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A Performance Evaluation of a One Hectare Gravity Fed Drip Irrigation System Under Varying Vertical Head

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Abstract

Determination of emitter discharge variation and water application uniformity is very important in designing drip irrigation system and could serve as the basis for optimizing water use efficiency and crop productivity. This study was carried out at Eureka Farm in Sanyati District- Zimbabwe, to evaluate the performance of one hectare gravity-fed drip irrigation system under varying vertical pressure heads. The drip system was tested for emitter discharge variation (Q_{var}), *coefficient of uniformity (CU) and distribution uniformity (DU). The drip kit comprised of a 10* m^3 *tank, on an adjustable stand, with one hundred and twenty sets of 100 m long 16 mm diameter drip lines which had the same types of emitters. The operating heads tested were 2 m, 3 m, and 4 m. Emitter discharge was measured at the drip line lengths 12.5 m, 25 m, 37.5 m, 50 m, 62.5 m, 75 m, 87.5 m and 100 m from the manifold. The performances were compared to The American Society of Agricultural Engineers (ASAE) Standards (1999) and used to select the optimum drip lateral lengths for different vertical pressure head. The results indicated as expected that the emitter discharge decreased as the lateral length increased. The emitter discharge variation was within the desirable recommended standard of d” 10% at 100m, 75m and 65m drip lateral lengths for 4m, 3m and 2m tank heights respectively. The results also showed that the coefficient of uniformity (CU) and the distribution uniformity (DU) generally increase with increasing heads and decrease with increasing drip lateral length. The minimum recommended standards for DU and CU for the kit to be considered as good was 80% and 85% respectively. On the basis of the results, appropriate recommendations on the relationship between vertical head and drip lateral length were formulated to minimize non uniformity of water distribution under field conditions.*

Keywords: Drip kit, Vertical head, Drip lateral length, Emitter discharge variation (Q_{var}), Coefficient of uniformity (CU) and Distribution uniformity (DU).

Introduction

Drip irrigation is the application of small amounts of water in the root zone of the plants at frequent intervals through emitting devices via a network of PolyVinyl Chloride pipes (PVC) consisting of the mainline, sub main, filtration unit, control valves, laterals and drippers (Mane 2006). According to Ascough et al, (2002), drip irrigation system is an acknowledged technique for achieving high efficiencies in water use of crops by wetting only a limited part of the root zone. For the above and many other reasons, drip irrigation is fast becoming popular in the developing world.

The Gravity Fed Drip Irrigation Technology

Over the years drip kits were designed for home gardens and covered only small areas such as 100m^2, 500m^2, 1000m^2 and 2000m^2. Recently Netafim introduced gravity fed drip irrigation system kits that cover bigger areas such as 0.4 ha, 0.5ha and 1 ha which they designed to operate at low pressure unlike the standard conventional drip system that operate at high pressures. The system layout is almost the same as the conventional drip system. A complete drip kit consists of a water tank and stand, a simple filter, the water delivery pipelines and the irrigation dripper lines (Fig 2). The system make use of an elevated water source using the elevation pressure and it has a head control that includes two valves which enable to irrigate half of the field each time. Farmers have an option of gradually increasing their irrigated area or installing conventional drip system as they realize financial benefits from the use of the drip kits.

In Zimbabwe drip irrigation system has often been associated with capital-intensive commercial farming community and has evolved to become a knowledge intensive, technology oriented operation such that smallholder farmers have not adopted it extensively (Maisiri et al, 2005). The largest barriers to its expansion to small-scale farmers have been attributed to high capital costs beyond their capacity and the lack of system sizes suitable for small plots. The introduction of the gravity fed drip irrigation systems provides an alternative low cost and low energy systems retaining the advantages associated with traditional drip irrigation. Gravity fed drip irrigation system can also be termed ‘Drip kit’ a name that was coined by Chapin who has developed and promoted, low cost, and efficient drip irrigation (FAO, 2002).

An Israel based company Netafim has brought into Zimbabwe, a wide range of affordable gravity fed low pressure drip kits that can fit small scale farmers. These drip kits include the one hectare drip kit which is being rapidly adopted by small scale farmers in Zimbabwe. However, the system was supplied without operational specifications such as discharge rates and application uniformity that would provide farmers information about the performance of the system under varying drip lateral length and vertical head.

Irrigation uniformity is a key component in overall irrigation efficiency and it plays an important role in scheduling of irrigation (Solomon, 1990). Water application uniformity is an important performance criterion that should be considered during the design and evaluation of micro-irrigation systems. According to Pereira (1999), several parameters are used as indicators of the uniformity of field water application. The most common are the Coefficient of Uniformity (CU), Distribution Uniformity (DU), and the Statistical Uniformity Coefficient (SU).

Rogers (1997) describes distribution uniformity as the percentage of average application amount in the lowest quarter of the field. He further postulates that it is a measure of how uniformly an irrigation system applies water to all parts of the field. Roberts (2001) observes that drip irrigation system, among other irrigation systems, delivers very high uniformity and this is one of the keys to its high potential efficiency. DU of water is one of the important parameters to characterize drip emitters and design drip irrigation system and it is a measure of the uniformity of water application to the area being irrigated, expressed as a percentage (Deba, 2008). Rain bird (2008) considered a

DU of less than 75% as poor; 75 - 90% as good, and greater than 90% as excellent. Mizyed and Kruse (2008) state that flow rate differences even between two supposedly identical emitters may exist due to some factors including pressure differences and emitters' sensitivity to pressure changes. Poor distribution uniformity can be a cause of low crop yield. This is because poor distribution of water across the whole field may cause other areas of the field to receive more water than others. Crops in areas that receive insufficient water usually suffer from moisture stress and potential reduction in crop yields is most likely. Conversely, excess water in some parts of the field may also reduce crop yields due to leaching of plant nutrients, an anaerobic rooting environment, and increased disease or failure to stimulate growth of economically valuable parts of the plant (Griffiths and Lecler, 2001). In order to obtain a better DU when designing an efficient drip irrigation system, the combination of operating pressure, lateral length and land slope should be considered.

Factors That Affect Uniformity

Some of the factors that affect uniformity for drip irrigation system are listed in Table1.

Table 1: Examples of factors that affect uniformity for drip irrigation (Burt et al, 1997)

Uniformity component	Factors causing non-uniformity
Difference in discharge between emitters	Pressure differences Plugging of emitters Manufacturing variation Soil differences for buried emitters Temperature differences along a lateral
Volumes applied not proportional to plant area assuming the same plant age	Variations in plant spacing are not matched by emitter spacing or irrigation scheduling. Unequal discharge during start-up and drainage.

Lateral Length and its Effect on Uniformity

Length of run has a direct effect on the uniformity (DU) of each drip lateral. If laterals are too long, pressure losses cause a higher application rate at the beginning of the run than at the end. In general however, longer run lengths with good uniformity are possible with low flow rate and/or large diameter drip laterals. The DU of a single lateral is determined by its length, slope, operating pressure, flow rate and the manufacturer's coefficient of variation (Cv). Performance Charts published by most drip lateral manufacturers summarize all of these effects, and tell how long the drip lateral can be for a given set of conditions (Burt et al., 1997).

Hydraulics of drip irrigation lines

Flow in the drip irrigation lines is hydraulically steady, spatially varied pipe flow with lateral out flows. The total discharge in the drip irrigation lines decreases with respect to the length of the line. The lateral and sub main can be considered as having the same hydraulic characteristics and are designed to maintain the smallest pressure variations along the line (Mane et al., 2006).

When a drip line is laid going upslope, it will lose pressure and when the line is going laid down slope, it will gain pressure. The loss or gain in pressure is linearly proportional to the slope and length of the line. Hydraulically, the pressure variation on lateral line will cause an emitter flow variation along the lateral and a pressure variation along a sub main will cause a lateral line flow variation (into each lateral line) along a sub main (Mane et al., 2006).

According to Mirjat et al (2010), the uniform distribution of water is reflected by the values of uniformity coefficient which in turn relates to the performance parameters associated with the variability in the whole system. A system with uniformity co-efficient of at least 85% is considered appropriate for standard design. Such a high uniformity coefficient is only possible through properly designed emitters (Al-Amound, 1995).

The one hectare gravity fed drip irrigation system introduced in Zimbabwe was supplied with few technical data for drip emitters operating under low pressures. Also the system was supplied with no guidelines regarding the optimum combination of operating pressure head, lateral length and land slope. As a result many questions were being asked about the performance of the system as farmers were not so sure about its water application uniformity, discharge rates and its coefficient of variation. This came after the realisation that in some cases, plants especially at the tail ends of drip laterals and those planted at the furthest points of the mainline were not performing as those nearest to the tank, consequently resulting in low yields. The supplier of the drip kits recommended farmers to put the water tank at a minimum height of two meters. The researchers involved in this study suspected that this height was too low to create enough system pressure, hence resulting in water stress to plants located at the tail end of the laterals. Considering that more and more farmers are adopting the one hectare gravity fed drip irrigation systems that are being sold as one-size-fit-all solution without regard to design to fit site specific conditions on the ground, the researchers sought to develop some guidelines on the relationships between the tank height and the lengths of laterals that ensure that the system uniformity of water distribution remains in the recommended ranges when the drip kits are installed. This study therefore sought to help solving the poor water distribution problems and also provide data on the local performance of the kit. To achieve this, the study had the following objectives:

- To compare distribution uniformity at different lateral length and tank stand height (vertical head).
- To compare the coefficient of uniformity at different lateral lengths and vertical head,
- To determine the optimum lateral length at different tank stand heights that will result in acceptable system performance.

Methodology

Site Description

The study was conducted at Eureka Farm in Sanyati district (Fig 1), Kadoma (Zimbabwe) and the site lies at 17°44’ S and 31°04’ E with an altitude of 1508m above sea level. The area is situated in Natural Ecological Region IIb and its average annual rainfall ranges from 750mm-1000mm (Vincent and Thomas, 1960). The study area has clay soils. A one hectare (100 m by 100 m) flat land with a slope of about 0 % was used to analyze the performance of the drip kit irrigation system.

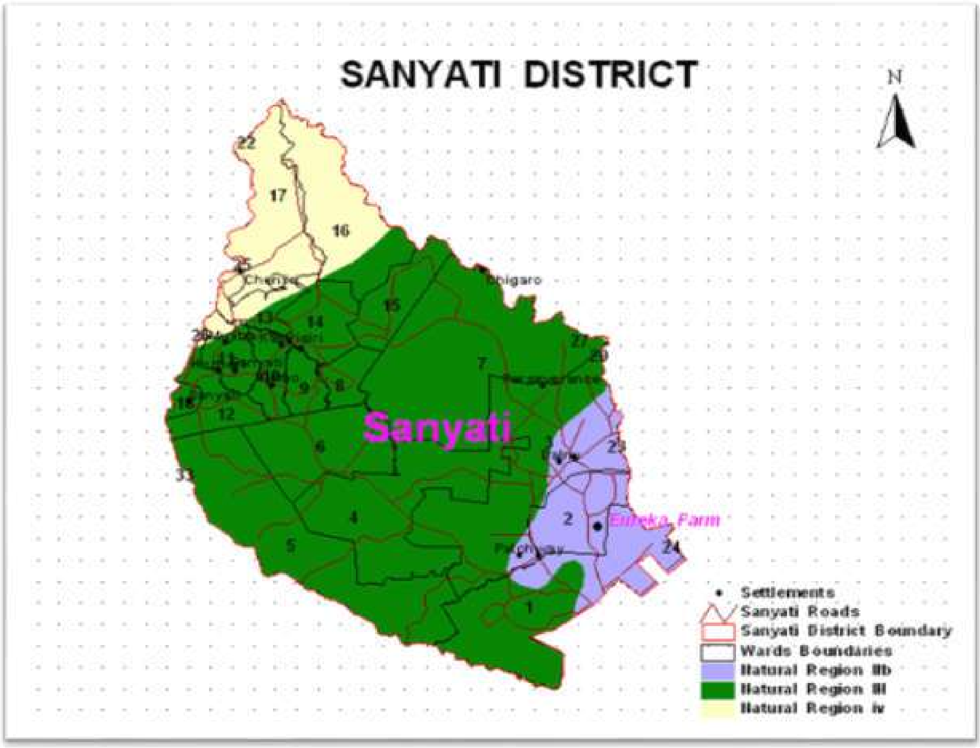

Figure1: The study site location in Sanyati District- Zimbabwe

Procedures

A one ha (100m*100m) gravity fed drip irrigation kit was installed at the experimental site. The system consisted of a 10000L tank, 50mm diameter polynet manifold, screen filter, control valves and 16mm diameter super typhoon drip lateral lines. The drip lateral line was made up of one type of in line non pressure compensated emitters with a spacing of 0.3m from one emitter to another. The tank which supplies water to the field was mounted at an adjustable tank stand. The kit was divided into two blocks; one block covers 0.5ha area with 62 drip laterals which were 0.8m apart and 100m long. From the 62 drip laterals in each plot, 16 drip laterals were selected systematically for discharge measurement and eight points which were located at 12,5m, 25m, 37,5m, 50m, 62,5m, 75m, 82,5m and 100m along the length of the laterals. The systematic way of selecting point to put catch cans was done to ensure coverage of the whole plot. One litre catch cans were used to collect emitter discharge for 15 minutes at selected points. The area under the emitter was excavated and a catch can was placed beneath the emitter for discharge collection. The average emitter discharge was computed at each point along the drip line. The emitter discharge was measured under three different stand heights which were 2m, 3m and 4m. The same procedure of collecting emitter discharge was done for plot 1 and 2. The collected volume in a given time was used to calculate distribution uniformity (DU), coefficient of variation (CV), Christiansen's coefficient of uniformity (CU**)** and other evaluation parameters. The experimental layout is outlined in Figure 2.

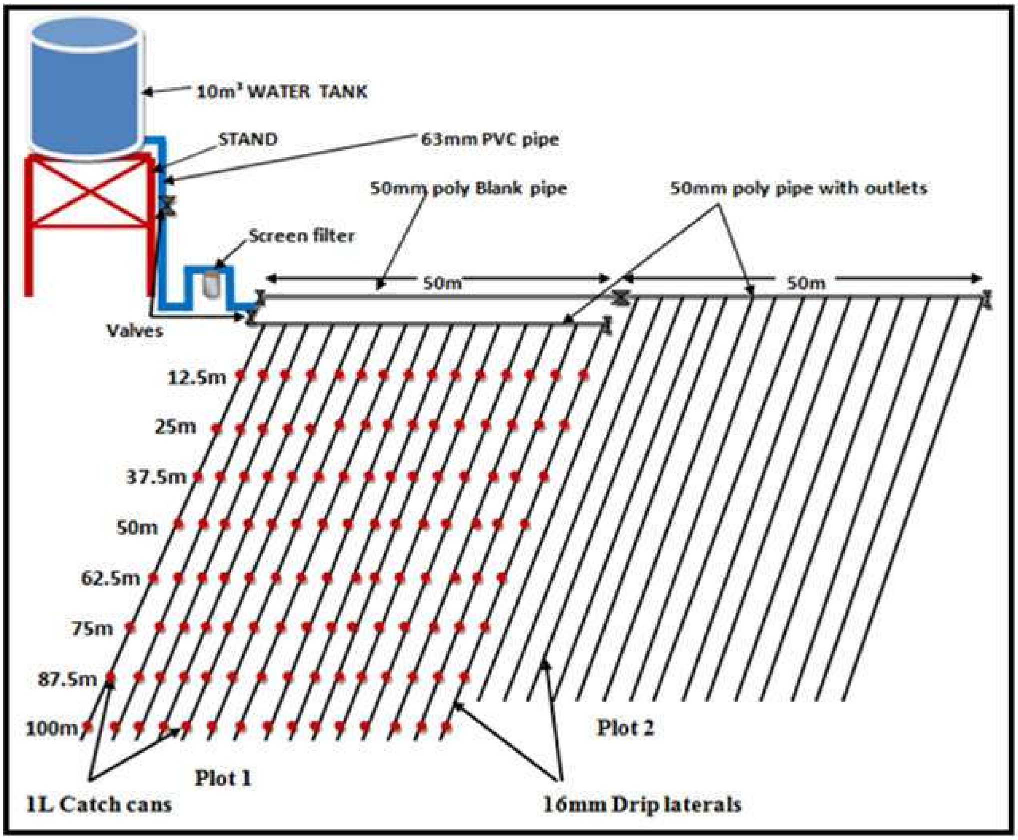

Figure2. *Layout of the experimental plot*

Evaluation Parameters Calculations

Coefficient of Variation Calculation

The coefficient of variation (CV) was taken as the ratio of the standard deviation of the emitter discharge to the average flow rate, and expressed as a percentage. In other words, the CV was calculated by dividing the standard deviation of emitter flow by average emitter flow rate of the observed volumes. This was summarized using equation 1 adapted from ASAE (2002).

$$\mathbf{CV} = \frac{S_q}{q_a} \times \mathbf{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where;

CV = coefficient of variation of emitter flow,
Sq = standard deviation of emitter flow L/hr, and
q_a = average emitter flow rate L/hr.

The calculated coefficient of variation (CV) was classified based on ASAE (2002) standards. These standards states that coefficient of variation (CV) is considered as perfect for < 5%, good for 5-7%, marginal for 7-11%, poor for 11-15%, unacceptable for > 15% .

Distribution Uniformity Measurement

The distribution uniformity was calculated using equation 2 adapted from (Mosh, 2006)

$$D_U = 100\left[\frac{V_{LQ}}{V_{avg}}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where; D_U = Distribution uniformity (%)

V_{LQ} = Average of the lowest quarter volume of water collected,

V_{avg}=Average volume collected.

The values of DU obtained were compared to ASAE (1999b) standards (Table 2).

Table 2: Micro-irrigation system uniformity classification based on distribution uniformity

Distribution uniformity (%)	**Comment**
94 – 100	Excellent
81 – 87	Good
65 – 75	Fair
56 – 62	Poor
Below 50	Unacceptable

Source: **ASAE (1999b). Note Discontinuities in the DU scales is to cater for the 95% confidence limits of the measures, and these tend to be high for low uniformities (Bralts and Kesner, 1983)**

Coefficient of Uniformity Measurement

To determine the coefficient of uniformity, equation 3 (ASAE, 1993) was used.

$$CU = 100 \times \left[1 - \frac{D}{M}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where; ***CU*** = Coefficient of uniformity (%)

D = average of the absolute values of the deviation from the mean catch can discharge,

$$= \frac{1}{n}\sum_{i=1}^{n}|Xi - M|$$

M = average of catch can discharge values

$$= \frac{1}{n}\sum_{i=1}^{n}Xi$$

Xi = emitter discharge

n = number of observed discharge values

The obtained CU values compared to ASAE (1999a) standards (Table 3).

Table 3: Micro-irrigation system uniformity classification based on uniformity coefficient

Uniformity coefficient, UC (%)	**Classification**
Above 90	Excellent
90-80	Good
80-70	Fair
70-60	Poor
Below 60	Unacceptable

Adopted from ASAE (1999a) Standards EP 458

Data Analysis

Data was analyzed with a Genstat package 14th edition. Analysis of Variance was done at 5 % significant level on Emitter Discharge, DU, CU and SU. This was done to find out if there was any significance difference in emitter discharge, DU, CU and SU values of a one hectare gravity fed drip irrigation system operated under varying drip lateral length and vertical head.

Results and discussion

Emitter Discharge Variation (Q_{var})

The study revealed that the highest value of emitter flow rate of 0.73 L/hr was obtained at 12.5m; 25m and 37.5m along the drip lateral lengths at 4m stand head for plot 1(with a 50m long manifold). The lowest emitter flow rate of 0.42 L/hr was observed at 2m vertical pressure head at 100m drip lateral length in plot 2 (with a 50m main line and a 50m long manifold). The rest of the results of emitter discharge values are shown in Tables 4 and 5 and Figures 3 and 5.

Table 4: Average emitter discharge (l/h) values for plot 1

Tank height (m)	Distance along lateral lengths (m)							
	12.5	**25**	**37.5**	**50**	**62.5**	**75**	**87.5**	**100**
2	0.60	0.59	0.59	0.57	0.55	0.52	0.51	0.45
3	0.66	0.66	0.65	0.64	0.62	0.60	0.57	0.50
4	0.73	0.73	0.73	0.72	0.72	0.71	0.70	0.68

Table 5: Average emitter discharge (l/h) values for plot 2

Tank height m)	Distance along lateral lengths (m)							
	12.5	**25**	**37.5**	**50**	**62.5**	**75**	**87.5**	**100**
2	0.60	0.60	0.59	0.58	0.52	0.49	0.44	0.42
3	0.65	0.64	0.62	0.61	0.60	0.58	0.55	0.49
4	0.73	0.73	0.72	0.72	0.69	0.68	0.67	0.64

The results showed that emitter discharge decreases as lateral length increases. This was evidenced by high values of emitter discharge at shorter distances along the drip lateral length and lower values at tail ends of drip laterals. The decrease in flow rate was anticipated because the pressure at the head of laterals was greater as compared to the middle and tail end; also the head losses due to friction might have affected the discharges towards the middle and subsequently at the tail end. In plot 1, emitter discharge variation values of 7.6%, 25% and 25% were observed for 4m head, 3 m head and 2 m head respectively at 100 m drip lateral lengths. For plot 2 the emitter discharge variation increased to 31%, 24% and 13% for 2m, 3m and 4m respectively at 100m drip lateral lengths. This was probably because of the existence of the 50m long mainline which contributed friction loses. According to Braltes et. al (1987), the general criteria for classifying emitter discharge flow variation is as follows: d”10% desirable, 10-20% acceptable and >20% unacceptable. Thus, these results showed that of all the three tank heights observations only 4m head was within the desirable range of the recommendation which were having less than 10% emitter discharge variation at 100 m lateral lengths for plot 1. At 87.5m distance along the drip lateral lengths, the emitter discharge variation falls within acceptable and desirable ranges for all tank heights except for 2m vertical head in plot 2. The results for plot 2 show that at 2m tank height, the emitter discharge variation was unacceptable at lateral lengths longer than 75m. The rest of emitter discharge variation results are shown in Tables 6 and 7.

Table 6: Emitter discharge variations along drip laterals at different pressure heads; plot 1

Tank height (m)	Distance along lateral lengths (m)							
	12.5	**25**	**37.5**	**50**	**62.5**	**75**	**87.5**	**100**
2	0.000	0.009	0.023	0.040	0.086	0.124	0.154	0.249
3	0.000	0.010	0.027	0.035	0.069	0.094	0.135	0.253
4	0.000	0.004	0.012	0.017	0.021	0.037	0.050	0.076

Table 7: Emitter discharge variations along drip laterals at different pressure heads; plot 2

Tank height (m)	**Distance along lateral lengths (m)**							
	12.5	**25**	**37.5**	**50**	**62.5**	**75**	**87.5**	**100**
2	0.000	0.007	0.020	0.038	0.129	0.191	0.269	0.307
3	0.000	0.006	0.034	0.061	0.076	0.110	0.155	0.243
4	0.000	0.004	0.013	0.018	0.048	0.066	0.084	0.127

Tables 6 and 7 and Figures 4 and 6 show that as tank height and hence vertical pressure head for a given drip lateral length increases, emitter discharge variation decreases.

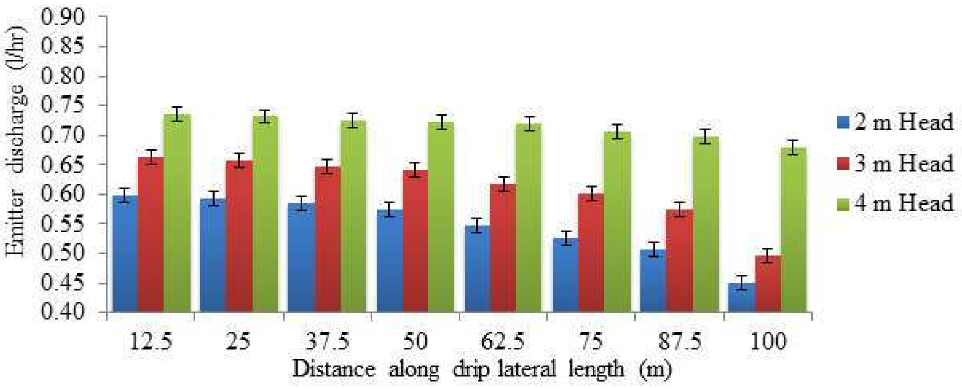

Figure 3: Emitter discharge values for plot 1 at different vertical pressure heads

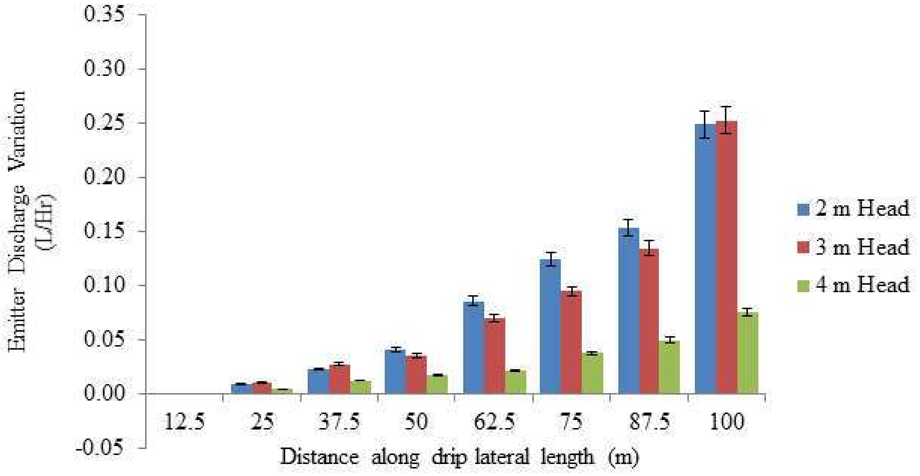

Figure 4: Emitter discharge variation for plot 1 at different vertical pressure heads

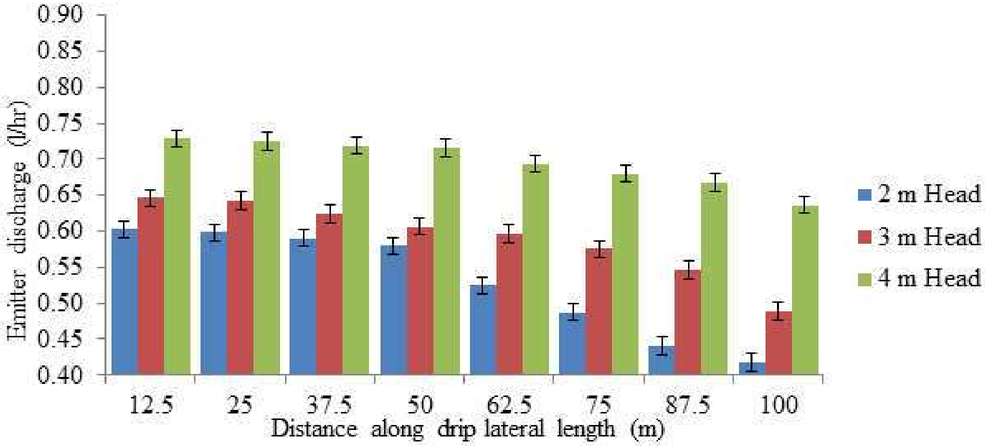

Figure 5: Emitter discharge values for plot 2 at different vertical pressure heads

The statistical analysis suggested that the variation of emitter discharge at different vertical pressure head and drip lateral length was significant ($p < 0.05$) as shown in the appendix. This indicates that as drip lateral length increases emitter discharge variation increases. These findings are in agreement with the previous results by Senzanje et al.(2004), who observed that there was fall in the emitter discharge with increasing drip line length.

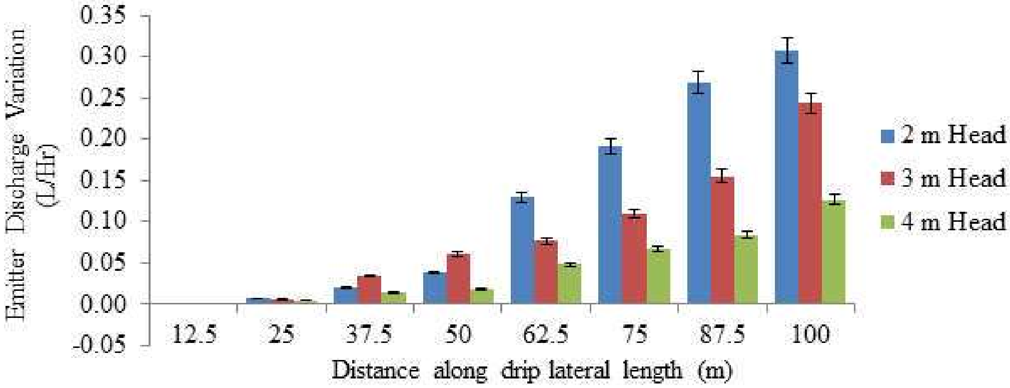

Figure 6: Emitter discharge variation for plot 1 at different vertical pressure heads

The results of emitter discharge in this study also concurred with those of Murjat et al. (2006), who reported that emitters located at the beginning of a lateral showed higher flow rates as compared to those located towards the tail ends of drip laterals. Ella et al (2009) in their study of assessing the effect of hydraulic head and slope on water distribution of low-cost drip irrigation, found out that maximum discharge was obtained at maximum operating head. The results of emitter discharge variation for all vertical pressure head was also described with polynomial regression models (Table 8).

Table 8: Regression models for and lateral lengths at various vertical pressure head

Pressure head (m)	Polynomial Regression model	R^2
2.0	Q_{var}= 3E-05L^2 - 0.000L - 0.001	0.92
3.0	Q_{var}= 3E-05L^2 - 0.001L + 0.018	0.97
4.0	Q_{var}= 1E-05L^2 - 0.000L + 0.003	0.86

Q_{var}= emitter discharge variation; L = drip lateral length

Distribution Uniformity (Du)

Average maximum (DU) values of 99.23% was obtained in plot1 at 4 m vertical pressure head for drip lateral lengths of 12.5m and 25m **(**Fig 7) and the lowest distribution uniformity value of 87.48% was obtained in plot 2 at 100m drip lateral length at 4m tank height **(**Fig 8**)**. The highest distribution (DU) of 96% was observed at 3m vertical pressure head at shorter lateral lengths for both plots 1 and 2 and the lowest value of distribution uniformity was 75%. At 2 m head the highest distribution uniformity (DU) value was 94.3% at 12.5m drip lateral length in plot 1 and the minimum value was 67.8% at 100m drip lateral length in plot 2. The rest of the results are shown in figures 7 and 8. Tables 9 and 10 show the comparison for different vertical pressure heads and drip lateral lengths with ASAE (1999b) standards.

Table 9: DU results and comments using ASAE (1999b) standards for plot 1

Lateral length (m)	**Vertical pressure head(m)**					
	2m		**3m**		**4m**	
	DU (%)	**Comment**	**DU (%)**	**Comment**	**DU (%)**	**Comment**
12.5	94.26	Excellent	96.01	Excellent	99.23	Excellent
25	93.79	Good	95.67	Excellent	99.16	Excellent
37.5	93.02	Good	94.31	Excellent	98.26	Excellent
50	89.69	Good	94.07	Excellent	98.23	Excellent
62.5	82.37	Good	89.82	Good	95.53	Excellent
75	79.12	Fair	88.71	Good	93.34	Good
82.5	73.98	Fair	84.14	Good	92.09	Good
100	69.89	Fair	82.42	Good	88.95	Good

Table 10: DU results and comments using ASAE (1999) standards for plot 2

Lateral length (m)	Vertical pressure head (m)					
	2m		3m		4m	
	DU (%)	Comment	DU (%)	Comment	DU (%)	Comment
12.5	93.44	Good	95.28	Excellent	98.11	Excellent
25	93.12	Good	93.34	Good	98.00	Excellent
37.5	91.32	Good	92.89	Good	96.64	Excellent
50	88.95	Good	92.15	Good	96.49	Excellent
62.5	79.12	Fair	89.30	Good	94.97	Excellent
75	75.49	Fair	85.35	Good	93.90	Good
82.5	69.81	Fair	79.16	Fair	89.70	Good
100	67.80	Fair	75.27	Fair	87.48	Good

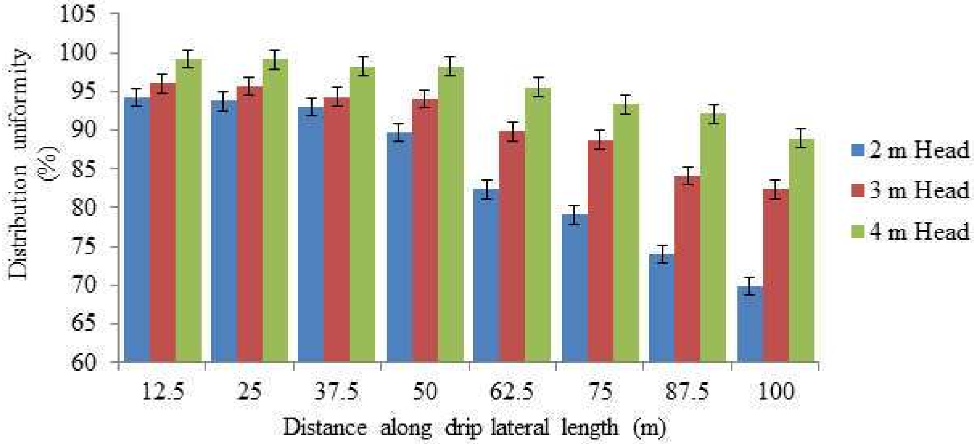

Figure7: DU (%) values for drip lateral lengths at different vertical pressure heads; plot 1

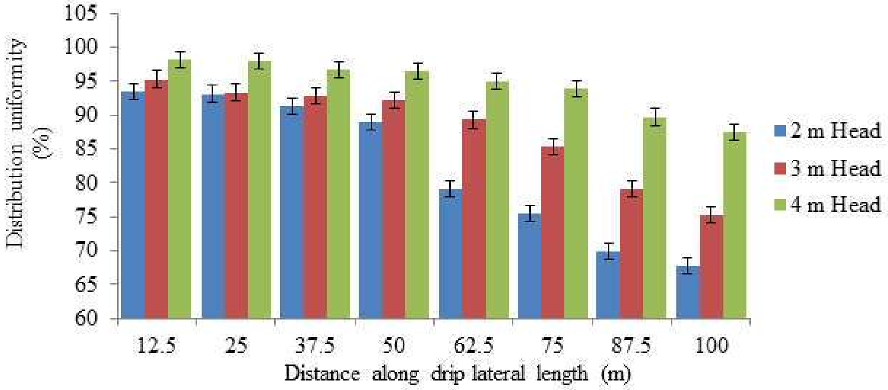

Figure8: DU (%) values for drip laterals lengths at different vertical pressure heads; plot 2

The results show that there was significant difference ($p<0.05$) in DU values between drip lateral lengths and vertical pressure heads (see Appendix). This was noticeable at longer drip lateral lengths of 50m to 100m. This considerable variation in DU values might be due to insufficient hydraulic pressure along the drip laterals, especially at 2m and 3 m vertical pressure heads in plot 2. Figures 7 and 8 show that water DU decreases substantially with increasing drip lateral lengths. A similar trend was reported by Senzanje (1998) who observed that DU show a general decrease with increasing drip lateral length for the 1 m and 1.5 m operating heads.

These findings are also supported by Moller (2007) who noted that DU was lower in sections where lateral end line pressure was low. At shorter distances along the drip lateral lengths of 12.5m to 50 m the graphs depicted that an increase in vertical pressure head has no significant effect on the DU values. These results concurred with the results which were found by Burt, (1995) who reported that if laterals are too long, pressure losses cause a higher application rate at the beginning of the run than at the end, hence affecting distribution uniformity across the whole field.

ASAE standards, (1999b) require a minimum DU value of 80 % to be considered as good for drip irrigation. The system only managed to meet this minimum standard DU from 12.5m to 62.5 m drip lateral lengths for 2m tank height in plot 1 and up 50m for the 2m tank height in plot 2. The same trend was observed at 3 m head in plot 2, where the system managed to meet the minimum standard at 75m drip lateral length. The fall in DU, below the minimum standards, with increasing drip line length was attributed to increasing head losses due to friction in the main line, manifold and drip lines especially in plot 2. Thus this also resulted in an increase in emitter flow variation as the DU decreased. The system met the minimum standards of DU values of 80% at 4m vertical pressure head in both plots 1 and 2. These same results were observed by Ella et al. (2009), who found out that DU generally increases linearly with head.

The observed results of distribution uniformity (DU) were also described using polynomial regression models (Table 11). The models revealed a relatively high explained variance R^2,which was 0.96 0.91 to 0.96 for 2m, 3m and 4m vertical pressure heads respectively.

Table 11: Regression models for DU and lateral lengths at various vertical pressure head

Pressure Head (m)	Polynomial Regression model	R^2
2.0	$DU = -0.002L^2 -0.086L+96.58$	0.96
3.0	$DU = -0.002L^2 +0.051L+95.08$	0.91
4.0	$DU = -0.001L^2 + 0.045L+98.27$	0.96

DU= distribution uniformity; L= drip lateral lengths

Coefficient of Uniformity (CU)

The highest CU obtained was 96.5 % at 4 m vertical pressure head. At 3 m vertical pressure head the highest CU obtained was 95.05% and at 2 m vertical pressure head CU was 94%.

All these occurred in plot 1. Lowest coefficient of uniformity obtained was 89.2%, 81.15% and 76.4% at 4m, 3m and 2m vertical pressure heads respectively. These values were obtained in plot 2. These results showed a general decrease in CU values with increasing drip lateral length for all vertical pressure heads. The results show that the CU increased as the vertical pressure head increased with respect to all lateral length. The rest of the results are shown in Tables 12 and 13 as well as figure 9 and 10. The CU values were compared to ASAE standards (1999a).Taking into account ASAE (1999a) classification shown in Tables 12 and 13, CU was considered as excellent at 12.5m and 82.5 m drip lateral lengths and good at 100m drip lateral length for 4 m vertical pressure head. At 3 m vertical pressure head, CU was excellent from 12.5m to 75m drip lateral lengths and good from 82.5m to 100m drip lateral lengths. At 2 m vertical pressure head, the CU falls into excellent range from 12.5m to 50 m drip lateral lengths, good and fair range was from 62.5 m to 100m drip lateral lengths. This trend of results shows that as operating head decreases and drip lateral length becomes long, the coefficient of uniformity (CU) decreases.

Table 12: CU results and comments using ASAE (1999) standards for plot 1

Distance along lateral length (m)	**Vertical pressure head (m)**					
	2m		**3m**		**4m**	
	CU (%)	**Comment**	**CU (%)**	**Comment**	**CU (%)**	**Comment**
12.5	94.57	Excellent	94.95	Excellent	96.53	Excellent
25	93.86	Excellent	94.77	Excellent	96.41	Excellent
37.5	93.26	Excellent	93.99	Excellent	95.79	Excellent
50	91.64	Excellent	93.76	Excellent	95.72	Excellent
62.5	87.88	Good	93.05	Excellent	95.00	Excellent
75	83.67	Good	90.78	Excellent	94.51	Excellent
82.5	80.73	Good	88.33	Good	93.06	Excellent
100	77.06	Fair	86.56	Good	89.89	Good

Table 13: CU results and comments using ASAE (1999) standards for plot 2

Lateral length (m)	**Vertical pressure head (m)**					
	2m		**3m**		**4m**	
	CU (%)	Comment	CU (%)	Comment	CU (%)	Comment
12.5	94.34	Excellent	95.05	Excellent	96.30	Excellent
25	94.05	Excellent	94.72	Excellent	96.21	Excellent
37.5	93.01	Excellent	93.84	Excellent	95.79	Excellent
50	91.91	Excellent	93.12	Excellent	95.53	Excellent
62.5	83.67	Good	91.64	Excellent	93.58	Excellent
75	80.38	Good	88.84	Good	92.35	Excellent
82.5	76.89	Fair	86.15	Good	91.41	Excellent
100	76.43	Fair	81.15	Good	89.18	Good

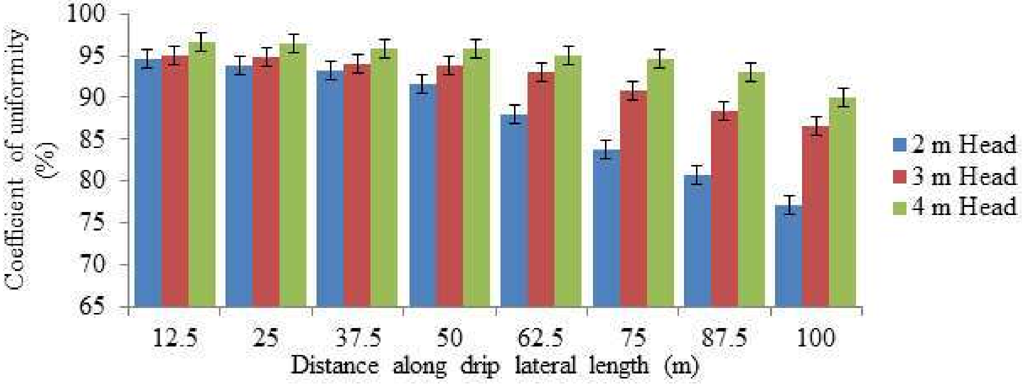

Figure 9: CU Variation for drip lateral lengths at different vertical pressure heads (Plot 1)

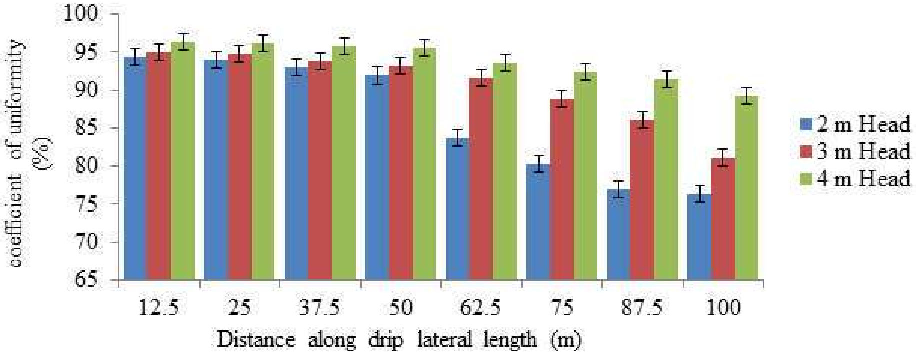

Figure 10: CU Variation for drip lateral lengths at different vertical pressure heads (Plot 2)

The graphs above show that there is considerable variation of CU values at different drip lateral lengths and vertical pressure head. There was significant different ($p < 0.05$) in CU values between drip lateral lengths and vertical pressure heads (Appendix). This was noticeable at drip lateral lengths of 50m to 100m. However, drip lateral lengths of 12.5m to 50m show that there is no considerable variation in CU values in all vertical pressure heads. This indicates that operating head have less effect to CU values at shorter drip lateral length. Ella *et al* (2009) had similar findings when he observed a head differential of 0.5 m did not cause any significant change CU at shorter drip laterals. As shown in figure 9 and 10 above, the coefficient of uniformity generally decreased linearly with increasing drip lateral lengths for all vertical pressure heads. A slight departure in linear trend occurred between 62.5m and 100m drip lateral length at 2 m vertical pressure head. This causes significant differences of CU values at 2m vertical pressure head in relation to other vertical pressure heads. A fall in CU values at longer lateral lengths is mainly attributed to head losses along drip laterals that might cause higher discharge rates at the beginning of the lateral than at the end. Al-Amond, (1995) noted that with increasing in lateral length, the inlet pressure head and the total head losses increase consequently reducing the coefficient of uniformity. Kang (2000), who reported that the coefficient of uniformity increased as the operating pressure increased. Victor et al (2008) supported the above statement when they found out that CU generally increases linearly with operating head.

The Coefficient of uniformity was also described with polynomial regression models. The models exhibited relatively high explained variance R^2, which was 0.933 0.913 to 0.928 for 2m, 3m and 4m vertical pressure heads respectively (Table 14).

Table14: Regression models for CU and lateral lengths at various vertical pressure head

Pressure Head (m)	Polynomial Regression model	R^2
2	$CU = -0.001L^2 -0.047L+96.12$	0.94
3	$CU = -0.001L^2 +0.075L+94.08$	0.91
4	$CU = -0.001L^2 + 0.042L+95.91$	0.93

Conclusions and recommendations

The study revealed that the emitter discharge variation falls within desirable range at 100m drip lateral lengths only at 4m vertical pressure head. The emitter discharge variation at 4 m stand height therefore showed that drip lateral lengths can be laid up to 100m for both plot 1 and 2 scenarios. At 3m vertical pressure head, emitter discharge variation falls within desirable range up to a distance 75m along the drip lateral lengths for plot 2 scenario where the system has a 50m long main line plus a manifold of 50m. This means that 75m is the optimum drip lateral lengths at 3m tank height when the 1ha drip kit system has a 50m long main line plus a manifold of 50m. At 2m vertical head, the desirable emitter discharge variation was observed up to 62.5 m drip lateral lengths. This means that to attain recommended emitter discharge variation at 2m tank height, up to 62.5m drip lateral lengths can be used in a 1ha drip kit system that has a 50m long main line plus a manifold of 50m. The recommended minimum DU value of 80% at 62.5m, 87.5m and 100m drip lateral lengths for 2m, 3m and 4m vertical pressure heads respectively were attained in plot 2. This means that for the drip kit to achieve good distribution uniformity, drip lateral lengths should be 62.5m, 87.5m and 100m for 2m, 3m, and 4m vertical pressure head respectively when the 1ha drip kit system has a 50m long main line plus a manifold of 50m.

The results revealed that at 3m and 4m heads the minimum recommended standard CU value of 80% was attained at 100m drip lateral lengths in plot 2. At 2m vertical pressure head, the system managed to meet the minimum recommended standard at 75m drip lateral lengths in plot 2.

Basing on the results from this study, the following is recommended;

- In cases where the 1ha drip kit system has a 50m long main line plus a manifold of 50m, the system performance could be improved by using shorter drip line laterals especially at low vertical pressure head. For example, at 2m vertical pressure head the optimum drip lateral lengths should be 50 m to improve distribution uniformity. However, 62.5m laterals can still be used for minimum standards.
- The water supply tank should be placed to supply water midway through the field length to eliminate the need for a 50m long mainline which increases head losses through additional friction losses in the system especially at lower tank heights of 3m or less for the 1ha drip kits.

Areas of Further Study

Since this study did not consider all factors that affect water distribution uniformity such as slope, there is therefore need for a further study to evaluate the technical performance of the gravity fed drip kit at various field slopes. Also there is need to evaluate the implications of gravity fed drip kit on yield and fertilizer application.

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