UNIVERSITY OF NAIROBI

DEPARTMENT OF ENVIRONMENTAL AND BIOSYSTEMS ENGINEERING

ASSESSMENT OF LOW HEAD DRIP IRRIGATION SYSTEMS UNIFORMITY OF APPLICATION

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A thesis submitted in fulfillment for the degree of MSc. Environmental and Biosystems Engineering in the department of Environmental and Biosystems Engineering in the University of Nairobi

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DECLARATION

I declare that this thesis is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other works or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements.

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This thesis is submitted for examination with our approval as University supervisors**:**

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ABSTRACT

Water application uniformity (EU) is an important performance criterion that must be considered in the design, operation and management of irrigation systems for increasing agricultural productivity. This research study was as a result of the previous studies done by Hassan F.A, Kabutha, *et al*. and Nyakwara *et al*., which reported about poor/non-uniformity of water application by low-head drip irrigation systems. The study identified systems widely adopted by the smallholder farmers alongside low-cost greenhouse farming technology, categorized and coded them using letter T based on layout configuration; height of stand for water tank, length of lateral, type of drip tube, size and number of emitters per spacing and assessed their water application uniformities using American Society of Agricultural Engineers (ASAE) standards 1996(a) for line-source drip irrigation systems performance rating. This was done in order to check/compare their EU performances and diagnose constraints to enhance agricultural productivity.

This research was done in Trans Nzoia West; Sub-Counties of Saboti and Kiminini of Trans Nzoia County, Kenya. Four replications of each identified six design configuration categories in operation (with crop in season) were selected by simple random sampling. Sampling of data points of each system was done using a pattern guide developed for sampling data points to improve fairness of sampling in the irrigation area. Water discharges filling a 10 ml cup (medicine dispenser) were timed from each of the thirty sampled emitters. The data collected was processed and Analysis of variance (ANOVA) procedure was used to statistically test for equality of the EU means between the categories as a way of checking/comparing their performances at a confidence level of 95%. The result obtained together with observations and the information gathered through semi-structured interviews was used in the conclusions and recommendations.

The result from this study showed that the uniformity of water application performance rating for common low-head drip irrigation systems are marginally fair (71%) on average except for the two categories,T_2 and T_5, with double emitters whose performances are very poor (< 65%). The result from ANOVA showed that EU means for T_{1}, T_{3}, T_4 and T_6 are statistically equal at 95% confidence level. Also there is a significant difference between the sample means (F-ratio >> F-table) attributed to differences in systems design configurations. Therefore choice of design configuration whose mean water application uniformity are statistically equal at 95% confidence level coupled with proper installation and management is needed for enhancement of agricultural productivity. The categorized design configurations whose water application performance ratings are very poor should not be promoted by extension providers and are recommended for further hydraulic uniformity test.

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List of abbreviations

ANOVA – Analysis of variance

ASAE – American Society of Agricultural Engineers

Avg – Average

CBO – Community Based Organization

cm – Centimeter

CRD – Completely Randomized Design

CV - Coefficient of variation

DU – Distribution Uniformity

e.g., – for example

et.al. – and others

EU - Emission Uniformity/water application uniformity

Fig. - Figure

gph. – Gallons per hour

ICRAF – International Center for Research in Agro forestry

KARI - Kenya Agricultural Research Institute

l/h - Litre per hour

M – Meter

Max – Maximum

Min - Minimum

ml/s – milliliters per second

NARL - National Agricultural Research Laboratories

NIB – National Irrigation Board

NPC – Non Pressure Compensating

Otl - Outlier

Pa – Pascal

PE – Polyethylene

psi – Pounds per square inches

PVC – Polyvinylchloride

UNDP – United Nations Development Program

USAID – United States Agency for International Development

1.0 CHAPTER 1: INTRODUCTION

1.1 Background Information

Irrigation is a method of delivering water to an area where it is needed, but not normally present in required amounts, for agricultural or landscaping purposes to either substitute or supplement the natural supply. In agriculture, irrigation is done for the purpose of achieving increased agricultural productivity (quality and yield improvement). The water supply is done through a set of interacting components forming an integrated whole referred to as a system. Irrigation systems are classified as drip, sprinkler and surface or furrow.

Drip/trickle/micro/low-flow/low-volume irrigation is the application of water at a slow, controlled rate through emitters spaced at pre-determined intervals. Emitters apply the water needed to keep plant's root zones well supplied without wetting the plants or watering the unproductive areas between the plants. For low head drip irrigation systems, water pressure is created by raising the supply container (bucket, drum, or tank) to 0.5 to 1.5 m, or connecting the drip system to a low pressured water supply, (www.gharainwater.or, accessed on 5th February, 2013). The drip irrigation efficiency is about 90 to 95 percent. Compared to flood/surface and sprinkler irrigation systems whose efficiencies are approximately 50 percent and 70 percent respectively, drip irrigation is the obvious recommendation for crop production in areas with little rainfall or scarce water as reported by Keller J and Karmeli D. (1974).

Water application uniformity is an important performance criterion that must be considered during the design and evaluation of irrigation system as seen by Shufang J. and Kang Y. (2010). It is a measure of how evenly the volumes of water are applied.

Drip irrigation applies the use of drip tubes (drip lines/tapes) along which the points for water discharges (emitters) are fixed. Whereas drip lines are thick walled tubing, drip tapes have thin walls and very flexible.

In the design of drip irrigation system, it is necessary to choose a specific emitter from those available from the various manufacturers/distributers.

Emitter selection will fix the flow rate per emitter (point-source) and for the line-source it is per given length in meters of the lateral. The discharge of the emitter chosen will then be used to establish the management guidelines for the irrigation system.

Dripper lines are drip lines/tapes with line-source emitters. They are drip tubes with factory preinstalled emitters at fixed spacing along their length. There are various spacing options available. The line-source tubing serves both as the lateral pipe and the emitters. Line-source emitters also work well for vegetables and row crops.

Drip irrigation technologies which were developed and imported into the country initially were operating under high pressure (>10m water pressure) and are reliant on piped water supply as reported by Ngigi S.N. (2008). The introduction of low pressure drip lines/tapes in the market coupled with greenhouse technology and their combined attractive attributes has led to widespread adoption of low cost/ gravity flow drip irrigation systems by the smallholder farmers in many parts of Kenya. The main factors which have favored the adoption of low pressure drip lines over the high pressure ones are the use of low-cost materials, easy to understand, operate and maintain and the fact that high pressure pump is not required hence low operating cost. Many smallholder farmers in Trans Nzoia County, like in other parts of the country have adopted the technology for horticultural production

Emphasis is being put on the use of low cost (low head pressure) drip irrigation in Kenya as a way of enhancing agricultural production and attaining food sufficiency. There are many International Organizations, CBOs, Kenya Agricultural Research Institute (KARI) and Ministry of Agriculture involved in promotion of low cost drip irrigation systems alongside greenhouse technology

An efficient drip irrigation system should apply/emit water uniformly along a drip line/tape (lateral). Low emission uniformity (EU) leads to either over-irrigation and or under-irrigation along different sections of the laterals and hence low irrigation efficiency as reported by Hassan F.N. (Undated).

Despite the adoption rate, the farmers and the extension agents have identified some challenges/problems that need to be addressed to improve the performance and sustainability as reported by Kabutha *et al*, (2000). The areas of concern are;

(a) Crop performance is based on how well the water is supplied to each plant root zone along the lateral. It has been observed that in some instances water distribution is not uniform; some portions or points do not get enough water resulting in very poor crop yields.

(b) In order to carry out proper water management and realize good crop yields, the most commonly asked question by the farmers is the duration per irrigation of low head drip irrigation systems.

(c) Given that there are different types of drip line/tapes in the market operating under low pressures and the observation from the farms is that water reservoirs providing the pressure heads are raised at varying heads; how do their water application uniformities compare.

This research intended to assess water application uniformity of low head pressure drip irrigation systems which are highly being adopted by the smallholder farmers with a view to coming up with possible solutions/ recommendations to enhance agricultural productivity.

1.2 Problem Statement

It has been noted that some portions of drip irrigation systems receive little or no water discharges leading to poor crop yields as seen by Kabutha, *et al*. (2000). Farmers are addressing this problem by supplementing the watering using hose or bucket irrigation thus reducing the gains in uniform distribution of scarce water and root zone applications which are important attributes of drip irrigation. In some cases poor crop yields, from the high value crops planted, as a result of poor water distribution and difficulty in supplementing watering has led to complete abandonment of the use of the system altogether. In the study of social and financial evaluation of low head drip irrigation systems for small scale farmers in Moiben Division, Uashin Gishu District by Nyakwara *et al*, (undated, KARI) found that lack of knowledge by farmers on amount of water to apply, uneven water distribution, bias by technical staff to crop extension rather than irrigation and lack of knowledge on proper water management (how much water to apply) were major constraints. The study recommended that research should be done to address the technical constraints in order to enhance agricultural productivity and hence the need to assess the water application uniformity performance.

1.3 Objectives

The overall objective of the study was to assess water application uniformity of common low-head drip irrigation systems as a way of checking and comparing the level of performance and diagnosing constraints to help improve agricultural productivity.

The specific objectives were;

(i) To identify the common low head drip irrigation systems; layout design configurations used by smallholder farmers in low cost green houses in the field.

(ii) To assess the water application uniformity of common low head drip irrigation systems in the field.

(iii) To identify factors influencing water application uniformity in low head/gravity drip irrigation systems.

(iv) To make recommendations on how to improve water application uniformity of low pressure drip lines/tapes.

1.4 Justification for the study

Uniformity of water application is the critical output of an irrigation system. It is affected by both the water pressure distribution in the pipe network, which is a function of the systems design and by the hydraulic properties of the piping and emitters used as noted by Smajstrla A.G *et al*. The emitter hydraulics include the effects of emitter design, water quality, water temperature, and factors such as emitter plugging, and wear of emitter components. An assessment of pressure variations in the pipe network (hydraulic uniformity) and variations due to the emitter characteristic (emitter performance variation) and uniformity of water application in low head drip systems help in comparing and checking the level of performance and the corrections that may be required to improve the uniformity of water application. This study was considered relevant, important and urgent to assist farmers, irrigation specialists and extension providers make informed choice of system design (layout design configurations) and improve on management of low head drip irrigation systems to enhance agricultural productivity.

CHAPTER 2: LITERATURE REVIEW

2.1.1 Importance of irrigation

Irrigation is a method of delivering water to an area where it is needed, but not normally present in required amounts, for agricultural or landscaping purposes to either substitute or supplement the natural supply. The water supply is done through a set of interacting components forming an integrated whole referred to as a system. In agriculture, irrigation is done for the purpose of achieving increased agricultural productivity (quality and yield improvement). There are two sets of irrigation;

a. Total irrigation – rainfall as a natural water supply is not considered. This is the one practiced in green housing agriculture.
b. Supplementary irrigation – done to supplement rainfall to improve quality and increase yields.

2.1.2 Types of irrigation systems.

Irrigation systems can be classified in a number of ways based on the prime mover e.g pressurized systems (pump irrigation versus gravity driven irrigation systems), conveyance conduits used e.g canal versus piped irrigation systems, volume of water used e.g big or small irrigation systems, or how the water is applied. Based on how the water is applied, there are three types of irrigation systems;

a. Surface irrigation – involves applying water over the surface of the soil. The water is conveyed over the soil surface and infiltrates into the soil at a rate determined by the soils infiltration capacity. Surface irrigation methods include basin, border and furrow. Surface irrigation methods are not appropriate for porous soils such as sandy soils. In many circumstances only a half of the water applied by surface irrigation is utilized by the crops.
b. Sprinkler or overhead irrigation system;- This is where water is distributed by pipes under high pressure and sprayed into the air so that it breaks up into small water droplets that fall to the ground like natural rainfall. The sprinkler irrigation methods types include conventional

impact sprinklers, rain guns and center move/pivot. Compared to surface irrigation, the sprinkler system require less land leveling and can be adapted to sandy and fragile soils and require less labor. The sprinkler systems require higher energy to create high pressure to operate the sprinklers. The rate of water application, however, must be lower than the infiltration rate of the soil. The efficiency of the sprinkler irrigation system is estimated to be 70 to 75 percent.

c. Drip/trickle/micro-irrigation system applies water into the soil through a small opening directly on the soil surface or buried in the soil. Drip irrigation applies water at a very slow rate (0.2 to 20 l/h) to the roots of individual plants as desired and at a relatively low pressure. Water is applied close to the plant root so that part of the soil surrounding the plant root is wetted. The volume of soil irrigated by each emitter and the water flow along the soil profile is a function of the soil characteristics and the emission rate. Applications are usually frequent (every 1 - 2 days). Drip irrigation has an efficiency of about 90 to 95 percent. It can be used in fields with wide range of infiltration rates and where water is scarce and expensive.

2.1.3. Low head/cost drip irrigation development and adoption

The use of low pressure head drip lines/tapes irrigation technology has been in Kenya for the last 26 years. The technology was introduced by Mr. and Mrs. Gene Lewton of World Gospel Mission Missionaries from USA at Good Samaritan in Karen, Nairobi in 1988 as reported by Sijali I.V and Okumu R.A (2000). In 1996, the Kenya Agricultural Research Institute (KARI) in collaboration with Chapin Watermatics, manufacturer's of the drip tape (T-Tape), supported by USAID, embarked on promotion of low head (low cost) drip irrigation technology to small scale farmers. Small scale famers tend to look for irrigation technologies that they can understand and afford. The emergence of low head drip irrigation and cheaper greenhouse technology alternatives that small scale farmers can understand and invest in to grow crops for food and cash using little water has led to rapid and widespread adoption.

Emphasis is being put by the government, development partners' e.g UNDP, Community and Faith Based Organizations in promotion of low head drip irrigation alongside low cost green house technology. The effort is directly addressing the country's development blueprint of vision 2030 where irrigation is highlighted to play an important role in helping Kenya realize food security. The key elements or interventions which the government has put in place to meet the objective as reported by National Irrigation Board (NIB), (Daily Nation news paper, 18^{th} November 2012), are;

a. Accelerating availability of low head drip kits and supporting introduction of drip irrigation
b. Establishing the Irrigation Fund to support smallholder irrigation farming
c. Increasing availability of greenhouse kits at affordable prices in areas where they can be used
d. Increasing Water Harvesting in arid and semi arid areas and on general water storage including on farm storage in all areas.

2.2.1 Low head drip irrigation; components and types

The first low pressure drip irrigation system introduced into the country was the Bucket Kit using drip tapes from Chapin Watermatics. It comprises of a 20 litre water reservoir and two lines or laterals of 15m long. It was followed by the Drum Kit, KARI Drum Kit, Eighth-acre Kit, Wagon Wheel, Family Drip, Micro-Tal and ¼ acre Gravity (Agro Irrigation) systems respectively. All these drip kits have lateral length of 15m as described by Sijali I.V. (2001) except ¼ acre Gravity System which has a lateral length of 20m. Apart from the original system designs, modifications have been made leading to various numbers of laterals, lengths, and water heads (height of stand for water tank). The basic components of low cost drip irrigation systems comprise mainly of the following

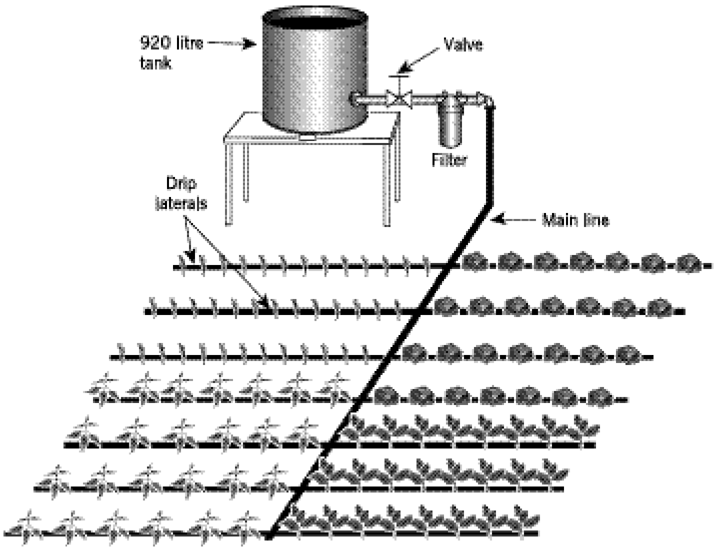


Fig. 2.1 Basic components of low pressure drip irrigation systems
(Source – Technical Handbook Series No. 24 by Sijali I.V)

(a) Water reservoir – tank mounted on a stand and filled water provide the amount of water required at the necessary pressure to distribute and push water out of the emitters. For gravity flow systems the height of water tank stands range from 0.5 m to 4 m. Drip irrigation systems operate within certain pressure ranges; depending on the operational pressure of the drip emitters. A drip system should therefore be set to meet the required demand in terms of water flow and pressure. Pressure gives the driving force for the water to be released from the emitters into the soil. For water at rest in a container, the maximum pressure (pressure is also referred to as "head") is the relative height of water above the point of measurements. An operating irrigation system has water flowing through the pipes, valves and other components resulting in continuous pressure loss as the distance from the source increases. The tank is periodically filled with water manually or by the use of a pump which abstracts water from the surface or from a well.

(b) Control valve – For a water system, valves may be required for pressure regulation, pressure cutout, flow division or system automation. In common low pressure head drip irrigation systems, control valves are mainly used to open, close and divide the water flowing through the system. There can be one or more control valves depending on the design layout of the system.

(c) Filter – to remove particles from the irrigation water that may clog the drip emitters. The filtering unit should be large enough to filter the flow rates required for the largest sub area. Operation and maintenance of emitters is affected by clogging. The relative sensitivity of a particular emitter to clogging is influenced by the dimensions and configurations of the flow passages. Inorganic material such as salt, silt, clay and chemical precipitates or organic materials such as algae and bacterial slimes can clog the passageways. Filters require back flushing time and again depending on the source of water used. There are two types of filters; (i) screen filters – is a type of filter using rigid or flexible screen to separate sand and other fine particles out of water in the range of 150 – 75 microns, (ii) media filters – to remove particle sizes in the range of 100 - 50 microns. (iii) nanofilters – are most often used in the purification of water with low total dissolved solids with the purpose of softening and removal of disinfection by-products precursors such as natural and synthetic organic matter. The drip kits in the market are fitted with screen filters of 120 microns.

(d) Main and sub- main lines – to convey the water and distribute to the laterals. They are usually made of plastic (PVC/PE), although steel pipes can also be used. The size depends on the required water flow. Large main lines are connected to smaller sub mains, which are in turn connected to laterals. For low pressure systems, they may just need a mainline.

(e) Drip laterals – to carry and distribute water to the emitters. The laterals are either drip lines or drip tapes. Drip tape is a type of thin walled dripper line with emitters embedded along its length at fixed spacing used in drip irrigation. Drip line, compared to a drip tape, is a thick walled tube, made from heavy-duty polyethylene, with emitters embedded along its length at fixed spacing. To get good water distribution uniformity it is important to keep the laterals as short as possible.

(f) Emitters or drippers – to discharge/emit water from the laterals to the soil near the root zones. Typically emitter flow rates are from 0.6 - 16 l/h (0.16 to 4.0 gph). In many emitters, flow will vary with pressure, while some emitters are pressure compensating - these employ silicone diaphragms or other means to allow them to maintain a near – constant flow rate over a range of pressure and elevations. Line-source emitter is a tube or drip line/tape with the individual emitters embedded (pre-installed) in the tube or drip line/tape. The line-source tubing serves both as the lateral pipe and the emitters. The emitters are normally spaced at intervals of 15 20, 30, 45 and 60 cm along the lateral. The variation in emitter discharge rates between individual emitters and the average discharge for the lateral should not exceed twenty percent. Along a drip lateral, the average difference in emitter discharge for the lateral should not exceed ten percent. The required operating pressure ranges from 2 to 30 psi (1 psi = 0.7m and 1 bar = 100 kPa = 0.987 atmosphere at sea level = 14.5038 psi), with pressures of 10 psi to 15 psi (1 bar) being most common. For the gravity systems, pressures of 2 to 6 psi (1.4 to 4.2 m) are most common (head in m x 1.42 = psi). Line-source emitters also work well for small fruits, vegetables and row crops. Line-source emitters are selected so the emitter spacing chosen provide nearly uniform wetting of the root zone within each row of plants. Emitter spacing should not exceed the wetted diameters of given soil types. Emitter spacing that are less than wetted-diameter criteria are fine, especially for close growing crops. The line-source emitter spacing of 30 cm for close growing crops in Kenya is most common as recorded by Sijali I.V (2001).

2.2.2 Sources of drip lines/tapes and kits in the market

The sources of drip lines/tapes and kits in the market are; Amiran Kenya Ltd., G. North and Son, IRRICO International, Agro Irrigation and Pumps Services, Belba Ltd, Twiga Chemicals, Greener Earth Technologies, Hortipro Ltd, Shade Net/Victoria, KARI and Kenya Rainwater Association (ICRAF). Whereas all the sources only do distribution, Shade Net Ltd is the only locally

based company which does manufacturing of drip tape (16 mm) and other associated accessories. Amiran Kenya Ltd sells products mainly from Netafim, an Israel based company, well known for drip irrigation. Some of these companies are also the distributors of greenhouse materials and kits.
The photographs and specifications of some of the low pressure drip line/tapes are as shown in the figure 2.2 and table 2.1 below;

Fig. 2.2 (a) Drip line

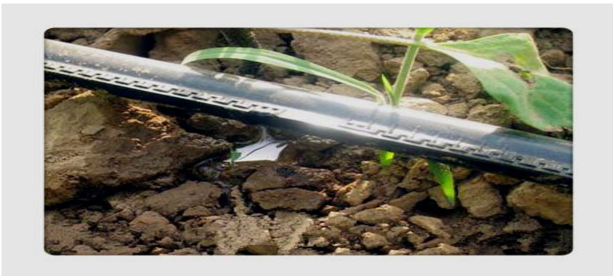


Fig. 2.2 (b) Labyrinth drip tape

Fig. 2.2 © Drip tape with flat emitter

Table 2.1: Specifications of drip lines/tapes

	Cylinder drip line	Labyrinth drip tape	Drip tape with flat emitter
Diameter (ID)	6, 12, 16 mm	12,16 mm	12,16 mm
Wall thickness	0.6 – 2 mm	0.2, 0.3 mm	0.15 – 0.6 mm
Dripper spacing	20 – 50 cm	20, 30, 40,60 cm	20, 30, 40, 60 cm
Pressure	0.6 – 4 bars	0.4 - 1.5 bars	1 bar
Flux (Flow rate)	1.3 – 3 l/h	2, 3, 4 l/h	1.3, 2.2, 2.79, 3.0 l/h
Roll length	500, 600, 800,1000 m	200, 500, 600 m	1000,1500, 2000, 2500m

Source; www.omenco.com, (accessed on 10th December, 2012).

The recommended emitter flow rates for spot watering emitters pre-inserted in 6mm drip lines and16mm drip tapes are 1 l/h (0.25gph), 2l/h (0.5 gph), or 4 l/h (1gph) for vegetable growing depending on the type of soil. (http://www.irrigationtutorials.com/dripirrigation-emitters accessed on 14th December, 2013)

2.2.3 Indicators of performance in drip/trickle irrigation.

Irrigation systems are generally rated with respect to application efficiency, which is the fraction of the water that has been applied by the irrigation system that is available to the plant use. The drip irrigation water application efficiency is about 90 to 95 percent. It is the most important indicator on how well the water is distributed through the emission/discharge points supplying water to the plants as noted by Smajstrla A.G *et al*,(2012). Drip systems do not reduce the crop water requirement, but usually increase evapo-transpiration (water consumptive use) because water is applied frequently in small quantities. An efficient drip irrigation system should apply/emit water uniformly along a drip line/tape (lateral). Low emission uniformity (EU) leads to either over-irrigation and or under-irrigation along different sections of the laterals and hence low irrigation efficiency as observed by Hassan F.A., (Undated). Over- irrigation is said to occur when more water than the required amount is applied resulting in flooding and deep percolation. Under-irrigation occurs when less than the required amount of water is applied by an irrigation system to plant root zones resulting in poor root development and crop failure. The EU can be thought of as distribution uniformity (DU), which is the amount of water applied at the point receiving the least water to the average amount applied. The uniformity of water application from micro irrigation system is affected both by the water pressure distribution in the pipe network and by the hydraulic properties of the emitters used. The emitter hydraulic properties include the effects of emitter design, water quality, water temperature, and other factors on emitter flow rates. Factors such as emitter plugging and wear of emitter components will affect water distribution as emitter age. There are three useful tests to evaluate the performance of drip irrigation system: (1) overall water application uniformity; is a measure of how evenly the volumes of water are applied from each emitter (2) hydraulic uniformity; refers to the effects of pressure variation on the uniformity of water application from a micro irrigation system and (3) emitter performance variation; this refers to non-uniformity in water application that is caused by the emitters. These tests should be performed in the order indicated because, if the overall water application uniformity is high, there is no need for further tests as recommended by Smajstrla A.G *et al*. (Reviewed January 2012). In other systems, distribution uniformity is usually defined in relation to the average amount of water applied to the quarter of the field receiving the least amount of water. EU is however recommended by Shufang Jiang and Kang Y., (2010) for evaluation of micro irrigation system uniformity by ASAE 2003 standards. In evaluating the EU, the two most important variables in consideration are emitter flow rate and pressure and maintaining other factors such as pipe size, and configuration constant. The equations which have been widely used in the evaluation of EU and flow variation (CV) in drip irrigation as reported by American Society of Agricultural Engineers, (ASAE), 1996a and 1996b; Senzanje *et al*, (2004), Shufang Jiang *et al*, (2010), and Smajstrla A.G *et al*, (2012); are as follows;

$$EU = \frac{Qmin}{Qavg}(1 - 1.27CV)100. \quad \textbf{(2.1)}$$

$$CV = 1 - \frac{Qmin}{Qmax} \quad \textbf{(2.2)}.$$

Where Q_{max} = maximum average flow rate calculated from 1/6 of the number of data points fastest times or highest volumes measured. That is, divide the number of data points by 6. For example, if 30 data points were measured 1/6 of this is 5.

Q_{avg} = average of all emitter discharge (flow rate) measured

Q_{min} = the minimum average flow rate calculated from 1/6 of the number of data points slowest times or lowest volumes measured

CV = statistical coefficient of variation of emitter discharge rate. It is defined as the standard deviation of the emitter flow rate divided by mean value of emitter flow rate. Its formula is as shown in equation 2.2 above.

From equation 2.1, when the coefficient of variation in emitter flow rates increases, the uniformity of water application decreases.

The general performance evaluation criteria for EU values, adopted from ASAE, 1996(a), are > 90%, excellent; 80-90%, good; 70 - 80%, fair and < 70%, poor. The general criteria for CV values recommended by ASAE 1996(b) for line-source are: ≤ 10%, good; 10 - 20%, average; and ≥ 20%, not acceptable.

Since it is not easy to collect the discharge from all the emitters along the drip laterals, sampling of the data points is necessary for estimation as recommended by Smajstrla A.G *et al*. (Reviewed January 2012). To accurately determine uniformity, the data points should be made of a minimum of eighteen points located throughout the irrigation zone. More may be required for greater accuracy. Computation is simplified if the number of points is measured as a multiple of six.

2.2.4 Previous low head Drip irrigation evaluation studies.

In the study of technical evaluation and development of low head drip irrigation systems in Kenya by Ngigi S.N. (2008), the focus was on the flow variation, emission uniformity and adaptation of existing systems. This was a laboratory experiment and it concluded that the combined effects of water head, land slope and lateral length affect the performance of drip lines/tapes. EU increases between 0.5 to1 m but has no significant change between 1 to 1.5 m. It decreases drastically as the land slope increases and gradually with increase in lateral length beyond 15 m. Another study on evaluation of low head drip irrigation kits in Zimbabwe by Chigerwe, *et al*. (2004), concluded that farmers can opt to invest in low head drip systems with line-source emitters with flow rates less than 0.3 l/h. Evaluation of the effects of pressure variation in the drip irrigation laterals (hydraulic uniformity) and variations due to the emitter characteristics (emitter performance variation) on uniformity of water application are key tests as seen by Smajstrla A.G *et al*. (Reviewed January 2012). Another study by Deba P.D (2008) noted that low pressure data for drip emitters are not available from the manufacturers. The study concluded that except for Netafim product, all other tested products (emitters) were effective under low operating pressures as were under high operating or recommended pressures. Netafim product had no emission under low pressures. A study by Sharma P., (2013) found that line-source emitter of 1.3 lph capacity and optimal pressure 100 kPa is required to achieve uniformity coefficient of 85% and emission of 85.81 per cent respectively. Manufacturing coefficient of variation for the 1.3 lph capacity emitter was 0.128 respectively. Knowing these factors help in identifying the causes of low water application uniformities and the correction that may be required. EU equal to 90 percent are typically used for new system design and could be designed for values up to 95 percent, but field topography can cause the design values to be as low as 75 percent as recorded by Westlands Water District (2001). (www.westlandswater.org/resources/wmh/evaluation.pdf accessed on 15th December, 2013).

2.2.5 Drip irrigation intervals

The irrigation period is dependent on the flow rates within the system. The emitter flow rate is a function of the pressure head which provide the energy driving the water in the system. In order to maintain proper optimum soil-moisture regime, amount of water should be applied at the right frequency depending on the type of soil and the stage of crop growth (3 - 7 mm/day). Most soils can't absorb the higher flow rates, so the extra water tends to puddle around the emitter where it evaporates, or it may even run off into the gutter. With drip irrigation the desire is for the water to be immediately absorbed into the soil as it comes out of the emitter. If the soil is sandy, the use of emitter with a flow rate of 4.0 l/h (1gph) or higher is recommended. In sandy soils the water tends to just go straight down the soil, using a higher flow rate will force water to move sideways further.

CHAPTER 3: METHODOLOGY

3.1.1 Study area

This research was conducted in Trans Nzoia West; comprising of Saboti and Kiminini sub counties of Trans Nzoia County, Kenya. The area is about 380 km North West of Nairobi and lies at an average altitude of 1800 m above sea level. It is classified as agriculturally high potential area. Many smallholder farmers in the area, like in other parts of the country are embracing the use of low head drip irrigation alongside low cost greenhouse farming for vegetable production.

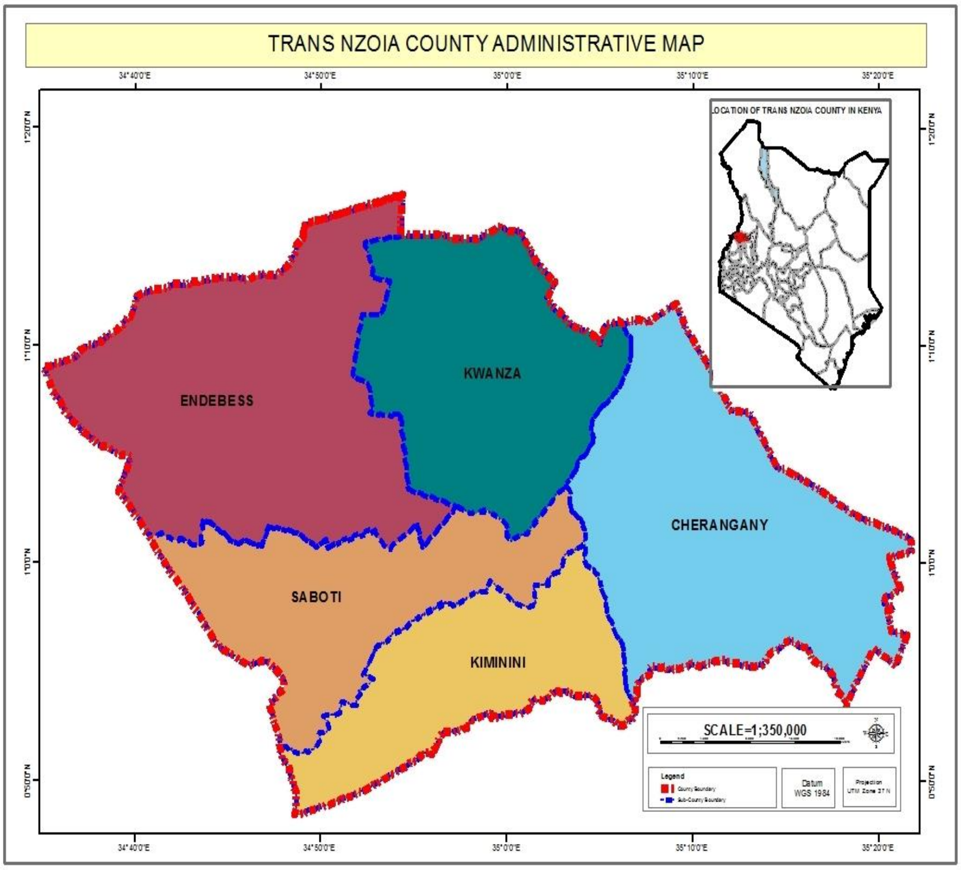


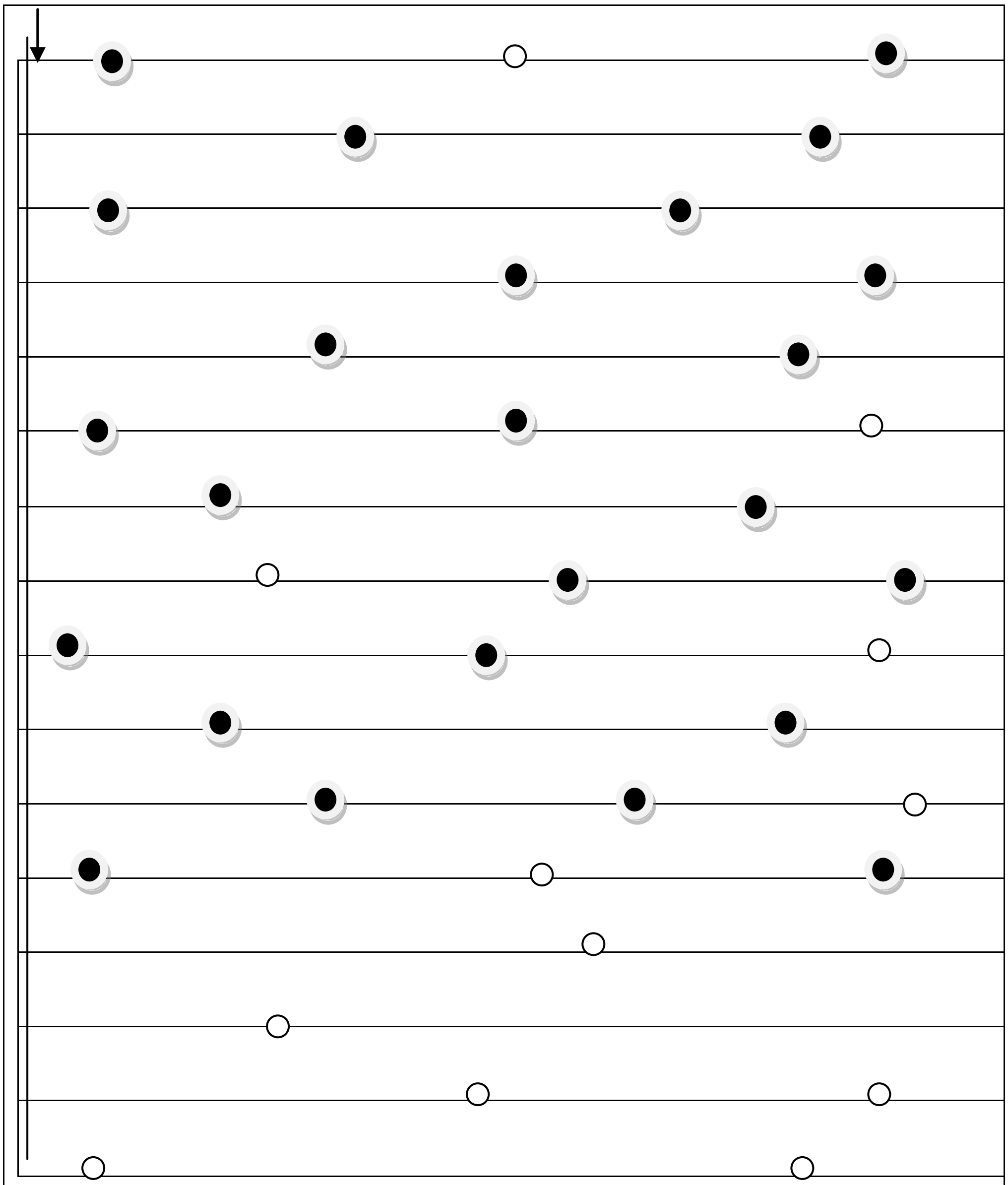
Fig. 3.1: Map of Trans Nzoia County showing sub-counties

3.1.2 Experimental design and Sampling

Low-head drip irrigation systems with common lateral emitter spacing of 30 cm in operation (with crop in season) in the smallholder farms were identified using a list drawn from the field by the help of field agricultural extension officers from Trans Nzoia West sub-counties who had earlier been briefed and asked to gather information about the low head drip irrigation systems alongside greenhouse farming in their extension units. From the list drawn from the field, categorization of the systems was done on the basis of system design; layout configuration, height of water tank stand, length of lateral, type and size of drip tubes and number of emitters per 30cm spacing. Six categories (treatments) identified were coded using letter T_i (i = 1, 2, 3 . . , 6) as shown in table 4.1.

From the list of the categorized systems, the ones with crop in season were used for the study. This was done to avoid selecting systems which would otherwise have a problem when the owner was asked to put water into the tank for the purpose of the study only. The selection was done in such a way that four replications of each identified categorized system in different farms were sampled. Since every sample of each category was assigned to the farms at random, the experimental design was a completely randomized design (CRD). For every sample of each category, thirty data points (water discharge points), to increase accuracy, were sampled using numbered short pegs to help in capturing data without any omission following a sampling pattern guide developed to help in repeating the process of sampling in the irrigation area as shown in figure 3.2 below.

The data points represented the emitters from which the discharges along the systems laterals were collected and sampling was done to give fair representation of all the emitters in the laterals in the system. Care was taken to distribute the sampling data points throughout the irrigated area; some points were located near the inlet, some near the center and some at the distant end. However the specific sampled data points were randomly selected at each location along the laterals and to avoid being influenced by the appearance of the emitter as it operates, sampling and marking data points using marker pegs was done before the irrigation system was turned on. For laterals with double emitters, the first one in the direction of water flow at the sampled point was used as the data point.



KEY

● Sampling marker peg for twelve laterals

○ Sampling marker peg for twelve and for four additional lines for sixteen laterals

Fig. 3.2: Sampling pattern guide

3.3 Data Collection

3.3.1 Data type, materials and equipment

This study involved the collection of the following; volume of water (10 ml) emitted from sampled emitters along the laterals and time taken to fill the 10 ml catch cans (drug dispensers). Timing was done using a stop watch. The common low pressure drip irrigation systems used by farmers in the study have drip laterals with factory embedded line-source emitters i.e the emitter(s) cannot be replaced without changing the entire lateral. The cylindrical drip lines used are 6mm internal diameter and 2mm thick PE pipes with factory Netafim Techline pre-inserted short path or turbulent non pressure compensating (NPC) flow emitters with flow rates of 1.3 l/h spaced at 30 cm. The drip tapes are 16 mm diameter and 0.2mm thick wall with Toro Drip pre-inserted short path NPC flat emitters with flow rates of 1.3 l/h and spaced at 30 cm. The other information recorded was length of laterals, and height of stand for water tanks. Some primary information was obtained using informal semi-structured interviews listed in the data collection sheet in Appendix A. The time taken to fill each catch can was used to obtain the minimum, maximum and average discharges for the sample of each category. The secondary data obtained from journals and other reference materials for the purpose of this study was used in the analysis and interpretation of results.

Table 3.1: Data type, materials and equipment

Data Type	**Materials and Equipment**
Primary Data; Type, size, length and number of emitters per spacing on lateral. Time (seconds) taken to fill cans, number and length of laterals, height of tank stand. Also, extraneous information collected during the study was considered while interpreting the final results	Measuring tape, two stop watches, four catch cans (10 ml of drug dispensing cups), thirty marker pegs, penknife, and field bag.
Secondary Data; EU and CV equations, statistical tables, ASAE performance standards,	Reference materials; journals, text books, unpublished research report

3.3.2 Data collection method

Data collection was done in the field from the various sampled smallholder low head drip irrigation systems with crop in season. Data points were sampled and marked with numbered marker pegs using the sampling pattern guide developed for the exercise shown in figure 3.2. The marker pegs were fixed in the sampled points without following any order of numbering. The pegs were numbered to assist in capturing the discharges from the data points without any omission. By the use of 10 ml catch can (medicine dispensing cup) and stop watch, the time taken by each sampled emitter to fill the cup was recorded on the data sheet whose sample is shown in appendix A. For systems with double emitters per spacing, a discharge from the first emitter in the direction of water flow along the lateral was used as the data point. Timing of discharges from the sampled system was done five minutes after turning on the water supply to allow for the flow in the piping network become steady. Any point which was completely blocked was recorded zero. To avoid over irrigation, since the number of data points were many, two assistants were trained and assisted in timing and the third person recorded the data. The data for each sample was recorded in a data sheet to help in ensuring that all the information required (measured, observed and obtained using semi-structured interviews) was captured. The data obtained was processed and analyzed to assess the overall water application uniformity of the low head/cost drip irrigation systems in the smallholder farmers' fields.

3.3.3 Data Analysis

The recorded time taken to fill the 10 ml cup for every data point of each sampled system was arranged in ascending order (ranked) using an excel spreadsheet. From the result obtained, the outliers', the very smallest and longest time not consistent with the rest of the recorded time were left out. These outliers' represented points where the emitters were defective, seriously partially or fully plugged. A period of thirty seconds time lag from the rest of consecutive ranked data was used to identify the outliers from the sampled points. With the help of spreadsheet as shown in table 4.2, the average flow rates (Q), in ml/s, were calculated. The following steps were used to get the average, maximum and minimum discharges for each sample;

1. Calculated 1/6 of the number of emission data points measured i.e 30/6 = 5. This is the number of the fastest and slowest data point times used to calculate the minimum and maximum flow rates for each sample.
2. From the set of ranked data, the average time for the five fastest data points, leaving out the outliers, was used to calculate the average maximum discharge (Q_{max}).
3. From the set of ordered data, the average time for the five slowest data points was used to calculate the average minimum discharge (Q_{min}).
4. From the set of ordered data, the average discharge (Q_{avg}) was calculated.

The values of Q_{max}, Q_{min} and Q_{avg} obtained from each sample were used to calculate their CV and EU using equation 2.2 and 2.1 respectively. The average EU values were then calculated from all the four samples for each category and used to evaluate the performance according to the ASAE 1996(a) performance standard criterion for line-source emitters. Also since the objective of study was to check and compare the performance, the values were used to test a hypothesis that the mean EU is statistically equal across the design configurations using Analysis of variance (ANOVA) at 95% confidence interval. ANOVA is a statistical test used to determine if more than two population means are equal. In the ANOVA setting, the observed variance in a particular variable is partitioned into components attributable to different sources of variation. The test uses the F-distribution (probability distribution) function and gives information about the variances of each population (among) and grouping of populations (between) to help decide if variability between and among each populations are significantly different. The F ratio is the ratio of two mean square values. A confidence interval is the interval or range of values that most likely encompasses the true population value. The lower and upper limits of this interval are termed confidence limits. Since the observed difference is never 100% true, a commonly accepted level of 99% or 95% are used in the computation to allow that the conclusion have occurred by chance. A choice of 95% confidence interval means that there is less than 5% likelihood that the observed difference occurred by chance. The result of the analysis and the observations made during data collection was used to assess water application uniformity.

CHAPTER 4: RESULTS.

4.1.1 Identified common low head/cost drip irrigation systems

The common low head drip irrigation system design layout configurations adopted by smallholder farmers alongside low cost green housing technology identified were as described in table 4.1 and illustrated in figures 4.1(a), 4.1(b) and 4.1(c) below

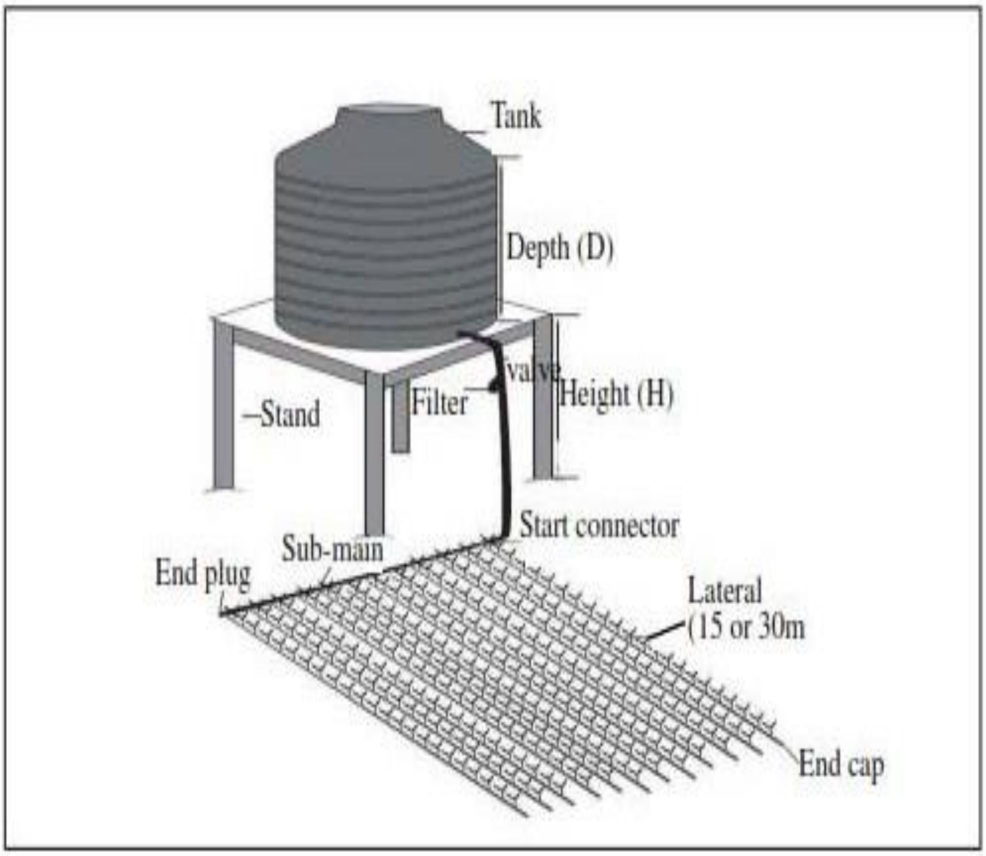


Fig. 4.1(a) Design configuration for categories coded T_1, T_2, T_4 and T_5

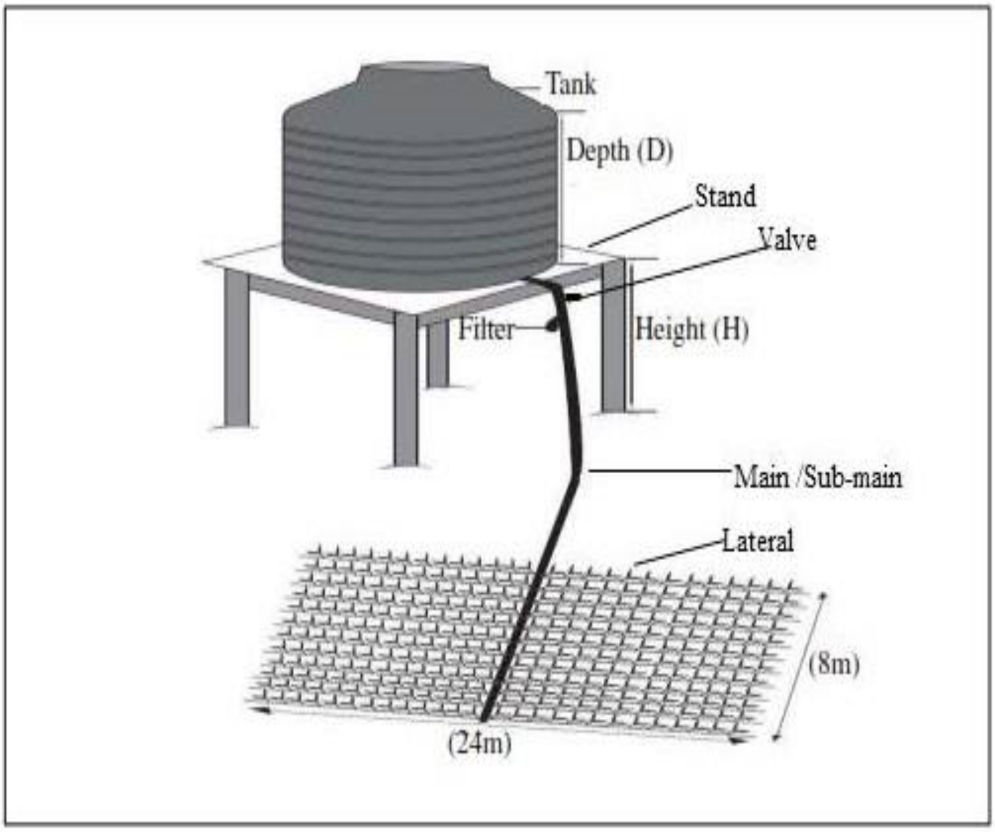


Fig. 4.1(b) Design configuration for category coded T_3

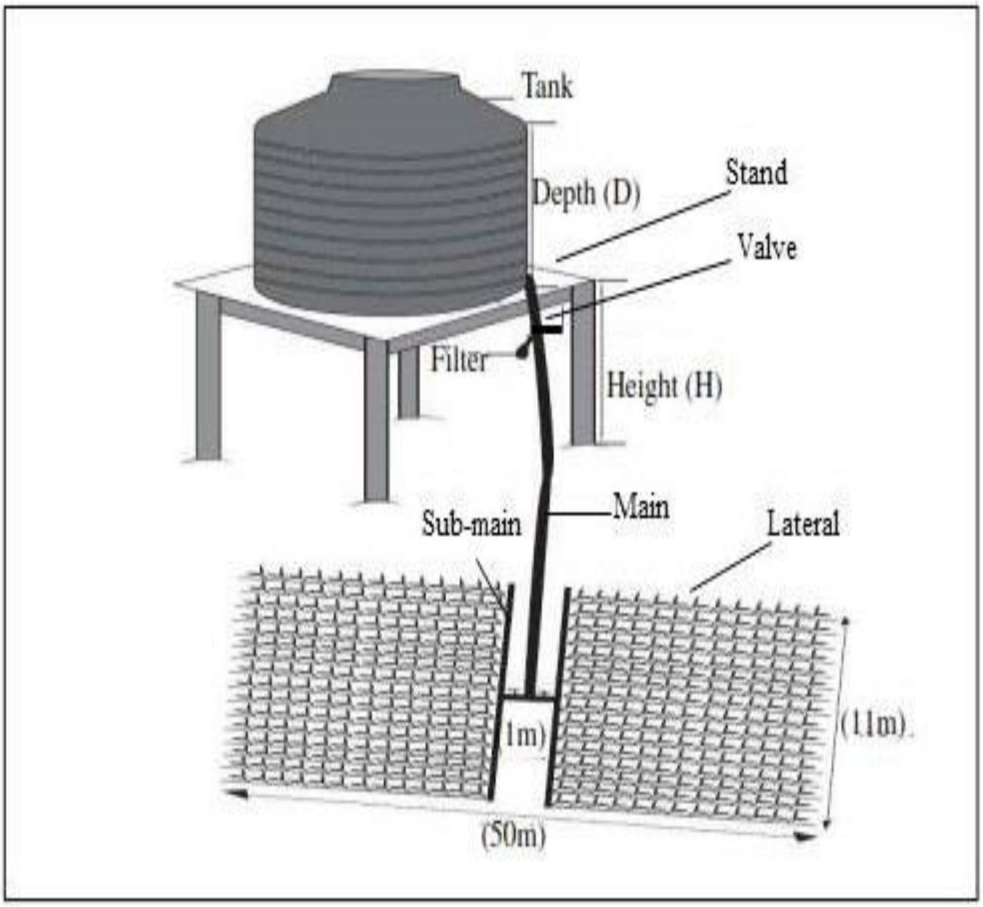


Fig. 4.1© Design configuration for category coded T_6

4.1.2 Categorized low head design system layouts for the study

The identified systems were categorized and coded using letter T (T_1, T_2, T_3, T_4, T_5 and T_6 for categories 1 to 6 respectively) as shown in table 4.1 below.

Table 4.1: Categorized common low head drip irrigation systems

	Category					
	T_1	T_2	T_3	T_4	T_5	T_6
Type of lateral	Drip line	Drip tape	Drip line	Drip tape	Drip tape	Drip tape
Size of lateral (mm)	8	16	8	16	16	16
Emitters per 30cm spacing	1	2	1	1	2	1
Length of lateral (m)	15	15	12	30	30	22
Height of tank elevation (m)	1.5	2	1.5	2	2.5	2.5
Total number of emitters	552	1104	888	1104	2208	1216
Design layout illustration reference	Fig. 4.1a (8mx15m)	Fig. 4.1a (8x15)	Fig. 4.1a (8x15)	Fig. 4.1a (8x30)	Fig. 4.1a (8x30)	Fig. 4.1c (11x24)

N.B All categories have twelve laterals except T_6 which has sixteen. The measurements in bracket in the last row refer to the width of the sub mains and length of the laterals in meters respectively.

4.2 Water application uniformity of low head drip irrigation systems

The individual processed and analyzed data for each category and their summarized analysis are as shown in tables 4.2 to 4.5 below.

Table 4.2: Data for Sample number 3 of category T_1

Data point	Time to fill 10ml cup (s) - ranked
12	39.53
26	40.75
11	40.95
4	41.9
25	41.25

29	41.37
22	41.38
5	41.71
13	41.75
6	41.81
3	42.03
15	42.17
30	42.25
21	42.56
19	42.75
24	42.9
17	42.93
7	43.09
27	43.1
20	43.16
2	43.26
16	43.32
14	43.53
23	43.88
9	43.96
18	44
1	44.13
8	45.32
28	47.37
10	48.63
Avg time (s)	42.8643
Avg.Q in ml/s	0.2333
Avg.Q_{max}	0.2456
Avg.Q_{min}	0.2195
CV	10.63% or 0.11
EU	80.9%

N.B How CV and EU in the table above were calculated for the sample. From Equation 2.2, CV= 1- Q_{min}/Q_{max} = 1 - 0.2195/0.2456. = 0.11 or 11%. And from eq. 2.1, EU = $Q_{min}/Q_{avg}(1-1.27CV)100$ = 80.9%.

Table 4.3: Summary for sample No. 3 of Category T_1

T_1	Median time (s)	Mean time(s)	Q_{avg} (ml/s)	Q_{max} (m/s)	Q_{min} (m/s)	CV (%)	EU (%)	Otl
1	41.87	42.4107	0.2358	0.2641	0.2107	20.21	66.44	1
2	38.84	38.9845	0.2565	0.2681	0.2416	9.88	82.38	1
3	42.825	42.8643	0.2333	0.2456	0.2195	11	80.9	0
4	40.75	41.0254	0.2438	0.2618	0.2235	14.66	74.61	2
Avg.		41.32	**0.2424**	**0.2599**	**0.2238**	**13.89**	**76.19**	

Table 4.4: Summary of analyzed data for all categories

	Category					
Attribute	T_1	T_2	T_3	T_4	T_5	T_6
Mean time (s)	41.32	68.95	42.75	56.32	55.08	50.18
Q_{max} in ml/s	0.2599	0.1847	0.2574	0.1955	0.2417	0.2225
Q_{min} in ml/s	0.2238	0.1159	0.2087	0.1615	0.1192	0.1770
Q_{avg} in ml/s	0.2424	0.1494	0.2346	0.1767	0.1817	0.2015
Avg. CV (%)	13.89	37.96	19.07	17.26	50.68	22.17
Avg. EU (%)	76.19	40.36	72.49	70.76	32.42	65.23
Avg. emitter flow rate (l/h)	**0.873**	**0.522**	**0.842**	**0.636**	**0.654**	**0.725**

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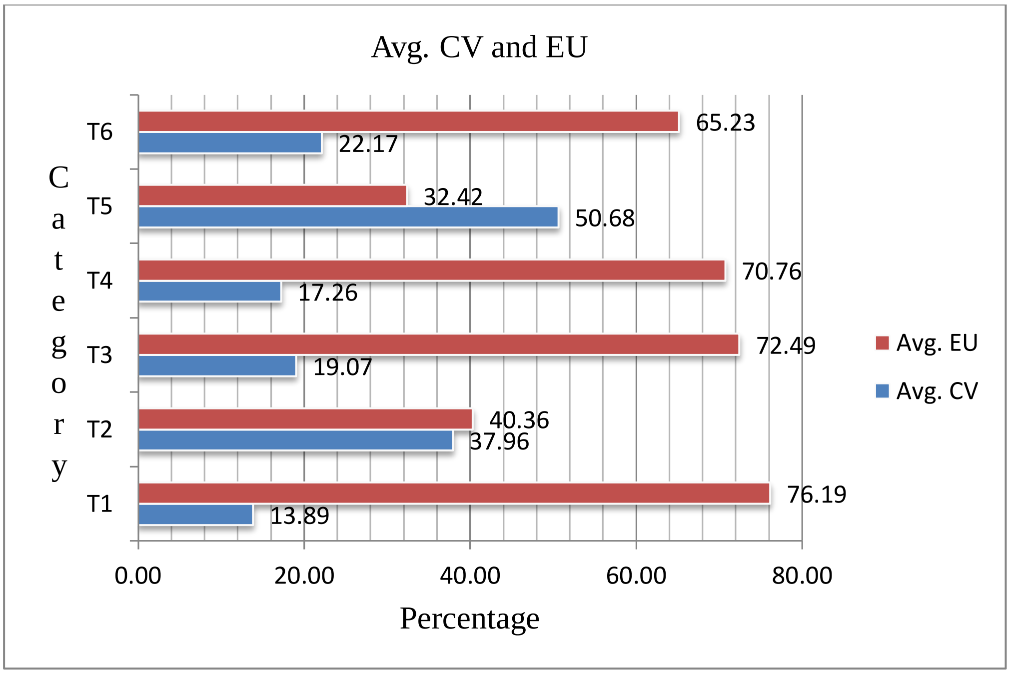

Fig.4.2 Average %CV and %EU

Table 4.5: EU performance based on ASAE standard criterion;

Category	% CV	Performance	% EU	Performance
T_1	13.89	Average	76.19	Fair
T_2	37.96	Not acceptable	40.36	Poor
T_3	19.07	Average	72.49	Fair
T_4	17.26	Average	70.76	Fair
T_5	50.68	Not acceptable	32.42	Poor
T_6	22.17	Not acceptable	65.23	Poor

4.2.1Analysis of variance

In this study the objective was to check/compare the mean EU of the six treatments (categories). Hence the null hypothesis was that the six systems have equal mean EU i.e $H_0 : \mu_1 = \mu_2 = \mu_3 = \ldots\ldots = \mu_{6.}$ And the alternative hypothesis was that at least one mean is not equal i.e, $H1: \mu_1 \neq \mu_2 \neq \mu_3 .. \neq \mu_{6.}$

The following data in table 4.6 below was used in the analysis of variance.

Table 4.6: Average % EU values for ANOVA.

		Category						
Sample	T_1	T_2	T_3	T_4	T_5	T_6		**Total**
1	66.44	35.06	68.2	75.85	32.66	64.47		**342.68**
2	82.38	52.91	74.79	70.07	33.68	67.58		**381.41**
3	81.34	42.28	72.04	68.12	35.02	61.06		**359.86**
4	74.61	31.19	74.91	70.19	28.32	67.8		**347.02**
Total	**304.77**	**161.44**	**289.94**	**284.23**	**129.68**	**260.91**		**1430.97**
Avg.	76.19	40.36	72.49	70.76	32.42	65.23		

The following notations are used;

N = the total number of replicates in the experiment = 24

t = the number of treatments in the experiment = 6

n_i = the number of samples that received treatment i, $i = 1,2,..,t$

r = the number of samples for the treatments = 4

j_i = the number of sample replicates i, i = 1, 2, .., r

Thus $N = \sum n_i$

SS_{total} = Total Sum of Squares

$SS_{between}$ = Between Sum of Squares

$SS_{treatment}$ = Treatment Sum of Squares

SS_{err} = Error Sum of square for error

$SS_{total} = SS_{treat} + SS_{error} + SSBlock$

$$\frac{\left(\sum x\right)^2}{N} = \text{Correction Factor (C.F)}$$

$$\frac{(1430.97)^2}{24} = \text{C.F} = 85319.8$$

To obtain the total sum of squares treatment (categories) we require the total % EU for each sample.

$$SS_{total} = \sum x^2 - \frac{\left(\sum x\right)^2}{N}$$
$$= 66.44^2 + 74.61^2 +,..,+ 67.8^2 - CF$$
$$= 92726.80 - 85319.80$$
$$= 7407$$

Let B_j stand for the total of the EU in sample j. We now have the sum of squares between to be

$$SSBlock = \frac{\sum B_j^2}{t} - C.F$$
$$= \frac{342.68^2 + 381.41^2 + 359.86^2 + 347.02^2}{6} - 85319.80$$
$$= 85470.878 - 85319.80$$
$$= 151.08$$

If T_i represents the total % EU in the experiment for treatment t_i then,

$$SS_{treatment} = \sum \frac{T_i^2}{n} - CF$$

$$= \frac{304.77^2 + 161.44^2 + ... + 260.91^2}{4} - 85319.80$$

$$= 92172.61 - 85319.80$$

$$= 6852.81$$

And to get the sum of squared error;

$$SS_{error} = SS_{total} - SSBlock - SS_{treat}$$

$$= 7407 - 151.08 - 6852.81$$

$$= 403.11$$

Since it follows the F-distribution, for treatment F_{ratio} = MS/MS_{Error} and the F-table = $F_{0.05,(df1,df2)}$, where d.f means degree of freedom and 1 and 2 refer to the numerator ($_{v1)}$ and denominator (v_2) respectively as referenced in the statistical table.

Hence, F-table for treatment = $F_{0.05,(5,15)} = 3.58$. Similarly F-table for among sample is $F_{0.05,(3,15)} = 4.15$.

Table 4.7 shown below shows the summarized computation of ANOVA.

Table 4.7: Analysis of variance

Source of variation	Degree of freedom (d.f)	SS	MS	F-ratio (computed)	F-table (5%)
Among (Block)	4-1 = 3	151.08	151.08/3 = 50.36	1.87	4.15
Treatment (Between)	6-1 = 5	6852.81	6852.81/5 = 1370.62	51.01	3.58
Error (within)	(4-1)(6-1) = 15	403.11	403.11/15 = 26.87		
Total	24-1 = 23	7407			

Since F-ratio > F_{-table} i.e 51.01 > 3.58, we reject the null hypothesis. Also, since F-ratio is much larger than one i.e 51.01 >> 1, it shows that there is significant difference between the mean EU of the six categories. For variation among the samples, since F-ratio < F-table, i.e 1.87 < 4.15, there is no statistical difference among mean EU samples of the treatments.

Determination of which mean(s) Is/Are Different

Since the null hypothesis is rejected, a separate test was done to determine which mean(s) are different. The most common test is the Least Significant Difference test (LSD).

LSD = $\sqrt{\frac{2MSEF}{r}}$, F is at $F_{(1,df)}$ i.e $F_{(1,15)}$ = 4.54, from the F table. The letter r is the rows i.e number of replicates for the treatments and d.f is for error

Hence LSD = $\sqrt{\frac{2(26.87)4.54}{4}}$

= 7.81

For pair wise, $T_1 - T_2$ = 76.19 – 40.36 = 35.83 > 7.81 and $T_2 - T_4$ = I-30.4I > 7.81

Table 4.8 below shows the pair wise comparisons of mean EU of the categories. The value absolute of the mean EU difference between pair treatments greater than 7.81 in the columns marked X in the table, are not statistically equal.

Table 4.8: Pair wise comparisons of mean EU

$T_1 - T_2$	$T_1 - T_3$	$T_1 - T_4$	$T_1 - T_5$	$T_1 - T_6$	$T_2 - T_3$	$T_2 - T_4$	$T_2 - T_5$
35.83	4	5.43	43.77	10.96	-32.13	-30.4	7.94
X			X	X	X	X	X

$T_2 - T_6$	$T_3 - T_4$	$T_3 - T_5$	$T_3 - T_6$	$T_4 - T_5$	$T_4 - T_6$	$T_5 - T_6$
-24.87	1.73	40.07	7.53	38.34	5.53	-32.81
X		X		X		X

Calculation of Confidence Interval

The confidence interval for a single mean, μ_i, follows a t-distribution and is given by

$$\bar{x}_i \pm t_{(\alpha/2, d.f.(error))}\sqrt{\frac{MSE}{r}}$$

Where r is equal to the number of blocks or replicates.

Hence for T_1, $\bar{x}_1 = 76.19 \pm t_{(0.025,15)}\sqrt{\frac{26.87}{4}}$ = $76.19 \pm 2.13(2.59)$

$= 76.19 \pm 5.52$.

From the result, it shows that the range or variability of sample mean EU for treatments in the study is 5.52% at 5% level.

For T_1, the upper and lower mean EU limits are 81.71% and 71.67% respectively. The confidence intervals for single mean for other categories were calculated in a similar way and the results are as shown in figure 4.3 below.

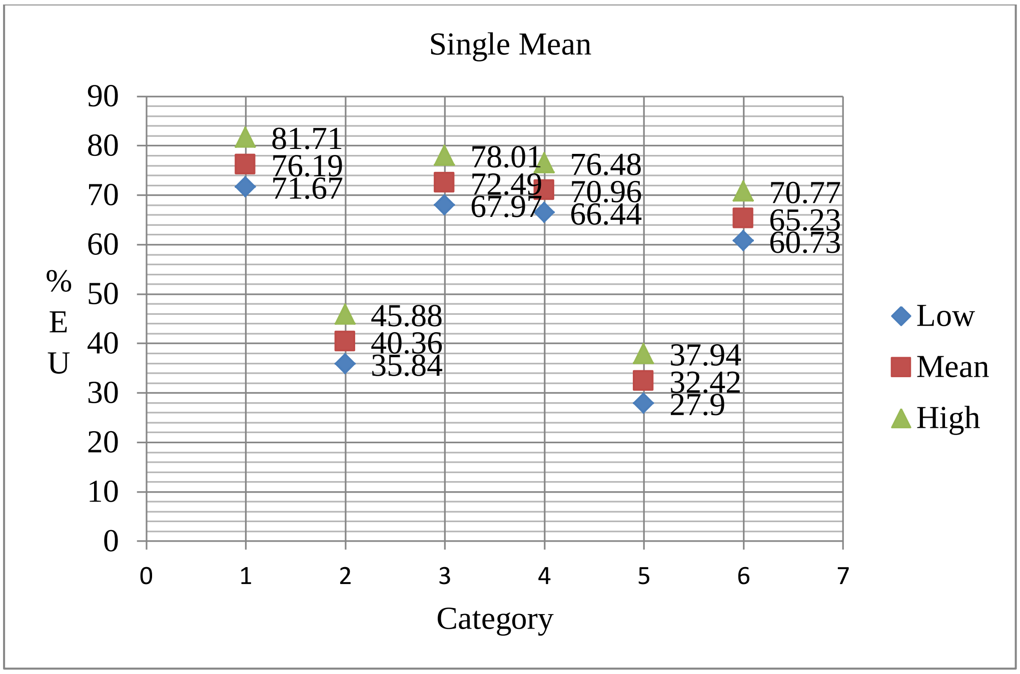

Fig. 4.3 Single mean at 95% confidence interval

The figure shows the upper and lower limits for mean EU at 95% confidence interval.

4.3 Identified factors affecting water application uniformity

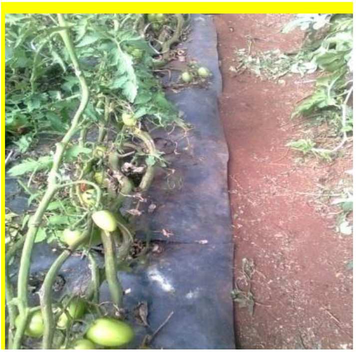

Fig.4.4 (a) Laying of tomato fruits on drip tapes affect EU

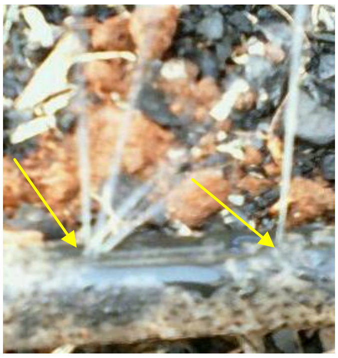

Fig.4.4 (b) Defective emitters

Fig. 4.4 (c) Clogged filter

Fig. 4.4(d) Filter after cleaning

Fig. 4.4(e) Start connector not parallel to the bed restricts water flow

Fig.4.4 (f) Start connector parallel to the ground

Fig. 4.4(g) Knocking of clogged emitter using a short peg

CHAPTER 5: DISCUSSIONS

5.1 Identified common low head drip irrigation systems

This research identified three common low head/cost classified irrigation systems used in low head/cost greenhouses in the field. The systems are Chapin, Family and Micro-Tal. The distinguishing factor between the systems is the layout arrangement of the laterals from the main or sub main supply and not the type of drip tube or emitters used. The categories identified for the purpose of this research, fall under the classified systems as indicated in table 5.1 below.

Table 5.1: Identified drip irrigation systems

Categorization for research study	System Classification.	Reference for Design layout configuration
T_1, T_2, T_4, T_5	Chapin	Fig. 4.1a
T_3	Family	Fig. 4.1b
T_6	Micro-Tal	Fig. 4.1c

The details of the parameters for categorization are as indicated in table 4.1. Some systems in the field are not basically the same as the original classified systems designs in terms of lateral length (15m), number of emitters per spacing (one) and height of stand for water tank, as a result of modifications. They however have the same layout configurations.

5.2 Assessment of water application uniformity

The data collected was used to compute the coefficient of variation and water application uniformity of the low cost drip irrigation systems. The result obtained was used to assess the performance of the drip irrigation systems based on the ASAE 1996(a) standard criteria for line-source emitters as shown in table 4.5. The result shows that mean EU for T_1, T_3 and T_4 are fair (70 - 80%) and the remaining ones are poor (<70%). Analysis of variance (ANOVA) procedure was used to statistically test for equality of the EU means between the categories as a way of checking/comparing their performances at a confidence level of 95%. From table 4.7, since the calculated F-ratio (51.01) is greater than the F-table (3.58), the null hypothesis of this study that the mean uniformity of water application between the six categories of common low head drip irrigation systems is statistically equal at a confidence interval of 95% was rejected. Since the null hypothesis was rejected, the Least Significant Difference tests (LSD) was done to determine which mean(s) are different. LSD computation was used to come up with table 4.8 for the pair wise comparisons of the treatments. From the test it was concluded that the EU means for $T_{1,}$ $T_{3,}$ T_4 and T_6 are statistically equal at 95% confidence level. T_1 showed the best water application uniformity with the upper limit in the good performance range (80- 90%) at the confidence interval of 95% for single mean shown in fig.4.5. Whereas T_2 and T_5 have double emitters which increase the rate of water discharges to plant root zones and lowers the probability in case of clogging, their mean EU are not equal to the rest of the treatments. T_1 and T_2 are the same in length but differ in the number of emitters per spacing and water head. The same applies to a comparison between T_4 and T_5. The poor performance of T_2 and T_5 with double emitters and higher water heads compared to T_1 and T_4 with single emitters respectively is attributed to poor hydraulic uniformity in the systems design. For variation among the treatment samples, since F-ratio < F-table (1.87 < 4.15), the samples means among the categories are statistically equal. However the range of the EU mean of 5.52% at confidence 5% level could be due location effects. The location effects could be as a result of poor installation, differences of water depths in the tank at the time of running the tests, differences in field topography, age of the systems and management levels.

5.3 Factors influencing water application uniformity in low head system

The water application uniformity performance based on ASAE standard criterion shown in table 4.5, the analysis of variance, the information gathered by observations (figures 4.3(a) to 4.3(g)) and semi-structured interviews during data collection was used to identify factors affecting water application uniformity. These are;

(i) Poor installation of drip irrigation systems; Proper installation requires that the laterals are fitted to sub main at horizontal level to the planting beds as shown in figure 4.4 (f). Also the fittings should be water tight as not to allow for leakages which result in pressure. The start/header barbed connectors from the sub mains in nine out of the total samples to the laterals were not in the same level with the laterals on the planting beds as shown in figure 4.4 (e). When the level of the planting beds are higher than the level of the sub mains there is a steep rise by the laterals which make the drip tapes flatten thus restricting water flow and causing water pressure loss in the system. In three out of the twenty four samples, water tank stands on a lower level with respect to the planting beds resulting in loss of pressure which would otherwise be used to provide the energy for driving the flow.

(ii) Clogging filters – the clogged filters, as shown figure 4.3(c), reduce the flow rate of the water supplied to the system at a given water head. The water source for the sampled irrigation systems were mainly from shallow wells and piped water hence clogging is of physical nature i.e due to silt and clay. In five out of the total samples had their filters cleaned regularly.

(iii) Number of emitters per meter of laterals and in the irrigated area – there is pressure reduction as water is discharged from one emitter to the other along the laterals. This can be seen by comparing T_1 and T_2 and T_4 and T_5 respectively where the lateral lengths are equal and the number of emitters is doubled. Compared to T_4, poor performance of T_6 is attributed to additional four laterals which resulted in increase in the number of emitters.

(iv) Leakages in the system – these contribute to sudden pressure losses which would otherwise be used in increasing the flow rates and hence the water application uniformity. An example is shown in figure. 4.3(b) obtained from sample number 3 of T_6 and is attributed to its lower EU compared to the rest in the treatment.

(v) Unevenness of the field – the beds are not flat therefore any change in topography uphill has a negative impact.

(vi) Emitters clogging with time – there is slow accumulation of clogging agents which reduce the emitter flow rates with time as could be seen from the newly installed systems compared with the old ones e.g sample No.1 in T_3 as recorded in appendix B, table B7: summary for outliers.

(vii) Crop management – When crops whose management require trailing like tomatoes are irrigated, the trailing should not be done as to lay the fruits to be the drip tape laterals as in figure 4.4 (a). Since the tapes have thin walls they collapse when the fruits are laid on them thus restricting the flow of water and hence loss of pressure. This practice was observed in four samples where tomatoes had reached the of trailing/stacking/layering stage

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

Water application uniformity is one of the key factors that influence the crop-water production function. Its assessment as an attribute is important as it helps to check/compare the performance of low head drip irrigation systems. Since the assessment is done to improve systems performance, diagnose constraints and compare performance, the study has shown that uniformity of water application performance rating for common low head drip irrigation systems in the smallholder farms are ranging from poor to fair and only one category (T_1) has an upper limit at a confidence interval of 95% being good according to the ASAE 1996(a) standards. Apart from T_2 and T_5, all the other design configurations mean EU is statistically equal at 95% confidence interval. Improvements on the systems design, proper installation and management need to be done to aim at water application uniformity performance ratings of good. In order to enhance crop productivity, systems, T_2 and T_5 whose mean water application uniformity are statistically not equal to the other categories should not be promoted by irrigation specialists and extension providers. Also to increase the area for irrigation, the design layout for the systems adopted should be well planned and properly installed to irrigate sub areas.

6.2 Recommendations

The following are the recommendations from the research study;

1. The systems should be properly installed and fittings to be leakage proof; where short start connectors are used for connecting irrigation drip tape laterals, the sub main should be at the same level with the raised planting beds. In areas where the land topography is not flat, the tank should be placed uphill in relation to the irrigated area. All fittings during installation and operation of the systems should be leakage proof to minimize pressure losses.
2. The filters should be cleaned frequently during the crop season. Also, emission discharges from emitters should be checked by looking at the wetted soil around the root zone to identify clogged ones for knocking using a short peg before eventually flushing the system as a copping strategy as shown in figure 4.4 (g).
3. The lateral lengths and irrigated area should be limited depending on number of emitters per meter length as they are non pressure compensating and the water pressure that would be required to overcome the friction losses associated with water delivery and filtration. Rather than increase the lateral lengths and lateral numbers of the systems to increase the scale of production, irrigation planning should be done in such a way that the installation of the chosen systems layout irrigates sub areas as in T_6.
4. In order to avoid under or over irrigation, an average emitter flow rate estimate for the installed system should be obtained to help in approximating the system run time (duration) for irrigation. This should be done early for every season.
5. Since location effect is one of the causes of poor uniformity of application, a further comparative EU evaluation study should be done using same water head and drip line/tape for different lateral lengths and sizes for each identified common system layout. Also T_2 and T_5, with double emitters per spacing, are recommended for further hydraulic uniformity or pressure variation test.

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APPENDICES

A: Data collection sheet

Data point	Time to fill 10ml catch can	Data point	Time to fill 10ml catch can
1		16	
2		17	
3		18	
4		19	
5		20	
6		21	
7		22	
8		23	
9		24	
10		25	
11		26	
12		27	
13		28	
14		29	
15		30	
Mean time (seconds)			
Q_{avg} (ml/s)			
Avg.$Q_{max.}$			
Avg.Q_{min}			

*= lowest 1/6 of the Measurements Avg. Q_{min} =

*****= highest 1/6 of the Measurements Avg. Q_{max} =

Height of tank stand

..…………………………………………………………………………..

What is the source of water

…………………………………………………………….

Number of laterals

………………………………………………………………………..

Length of laterals

…………………………………………………………………………

Spacing on laterals

…………………………………………………………………………

Size of drip line/tape

……………………………………………………………………….

Layout of laterals are uphill/down slope/fairly flat

…………………………………………

Is filter in place? Yes/No

When were the system installed and/or laterals replaced?

Is there any observed area(s) receiving no/little/more water?...Yes/No. If yes, what do you do to solve the problem?

....

Is the filter cleaned? ... Yes/ No. If yes, how often?

…………………………………………

Is there any leakage(s) in the system? …… Yes/No. If yes, how do you solve the problem? .

……………………………………………………………………………………

B: Summary of processed data for each category

Table B1: Summary for T_1

T_1 samples	Median time (s)	Mean time (s)	Q_{avg} (ml/s)	Q_{max} (m/s)	Q_{min} (m/s)	CV	EU	Otl
1	41.87	42.4107	0.2358	0.2641	0.2107	20.21	66.44	1
2	38.84	38.9845	0.2565	0.2681	0.2416	9.88	82.38	1
3	42.825	42.8643	0.2333	0.2456	0.2195	11	81.34	0
4	40.75	41.0254	0.2438	0.2618	0.2235	14.66	74.61	2
Avg.		41.32	**0.2424**	**0.2599**	**0.2238**	**13.89**	**76.19**	

N.B:- Otl., means outliers.

Conversion to l/h

1. Emitter flow rate (Q) when x ml is collected in t seconds to l/h = $\frac{360}{xt}$ l/h

2. ml/s to l/h is .... Q*3.6 l/h, Where Q is discharge rate in ml/s.

Table B2: Summary for T_2

T_2	Median	Mean	Q_{avg}	Q_{max}	Q_{min}	CV	EU	Otl
1	76.46	81.6090	0.1225	0.1678	0.0952	43.23	35.06	0
2	54.40	56.4014	0.1773	0.2004	0.1448	28	52.91	1
3	54.72	58.0343	0.1723	0.2067	0.1330	35.62	42.28	2
4	77.06	79.7414	0.1254	0.1640	0.0906	45	31.19	1
Avg		68.95	**0.1494**	**0.1847**	**0.1159**	**37.96**	**40.36**	

Table B3: Summary for T_3

T_3	Median	Mean	Q_{avg}	Q_{max}	Q_{min}	CV	EU	Otl
1	45.36	46.7320	0.2140	0.2438	0.1827	25	68.20	6
2	39.37	40.5493	0.2466	0.2670	0.2140	19.85	74.79	0
3	42.05	42.01	0.2380	0.2617	0.2179	16.76	72.04	0
4	41.63	41.7125	0.2397	0.2572	0.22	14.46	74.91	0
Avg.		42.75	**0.2346**	**0.2574**	**0.2087**	**19.07**	**72.49**	

Table B4: Summary for T_4

T_4	Median	Mean	Q_{avg}	Q_{max}	Q_{min}	CV	EU	Otl
1	54.59	54.38	0.18	0.2	0.17	14	75.85	2
2	56.59	57.4723	0.174	0.1947	0.159	18.34	70.07	0
3	56.32	58.0438	0.1723	0.1890	0.1538	18.64	68.12	1
4	54.95	55.3962	0.1805	0.1981	0.1632	18	70.19	1
Avg.		56.32	**0.1767**	**0.1955**	**0.1615**	**17.26**	**70.76**	

Table B5: Summary for T_5

T_5	Median (s)	Mean (s)	Q_{avg} (ml/s)	Q_{max} (ml/s)	Q_{min} (ml/s)	CV	EU	Otl
1	48.485	55.5679	0.1800	0.2419	0.1136	53.03	32.66	2
2	51.89	56.8610	0.1759	0.2391	0.1143	52.22	33.68	0
3	49.205	54.8717	0.1822	0.2423	0.1183	51	35.02	0
4	50.69	53.0138	0.1886	0.2435	0.1304	46.47	28.32	1
Avg.		55.08	**0.1817**	**0.2417**	**0.1192**	**50.68**	**32.42**	

Table B6: Summary for T_6

T_6	Median	Mean	Q_{avg}	Q_{max}	Q_{min}	CV	EU	Otl
1	49.31	49.8824	0.2005	0.2195	0.1746	20.45	64.47	1
2	58.5	58.82	0.1700	0.1837	0.1499	18.39	67.58	1
3	42.185	42.3689	0.2360	0.2674	0.2049	23.36	61.06	0
4	49.31	49.6641	0.2014	0.2195	0.1787	18.58	67.80	1
Avg.		50.184	**0.2015**	**0.2225**	**0.1770**	**22.17**	**61.66**	

Table B7: Summary of outliers

Category	T_1	T_2	T_3	T_4	T_5	T_6
1	1	0	0	2	2	1
2	1	1	0	0	0	1
3	0	2	0	1	0	0
4	2	1	6	1	1	1
Total	4	4	6	4	3	3

Table B8: Sample 2 of T_3; ranked data on spread sheet

Data point	Time in sec
1	36.65
6	37
25	37.47
26	38.06
24	38.09
23	38.1
15	38.19
3	38.37
28	38.47
4	38.68
19	38.75
21	38.84
14	39
27	39.16
8	39.32
10	39.41
20	39.57
11	39.72
12	39.94
22	40.29
9	40.38
2	40.5
13	40.91
29	41.22
5	41.34
17	41.56
30	42.09
16	43.12
18	43.28
7	69
Avg. time	40.5493
Avg.Q	0.2466
Avg.Q_{max}	0.2670
Avg.Q_{min}	0.2140
CV	19.85%
EU	74.79%