip irrigation system can be considered as steady and spatially varied with lateral outflows. The flow from submain into laterals is controlled by pressure distribution along the submain and the lateral lines. If the design allows a certain variation of emitter outflow along a lateral line, uniform irrigation can be achieved.

1.2 Problem statement

Drip irrigation technology offers the best opportunity to optimise irrigation water, nutrients and air regimes in the root zone (Rawitz and Hillel, 1974). The drip system supplies water directly to the crop root zone and therefore, it is the most efficient irrigation system when compared with the other water application systems (Wu, 1995). In spite of the high water efficiency which drip irrigation system seeks to offer (Cornish, 1997), coupled with other benefits like improved control of timing and depth of irrigation, reduced labour demand, better uses of small discharges and better use of poor quality water if management levels are adequate, it is confined to large scale commercial farming and not yet adopted by small-scale farmers (Senzanje, 1997). These small-scale farmers are therefore missing the advantages that the technology seeks to offer.

Hillel (1989) listed the following attributes for drip irrigation technology for adoption by smallholder farmers: simplicity of design and operation, low cost, reliability, longevity, easy maintenance, low energy requirements and few manufactured parts that must be imported. These attributes ensure that a system developed, would be appropriate for the smallholder farmers. System divisibility, low risk, easy maintenance, durability, and operational and maintenance skills of the farmers are significant technical factors relating to the operation and maintenance of irrigation system that influence a system sustainability for smallholder farmers (Keller, 1990).

Kandiah (1997) observed that lack of access to improved irrigation technologies is often cited as one of the major reasons for the relatively low rate of irrigation development. This has suppressed productivity in smallholder farming in developing countries. Cost of irrigation equipment, lack of capacity by farmers to invest in improved irrigation technology and constraints to local manufacturing and servicing of equipment are among the reasons for lack of access to improved irrigation technologies by smallholder farmers.

Simple low cost drip irrigation concept has not received scientific consideration despite the fact that drip irrigation can result in very high water use efficiency. Little work on low cost drip irrigation system has been done (AVRDC, 1987; Albertse, 1996; Sengzanje, 1997). More scientific work is therefore, required to evaluate the performance and robustness of these drip systems.

This study seeks to design and construct a low cost drip irrigation system, which will be suitable for smallholder farmers. The technical performance of the system will be evaluated.

It is hypothesised that this low cost drip irrigation system will have the same technical performance characteristics like that of the commercial high cost advanced drip irrigation system.

1.3 Objectives

The objectives of this study are:

1. To design and construct a low cost drip irrigation system suitable for smallholder farmers,
2. To evaluate the technical performance characteristics of the system under field conditions.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

A limited number of studies have, so far, been made on the subject matter of this study i.e. low cost drip irrigation system. In fact, a review of some of the pertinent literature on drip irrigation, in general, provided the basis of the present study.

This section therefore, attempts to discuss some work done by researchers on drip irrigation systems. The mathematical models for drip irrigation technical performance characteristics as well as the standards governing those parameters are also presented.

2.2.The need for drip irrigation

Wu (1995) stated that the development of micro-irrigation over the last 20 years has resulted in a tremendous improvement in irrigation technology. Irrigation water can be applied with greater efficiency to meet the crop water requirement.

FAO (1972) summarizes the following as the justification for drip irrigation development in our hungry world:

- The urgent need for an expanding agriculture, and the growing use of irrigation as a major factor in boosting crop production,
- The search for advanced, economical and more specialised ways in the application of often scarcely available water,
- The use of poor quality water,

- The most specialised response of certain crops and the new trends in intensification as practised in the greenhouse and under plastic tunnels,
- The better understanding and more specific approach in dealing with plant water consumption and stress.

These and many more contribute to the rapid development and expansion of drip irrigation.

2.3 Drip irrigation

Drip irrigation falls under what are commonly termed ‘Modern irrigation technologies’, which offer high water use efficiencies (Cornish, 1997). With a drip irrigation system, water is supplied to individual crops, trees, group of row crops by emitters placed on laterals delivering the flow. The stream size in each lateral is determined by the number and type of emitters, soil type, crop and allowable soil water depletion. In a well-operated system, a nearly constant low soil tension can be maintained in the root zone.

Maintaining near-optimum water content in the root zone usually involves frequent applications of small amounts of water. Drip irrigation systems are often designed to operate daily for nearly the entire day to supply water to only the root zone of the crop.

Under localised irrigation system, there appears to be a minimum extent of soil volume that is required for optimum growth. This volume is a fraction of the amount of water applied at each irrigation and it should be increased progressively as the crop developed (Doreen, 1972; Vermeiren and Jobling, 1980). In other irrigation systems, provided that water supply is adequate, there is a general tendency to over-irrigate to ensure that the plants receive enough water (Costin and Dooge, 1973; NAS, 1974). However, there is a limit to the amount of water that a plant can use (Clement, 1934), so the surplus is lost through deep percolation. This is always undesirable unless it is deliberately induced to leach out salinity in the soil. The high uniformity of drip irrigation system and its properly scheduled irrigation application can minimise or eliminate deep seepage to minimise groundwater contamination (Wu, 1995).

2.4 Materials for drip irrigation systems

Research indicates that PVC is not the only material for the construction of drip irrigation mains, submains and laterals. In designing low cost drip irrigation systems other locally available materials could be used. For example, Md. Abdul and Honorato (1994) reported that bamboo-polytube system of drip irrigation compared favourably with the commercial type, provided the bamboo is treated chemically to increase its life span. In the study, Md. Abdul and Honrato (1994) reported average fieid emission efficiency of 95% with application efficiency ranging between 96 and 98% for the bamboo- polytube system. These values are quite acceptable under international standards for such a low cost system.

The cylindrical, hollow structure and rigid cross-wall of bamboo give resistance to collapse from bending. Furthermore, tissues of high tensile strength are concentrated near the surface giving it a high mechanical and firm resistance shell. The outer covering is highly cutinised and infiltrated with silica making it a good covering (Puruganam, 1959). However, experience indicates that bamboo is easily destroyed by termites, powder-pest-beetles and decay fungi. Under ordinary conditions and in contact with the soil, its average life span is 1 to 3 years (Esguererra, 1989).

2.5. Components of drip irrigation system

Basically, a drip irrigation system consists of a mainline, submain, laterals and emitters (Fig 2.1). The main line delivers water to the submain, and the submain into the laterals. The emitters are attached to the laterals, which distribute water for irrigation. The ancillary components include pressure regulator, fertilizer applicator, filters, pressure gauge etc. The head of the system consists of a pump to lift the water and produce the desired pressure and distribute the water through the emitters. The field installation of the drip system requires knowledge of the use of different joints and fittings and understanding of the type of connections for the mains, the submains, the laterals and other special items.

The mains, submains and laterals are usually made of black PVC (poly vinyl chloride) tubings. The emitters are also usually made of PVC materials. PVC material is preferred for drip systems, as it can withstand saline irrigation water and is also not affected by chemical fertilizers.

A material with high durability as well as excellent hydraulic characteristics is very suitable for the construction of the major drip irrigation components. Figure 2.1 below shows a typical schematic diagram of a commercial drip irrigation system provided by Povoa and Hills (1994).

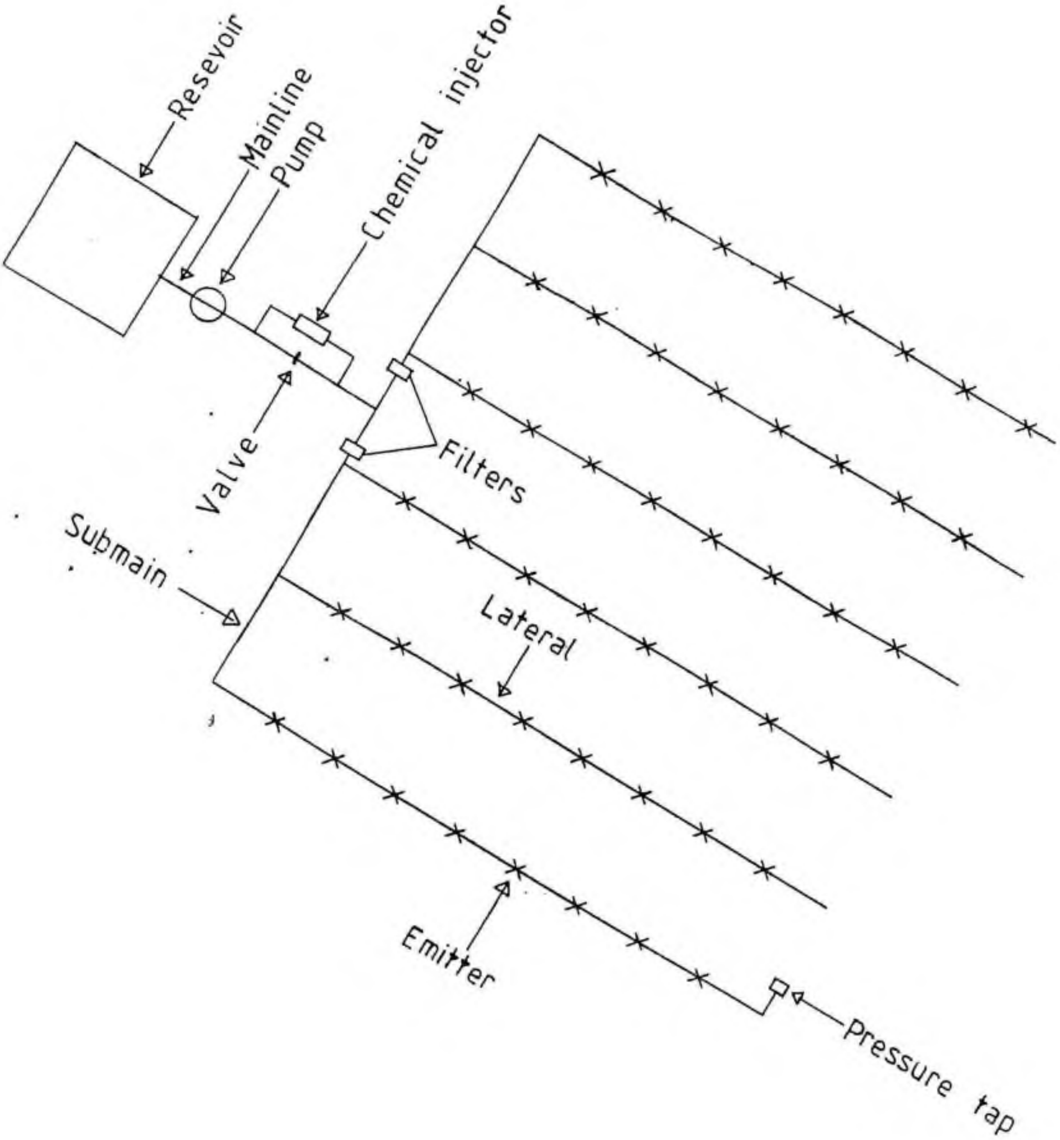

Figure 2.1. Components of drip irrigation system (not to scale). Adopted from Povoa and Hills (1994)

2.6. Emitters

These are provided at regular intervals on the laterals. They allow the water to emit at very low rates. The amount of water dripping out of each emitter depends mainly on the pressure at the emitter, size of the emitter opening and frictional resistance due to length.

These emission devices include point- and line-source emitters that operate either above or below the ground surface. Point-source and line-source emitters generally have smaller passages for discharging water and are more prone to physical, chemical and biologically induced clogging than are bubbles or micro sprinklers.

2.6.1. Point- source emitters

There are many types and designs of point-source emitters. Most point-source emitters are either on-line or in-line emitters. The primary difference between on-line and in-line emitters is that the entire flow required downstream of emitter passes through an in-line emitter. There is usually more head loss along a lateral with in-line emitters. This is because the barbs of in-line emitters obstruct flow and create additional head loss in the lateral. On the other hand, on-line emitters can normally be replaced easily when they fail or become permanently clogged. It is usually necessary to shut off flow to the lateral and cut the pipe to replace a malfunctioning in-line emitter.

Solomon (1979), has provided sketches of the following types of emitters (Figure.2.2):

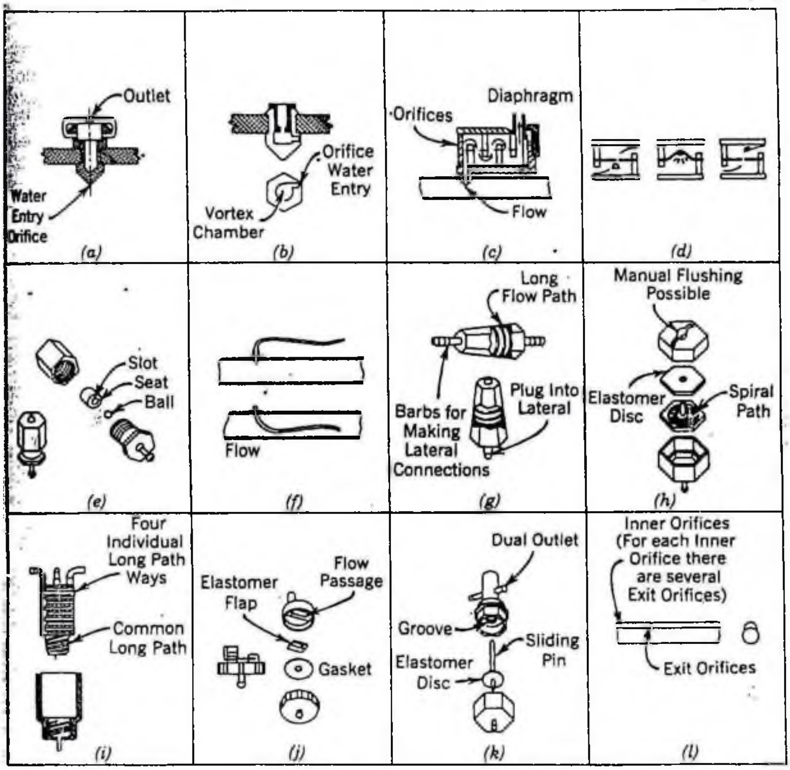

Figure 2.2. Sketches of several emission devices.

Source (Solomon, 1979).

(a) Orifice emitters.(b) Orifice-vortex emitters

(c) Emitter using flexible orifices in series. (d) Continuous flow principle for multiple flexible orifices. (e) Ball and slotted seat. (f) Long-path emitter tube. (g) Long-path emitter. (h) Compensating long-path emitter. (i) Long-path multiple-outlet emitter.(j) Groove and flop short-path emitter. (k) Groove and disc short-path emitter.(l) Twin-wall emitter lateral

2.6.2 Line-source emitters

Porous pipes or tape, perforated pipes that discharge water along their entire length, laterals with closely spaced point-source emitters provide a line source of water. Although line source are used primarily to irrigate row crops, they have also been used with other crops. Porous tubes are generally made of polymer compounds with small pores through which water seeps out of the pipe a drop-at-a time. Complete filtration of water is required for proper operation of porous tubes since they are especially sensitive to clogging.

2.7 Drip irrigation water distribution system

In addition to the issue of how well the applied water is used, there is the important issue of how uniform the water is distributed to the crop (or the soil). A non-uniform distribution not only deprives portions of the crop of needed water, but also over-irrigates portions of a field. Over-irrigation creates water logging, which affects plant growth and development in some cases (Solomon, 1983). Distribution uniformity is defined here as a measure of the uniformity with which irrigation water is distributed to different areas in the field.

2.7.1 System uniformity

Karmeli and keller (1974) Suggested for micro-irrigation

$$E_u = \left(1 - 1.27\frac{CV_m}{\sqrt{n}}\right) \frac{Q_{lg}}{Q_{av}} \ x \ 100 \qquad 2.1$$

Where E_U =emission uniformity

CV_m= manufacturer's coefficient of variation for emitter properties

n= no. of emitters per plant

Q_{lg}= average of the low quarters (l/s)

Q_{av}= overall average of emitter discharges (l/s)

The first factor of equation 2.1 accounts for emitter variability and the second accounts for system pressure changes (Karmeli and Keller, 1974).

The advantage of the approval of equation 2.1 is its simplicity. Unfortunately, averages of the low quarter do not always combine in predictable ways and the proper form of their combination does not always follow the simplicity of the proceeding equations (Clement et al., 1997).

A drip irrigation system that supplies water directly to the root of the crop is the most efficient irrigation system when compared with the other irrigation systems, such as surface irrigation (Wu, 1995). The distribution efficiency or uniformity coefficient measures how uniform the irrigation system can apply water to the field. The uniformity of the drip irrigation system depends on the hydraulic design, the manufacturer's coefficient of variation of the emitters, temperature effects and potential clogging. Temperature effects can be considered insignificant by using turbulent flow emitters (Wu and

Phene, 1984). Plugging can be controlled at less than 20% for turbulent flow emitters even when using sewage effluent (Wu et al., 1991).

The overall system uniformity affected by hydraulic design, manufacturer's coefficient of variation of emitters and clogging was evaluated statistically (Bralts et al., 1981) and verified through computer simulation (Wu et al., 1988a). The water application function of a drip irrigation system for trees from various combinations of hydraulic design, manufacturer's coefficient groupings and clogging determined by computer simulation show that clogging was the most significant factor affecting the uniformity (Wu, 1993a).

The concept of distribution uniformity applies to all irrigation methods. A complicating factor with traditional evaluation is that reported distribution uniformity are rarely global, i.e., they have not taken into account all the factors that influence uniformity across field (Burt, 1980). Worthy of note is that, the distribution uniformity calculated for drip irrigation and sprinkler systems for trees and vines does not account for non-uniform wetted pattern around the individual plant, even though a uniform wetted pattern may be important for various agronomic reasons (Burt et al., 1997).

2.7.2 Spatial Uniformity

In the irrigation of high density planting crops, the spatial uniformity for the water application in the field or along the row crops will be more important than the uniformity of the irrigation itself. Emitter spacing will play a significant role in this aspect. A super-imposition technique proposed by (Wu et al., 1989) evaluates the spatial uniformity along the lateral by adding soil pattern from all emitters with various specified spacing. The wetted soil pattern from under a single emitter along a lateral line can be expressed as half a circle. The total infiltration expressed as depth of water along the lateral line by the single emitter can be expressed as a triangular or a quasi-triangular pattern depending on the soil moisture gradient within the wetted pattern. The total infiltration pattern along the lateral line by all emitters with overlapped wetting pattern was used to determine the spatial uniformity in the field.

The water application by the drip irrigation system as well as the water infiltration in the field can be considered as a normal distribution (Wu, 1988). Using a straight line can approximate this normal distribution curve. This linear cumulative frequency curve offers a direct and easy solution of irrigation application efficiency and scheduling (Karmeli et al., 1978, Seginer, 1978). A computer simulation was used to verify the linearization approach in the determination of irrigation application efficiency as long as the coefficient of variation of emitter flow or spatial uniformity is less 30% (Wu 1988).

Wu (1988), shows a plot of the relationship between the percent of area and the relative irrigation depth. The relative irrigation depth, Ξ, is the required irrigation depth X_i (mm) to the mean irrigation application $\bar{x}$ (mm)

$$x = \frac{xi}{\bar{x}} \tag{2.2}$$

According to Wu (1988),

$$C_V = 0.29b \qquad 2.3$$

Where the coefficient b reflects the spatial uniformity of the water distribution and it can be determined by the coefficient of variation C_V.

Equation 2.3 with slope b and a horizontal line showing the required relative depth will intercept and form two areas; the area below the required relative depth is deep seepage, A_{ds} (m^2) and the area above the required relative depth is deficit, A_d (m^2). Both deficit and the deep seepage, according to Wu (1988), can be expressed by an equation

$$A_d = \left(\frac{x-a}{b}\right) \qquad 2.4$$

Where a = is a coefficient

b = a coefficient as defined in equation 2.3

X = relative irrigation depth

The percentage of area where deep seepage, A_{ds}, occurs can be expressed as

$$A_{ds} = 1-\left(\frac{x-a}{b}\right) \qquad 2.5$$

Where symbols have meanings as defined above.

The two coefficients, a and b, according to Wu (1988) can be expressed as

$$a = 1-\frac{b}{2} \qquad 2.6$$

When the uniformity of the irrigation system or spatial uniformity expressed as C_V is determined, the coefficient b can be calculate. Since the coefficient a is a function of b (equation 2.6), the area and volume of deficit and deep seepage can be determined by only two parameters; the slope b of the straight line specifies the uniformity of the water application and the relative depth x, indicates the irrigation depth required and the total amount applied for each irrigation application.

2.7.3 Application efficiency

The concept of efficiency is a measure of the output obtained from a given input. Irrigation efficiency can be defined in different ways, however, depending on the nature of the input and output considered. For example, one can define as an economic criterion of efficiency the financial return in relation to the money supply and delay system. The problem is that cost and prices fluctuate from year to year and very widely from place to place. Perhaps a more objective criterion for the relative merits of alternative irrigation system is an agronomic one, namely a comparison of marketable yield per unit of land area or, per unit of water added to the net amount of water applied.

Hillel and Rawirz (1972) referred to application efficiency as the net amount of water added to the root zone divided by the amount of water taken from some source. This criterion of efficiency, therefore, can be applied to complex regional projects, or to individual farms, or to specific field. In each case, the difference between the net and the amount withdrawn from the source represents the loss incurred in conveyance and distribution.

Irrigation application efficiency is a measure of how well the irrigation water is applied with respect to the water requirements in the root zone. It is defined as the amount of water stored in the roof zone available for crop use expressed as a percentage of the total amount of irrigation water applied. Based on the concept of the normal distribution of emitter flow, Anyoji and Wu (1994) expressed the application efficiency as;

$$E_a = \left[1 + a \quad \alpha \quad q_{cv} - \frac{1}{\sqrt{2\pi}} \ell^{-\frac{\alpha^2}{2}} \quad qcv \right] x \ 100 \qquad 2.7$$

Where

E_a= application efficiency

a = the cumulative probability density function defined as

$$a \quad = \quad \int_{m+\alpha\sigma}^{\infty} f(y) \, dy \qquad 2.8$$

f(y)= the probability function of the normal distribution

m = the mean of the population

σ = the standard deviation of the population

$\propto$ = specifies the deviation in terms of the standard deviation

q_{CV} =coefficient of variation of emitter flow (l/s)

The irrigation application efficiency is 100% when ail the applied irrigation water is stored in the roof zone. Under deficit irrigation conditions, the irrigation application efficiency is always higher than that of the full irrigation without deficit (Anyoji and Wu 1994).

It is important to evaluate the storage efficiency, which is defined as the amount of irrigation water stored in the root zone as a percentage of the total amount of irrigation required in the roof zone. Anyoji and Wu (1994) expressed the storage efficiency based on the normal distribution of emitter flow as

$$E_s = \left[\frac{1 + a \ \alpha \ q_{cv} - \sqrt{\frac{1}{2\pi}} \, \ell^{-\frac{\alpha 2}{2}} \ q_{cv}}{1 + \alpha \ q_{cv}} \right] x100 \qquad 2.9$$

Where

E_s= storage efficiency. All other terms in equation 2.9 have meanings as defined in above.

When the ∝ value in equations 2.9 and 2.8 is set at zero, this indicates that the total amount of irrigation water applied is exactly the same as the total amount required. No extra amount is scheduled to compensate for the non –uniformity of the irrigation system (Anyoji and Wu,1994).

The emitter flow of drip irrigation can be considered to have a normal distribution because of its high uniformity (Solomon, 1983; Bralts and Kesner, 1983; Wu and Gitlin, 1983). This implies that the cumulative probability density function of the normal distribution can be used for determining irrigation application efficiency for sprinkler irrigation (Hart and Reynolds, 1965) and drip irrigation (Nakayama et al., 1979; Wu and Giltlin, 1983).

It is difficult to set a criterion for the irrigation application efficiency and the storage efficiency for an irrigation practice. An optimal solution can be achieved only if the price of water and the cost of yield reduction due to deficit irrigation are known (Wu, 1988). A complete optimisation solution including the evaluation of damages caused by deep seepage is difficult to achieve because of the lack of available information on the cost of the possible contamination hazards to streams or groundwater systems.

The equation for the irrigation application efficiency based on the cumulative probability density function is difficult to solve directly (Anyoji and Wu, 1994). Design charts, as well as tables, are prepared for determining application efficiency. In view of the desirability of high application efficiency, Anyoji and Wu (1994) developed a relation for the application efficiency as a function of only coefficient of variation of emitter flow. This simplified relation is based on the normal distribution concept for evaluating both drip irrigation and sprinkler irrigation.

2.7.4 Changes in flow rates of drip irrigation system

Bralts et al.(1982) predicted emitter plugging rates based on the lateral flow rate change. These predictions used the assumption that clogging is uniformly distributed along the lateral. Lau et al.(1978) conducted field experiment in which they showed that plugging is localised in downstream sections of the lateral. Wu et al. (1991) confirmed that clogging is not uniformly distributed along the lateral, but clogging is concentrated in the downstream section of the lateral.

Kafshgiri (1979), studying the effects of partial clogging of the hydraulics of a micro-irrigation system, derived an equation to relate emitter flow rate to available head and the degree of partial clogging

$$q_i = (l - P)KH^x \qquad 2.10$$

Where

q_i = emitter flow (l/s)

P =fraction of emitter clogging (partial and complete)

H = pressure head (m)

K = emitter constant

X =discharge coefficient.

Changes in flow rates of drip irrigation system may also be attributed to damaged hardware caused by man (implement or vandalism) or by animals (rodents, birds etc) making holes in the lateral in search of water (Dasberg and Brester, 1985). Mechanical damage to laterals due to seasonal moving include tube cracking, loss of emission devices, and lateral rupture due to excessive pulling. Stress cracking causes damage to polythene tubes. Stress cracking refers to splitting or cracking of tubing that has been exposed to the environment (von Bernuth and Solomon 1986; and Boswell 1990).

2.7.5 Losses in drip irrigation distribution system

Drip irrigation lateral design procedure requires accurate evaluation of both the head losses and local losses that are due to the protrusion of emitter barbs. These local loses, (in relation to the high number of emitters located along the line) can become significant compared to the overall energy loss (Howell and Hiller, 1974; Howell and Barinas, 1980; Al-Amound, 1995).

Experimental research had shown that head losses of small diameter pipe could be evaluated by choosing a proper estimating procedure of the Darcy-Weisbach friction factor (von Bernuth and Wilson, 1989, von Bernuth, 1990, Bagarello et al., 1995). Using the Darcy-Weisbach friction factor

$$J = f\frac{V^2}{2gD} \qquad 2.11$$

Where

J= pipe head loss per unit length

V= mean flow velocity (m/s)

D= inside pipe diameter (m)

g= acceleration due to gravity (m/s^2)

Bagarello et al. (1995) used J measurements obtained from 16,20 and 25mm nominal diameter pipe for Reynolds number (R) values ranging from 3,000 to 3,600. Using the Blasius equations

$$f = \frac{C}{R^m} \qquad 2.12$$

Where

f = friction factor

m,c = coefficients

Bagarello et al. (1995) proposed two simple criteria of f estimation based on a purely empirical approach and a semi-theoretical analysis of the link between the flow-resistance law and the power law velocity distribution in the pipe cross section. According to the empirical approach, the C coefficient of the Blasius equation (equation 2.12) assumes a constant value equal 0.303. According to the semi-theoretical approach, Bagarello et al. (1995). used the following equations to estimate the coefficients C and M.

$$C = \frac{6.152}{R^{0.183}} \qquad 2.13$$

$$M = \frac{2}{8-\left(12.40/R^{0.157}\right)} \qquad 2.14$$

In both approaches the estimated error of the pipe head loss is low, in fact 96 – 97% of the experimental runs resulted in a range of values of ± 5% (Bagarello et al., 1995).

The local losses are due to the contraction and subsequent enlargement of the flow paths caused by the protrusion of emitter barbs in the flow (Bagarello etal. (1997). The application of the momentum equation to a pipe length, L (m), in which one emitter is located establishes that the local loss is due to the drag force of the flow from the emitter (Petryk and Bosmajian, 1975).

$$\lambda_i = C_{di} \ V^2 A_i \ \frac{\gamma}{2g} \qquad 2.15$$

Where λ_i = local loss (m)

C_{di} = drag coefficient (M/N) which depends on the size and the shape of the emitter protrusion and on the Reynolds number

A_i = protrusion area measured in flow cross section (m^2)

Υ =specific water weight (N/m^2).

The local losses λ_i can be expressed as an equivalent length of straight pipe, L_e (m), which produces a pipe head losses equal λ_i, or by increasing pipe head loss per unit length in order to take into account the emitter connections loss (Karmeli and Keller, 1975). Since local losses depend on the protrusion shape, the morphological (shape and size) availability of the commercially available drip-irrigation emitters requires particular experimental investigation.

Howell and Barinas (1980), carried out experimental investigation on six types of on-line emitters, and deduced the following empirical relationship between the equivalent length l_e (m) of the pipe and the flow rate, Q(l/s), as

$$l_e=C_eQ^M \qquad 2.16$$

where C and M are constants , which depend on the type of emitters.

Watters and Keller (1978), using the experimental data of Urbina (1976), proposed a diagram that allows evaluation of the equivalent length for a truncated cone emitter protrusion inside a pipe diameter. In that diagram, three curves are plotted and each one is characterised by a given size class (large, standard, small) of the emitter protrusion. Recently, Al-Amound (1995), using eight different types of on-line emitters, experimentally confirmed that local losses increase with increasing protrusion size and decreasing pipe diameter. He also presented a relationship between the equivalent length and the protrusion area for the investigated pipe diameter.

Attempting to generalise the estimating criteria of local losses, researchers generally classified emitters as commercial types and measure the geometrical size of the protrusion with a calliper (Watters and Keller, 1978; Al-Amound, 1995).

2.7.6. Distribution Properties.

The distributions of many irrigation components are reasonably well represented by a normal distribution. It should be noted that for various components, the variable of interest is not the measured quantity, but the influence the measured quantity has on the distribution (Clement and Solomon, 1997). For example, in a pressurised system, it is the variation in accumulated depth resulting from the variation in pressure that is of interest, not the variation in pressure.

Examples of irrigation component distributions that are essentially normally distributed include micro-irrigation emitter manufacturer's coefficient of variation, sprinkler overlap distribution patterns, many surface-irrigation soil infiltration variations (Clement and Solomon, 1997).

The emitter flow variation along a lateral line is affected by hydraulic pressure variation, temperature variation along the lateral line, manufacturer's coefficient of variation, and plugging of emitters. If the turbulent flow emitter, which is less affected by temperature change is selected, and if plugging can be controlled with filtration systems, the emitter flow variation will be affected by only the hydraulic pressure variation and the manufacturer's coefficient of variation of selected emitters (Anyoli and Wu, 1994).

While there are several ways of expressing hydraulic variation (Wu and Irudayaraj, 1987), the manufacturer's coefficient of variation is expressed only by a common statistical term, the coefficient of variation, which is the ratio of standard deviation to the mean of a population of emitter flows (Clement and Solomon, 1997). When the hydraulic variation is expressed as the coefficient of variation, the variation is a combination of hydraulic and manufacturer's coefficient variation (Braths et al., 1981,1987; Anyoli and Wu, 1987).

The emitter flow of a drip irrigation system can be considered to have a normal distribution because of its high uniformity (Bralts and Kesner, 1983, Wu and Gitlin, 1983; Wu, 1988). The emitter flow is expressed as flow rate, and the amount of irrigation water released from an emitter is the flow rate multiplied by irrigation time. Since the irrigation time is constant for all the emitters, the emitter flow as well as the total amount of water discharged by emitters can be considered to have a normal distribution.

2.7.7 Errors in distribution estimation

In sprinkler and drip irrigation systems, pressure distribution patterns in a field are influenced by the presence or absence of individual pressure regulators; by topography, flat or hilly; by the length of laterals, long or short. They also depend on the existence of pressure regulators of sprinkler laterals or drip irrigation submain and the design logic used to size pipelines downstream of pressure regulators (Clement and Solomon, 1997). It is therefore difficult to characterise the pattern of uniformity without a large number of measurements. Errors in these measurements, for example, from inaccurate pressure gauges and flow meters influence the estimated value of distribution uniformity and are difficult to avoid.

2.8. Drip irrigation system in relation to crop production

2.8.1 Crop yield in relation to row spacing.

Subsurface drip irrigation has been shown to enhance crop yield and reduce application losses (Phene et al., 1987). Camp et al. (1989) reported lower corn yield for surface drip lines spaced in alternate rows compared to surface lines in the crop rows. Camp et al. (1993b), however reported successful irrigation of vegetable with surfaces drip lines spaced in alternate rows (1.52 m apart), but under cotton production reported lower cotton yields with every row drip line placement compared with alternate row placement. In another development, Lamn et al. (1995) used alternate row spacing for drip lines for corn and reported water saving of approximately 25% while maintaining yield in excess of 1.25 kg / m^2. Also Lamn et al. (1992) reported that 1.5m drip line spacing performed better than wider drip line spacing. These studies emphasise the importance of drip line spacing with respect to crop production under drip irrigation system.

Irrigation interval had been found not to have an effect on corn and cotton yield on silt loam soil and clay loam soil (Caldwell et al. 1994; Bucks et al. 1973). However, irrigation frequency (or intervals) has been reported to affect crop performance with drip irrigation (Radin et al. 1989; Davis et al., 1985 and Phene et al., 1987).

2.8.2 Water use efficiency

Dawood and Hamond (1985) found the yield of trickle-irrigated lima beans to be twice as that of sprinkler-irrigated. Tollenfson (1985) reported a 30% average increase in cotton yield with drip irrigation as against furrow irrigation. Also in his study, Sammis (1980) reported higher water use efficiency for trickle and subsurface irrigation as compared to sprinkler and furrow for potatoes. Clark (1979) compared the relative efficiencies of drip irrigation, sprinkler irrigation and furrow irrigation for corn production in Texas. He found water use efficiencies of 1.40, 1.19 and 1.15 Kg/m^3 with drip, sprinkler and furrow irrigation systems respectively. These studies showed that drip irrigation has the most water use efficiency among the three methods.

Safontas and di Paola (1985) reported increase of up to 35% in maize yield with drip irrigation. Camp et al. (1989) evaluated drip irrigation for corn production in the South-eastern Coastal Plains of the United States and found out that subsurface drip irrigation requires less irrigation water than surface drip irrigation.

These studies emphasise the ability to increase yield or water use efficiency of drip irrigation system compared with other irrigation systems. However, the smallholder farmer cannot access the advantages associated with drip irrigation due to high cost (Kandiah, 1997). The Low cost drip irrigation system is all that the resource poor farmers can afford under their circumstances.

2.9 Limitations of drip irrigation

The justifiable enthusiasm for drip irrigation carries certain dangers. Hasty adoption of drip irrigation without enough care in adaptation to local crop conditions can result in disappointments. Drip irrigation offers many potential advantages, yet it is not a panacea. Inefficiency is just easy to achieve in the operation of a drip irrigation system as it is in the operation of conventional systems.

The initial cost of the drip irrigation equipment is considered to be a limitation for large-scale adoption. The special equipment needed to control clogging as well as the amount of pipes, emitters and valves typically used in drip irrigation system often makes the per acre cost of these systems high. This high cost limits its application, especially in developing countries.

The fact that drip irrigation wets only a small fraction of the soil volume can also become a problem. If the system does not operate perfectly and continuously, crop failure could be unavoidable as the soil-moisture reservoir available to the plant is extremely small.

Apart from the technical problem of maintaining the water delivery system in perfect operation without interruption, there is the initial problem of tailoring the emitter spacing specifically for each crop and stage of development, the optimisation of emitter discharge rate in relation to soil infiltrability and lateral spread of water, the optimisation of irrigation pulse duration and frequency, and the determination of irrigation quantity variation during the season.

Other possible problems associated with drip irrigation are the accumulation of salt at the periphery of the wetted circles surrounding each emitter and excessive through-flow and leaching, which can take place directly under the drip emitters. Clogging of emitters is a frequently encountered problems, either due to the presence of suspended particles or algae or to salts, which tend to precipitate.

These limitations of drip irrigation are not to be considered as obstacles hindering advancement in the technology, but should be seen as challenges to propagate the technology especially making the technology cost-effective for the smallholder farmer, since research has shown that drip irrigation is the most efficient water application method (Wu, 1995).

2.10. Drip irrigation system design and basic hydraulics

Drip irrigation system can be designed, taken into consideration certain general requirements. Water source is provided by means of a well, stream or reservoir. The spacing of emitters on laterals is dependent on crop type since different crops require different plant spacing. It is also important to know the topography of the field in order to determine the size and location of the main and the submain lines of the drip system. Means of moving irrigation water through the system either by a pump or gravity should also be considered (FAO, 1972).

2.10.1 Design of pipe network of drip irrigation system

The general layout of drip irrigation system includes an extensive pipe network of laterals and submains connected to the mainline.

Physical factors such as field dimension and slope, obstacles and topography will influence the layout of pipe networks. There is no fixed rule to follow to obtain an ideal layout. In some cases, it may be necessary to prepare alternative plans and to compare the cost of each in relation to the designs. On sloping fields the laterals should be laid on the contour line whenever possible. The uphill portion of the submain should be kept as short as possible. On flat terrain, an even split of water flow on both sides of a submain will lead to the best layout (FAO, 1972).

2.10.2 Head loss in pipe

Friction losses in a pipe depend mainly upon the roughness of the inside surface of the pipe, its cross section area, length and velocity with which the water flows in the pipe. The Darcy-Weisbach equation is used to compute head loss (FAO, 1972).

2.10.3 Local head loss in mainline and submain

Different types of fittings (tees, elbows, valves etc) are located at several points along the pipe network. Consequently, local head losses should be taken into consideration when designing a system (FAO, 1972)

2.10.4 Water hammer consideration

Water-hammer pressure develops whenever flow is changed. Flow changes occur by operating valves, by starting or stopping pumps or by sudden release of entrapped air. The intensity of the effect of water hammer depends on the rate of change. The way in which it can be contained within acceptable limit is a major consideration, which often is ignored (FAO, 1972).

One way of reducing the effects of water hammer in a pipe network is the slow opening and closing of the operating valves.

2.10.5 Pressure distribution along a lateral:

Flat terrain

On flat terrain, the variation of pressure in a lateral is due to friction losses within the pipe. Keller and Karmeli (1974) indicate that the general shape and characteristics of head loss curves are essentially independent of the distributors' exponents and the amount of lateral head loss.

The shape of the head loss curve could be determined from detailed calculation based on the Hazen-William or other equations. But this approach is laborious. Solomon and Keller (1974) proposed that if the average distribution outlet on a lateral is defined as that outlet which has the average discharge value, then the average head loss for the lateral is defined as that head for which the distribution flow is average. Keller and Karmeli (1974) found that for a wide range of distribution experiments and pressure losses, the average head loss occurs at L = 0.39. Furthermore, they found that approximately 77% of the total lateral head loss occurs between L = 0.0 and L =0.39, while the remaining 23% occurs between L = 0.39 and L = 1.0, where L is a unit length of a lateral (m).

Slopping and undulating terrain

In designing lateral lines along slopping or undulating fields the difference in altitude should be considered. Undulating terrains introduce non-linear loss of elements (gains or losses) into the analysis, and the results are unpredictable. When the terrain has a fairly gentle slope, the head difference is characterised by linear loss (or gain) curves. Generally, if the slope is not too pronounced, the differences are not too great between a system with all losses due to friction and/or when some of the head losses are due to friction and some due to elevation.

2.11 Theoretical consideration

The flow conditions in the submains and the laterals of a drip irrigation system can be considered as steady and spatially varied with lateral outflows. The flow from submains into laterals or the outflow of each emitter from a lateral is controlled by the pressure distribution along a drip irrigation submain or lateral, caused by the energy drop through friction and the energy gain or loss due to either down or up slopes. If the pressure distribution along a lateral line can be determined, uniform irrigation can be achieved. This can be achieved by adjusting the length and size of the laterals, or adjusting the spacing between emitters.

The variation of discharge from emitters along a lateral line is a function of the total length and inlet pressure, emitter spacing and total flow rate.

The pressure variation (the change of pressure with respect to length) can be determined as a linear combination of energy slope and line slope by assuming that the change of velocity head in the line is small and hence negligible (Wu and Gitlin, 1974). Pressure variation along a lateral line causes emitter flow variation along the lateral and pressure variation along the submain and also causes lateral line flow variation along a submain (Wu and Gitlin, 1974).

2.11.1 Lateral discharge equation

The literature contains studies of pressure head of a lateral and lateral discharge rates. For example, to express the relationship between the inlet discharge and inlet pressure head of a lateral, Kang and Nishiyama (1994 b) presented the lateral discharge equation as

$$q_l=C_O+C_1H+C_2H^2+C_3H^3+C_nH^n \qquad 2.17$$

where C_3, C_2, C_1,... C_n = coefficients determined using the least square method.

q_l = inlet discharge of the lateral(l/s)

H = inlet pressure head of the lateral (m)

n= 3 ~7 depending on the lateral parameters, emitter types, and field slopes

Equation (2) can be simulated easily when a group of data samples (inlet discharges of a lateral with corresponding inlet pressure heads) is known. It was reported that the error of the lateral discharge equation could be less than 0.1% (Kang and Nishiyama, 1994; Kang and Nishiyama, 1995) if the range of pressure head is well chosen in the simulation. This implies that the lateral flow rate equation can adequately express the relationship between the inlet flow rate and inlet pressure head of a lateral. If the length and diameter of a lateral are given, the data can be calculated using the back-step method (Kang and Nishiyama, 1995). The general equation of the back step method can be expressed as:

$$H_i=H_{i-1}+(Z_{i-1}-Z_i)+f_{i-1}8SQ^2_{i-1}/g\pi^2D^5 \qquad 2.18$$

where

S = lateral element length (emitter spacing)(m)

D = lateral diameter (m)

H_i = pressure head at the inlet of emitter i (m)

Z_i = elevation head at inlet of emitter i (m)

g = acceleration due to gravity (m/s^2)

f_{i-1}= friction factor of the lateral element

i-1

Q_{i-1}= flow rate of lateral element $_{i-1}$(l/s)

Kang and Nishiyama (1996a) reported that the length and diameter of a single lateral have a unique solution in a zero and uphill slope conditions when the lateral is designed to meet a uniformity of water application and an average emitter discharge.

2.11.2 System friction losses

A drip irrigation system is made by a combination of different sizes of plastic pipes, which are usually considered as smooth pipes. For this reason, losses in drip irrigation system lateral are determined using the Watters-Keller (1978) equation, which is simpler and avoids the underestimation of friction losses of the Hazen-William equations for smaller pipes, or the Darcy-Weisbach equation which needs charts.

The Watters- Keller equation for small plastic pipes (<125mm diameter) is as follows:

$$J = K\,Q^{1.75} / D^{4.75} \qquad 2.19$$

$$h_f = JFL/100 \qquad 2.20$$

where

J = headloss gradient (m/100m

K = metric unit constant (7.98 x 10^7)

Q = flow rate in the pipe (l/s)

D = internal diameter of the pipe (mm)

F = friction factor for multiples outlet pipeline (0.36 for 20>outlets)

L = length of pipe (m)

h_f = headloss due to pipe friction (m)

The local loses are due to the contraction and subsequent enlargement of the flow paths caused by protrusion of the emitter barbs into the flow (Karmeli and Keller, 1975), which can be expressed as a fraction of kinetic energy.

2.11.3 Emitter flow variation

The emitter flow variation, q_{var}, describes the variation in emitter discharge rates throughout a drip irrigation system for a given set of operating conditions. It is calculated from the equation

$$q_{var} = (1 - q_{min}/_{max}) \qquad 2.21$$

where

q_{var} = emitter flow variation along the lateral line

q_{min} = minimum measured emitter flow rate along the lateral line (l/h)

q_{max} = maximum measured emitter flow rate along the lateral line (l/h)

2.11.4 Pressure variation

The pressure variation, $h_{var,}$ is defined by the equation

$$h_{var} = (1 - h_{min}/h_{max}) \qquad 2.22$$

where

h_{var} = pressure variation along the lateral (or submain)

h_{min} = minimum pressure head along the lateral (or submain) (m)

h_{max} = maximum pressure head along the lateral (or submain) (m)

The pressure variation and emitter flow (or lateral line flow) variation q_{var} are related and can be expressed as

$$q_{var} = 1 - (1 - h_{var})^{0.5} \qquad 2.23$$

where the symbols have been defined above.

2.11.5 Coefficient of variation

The coefficient of manufacturer's variation, $q_{cv,}$ describes the quality of the process used to manufacture the emission devices. Hence it qualifies the unit-to-unit discharge variation of the emitters.

The coefficient of variation, $q_{cv,}$ is determined from flow measurements for several identical emission devices (James, 1988) and it is computed as

$$q_{cv} = \Sigma(q^2 - nq_{av}^2)^{1/2} / q_{av}(n-1)^{1/2} \qquad 2.24$$

where

q_{cv} = coefficient of variation of emitter flow

q = emitter flow rate (l/h);

n = number of emitters tested;

q_{av} = mean emitter flow rate (l/h).

2.11.6 Application efficiency

Application efficiency, E_a, is given by the relation

$$E_a=(1-0.4q_{cv})x100 \tag{2.25}$$

Where q_{cv} = coefficient of variation of emitter flow

This equation is based on the normal distribution concept. The equation was simplified by Anyoli and Wu (1994) from the cumulative probability density function of the normal distribution.

2.11.7 Statistical uniformity

The statistical uniformity, U_s, gives an estimate of the uniformity of emitter discharge rates throughout an existing system. It is calculated as

$$U_s =(1-q_{cv}) \times 100 \tag{2.26}$$

where

U_s = statistical uniformity

q_{cv} =coefficient of variation of emitter flow

In system evaluation, U_s is preferred because of its ability to differentiate between the various factors affecting emitter discharge variation (ASAE, 1984)

2.11.8 Field emission uniformity

The field emission uniformity, E_u, gives an indication of the uniformity of emission of discharge of all emitters in a drip irrigation system. It is obtained from the equation

$$E_u=(q_{min}/q_{av}) \times 100 \qquad 2.27$$

where

E_u = field emission uniformity

q_{min}= minimum emitter emitter discharge (l/h)

q_{av} = mean flow rate of emitter at constant temperature (l/h)

2.11.9 Absolute emission uniformity

The absolute emission uniformity, E_{ua}, gives a concept of the overall uniformity of an operating drip irrigation system. It is a function of the minimum, mean and maximum emitter discharges. It is defined by the equation

$$E_{ua}=\tfrac{1}{2}(q_{min}/q_{max}+q_{av}/q_x) \times 100 \qquad 2.28$$

where

E_{ua} = absolute emission uniformity

q_x = mean of the highest one eight of emitter flow rates (l/h)

q_{min} = minimum emitter discharge(l/h)

q_{max} = maximum emitter discharge (l/h)

q_{av} = mean flow rate of emitter a constant temperature. (l/h)

Table 2.1. Classification of coefficient of variation of drip irrigation system.

Emitter type	q_{cv} range	Classification
Point source	<0.05	Good
	0.05 - 0.10	Average
	0.10 -.0.15	Marginal
	>0.15	Unacceptable
Line source	<0.10	Good
	0.10-0.12	Average
	>0.20	Marginal to unacceptable

Source: ASAE (1985)

Table 2.2. Recommended criteria for field emission uniformity E_u, absolute emission uniformity E_{ua} and statistical uniformity U_s

90% or greater	Excellent
80% - 90%	Good
70% 80%	Fair
Less than 70%	Poor and unacceptable

Source: ASAE(1984)

Table 2.3. Recommended Range of design Emission Uniformity (E_u)

Emitter type	Spacing (m)	Topography	Slope	Eu Range (%)
Point source	>4	Uniform Steep or undulating	<2 >2	90 – 95 85 - 90
Point source	<4	Uniform Steep or undulating	<2 >2	85- 90 80 - 90
Line source	All	Uniform Steep or undulating	<2 >2	80 – 90 70 - 85

Source: ASAE (1989)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This section of the manuscript considers the materials and methods adopted for the design of the low cost drip irrigation system. Testing and evaluation of the low cost drip irrigation system for technical performance characteristics as well as that of the commercial drip irrigation system are considered in this chapter of the manuscript.

3.2 Low cost drip irrigation design Principles

Hillel (1989) listed the following attributes for drip irrigation technology for adoption by smallholder farmers:

- simplicity of design and operation
- low cost
- flexibility
- longevity
- easy maintenance
- low energy requirement, and
- few manufactured parts that must be imported.

It is, therefore, essential to feature these important considerations in the design.

3.3 Design criteria

Non-uniformity of drip irrigation is one of the problems that impair the satisfactory performance of the system. For low cost drip irrigation system, leakages due to poor emitter design and poor system pipe network contribute substantially to non-uniform water application resulting from increased system frictional losses. Therefore, the low cost drip irrigation system is constructed to address these problems.

3.4 Design calculations

The detailed design calculations leading to the selection of the components of the low-cost drip irrigation system are presented in the Appendix A.

3.5 Design features

The low cost drip irrigation system is made of component parts comprising of a water tank to store irrigation water and to provide system operating pressure head; a standard water tap to regulate water flow from the tank; a PCV mainline and submain with laterals and emitters equally spaced on the laterals (Figure 3.1). Because the system is low cost, ancillary components like pump, filters and pressure taps are absent in the system.

One unique feature of the current design of the low cost system is that it permits irrigation to be accomplished in units. The system is movable from one unit of plot to another on the same farmland (Figure 3.1).

3.6. Choice of materials

As pointed out in the literature review, the high cost of irrigation equipment is a hindrance to small-scale farmers in developing countries to invest in improved irrigation technology (Kandiah, 1997). Therefore, in designing the low cost drip irrigation system, cost and availability of construction materials played a pervasive role in the choice of materials. Based on the design calculations (Appendix i –xi), the laterals of the low-cost system were made shorter to reduce the cost. However, this design methodology provided a relatively smaller area of land per irrigation.

The PVC materials were selected for the design because of the following benefits in comparison with more conventional materials (Arnold, 1995) and the fact that it is readily available:

- Low weight (relative density: 1.4 – 1.5)
- High tensile and pressure resistance (at 23 ^{o}c: 2250 Mpa)
- High durability;
- Good creep characteristics;
- Good abrasion resistance;
- Good resistance against bacterial growth;
- Easily to manufacture joints;
- Excellent hydraulic characteristics.

The 220-litre capacity drum selected maintains approximately 0.8 m head of irrigation water. This is suitable for low cost drip irrigation system. The structure of 9 cm x 2 cm x 0.5 cm foam material selected for the emitter design as well as the 9 cm x 5 cm lace material are suitable for regulating the flow and making the flow comes out in drips.

3.7 Low cost drip irrigation emitter design

Holes of 2.5 mm diameters were drilled using a hand-power drill on a straight line along the 12 mm PVC laterals selected. Each hole was covered with a 9 cm x 2 cm x 0.5 cm foam material wound around by a 9 cm x 5 cm lace cloth. These materials were firmly secured on the drilled holes using rubber bands.

This method of emitter design for the low cost drip irrigation is expected to perform better than the earlier work done by Seizanje (1997) who used a 16 mm thick sponge with rubber band to cover the drilled holes under laboratory and field conditions.

3.8 Design specification for low cost drip irrigation.

The diameter and lengths of the laterals and the submain, emitter size are all obtained from the design calculations presented in the Appendix.

Steel drum

The pressure necessary to move irrigation water through the system is provided by a 220-l steel drum, which has the capacity of maintaining 0.8 m of irrigation water.

Mainline and Submain

The mainline is a flexible rubber hose of diameter 12.5 mm and length 0.8 m. A 4.0 m long PVC pipe of diameter 18.75mm constitutes the submain of the system. This submain is fitted with five tees, each connected to the mainline and the other four tees connected to the laterals.

Water tap

A standard water tap of diameter 12.7mm was selected for the design. This is fitted at the base of the 220-l capacity steel drum.

Laterals

The low cost drip irrigation system has four laterals. Each lateral is a PVC pipe of diameter 12.5mm and length 7.0 m.

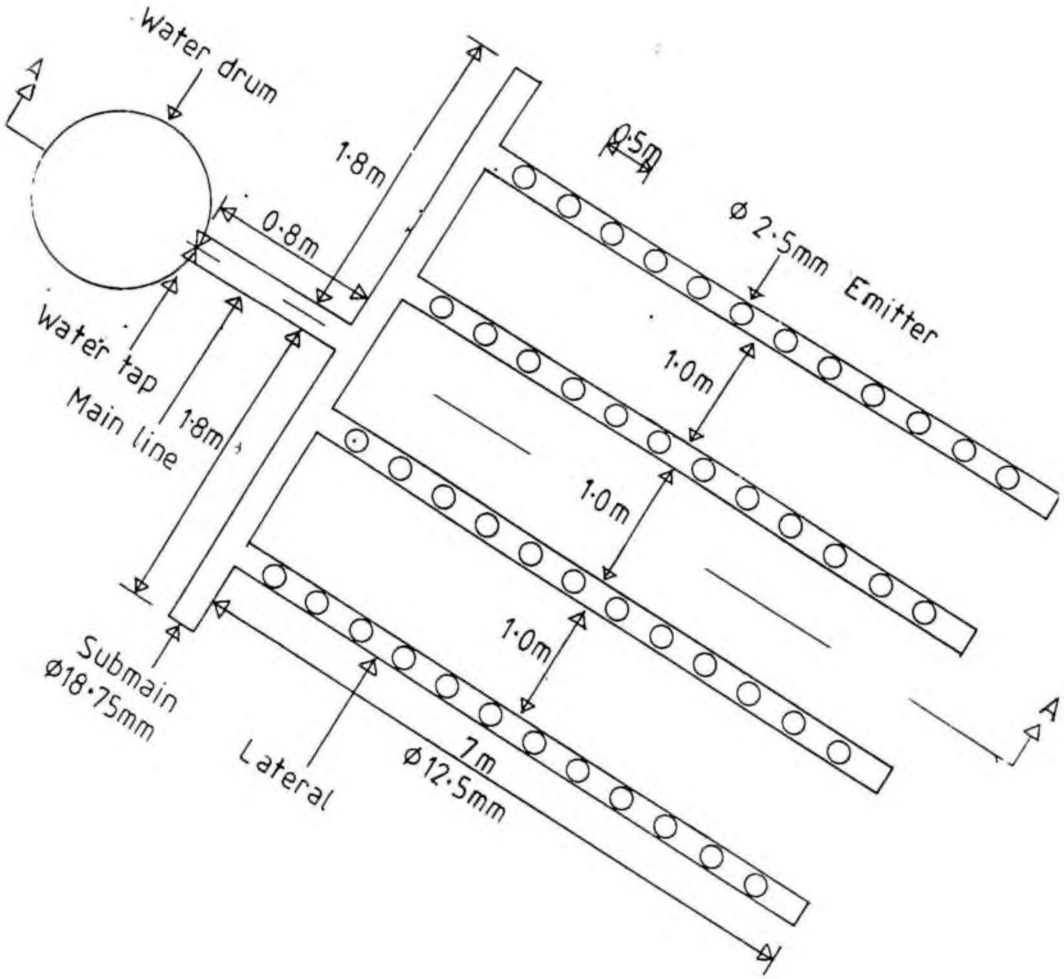

Figure 3.1 Low cost drip irrigation system layout (not to scale)

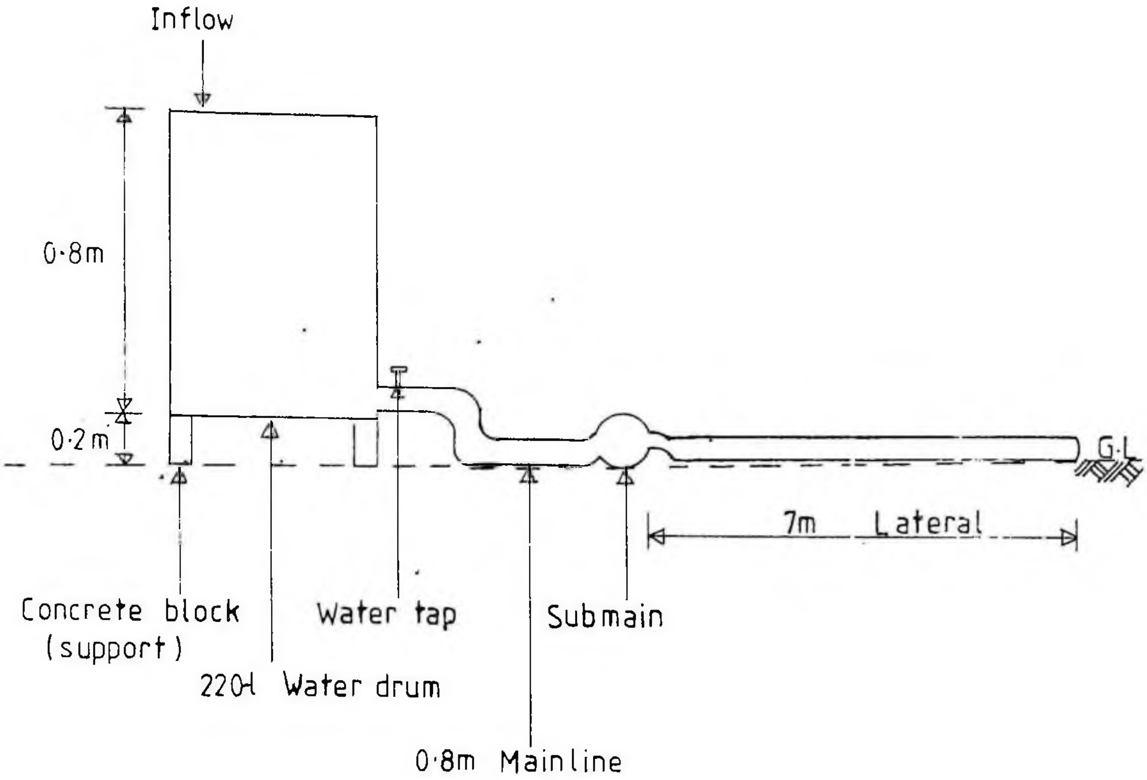

Figure.3.2. Section A – A (Figure 3.1)

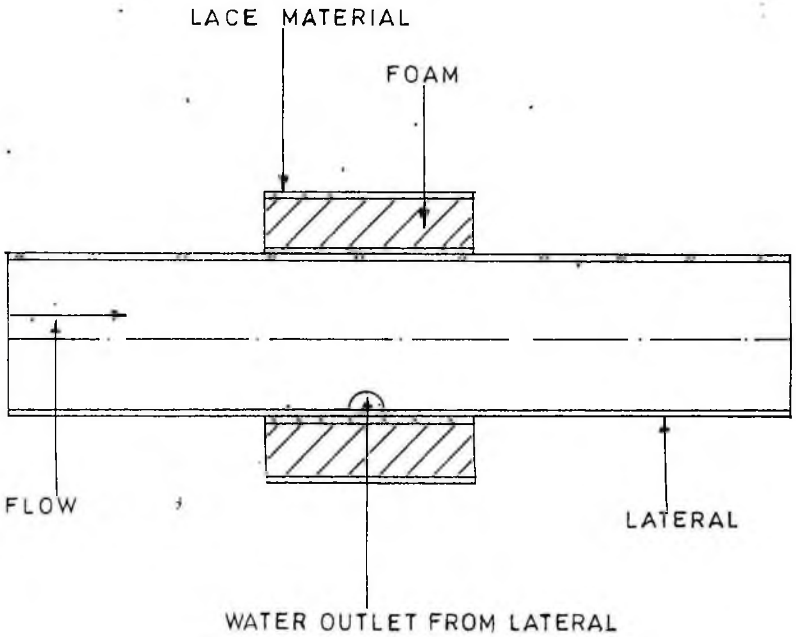

Figure 3.3: Low cost drip emitter (longitudinal section)

3.9 Assembling of system components

With reference to the system layout (Figure 3.1), the components of the low cost drip irrigation system were assembled together accordingly. The 12.7 mm standard water tap was screwed through a drilled hole at the base of the 220-l capacity steel drum. One end of the 12.5 mm diameter flexible hose mainline was connected to the standard tap and the other end connected to a tee located at the mid-section of the submain. The other four tees were connected to the laterals and the submain. The mainline-tee joints and the submain-tee connections were made watertight using adhesive materials. However, the lateral-tee joints were made force-fit to facilitate disassembling from the tees after water application or whenever desirable.

The whole assembly system was set up in the field for testing and evaluation of its technical performance characteristics.

3.10. Testing and evaluation of the low cost drip irrigation system

3.10.1. Introduction

Testing is designed to ensure that the entire hydraulic system of the low cost drip irrigation system is functioning satisfactorily; that the emitters are discharging in drips and not jet flow; that any excessive system leakages especially at the joints, if any, identified and solution provided; that any non-emitter flow investigated and solution found prior to system evaluation.

The system was evaluated against ASAE standards for drip irrigation. Meeting the standards provides good evidence that the low cost drip irrigation system will be robust and perform according to the system design specifications.

The objectives to be met may vary depending on the sophistication of the design of the drip system. For example, whilst the farmer may be interested in continuous supply of water to the crops, the irrigation system engineer may be very keen on the avoidance of over irrigation and its adverse effect on the crops.

3.10.2. System testing

Before the assembling of the system components, the developed laterals were tested using domestic water supply. All emitters of the laterals were observed to be discharging flow in drips. However, no measurement was taken at this stage since the domestic water pressure was considered to be too high for the low cost system.

The system components were assembled in the field at the Agricultural Engineering Department, University of Ghana, Legon. The gradient of the field was approximately flat. This annulled the effect of pressure variation due to elevation. A flexible water hose was connected from a domestic water source to fill the 220-l capacity steel drum to provide the minimum head of 0.8 m. The standard water tap, fitted to the base of the drum, was opened gradually to avoid water hammer effects of the pipe network. The steel drum was maintained at the 0.8 m of water by balancing inflow of water from the domestic water source and outflow from the emitters.

Flow through the entire system was maintained for three hours during which the system was observed to be working properly. At this stage all lateral-tee joints were further tightened to avoid leakages during the system evaluation.

3.10.3. Flow measurements and system performance Evaluation

The method used to collect data for determining the technical performance parameters of the drip irrigation have been outlined in Bucks and Nakayama (1986) with some minor modification for the low cost drip system under evaluation. For every lateral, 10 emitters had their discharges measured and these were 1st, 2nd, 3rd, 5th, 6th, 7th, 9th, 10th, 11th and 12th emitters. Each emitter flow rate was measured three times using a graduated cylinder and an electronic stopwatch. The average of these three discharge values for each emitter was found and recorded. In all, 40 emitters had their discharge measured, which met the minimum requirement for the statistical analysis.

The emitter discharge values obtained were recorded and analysed for variance using the least significance difference (LSD) criteria.

3.11. Commercial drip system evaluation

The commercial drip system was evaluated the same way as the low cost system. Under the commercial drip system four representative laterals were selected for evaluation after the initial testing. Ten emitters per lateral had their discharges measured yielding a total of 40 discharge volumes. The emitter positions tested per lateral were 1st, 2nd, 5th, 11th, 13th, 15th, 24th 30th 31st and 32nd emitters. In all there were 32 emitters per lateral.

3.12. Technical performance parameters and system friction loss computations

The system friction losses were computed from the flow measurements using equations (2.19) and (2.20). The technical performance parameters from the flow measurements were as follows:

i) the coefficient of emitter flow q_{cv}, ii) emitter flow variation $q_{var,}$ iii) statistical uniformity $U_{s.}$ These were computed respectively from equations (2.24), (2.21) and (2.26). Also, iv) the application efficiency E_a, v) absolute emission uniformity E_{ua} and vii) field emission uniformity E_u were also computed respectively from equations (2.25), (2.28) and (2.27).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The results of the evaluation of the low cost drip irrigation system are presented in Tables 4.1 and 4.2 below. The four laterals of the system tested are designated L_{LC1}, L_{LC2}, L_{LC3} and L_{LC4}.

Table 4.1. **Emitter flow volume † of low cost drip irrigation system**

Emitter position	L_{LC1} (cm^3)	L_{LC2} (cm^3)	L_{LC3} (cm^3)	L_{LC4} (cm^3)
1st	86.33	75.00	66.33	74.67
2nd	92.00	103.33	76.00	64.33
3rd	100.00	81.33	83.33	65.67
5th	75.00	101.33	64.67	97.33
6th	93.67	92.67	101.33	74.67
7th	85.33	78.67	64.67	93.33
9th	66.33	68.67	81.33	75.00
10th	95.33	96.67	92.00	64.67
11th	100.00	93.33	75.33	81.33
12th	92.67	91.33	83.67	104.67

† Average of three emitter discharges

Table 4.2 Emitter flow rates q for low cost drip irrigation system

Emitter position	L_{LC1} (L/h)	L_{LC2} (L/h)	L_{LC3} (L/h)	L_{LC4} (L/h)
1st	1.036	0.900	0.800	0.896
2nd	1.104	1.236	0.912	0.772
3rd	1.200	0.976	1.00	0.788
5th	0.900	1.216	0.776	1.168
6th	1.124	1.112	1.216	0.896
7th	1.024	0.944	0.776	1.120
9th	0.796	0.824	0.976	0.900
10th	1.144	1.112	1.104	0.776
11th	1.200	1.119	0.904	0.976
12th	1.112	1.096	1.004	1.266
Mean ± standarderror	1.064 ±0.079	1.053 ±0.083	0.9468±0.088	0.9548 ±0.0105

Table 4.3 Performance parameters for low cost drip irrigation system

Performance parameters	Value (%)
Coefficient of manufacturing variation , q_{cv}	15. 12
Emitter flow variation, q_{var}	38.50
Statistical Uniformity, U_s	84.90
Field emission Uniformity, E_u	76.83
Absolute emission uniformity, E_{ua}	73.90
Application efficiency, E_a	94.00

The q_{cv} value obtained (Table 4.3) is marginal according to ASAE (1984) standards and fairly reasonable. According to the standard (Table 2.1) the acceptable value should be less than 15 %. The value obtained is an indication that the low cost system can be developed to achieve high coefficient of variation. A high value of q_{cv} indicates a wide spread in the difference in emitter discharge. The marginal value obtained can be attributed to the difficulty in drilling the emitter holes to exactly 2.5 mm diameter. An improvement could be obtained by using work-holding device to secure the laterals before drilling the holes.

The q_{var} of 38.5% is greater than acceptable ASAE standards for drip irrigation systems since acceptable values should be 10% or less (Table 2.1). When q_{var} is high, the implication is that there is a large difference in emitter discharges. Because this low cost drip emitters are insensitive to clogging, the emitter flow variation could be due to hydraulic pressure variation and coefficient of variation of emitter flow (Anyoli and Wu, 1994).

The E_u and E_{ua} values obtained (Table 4.3) are both fair according to ASAE(1984) standards (Table 2.2), since these values lie between 70 and 80%. These values indicate fairly good uniformity of emitter discharges. Even though there were difficulties in drilling the emitter holes to exactly the same diameter, the tightening of these holes with rubber band at high tension probably helped in securing the foam with the lace material firmly, thereby minimising leakages at the emitters of the system.

According to ASAE (1984), the value 84.9% obtained for the U_s is good. This highlights the fact that even though the q_{cv} value obtained was marginal, it is reasonable.

4.4 Emitter discharges with respect to submain position of the low cost drip system

Table 4.4.1. Emitter flow along laterals

Lateral	Discharges* close to submain (l/h)	Discharges* at distances end of lateral (l/h)
L_{LC1}	1.078 ± 0.120	1.0552 ± 0.170
L_{LC2}	1.0886 ± 0.149	0.9528 ± 0.139
L_{LC3}	0.9408 ± 0.189	0.9528 ± 0.139
L_{LC4}	0.904 ±0. 168	1.0056 ± 0.199

* values not significant at $p< 0.05$

The results of the emitter flow analysis of the low cost system indicate that the emitter flow generally are not significantly different($p<0.05$) along the lateral when discharges close to the submain were compared with discharges at the far end of the lateral from the submain (Table 4.4.1). These observations are in agreement with the earlier work by Senzanje (1997), who found no noticeable difference in emitter discharge between those at the head (near the water tank supplying flow) and those at the tail end of the lateral.

The mean discharges of the low cost laterals follow the order $L_{LC1}> L_{LC2}> L_{LC3} >L_{LC4}$. This observation is due to pressure variation in the submain and also along the laterals (Wu and Giltlin, 1974).

4.5 Friction loss of low cost drip system

For a mean discharge of 1.00485 (±0.040) l/h of the system emitter flow and 12 emitter per 7m lateral, the friction headloss in the lateral was determined to be 0.57 mm using the method of Watter and Keller (1978).

Leakage at the joints of the low cost drip irrigation system network was observed to be very small. This development prevented unusual pressure variation along the laterals of the system (Table 4.4.1). Therefore, the head loss of the system could mainly be attributed to the characteristics of the pipe material and topography of the experimental site.

4.6 Commercial drip irrigation system evaluation

Under the commercial drip system, four representative laterals had their emitter discharges measured. These laterals were labelled L_1, L_2, L_3 and L_4. The results are presented in Tables 4.6.1 and 4.6.2 below.

Table 4.6.1. Emitter flow volume* of commercial drip irrigation system

Emitter position	L_1 (cm^3)	L_2 (cm^3)	L_3 (cm^3)	L_4 (cm^3)
1st	55.50	56.67	54.00	53.67
2nd	54.33	55.67	54.67	54.33
5th	55.67	55.00	54.33	53.67
11th	56.33	55.00	56.00	54.00
13th	55.00	53.33	55.67	54.67
15th	57.33	54.33	54.00	55.33
24th	55.67	55.33	55.67	54.67
30th	56.33	56.33	54.33	53.67
31st	54.33	55.00	56.33	54.67
32nd	55.33	55.00	55.67	55.00

*** average of three values**

Table 4.6.2 Emitter flow rate for commercial drip system

Emitter position	L_1(L/h)	L_2 (L/h)	L_3 (L/h)	L_4 (L/h)
1st	0.666	0.680	0.648	0.644
2nd	0.652	0.680	0.656	0.652
3rd	0.668	0.660	0.652	0.644
4th	0.676	0.660	0.672	0.648
5th	0.660	0.639	0.668	0.656
6th	0.688	0.652	0.648	0.664
7th	0.668	0.664	0.668	0.656
8th	0.676	0.676	0.652	0.644
9th	0.652	0.660	0.676	0.656
10th	0.664	0.660	0,668	0.660
Mean ± standard error	0.669±.0079	0.663± .0078	0.661±.0067	0.652±.0044

Table 4.6.3. Commercial drip irrigation performance parameters calculated.

Performance parameters	Value (%)
Coefficient of variation of emitter flow, q_{cv}	1.96
Emitter flow variation q_{var}	7.12
Statistical Uniformity, U_s	98.04
Field emission Uniformity, E_u	96.7
Absolute emission Uniformity, E_{ua}	95.64

According to ASAE (1984) criteria for drip irrigation (Table 2.1), the coefficient of variation of 1.96% obtained for emitter flow for the commercial system is classified as good. This indicates a very narrow spread in the distribution in emitter discharges. The reason could be due to a high precision in the manufacture of those emitters and adherence to strict engineering standards.

The values of E_u, U_s and E_{ua} obtained (Table 4.6.3) are all greater than 90%. These values are classified as excellent (ASAE, 1984).

Table4.6.4. Emitter discharges along the laterals for commercial drip system

Lateral	Discharges* close to submain (l/h)	Discharges * far end of lateral (l/h)
L_1	0.6644 ± 0.0096	0.6736 ± 0.0166
L_2	06638 ± 0.0093	0.6624 ± 0.0094
L_3	0.6592 ± 0.011	0.6624 ± 0.0126
L_4	0.6488 ± 0.005	0.656 ± 0.0079

* Values not significant at $p < 0.05$

There were no noticeable difference in mean emitter flow between those near the submain and those at the extreme end of the laterals (Table 4.6.4). The slight variation in mean discharge rates of the emitters along the laterals of the order of $L_1>L_2>L_3>L_4$ could be due to hydraulic pressure variation. This is because pressure variation along a lateral line causes emitter flow variation along the lateral and pressure variation along a submain causes lateral flow variation along a submain (Wu and Gitlin, 1974).

The emitter flow variation of 7.12 % obtained for the commercial drip system is acceptable according to ASAE (1984) standards for drip irrigation systems evaluation. This value obtained could be due to the fact that the coefficient of variation of emitter flow was very small (1.96%).

Table 4.7. Comparison of Low cost and Commercial drip systems technical performance parameters

Performance parameter	Low cost Value (%)	Commercial Value (%)	ASAE Recommended standards
Coefficient of variation of emitter flow, q_{cv}	15. 12	1.96	Accepted value: 15 % or less
Emitter flow variation q_{var}	38.50	7.12	Accepted value: 10 % or less
Statistical Uniformity, U_s	84.90	98.04	90% or greater: Excellent
Field emission Uniformity, E_u	76.83	96.7	80-90%: Good 70-80%: Fair
Absolute emission Uniformity, E_{ua}	73.90	95.64	Less than 70%: Poor/ unacceptable

From the results of the low cost system and the commercial drip system evaluation (Table 4.7), it is clear that the latter performed better than the former in terms of technical performance characteristics according to ASAE standards (Tables 2.1 and 2.2). This refutes the earlier assertion/hypothesis that the low cost drip irrigation and the commercial drip irrigation have the same technical performance characteristics.

The basic question one will like to ask is this ‘ is it possible for the performance parameters of the low cost drip irrigation system to be the same, as strict as that of the technically advanced high cost commercial drip irrigation system? From the current study, the performance of the low cost drip irrigation system has comparable performance parameters as that of the technically advanced high cost commercial drip irrigation system. It is possible that with some development of the low cost system, excellent performance parameters would be obtained. The development of the low cost system could mean additional system cost will be incurred. This means a balance for improved technical performance characteristics.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

This study underscores the possibility of designing low cost drip irrigation system from materials, which are cost effective and readily available. The performance parameters chosen for the evaluation of the low cost drip irrigation were that accepted for drip irrigation system evaluation according to ASAE standards.

It was found from the study that the low cost drip irrigation systems are easy to fabricate, easy to maintain and easy to operate. However, the design of the low cost drip irrigation emitters plays a critical role in the performance characteristics for the system. The technical performance characteristics for the low cost drip irrigation system designed, constructed and evaluated were not the same as the commercial drip irrigation system evaluated. The commercial drip irrigation system parameters had better technical performance characteristics than the low cost drip irrigation system fabricated. This observation was in disagreement with the initial hypothesis stated that the low cost drip irrigation system would have the same performance characteristics as the commercial drip irrigation system. However, the performance parameters obtained for the low cost drip irrigation system were reasonably good. The emitter flow variation was, however, unacceptable for the low cost drip system and future development of the emitters and system pipe network could help improve the situation. This indicates that there is future for the low cost drip irrigation system.

The development, field trials and applications of the low cost drip irrigation system would be a workable alternative to the technically high advanced drip irrigation systems. This would help smallholder farmers to use the technology to increase food production.

It is recommended from this study that more work on the low cost drip irrigation system be directed towards assessing emitter flow and the corresponding water distribution pattern in the soil. It is also recommended that agronomic performance of the low cost system is assessed under farmers' field conditions and acceptability of farmers analysed.

The low cost drip irrigation has the potential of increasing agricultural productivity of smallholder farmers in developing countries. This follows from the fact that the technology is low cost, which the smallholder farmer can afford, low risk, of low maintenance and fairly durable. The technology is viable and sustainable under the conditions of the smallholder farmer. Every effort should therefore be directed towards the development and application of the technology.

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APPENDIX A

DESIGN CALCULATIONS

1.1a The drip system pressure head

Since the drip irrigation system being designed is for smallholder farmers, energy requirements and cost are taken into consideration. For this reason, a low-pressure head in the range of 0.2 – 1.0m is selected for the design. Based on the pressure range indicated, and considering a cylindrical water tank to produce flow in the entire hydraulic system of the drip irrigation

$$V = \pi r^2 h \qquad 1$$

Where

V = volume of tank (m^3)

r = radius of tank (m)

h = height of tank (m)

From equation 1

$$h = \frac{v}{\pi r^2} \qquad 2$$

Thus from equation 2, knowing the capacity and radius of a cylindrical water tank, the column of water in such a tank when full can be calculated. V and r can be selected into equation 2 to meet the desired design pressure head range.

Putting v = 0.022m^3, r = 0.57m into equation 2

$$h = \frac{0.022 x 4}{\pi x (0.57)^2} \qquad = 0.862m.$$

Thus h = 0.862m is the maximum level of water the tank can contain when filled with water.

Allowing 10% of the column of water in the tank as dead storage (i.e. the column of water in the tank between the base of the tank and the mainline inlet), the column of water in the tank to produce flow in the drip system is

$$h_d = h - 10\%\ h \qquad 3$$

where

h_d = the column of water in the tank to produce flow (m).

Putting h = 0.862m into equation 3.

$$h_d = 0.862 - \frac{10}{100} \times 0.862 = 0.80\text{m}$$

For the low-cost drip irrigation system, $\frac{dh_d}{dt} = 0$ during field operations. Hence h_d = 0.80m = constant.

1.2a: Lateral and submain design

The length of the laterals and the submain are selected based on the unit of land to be irrigated at a time. The emitter spacing on laterals is based on the crop spacing (i.e. one emitter per crop along the lateral).

The area of land to be irrigated at a time is

$$A = L \times B \qquad 4$$

where

A = area (m^2)

L = length or land (m)

B = breadth of land (m)

The length of the unit of land to be irrigated at a time corresponds to the length of the lateral. The length of the submain corresponds to the breadth of the land to be irrigated at a time. Therefore, using linear relationship between laterals, emitter spacing and number of emitters per lateral, then.

$$L = S\ (n + 2) \qquad 5$$

where L = length of lateral (m)

s = emitter spacing (m)

n = No. of emitters per lateral.

If 12 plants per lateral are selected to make the lateral shorter in order to reduce cost and if the plant spacing along the lateral is 0.5m, then equation 5 becomes

$$L = 0.5\ (12 + 2) \qquad = 7.0\text{m}$$

The submain length is based on the lateral spacing or row spacing of the plant. Therefore using linear relationship between the submain and the lateral

$$L_{sm} = S_2\ (n_L - {}^1/_3) \qquad 6$$

Where

L_{sm} = submain length (m)

S_L = lateral spacing / row spacing (m)

n_L = No of laterals per submain .

The lateral spacing, S_L, corresponds to the row spacing of the crop to be irrigated. For the crop (e.g. Okro), the row spacing is set to be1.0m and the number of rows per unit of land to be irrigated is 4 for the design. Hence substituting into equation 6

$L_{sm} = 1.0\ (4 - \frac{3}{4}) \quad = 3.67\text{m}$

Substituting values of $L_{sm} = 3.67\text{m}$ (equation 6) and $L = 7\text{m}$ (equation 5) into equation 4

$A = 7\text{m} \times 3.67\text{m}$

$= 25.7\text{m}^2$

1.3a:. **Flow through the low – cost drip-pipe network** :

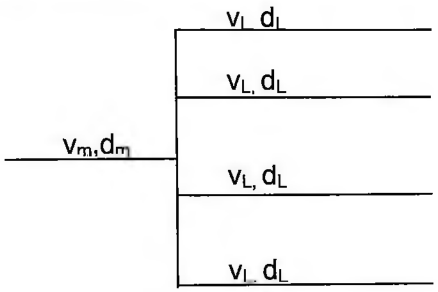

Figure 1.3a: Low cost drip pipe network.

Using the continuity equation for the drip network shown in figure 1.3a above.

$$V_m \frac{\pi d_m^2}{4} = V_L \frac{\pi d_L^2}{4} + V_L \frac{\pi d_L^2}{4} + \frac{V_L \pi d_L^2}{4} + \frac{v_L \pi d^2}{4} \qquad 7.$$

Where

V_m = velocity of flow in mainline (m/s)

d_m = diameter of mainline (m)

V_L = velocity of flow in the lateral (m/s)

d_L = diameter of lateral (m)

Equation 7 is simplified to

$$vmd_m^2 = 4v_L d_L^2 \qquad 8$$

1.4a Svstem frictional factor

Assuming the low-cost drip pipe networks are smooth, then using ka'rma'n-Prandtl equations

$$\frac{N_R\sqrt{f}}{r_o/k} = 17 \qquad 9$$

$$\frac{1}{\sqrt{f}} - 2\log\left(\frac{r_o}{k}\right) = 1.66 \qquad 10$$

where

N_R = Reynolds number

f = frictional factor

r_o = radius of pipe (m)

k = equivalent roughness projection (m).

Equations 9 and 10 are iterated to obtain the frictional factor for the low-cost drip system.

Assume $r_o/k = 15$, equation 10 becomes

$$\frac{1}{\sqrt{f}} = 1.66 + 2\log(15) = 4.012$$

$$\therefore \qquad f = 0.062.$$

Putting f = 0.062 in to equation 9

$$\frac{N_R\sqrt{0.062}}{15} = 17$$

$$\therefore\ N_R = 1023$$

Since $N_R = 1023 < 2000$, the flow is laminar.

For laminar flow

$$f = \frac{64}{N_R} \qquad 11$$

Putting N_R = 1023 into equation 11

$$f = 64/1023 \qquad = 0.0626.$$

According to karmeli and Keller (1975), the discharge of any emitter may be expressed by the power function.

$$q = kh^x \qquad 12$$

where

q = emitter discharge (l/s)

k = constant for each emitter

h = pressure head (m)

x = emitter discharge exponent.

Since flow is laminar, $x = 1$ in equation 12 (karmeli and keller, 1975).

Equation 12 becomes.

$$q = kh \qquad 13$$

Applying the continuity equation for any lateral of the low-cost drip system (figure 1.3a).

$$\frac{v_L \pi d_L^2}{4} = n\,q = nkh \qquad 14$$

Where symbols have meanings as defined above.

For a prudent design of the low-cost drip system, assuming the design discharge to be 2 l/h (based on the low pressure head range of 0.2 – 1.0m).

$$\text{But} \quad N_R = \frac{PDV}{\mu} \qquad 15$$

where

N_R = Reynolds number

p = density of water (kg/m^3)

v = velocity of flow (m/s).

μ = dynamic viscosity (N-s/m^2)

at temperature 20^{0}C.

From equation 15

$$v = \frac{N_R \mu}{pD} \qquad 16$$

Hence applying equation 16 on the low cost drip lateral and combining with equation 14:

$$nq = \frac{\pi d_L^2}{4} \cdot \frac{N_R \mu}{p d_L}$$

$$d_L = \frac{4nqp}{\pi N_R \mu} \qquad 17$$

Putting known values into equation 17

n = 12 , q = 2l/h

p = 1000kg/m^3, N_R = 1023

μ = 1.002 x 10^{-3} N-S/m^2

$$d_L = \frac{4x12x2x10^{-3}x10^{3}}{3600x\pi x1023x1.002x10^{-3}}$$

= 8.28 x 10^{-3} m

= 8.28 mm

From equation 14 above

$$V_L = \frac{4nq}{\pi d_L^2} \qquad 18$$

Putting known values into equation 18

$$V_L = \frac{4x12x2x10^{-3}}{3600x(8.28x10^{-3})^2 x\pi}$$

$$= 0.12 \text{ m/s}$$

The frictional headloss is given by the Darcy-Weisbach equation

$$h_f = \frac{fLV^2}{2Dg} \qquad 19$$

Where

h_f = frictional head loss (m)

L = length of pipe (m)

V = velocity of flow in pipe (m/s)

D = diameter of pipe (m).

g = acceleration due to gravity (m/s^2).

Putting known values into equation 19

f = 0.062 6 (from equation 11)

L = 7.0m (from equation 5)

V = 0.12 m/s (from equation 18)

d = 8.28 x 10^{-3} m (from equation 17)

$$h_f = \frac{0.0626x7x0.12^2}{2x(8.28x10^{-3})x9.81}$$

$$= 0.0388\text{m}$$

The total frictional head loss for the four laterals becomes 0.0388 x 4 = 0.155m.

1.5a **Mainline and submain hydraulics**

From the principles of continuity of flow, the flow in the submain (figure 1.3a) will be

$$q_{sm} = n_L q_L \qquad 20$$

where

q_{sm} = discharge in submain (l/s)

n_L = No of laterals on submain

q_L = discharge in lateral (l/s).

Putting known values into equation 20

$$q_{sm} = \frac{4x12x2x10^{-3}}{3600}$$

$= 96$ l/h

$= 2.67 \times 10^{-5}$ m^3/s.

From equation 8 above

$$Vmd_m^2 = \mu v_L d_L^2$$

For the low – cost design, $d_m = d_L$

$V_m = 4U_L$

$= 4 \times 0.12$

$= 0.48$ m/s

1f $V_m = 0.48$m/s, $q_{sm} = 2.67 \times 10^{-5}$ m^3/s then from continuity principles of flow

$$d_m = \left[\frac{4x2.67x10^{-5}}{0.48x\pi}\right]^{1/2}$$

$= 8.4 \times 10^{-3}$m

$=$ 8.4mm

Applying Darcy – Weisbach equation (equation 19) along the mainline, the mainline frictional head, h_{fm}

$$h_{fm} = \frac{0.0626x0.8x0.48^2}{2x8.28x10^{-3}x9.87}$$

$$= 0.07m$$

Considering equation 16 above and using continuity principles of flow for the submain .

$$q_{sm} = \frac{V_{sm}\pi d^2_{sm}}{4} \qquad 21$$

where

q_{sm} = discharge in submain (m^3/s)

v_{sm} = velocity of flow in submain (m/s)

d_{sm} = diameter of submain (m).

From equation 21,

$$V_{sm} = \frac{4q_{sm}}{\pi d^2_{sm}} \qquad 22$$

$$v = \frac{N_R \quad \mu}{pD} \qquad 16$$

Equating equations 22 and 16

$$d_{sm} = \frac{4p \quad q_{sm}}{N_R \mu\pi} \qquad 23$$

Substituting known values into equation 23.

$$d_{sm} = \frac{4x1000x2.67x10^{-3}}{1023x1.002x10^{-3}x\pi}$$

$$= 0.0331m$$

$$= 33.1mm$$

The velocity of flow in the submain is computed as (from equation 16)

$$v_{sm} = \frac{1023 \times 1.002 \times 10^{-3}}{1000 \times 0.0331}$$

$$= 0.031 \text{ m/s}$$

From Darcy - Weisbach equation (equation 19), the frictional head loss in the submain h_{fsm} is calculated as

$$h_{fsm} = \frac{0.0626 \times 3.67 \times 0.031^2}{2 \times 0.0331 \times 9.81}$$

$$= 0.0003\text{m}$$

Frictional head:	(m)
Submain loss	0.0003
Mainline	0.0700
Laterals	0.1550
Total	0.2253

1.6a: **Low – Cost emitter diameter / drilled holes size.**

The velocity of flow of water just before leaving the emitter openings is the same as the velocity of flow in the lateral. Therefore applying the continuity principles of flow

$$q_e = V_e A_e \qquad 24$$

where

q_e = design emitter discharge (m^3/s)

V_e = velocity of flow just before learning the lateral through the emitter openings (m/s)

A_e = cross – sectional area of emitter opening (m^2)

But

$$A_e = \frac{\pi d_e^2}{4} \qquad 25$$

where d_e is diameter of emitter opening (m).

Putting equation 25 into equation 24 and re-arranging .

$$d_e = \left[\frac{4q_e}{v_e \pi}\right]^{\frac{1}{2}} \qquad 26$$

Putting known values into equator 26:-

q_e = 2 d/h (design emitter discharge)

V_e = 0.12 m/s (from equators 18)

$$\therefore \quad d_e = \left[\frac{4 \ x \ 2 \ x \ 10^{-3}}{3600 \ x \ \pi \ x \ 0.12}\right]^{\frac{1}{2}}$$

$$= \quad 2.43mm$$

Thus the drilled holes along the lateral have diameter of 2.43mm.

1.7a Low – Cost drip irrigation pressure variation.

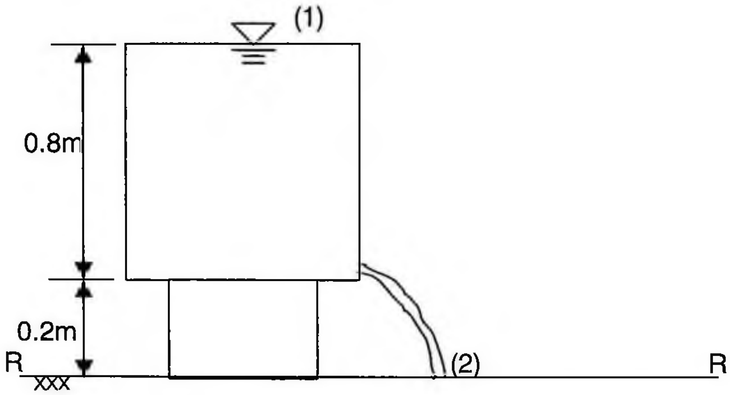

Figure 1.7a: water tank and pipe network

Taking datum at the soil surface,

R – R and assuming that

a). velocity is inform in the pipe

b). fluid is of constant density

c). flow is steady ,

then Bernoullis equation can be applied at point (1) and (2) (figure 1.7a)

$$\frac{v_1^2}{2g} + Z_1 + \frac{p_1}{pg} = \frac{v_2^2}{2g} + Z_2 + \frac{p_2}{pg} + h_s \qquad 27.$$

Where

V_1 = velocity of water in the tank (m/s)

Z_1 = elevation of the point (1) (i.e. water surface)

above the detune R – R (m).

P_1 = pressure of water at the point (1) (N/m^2)

p = density of the water (kg/m^3)

g = acceleration due to gravity (m/s^2)

V_2 = velocity of flow of water in the pipe at point (2) (m/s)

Z_2 = elevation of point (2) with respect to the datum R – R (m)

P_2 = pleasure of water in the pipe at the point (2) (N/m^2)

h_s = system frictional head turn point (1) to point (2) (m).

Putting known values into equation 27

$V_1 = 0$, $Z_1 = 0.8 + 0.2 = 1.0m$, $P_1 = 0$

$V_2 = 0.48m/s$ (Equation 8)

$h_s = h_m = 0.07m$, $Z_2 = 0.2m$

$$\therefore \quad 0 + 1 + 0 = \frac{0.48^2}{2x9.81} + 0.2 + \frac{p_2}{pg} + 0.07$$

$$\frac{p_2}{pg} = 1 \quad 0.2 - 0.07 \quad \frac{0.48^2}{2x9.81}$$

$$= 0.718m$$

$\therefore$ $P_2 = 0.718pg$

$= 0.718 \times 1000 \times 9.81$

$= 7043.6\ N/m^2$

Summary of pressure variation

Component	Pressure head (m)	Pressure (N/m^2)
Mainline :		
Maximum	0.8	7848
Minimum	0.718	7043.6
Submain		
Maximum	0.718	7043.6
Minimum	0.718-0.0003	
	0.717	7033.8
Lateral:		
Maximum	0.717	7033.8
Minimum	0.717-0.0388	
	0.68	6670.8

1.8a Low – Cost drip system components selection

Based on the design calculations presented, the components of the low-cost drip irrigation system are selected to meet the desired results.

Parameter	design calculation (mm)	Standard size selected (mm)
Mainline	8.28	12.5
Lateral	8.28	12.5
Emitter size	2.46	2.5
Submain	33.1	18.75

The drill bits for the emitters are in standard sizes. The size close to the design size of Φ2.46mm is Φ2.5mm. Hence a drill bit of size Φ2.5mm is selected to produce drill holes of size Φ2.5mm along the laterals.

The laterals and the mainline have the design diameters 8.28mm. A standard size close to Φ8.25mm is Φ12.55mm. Therefore, for the laterals and the mainline, the diameter selection is 12.5mm.

The submain selection presented much difficulty to the designer. Even though the design calculations put the diameter as 33.1mm, due to the difficulty in getting the corresponding T-joints of the submain and the laterals or mainline and submain, a standard size of Φ18.75mm is selected

The foam and the lace material are selected based on their qualitative characteristics. They are porous. The designer envisaged that the tortuosity of the pore system of the foam could help reduce the velocity of flow through the drilled – holes along the laterals.