Simple and Low-Cost Drip Irrigation System: An alternative approach to raise household farm productivity

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Abstract

It is estimated that more than 90% of the food supply in Ethiopia comes from low productivity rainfed small-holder agriculture. Hence, rainfall or access to irrigation water is the most determinant factor affecting the food self-sufficiency at household level and national food supply. Not only limited access to water has impeded the productivity of farming system but also lack of appropriate means of utilizing the available water more productively. In the history of irrigation, drip irrigation method has proven to be the most efficient technology that helps to irrigate the plants and not the 'soil'. However, the technology in its conventional design is expensive and can not be afforded by the poor. Raising the productivity of smallholders under Ethiopian condition requires a new approach to the design of simple and affordable irrigation systems. This paper describes the experiences with simple and low-cost drip irrigation system (bucket, clay pot drip irrigations) developed at Arba Minch University and successfully used by the farmers around Arba Minch. The simplicity and availability of the accessories of the system on the local market with reasonable price and the ease of assembling makes it appropriate and affordable to the poor farmers. It is also proposed to spread the technology to other parts of the country with the aim to increase smallholder farm productivity and ensuring food self-sufficiency at household level.

Keywords: drip irrigation, affordability, smallholder, productivity

1. Introduction

Huge proportion of the population (more than 85%) in Ethiopia is engaged in less productive agricultural activities. This low productivity rain-fed small-holder agriculture is the main source of food supply in the country. With this regard, unreliable distribution of rainfall represents critical constraint to food production and is the major cause for food self-insufficiency and famine in the country. Under these conditions, implementation of irrigation is considered as the only means to sustain food production.

Appropriate methods of water lifting and distribution are the most important aspects that determine the efficiency and success of an irrigation system. Also in terms of cost, the water diversion, conveyance and distribution systems are the most expensive parts of modern irrigation network. The distribution of modern irrigation development in Ethiopia is mainly concentrated along the plane of perennial rivers. Neither the poor smallholders have the capacity to install the expensive modern irrigation system nor can the already implemented and planned large, medium and small scale irrigation schemes benefit the majority of the poor. From the perspectives of poor farmers alternative methods such as low-cost smallholder irrigation technologies are vital and attractive.

Experiences from other developing countries show that coupling of low-cost irrigation technologies with water conservation and harvesting technologies allows better control and management of limited water resources and results in much higher returns to farmers. Small-scale, low-cost irrigation systems that can be easily afforded and managed by poor farmers contribute significantly to the endeavors of ensuring food self-sufficiency at household level.

2. Background

Efficient use of scarce water has gained attention during the recent years as key to crop production in arid and semiarid regions. Drip irrigation is widely recognized as one of the most efficient methods of applying water to crops. Rather than irrigating the entire field surface as with other methods with drip irrigation water can be delivered precisely to the root zones. There are reports indicating that drip irrigation brings about water savings of about 50% and reduced labour. However, the conventional drip systems are expensive and cannot be afforded by smallholder poor farmers. To solve this problem a number of innovative options have been developed in different parts of the world (references in Isaya V.S., 2001 and in Postel S. et. al., 2001). The aims of these innovations are being to improve the distribution and application of water. Attempts have been made to make them as simple as possible so that they can be manufactured at lower cost and operated and maintained easily.

Low-cost irrigation systems attempt to retain the benefits of conventional systems whilst removing the factors preventing their uptake by poor smallholders: purchase cost, the requirement of a pressurized supply, the associated pumping costs and complexity of operation and maintenance (FAO, 2001). Low-cost smallholder drip irrigation system can be grouped into bucket and drum drip irrigation kits (Isaya V.S., 2001).

Irrigation kits

In bucket kit drip irrigation, water flows into the drip lines from a bucket reservoir placed 0.5-1m above the ground to provide the required water pressure. Starting from 1995, International Development Enterprises (IDE) is an international NGO that has developed a variety of low-cost drip irrigation kits that are appropriately sized and affordable for smallholders (Isaya V.S., 2001). The kits operate under low pressure (up to 2m) and are successfully used for the production of fruits and vegetable as well as other row crops. The kits are expandable so that farmers can start small and scale-up as their capacity and experiences grow. The capacities of the kits vary from 20-liter bucket that can irrigate 20m^2 to customized system covering about 1000m^2.

Bucket kits

Each comprises a 20 liter bucket installed on a pole at shoulder height. The bucket is fitted with a 15m lateral line from which 26 micro-tubes extend (Figure 1). By placing the tubes midway between parallel crop rows it is possible to irrigate four crops per tube. Depending upon the type of the crop and growing stage, the buckets need to be filled two to four times a day. Each bucket kit irrigates more than 100 individual plants over an area of 25m^2. This technology helps the family not only to save water but also labour and time required to irrigate the garden which otherwise done by women.

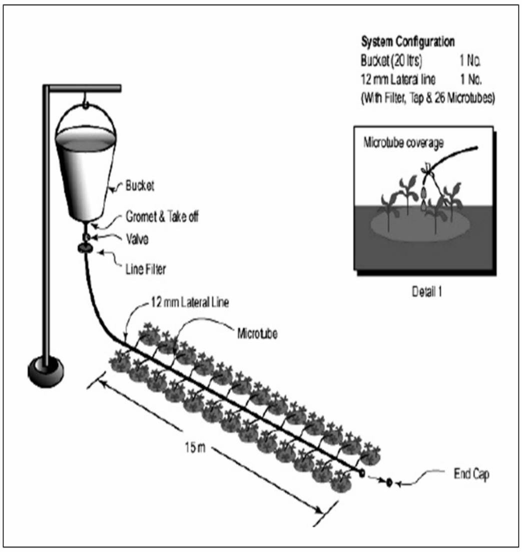

Figure 1. Schematics of a Bucket Kit System (Postel, S. et. al., 2001)

Drum Kits

These systems consists of a 200-liter drum from which up to five lateral extend. It operates also under a low pressure head of water (0.5-5 m). The higher the drum is placed the greater the area that can be irrigated. Each lateral line is 15 meters long and fitted with 26 micro-tubes allowing each drum kit to irrigate 125 m^2 plots (Figure 2).

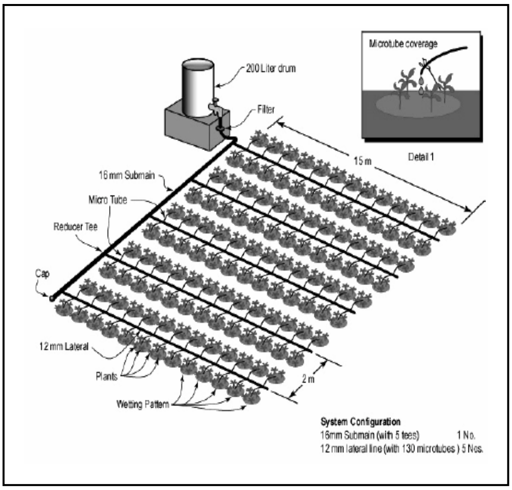

Figure 2. Schematic of a Drum Kit, micro-tube (Postel, S. et. al., 2001)

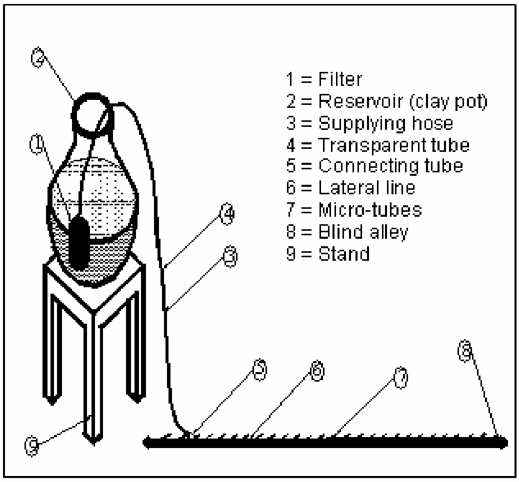

Figure 3. Low pressure drip irrigation system (Fassil, E. et. al., 2003)

Examples of different drum systems such as the KARI drum system from Kenya, the Waggon Wheel system from South Africa, the Family system, Plastro and Micro-Tal systems from Israel and the IDE drum used in India are presented by Isaya V.S. (2001).

In all of these systems attempt is made to take the advantage of the benefits of drip irrigation method without requiring expensive central pressurized water system. The accessories of the systems are mostly developed and manufactured in Israel. Each bucket kit is delivered with instructions on how to assemble it, operate and manage it.

3. Low-pressure Micro-tube Drip Irrigation

3.1. Description of the system

Fassil, E. et. al., (2004) have developed a Low-Pressure Drip Irrigation System. It consists of bucket or locally made clay pot and accessories as shown in Figure 3. The main feature of this system is that all the accessories are available on the local market for reasonable price and can easily be assembled by local farmers with little training and without or with little back-up support. The pots placed at 0.9 m above the surface

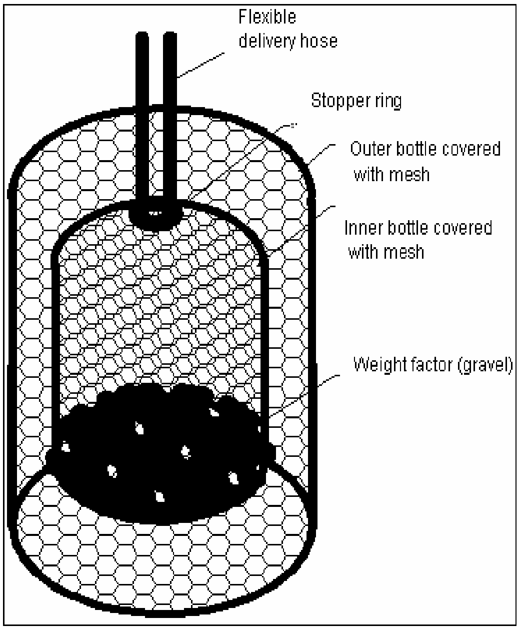

Figure 4. Arrangements of filter components

can supply water to a lateral line which is 15 m long and 16 mm diameter. On a lateral line there are about 28 micro-tubes spaced at 0.5m (spacing of most vegetables) that allow water to drip on the soil. The water enters into a 4.5mm supply hose after passing through a filter arrangement. Filtering of water from coarse materials and impurities is accomplished by outer fine mesh and perforated double plastic bottles inside the mesh (Figure 4). After detaching the hose at transparent tube and mouth sucking the flow of water in to the supply hose can be initiated. Immediately after making sure that the water is in continuous flow in to the flexible delivery hose, the hose can be reconnected.

3.2. Test Results

3.2.1. Dripper Discharge

The capacity of the system to distribute the required amount of water to the plant is determined by the discharges of the drippers. To know the discharge of each dripper and the uniformity of its distribution a catch can test was conducted. The results of the experiment are presented in Tables 3.1 and 3.2 and Figures 5 and 6. As can be seen from Figure 5, the discharges of all drippers are scattered around the average discharge line along the entire distance. It can be said that all drippers along the lateral line release water at almost a uniform rate..

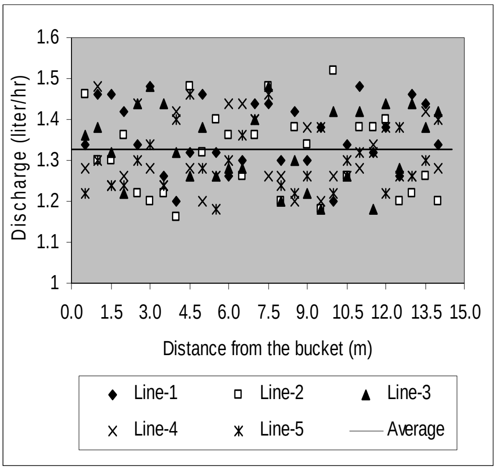

Figure 5. Discharge of drippers along five lateral lines (28 drippers on each lateral line located at 0.5m distance along the line)

No significant differences in water distribution rate has been observed between drippers at the head, middle and tail of lateral line. Uniformity in water distribution is maintained throughout the system

There is no significant difference between the average discharges of all lateral lines. Both standard deviation and coefficient of variation are very low, i.e., 0.08 to 0.1 and 0.06 to 0.08 respectively. The overall average dripper discharge is 1.326 liter/hour. This multiplied by 28 drippers is 37.12liter/hour which is the capacity of one lateral line. A 15 meter lateral line with its 28 drippers over 0.50 meter wide bed can irrigate an area of 7.5 m^2.

3.2.2. Uniformity parameters

Distribution Uniformity (DU)

For a uniform growth of the plant uniform application of water along the lateral line is essential so that each part of the irrigated area receives the same amount of water. However, as the water flows from one end of the lateral line to the other, there will be head loss which results in uneven distributions of discharge from the outlets over the lateral lines. Irrigation system needs to be carefully designed so that the variation in discharge is minimized.

The commonly used measures of uniformity are Distribution uniformity and uniformity coefficient. DU is a measure of a dripper's ability to apply water uniformly over the surface. A completely uniform application would have a DU of 100%. The more unevenly the system distributes water, the smaller the DU value. DU can be estimated as

$$DU\,(\%) = \frac{\bar{q}_{lowest\ 25\%}}{\bar{q}}$$

Where, $\bar{q}_{lowest\ 25\%}$ = average of the lowest quarter discharge

$\bar{q}$ = average discharge of all drippers

Table 3.1 Statistical parameters of catch can test

	Line 1	Line 2	Line 3	Line 4	Line 5	average
Average discharge (l/h)	1.361	1.314	1.337	1.311	1.305	1.326
SD	0.083	0.101	0.092	0.083	0.075	0.087
CV	0.061	0.077	0.069	0.063	0.057	0.066

Coefficient of Uniformity (CU)

CU as proposed by J.E. Christansen (1942) is widely used to estimate the uniformity of water distribution in sprinkler irrigation. It has been applied to all types of irrigation systems. In drip irrigation it is also known as Emission uniformity (EU).

$$CU = 1 - \frac{\left(\sum \left|q_i - \bar{q}\right|\right)}{n\bar{q}}$$

Where,

q_i = dripper discharge
$\bar{q}$ = average discharge
n = number of drippers

The results of DU and CU along the lateral lines are presented in Figure 6. The curves of both parameters of uniformity measures show similar trend with DU lying above that of DC. As can be seen the system have been observed to have consistently DU and CU above 89 % and 84 % respectively.

The results of water distribution uniformity of five sample lateral lines are calculated and given in the table 3.2. In average over the laterals the distribution uniformity is 92% while the coefficient of uniformity is 90% which signify an even distribution of water throughout the system.

Table 3.2. Summary of Uniformity Parameters

Lateral lines	Uniformity parameter (%)	
	DU	CU
1	92.1	90.1
2	90.9	88.5
3	91.0	88.9
4	93.7	90.3
5	93.5	91.9
Average	92.24	89.94

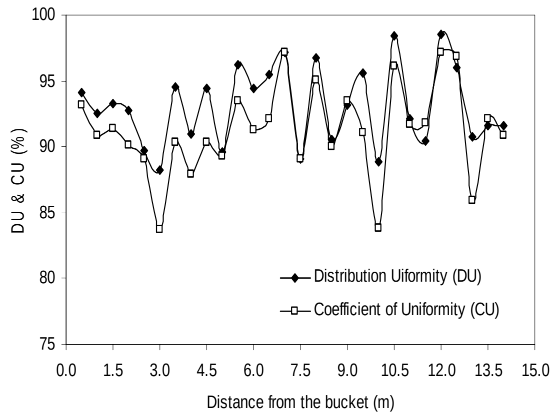

Figure 6. Distribution Uniformity and Coefficient of Uniformity along the Lateral Line

3.3. Wetting Pattern

The wetting pattern under a dripper varies according to the texture of the soil. In soils of capillary suction the horizontal and vertical infiltration will be similar and the wetting pattern will be approximate to a hemisphere. In coarse soil, with low capillary suction, the wetting pattern will be more elongated with a higher vertical movement.

Water flowing from dripper is distributed in the soil by gravity and capillary forces creating the counter lines. The exact shape of the wetted volume and moisture distribution depend on the soil texture, initial soil moisture, and to some degree on the rate of water application.

The moisture distribution patterns of the drippers after irrigation have been determined using gravimetric method. The results are presented in Figure 5 and 6. The results of dripper 2, 14 and 28 which are located respectively 1m, 7m and 14 m away from the bucket/ reservoir. Constant moisture content below 45 cm depth shows initial water content. Water application has brought about change in water content only in 45 cm soil layer (0-45cm) at the time of sampling. For some extent, further redistribution of water in vertical direction may take place between the wetted zone and the underlying dry soil. The distribution patters coincide with typical wetting pattern of soil under drip irrigation system.

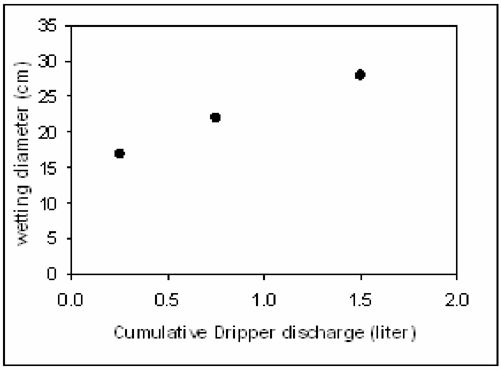

Figure 7. Relationship between dripper discharge and surface wetting

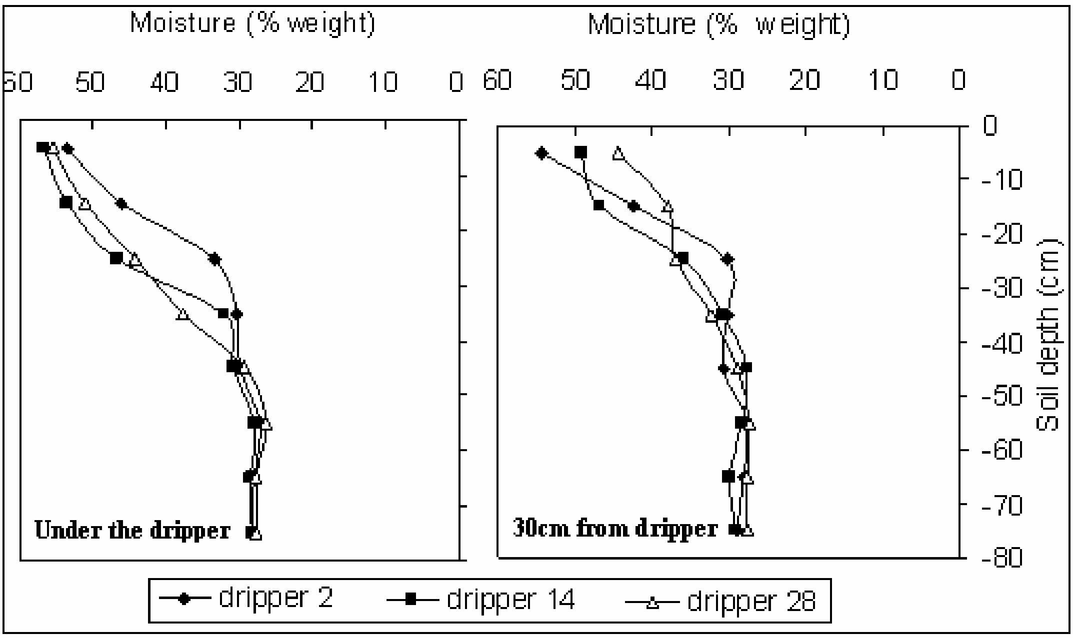

Figure 8. Moisture distribution patterns under different drippers located at different distances from bucket (dripper 2, 14 and 28 are located at 1.0, 7.0 and 14.0 m away from the water source/ bucket respectively)

Figure 8 shows that more uniform moisture distribution pattern over the entire lateral line can be obtained when the moisture distribution of the adjacent drippers overlaps. For closely spaced vegetables the dripper distances are also close to each other so that the wetting patterns overlie and create continuous moisture zone along the row/ lateral.

Moisture content in 30 cm from the dripper is higher than in 15 cm. Under single dripper the wetting front starts directly from the center of the dripper and advance both vertically and laterally (figure 7). In the practice series of drippers are arranged one after the other so that the wetting patterns of neighboring drippers overlap and produce more moist areas. This moisture distribution characteristic supply crops planted between the drippers with more water than those crops planted under the drippers.

At water application rate of 1.326liter/hour the surface wetting front will take about one hour to overlap with wetting front of the neighboring dripper. Figure 7 shows how the surface wetting advances with volume of water applied. This characteristic of moisture distribution is of course, as described above, the function of soil physical properties.

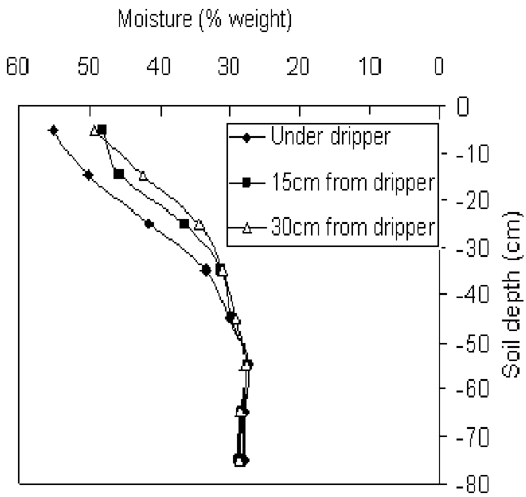

Figure 9. Average lateral and vertical moisture distribution patterns

Summary

Under the present condition, whereby water harvesting at householder level is widely practiced in Ethiopia with the aim to fight against poverty and food self-insufficiency, appropriate means of producing food out of water is an important issue that deserves attention. Low-cost drip irrigation systems can support such endeavors as they can save and supply water to the plant more efficiently and afforded by the poor farmers. When operated properly wastage of water can be minimized with increased water productivity. In addition to its simplicity, low-pressure micro tube drip irrigation system extremely save the precious water and labour needed to water plants each plant every time. Moreover, vegetables watered with low-pressure micro-tubes drip irrigation system have higher yields.

Experiences from Arba Minch shows that a single low-cost drip irrigation system of 60 -70 birr initial cost can supply family with fresh vegetable for home consumption. Figure 10 shows the cumulative harvest of fresh tomato from one row (0.5m × 15m) irrigated by one lateral line of the drip system. With the adoption of the system, a family has harvested every three days over more than one month which was enough for the family. Increasing the number of laterals or rows will increase the opportunity to produce more for local market and get more income.

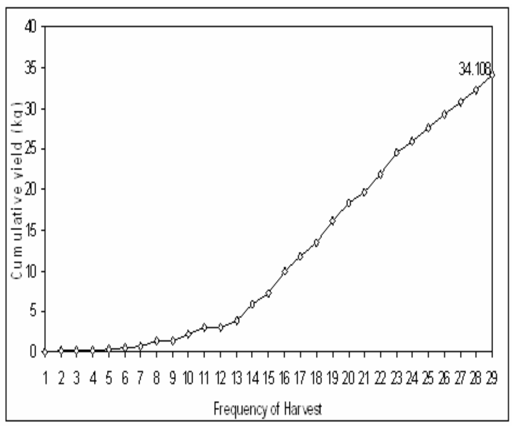

Figure 10. Cumulative harvest of tomato from field of a lateral line

The system has the water supply capacity of 1.326 liter/h/dripper × 28 (total number of drippers) = 37.12liter/hour. Satisfying the water requirement of the crop, which is the function of climatic condition, crop type and growth stage, is possible through adjusting time of application. Suppose the peak water requirement of tomato growing on 7.5 square meter bed is 5mm/day. The total daily water requirement is equal to 37.5 liter/day. If the tomatoes are to be irrigated every day by the lateral that drips 37.12 liter/hour, the operating time would be

$$\frac{(37.5\, liter/day)\times day}{37.12\, liter/hour} = 1.0\ hour$$

However, the capacity of the bucket is 20 liter so that the farmer needs to fill the bucket two times a day to meet the water requirement of tomato in this case.

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