Clay Pot Pitcher Irrigation: A Sustainable and Socially Inclusive Option for Homestead Fruit Production under Dryland Environments in Ethiopia (A Partial Review)

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Abstract

This paper aims to highlight the significance, in terms of household food and nutrition security, of such longstanding but yet neglected traditional method of irrigation system, more particularly for socially inclusive homestead-level fruit production across the dryland parts of Ethiopia. In so doing, attempts were made to review relevant findings and experiences elsewhere in world and recount their implications with achievements of the local interventions carried out in some dryland localities of Ethiopia. While similar attempts have been carried out by other institutions as well, the paper focuses on the interventions and accomplishments of the UN initiated Millennium Village Project (MVP), put into operation in Hawzen district, Tigray Regional State, Ethiopia. The findings of both the review work and practical appliances through the project correspondingly indicate that the system can help promote and integrate fruit production successfully into the existing cereal dominated dryland cropping systems in Ethiopia so as to bring about ecological, aesthetical, economical and nutrition improvements invariably for the rural communities located across all landscapes, climatic conditions and topographic regimes. The system can be made more useful when combined with small-scale water harvesting technologies (e.g. seasonal run-off collection ponds, roof-water reservoirs and use of treadle pumps attached to hosepipes) located close to household backyards. As a future line of investigation, the findings also emphasized the need for further research to improve the design, durability and overall efficiency of the existing clay pot pitchers.

Keywords: Pitcher irrigation, dryland, homestead fruit production, sustainability, social inclusiveness

1. Introduction

Irrigation is a crucial input for growing crops that call for high water supply in agriculture. Per se, it is commonly defined as the application of water for agricultural purposes through man-made systems to supply water requirements not satisfied by rainfall (Stein, 1998). In some cases, it is also defined as the application of water to land areas to meet both the water and nutrient (“fertigation”) needs of plants (Stein, 1998).

The dramatic increase in world population has resulted in a greater demand for food and nutrition security. Meeting the growing demand primarily requires optimizing agricultural production per unit area of land as well as unit volume of water application. However, water for irrigation is a very scarce resource in most parts of the world, more particularly in arid and semi-arid areas where there are extreme temperatures, uncertain rainfall, fast-depleting water resources, high rate of evapo-transpiration, and high level of soil salinity (Bainbridge, 2001).

In the alternative, under such circumstances, some dryland countries have adopted certain water saving technologies like drip and sprinkler systems to irrigate their crops so that their scarcely available water resources will not be depleted. Here again, although such irrigation methods are known to save about half of the water presently used for surface or furrow irrigation, their technical, economical (high investment and operational costs), and socio-cultural factors have remained a serious hindrance from adoption, especially by small-scale farmers (Theib and Ahmed, 2004). The use of such techniques has thus been limited to commercial farms and to those areas with relatively plain landscapes or topographies that are relatively located in closer proximity to water points. As such, the large majority of smallholder farmers in those areas are still by and large deprived of irrigated farming and so much exposed to food and nutrition insecurity.

All the same, in some dryland parts of Ethiopia, the traditional irrigation system is limited to certain pocket areas where there is limited amount of water resource. Besides, these areas are often located far away from farmers’ houses and so are exposed to various threats such as damages by wild and domestic animals as well as other malpractices including theft. As such, they have often remained a source of conflict and discontent for the farming households to expand fruit production under such conditions.

Understanding the situation, some dryland countries have adopted certain locally appropriate water efficient technologies such as the clay pot pitcher irrigation system mainly to ensure fruit production at household levels indiscriminately across all landscapes and topographic regimes.
Likewise, this paper attempts to emphasize the role and significance, in terms of household food and nutrition security, of such longstanding but yet neglected traditional methods of pitcher irrigation systems, more particularly for socially inclusive household-level fruit production across the dryland parts of Ethiopia. In so doing, the paper also tries to incorporate certain review findings of relevant worldwide experiences into some of the local achievements.

2. Pitcher Irrigation: An Overview

2.1. Background History and Development

As stated by Stein (1998), pitcher irrigation is an ancient irrigation system known to have originated in northern Africa and in Iran. In fact, it is even recorded in Chinese texts dating back to more than 2000 years (Sheng, 1974). Pitchers are the round earthen containers often used in rural areas for water storage, ranging from 10 to 20 liters in capacity. Functionally, they are similar to the drip systems, but very much less expensive to install. They are one of the most efficient traditional systems of irrigation known and are well suited for small farmers in many dryland areas of the world (Figure 1 & 2).

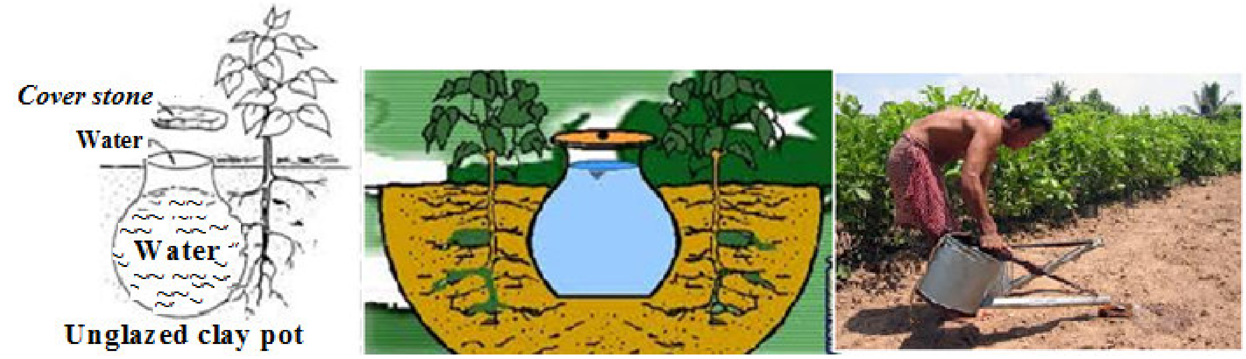
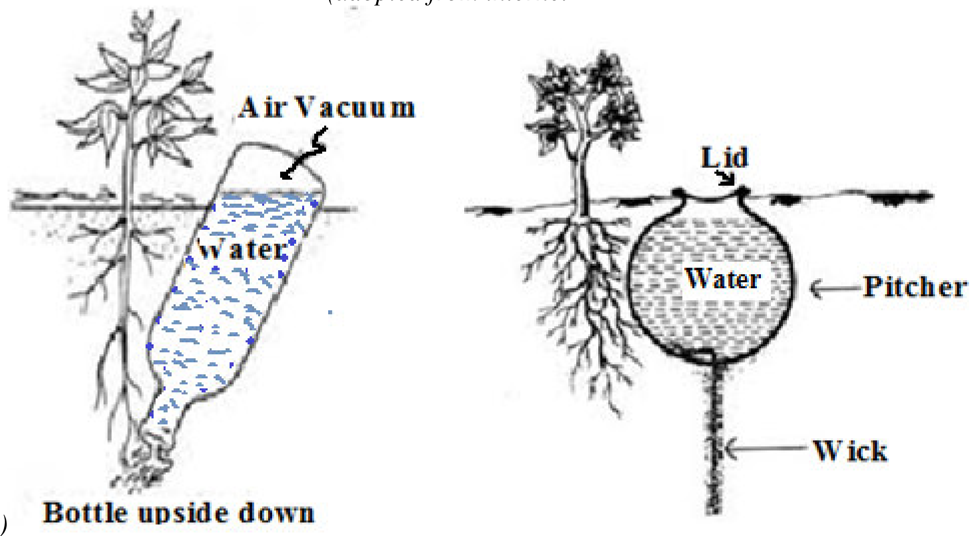


Figure1. Common traditional unglazed and porous clay pot pitchers used around the world *(adopted from internet*



sources)

Figure 2. Other lately developed optional systems commonly used for pitcher irrigation around the world *(adopted from internet sources)*

Pitchers area very efficient irrigation systems used to grow a wide range of annual and perennial plants in many arid and semiarid regions around the globe such as Pakistan, India, China, Iran, Mexico, Morocco, Algeria, Tunisia, Indonesia, and Brazil (Mondal, 1984; Soomro, 2002; Setiawan et al., 1998). The system is particularly known to be ideal for spreading plants such as gourd, pumpkin, and melon because few pitchers are needed per unit area. It is also very good for rooting cuttings, promoting deep root growth of saplings, for other vegetables such tomatoes and okra, and landscape gardening such as growing plants in containers (patios or porches) where the clay pots are buried in the planter boxes (Anonymous, 1978). as There also known to be ideal for nursing deep rooting large fruit crops in that, once the roots of such trees grow deep, they will be able to harvest moisture from the lower part of the soil system and become partially self-sustainable.

As reported by rajshekar (2009), eucalyptus trees planted in communal woodlots in Burkino Faso are watered through buried clay pots; in Zambia experiments have shown that fruit tree seedlings watered through buried clay pots grow faster and healthier than tree seedlings watered from above; and in Pakistan and the deserts of the USA, clay pots have been found very effective in reforestation programs. Owing to such amiable qualities, the pitcher technology is generally recommended for dryland areas with less than 500 mm rainfall per annum (rajshekar 2009).

2.2. Preparation, Hydraulic Conductivity and Adjustment Capability of Pitchers

Locally available selected clay soils are often used to make clay pot pitchers in many countries. In fact, a mixture of sand and clay as the base material for pitchers has proven to be a very effective and practical method to increase the saturated hydraulic conductivity and hence the seepage rates of pitchers (Bainbridge 1986). In addition, it was observed in many places that, besides the material composition, the method of production and firing process had a substantial influence on the permeability of the pitcher material (Bainbridge 1986).

Most commonly, pitchers, in their simplest form, consist unglazed baked earthen pots, which are buried to their neck in the soil and filled with water, directly feeding the roots of the plants with a steady supply of moisture (Saleem Shaikh and SughraTunio, AlertNet / August 29, 2012). They are essentially recognized as a simple, low-cost or cost-effective solution of controlled irrigation for dryland farming. The reasons for these properties are thought to lie in their high auto-regulative capabilities which arise from the close interaction between the pitchers and their environments, namely the soil, climate and plants (Stein 1998).

As stated by Stein (1998), pitchers do have a significance influence on the adequacy of the crop water supply, the degree of which depends on their individual properties. Water flow from the pitcher to the surrounding soil matrix is controlled by the permeability of the pitcher wall and soil suction gradient. That means, when the wall of the pitcher is in saturated condition, the suction gradient will be the main driving force controlling the water flow. Hence, in contrast to other irrigation systems, pitchers are functionally closely interconnected to the environment. They are thus affected in a distinct way by the environmental factors (soil and climate) and the irrigated crop. In other words, similar to other systems, the efficiency of pitcher irrigation is dictated by many factors including soil type, soil structure, soil fertility, plant species, weed competition, rate of evapo-transpiration, and the site microclimate. For example, when a clay pot filled with water and covered with a lid (i.e. plastic sheet, cloth, wooden or clay cover) is buried in the soil, the water gradually seeps or oozes out of the porous walls of clay pots by diffusion and capillary action to maintain plant growth around. This happens due to the hydraulic head difference or hydrostatic pressure/suction (i.e. moisture content difference) between the pot surface and the surrounding soil and continues up until the saturation level gets in equilibrium with the surrounding area (Stein, 1990). Similarly, the rate of seepage of water from the pitcher depends on the type of plant and soil and climatic conditions around it. Since the movement of water is dependent on the rate of uptake by the crop, the process of seepage will tend to continue as long as the plant takes it up (Stein, 1990).

As detailed by Bainbridge (1986), pitchers are also capable of adjusting their seepage rates according to changes in evapo-transpiration rates or crop water demands. The degree and capability of adjustment also is determined by the hydraulic conductivity of the pitcher material, and soil type. The increasing root growth around pitchers maximizes the seepage rates at first and decreases overtime with the increase in the length of the roots of certain deep rooting crops.

In addition to being simple and less expensive, pitchers are much more effective than traditional means of irrigation. Bainbridge (1986) reported that per cubic meter of water, the buried clay pot method can produce 2.5 to 6 kilograms of total plant yield, compared to 1.4 kg with drip irrigation, 0.9 kg with sprinklers, and 0.7 kg in closed furrow irrigation systems (Table 1). He also stated that with a seepage rate of 88 percent in just over 24 hours, the system saves up to 98.7 percent of water as compared to furrow or flood basin irrigation system used in sandy loam soils.

Similarly, Rajshekar (2009) reported that pitcher irrigation is more efficient than all other systems in terms of crop production per unit application of water. As shown in Table 1 below, this was more specifically substantiated by Siya et al. (2009) that a corn crop in Mexico produced higher yields when grown under pitcher irrigation system than other conventional irrigation methods.

Table1. Yield results of corn when grown under different irrigation techniques (kg/per plant/per cubic meter of water), Mexico, 2009

Irrigation technique	Productivity (kg/per plant/ per cubic meter of water)
• closed furrow (basin)	0.7
• sprinkler	0.9
• drip	1.4
• porous capsule (pressure)	1.9
• deep pipe	2.4
• porous capsule (no pressure)	2.5
• buried clay pot	2.5 to 6
• Wick	>4

2.3. Preparation of Trenches and Installation of Pitchers

As outlined by Siya et al. (2009) and Rajshekar (2009), the installation of pitcher irrigation generally trails through the following steps. First, an appropriate site is selected and a pit is dug, which is often about three times as wide and two times as deep as the pitchers to be buried out. In fact, in places where the soil is sandy or sandy loom, the pit is often dug as deep as the pitcher. The soil at the bottom of the pit should be broken up well with a fork. About 1⁄3 of compost or aged manure is mixed with the soil that was removed from the hole, breaking up the clods. If the soil is very heavy, some sand is mixed in. If the soil is very saline or alkali, some gypsum can be added. Then, the pitcher is placed inside the pit with its neck kept above the soil surface. Enough of the soil mix is put surrounding the outer wall of the pitcher and firmed up. The pitcher is then filled with water and the mouth must be covered with lid or any tight closing material to prevent evaporation, protect animals such as birds from drinking the water, and prohibit mosquitoes and other creatures from living inside. The pitcher should be positioned in a way that rainwater runoff cannot enter it directly; otherwise silt may block the pores. The spacing of the pitcher pot depends on the crop and the soil. The most common mistake observed at this stage is known to be placing the plants too far from the pitchers, outside the wetted soil zone. The pitchers should be regularly checked not to let them dry out. They are supposed to be refilled anytime when ¾th of the water is gone. The time between refills can normally vary during the growing season and small pitcher pots normally need refilling every few days, whereas the larger ones could last for some weeks between top ups.

Soluble fertilizers and water filtered compost or manure can also be mixed with the water and applied through the pitchers. If the water used for irrigation has high salinity, the pitcher location needs to be changed every 2-3 years. To increase the depth of irrigation, a wick (i.e. often a thread of water absorbent cotton made cloth) can be added to the pitcher. The hole in the bottom of the pitcher where the wick will be inserted needs to be made before firing the pots. At times, the cotton wick is firmly fixed into the hole to prevent plant roots from entering (Fiure 2). If pitchers are used for starting saplings, they can be removed after 1 or 2 years and used elsewhere in that the young trees could have developed deep roots to harvest moisture on their own from the soil system.

Selection of the most suitable size of pitcher pots and their placement, as well as the number of pitchers needed per hectare, normally varies or is governed by the type of crop. As stated by Rajshekar, (2009), creeping crops such as bitter gourd and cucurbits require 2,000-2500 pitchers per hectare. Upright crops, or crops producing a canopy around the pot also require more pots, i.e. up to 4,000-5000 pots per hectare. Other than the type of crop, the number and size of the pots needed depends on the distance or spacing between individual plants, and how long the farmer wants to leave between refills. Various studies also indicate that smaller pots of 6-12 liter capacity are sufficient to grow most vegetable crops and much bigger ones for fruit trees.

3. Promotion of Clay Pot Pitcher Irrigation in Ethiopia: The Case of Millennium Village Project (MVP) in Tigray Regional State, Hawzen District

3.1. The Project

Millennium Village Project (MVP) was a UN initiated project formulated to piloting the implementation of the Millennium Development Goals primarily in 14 sites of 10 Sub-Saharan African countries. In Ethiopia, it was officially launched in February 25, 2005 (Figures 3 & 4), and was operational in 11 intervention villages of the Hawzen district, Tigray Regional State, then comprising 67,219 people in 14,034 HHs (8636 MHH and 5398 FHH) and covering an area of 371 sq.km.

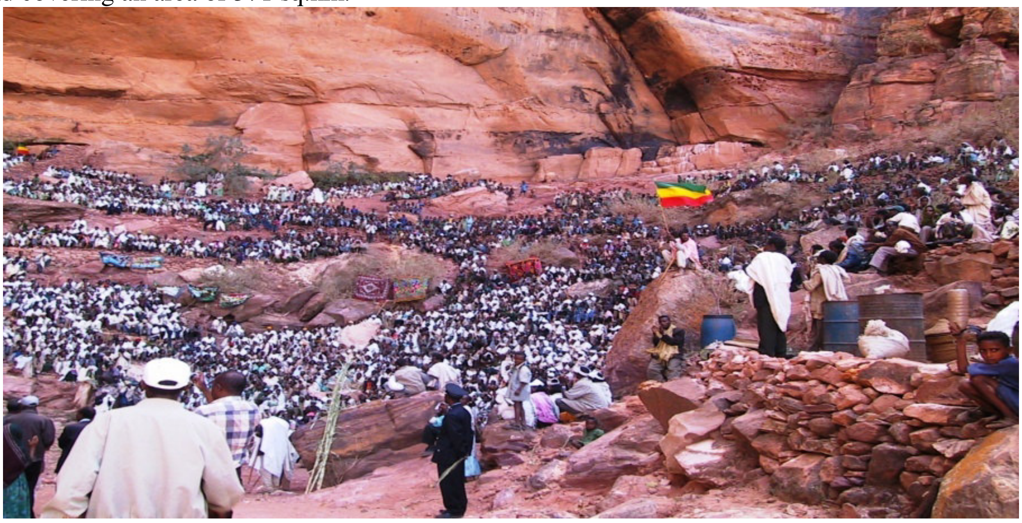


Figure 3. The launching ceremony of the Millennium Village Project (MVP) in Feb. 2005, Koraro research village, Hawzen district, Tigray Regional State, Ethiopia

Figure 4. Partial view of the then Millennium Village Project focal intervention village (Koraro village) in Hawzen district, Tigray Regional State, Ethiopia

Similar to most dryland parts of the world as well as Ethiopia, fruit production is in the Project intervention villages in Tigray is limited to certain pocket areas where there is water for irrigation. Thus, before the arrival of the Project, homestead fruit production was almost impossible as the houses are located more than 1.5 km away from the closest water points. Understanding the situation, the Project recognized the value of the clay pot irrigation system in promoting the production of high value fruit crops (i.e. sweet orange, mango, avocado and apple) into the closest vicinity or homesteads of the beneficiary farming households (Figures 5 & 6).

Five grafted/budded seedlings of the nationally released varieties of the above stated fruits, as appropriate to the climatic conditions of the intervention villages, were randomly distributed and planted at household level. Similarly, 20 seedlings were distributed across each of the then existing elementary and junior high schools located all across the intervention villages. Those seedlings planted at schools were watered and managed by the respective school students and supervised by the teachers. Acceding simplicity to rationality, the system had caught the interest of neighboring farmers and so the project had then managed to influence 1418 households and 24 schools in just its first two years of intervention (Table 2 & Figures 5 & 6).

Table 2. Number of clay pot pitchers and fruit seedlings distributed across the 11 Millennium Village Project sites, Hawzen district, Tigray Regional State, Ethiopia, 2007-2009

-	Intervention village	No. of clay pots distributed	No. of beneficiary households	No. of beneficiary schools
1	Koraro	910	65	2
2	Megab	1418	127	2
3	Freweini	1190	107	2
4	Digum	1680	186	3
5	Debre-Birhan	1624	154	2
6	Selam	1665	161	2
7	Siluh	1355	130	2
8	Ara-Aras	1153	109	2
9	Tsenkanit	1103	104	3
10	Hatset	1333	127	2
11	Hayelom	1543	148	2
	Total	14974	1418	24

During the dry season, it was observed that farmers often need to water their individual fruit trees without pitchers at least 4 times a month using the same capacity containers (20 liters capacity Jeri-cans), i.e. while it was procedurally only once a month under the pitcher system. Fruits were also observed performing much better under the pitcher system, in all aspects including survival rate, growth and earliness to fruiting.

Figure 5. Sample pictures of homestead sweet orange (left), avocado (middle) and apple (right) production using clay pot pitcher irrigation, Millennium Village Project, Hawzen district, Tigray Regional State, Ethiopia (all only 18 months old grafted plants)

Figure 6. Demonstrating household level water-efficient technologies, including clay pot pitcher irrigation for fruits and single-line drip system for vegetables, Millennium Village Project, Hawzen district, Tigray Regional State, Ethiopia

3.2. Design, Placement and Management of the Clay Pot Pitchers

Unlike those used in other dryland countries, the design of the clay pots employed by the Project was modified to be fully fired at high temperatures in a similar way as those used for fetching water by the local villagers (Figure 7). In this case water diffuses out through the three minute holes prepared by the pot-makers themselves at rectangular angle about 3-5 cm above the bottom of the pots. The holes were located only on one side of the pots and during installation put directing towards the seedlings situated in between. Two pots were used for one fruit seedling, which were situated 35cm to 40 cm away from the seedling and about 20 cm from both ends of the 2 m long trench. The water from the pots thus seeps out into the soil next to the roots of the plant through the three minute holes from each pot. As the plant uses up the water, water continues to seep out from the pots. In this way, the pots were able to feed exactly the right amount of water required by the plants. The farmers regularly check the pots at intervals and refill or top them up before they run out.

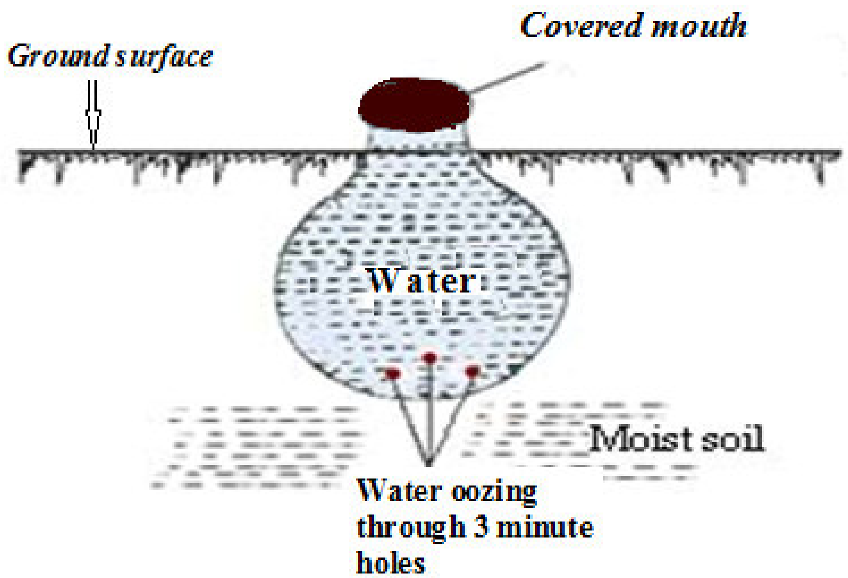


Figure 7. Modified design of fully fired and impervious clay pot pitcher irrigation system developed by Millennium Village Project (MVP), Hawzen district, Tigray Regional State, Ethiopia

The pots were a conical body and narrow neck with a capacity of 20 to 25 liters of water and with the mouths exposed but closed. Two pots were buried to their necks in the soil within the 2m long x 0.70cm deep x 07cm wide trench and filled with water every 25-30 days during the dry season, depending on the soil type, climatic conditions and stage of growth of the plant, to provide controlled irrigation. Before planting, the trenches were kept open for about two weeks for proper aeration and then filled with well decomposed farmyard manure or compost to about 50% of their total area. After planting of the seedlings in between two pitchers, the top soil, which was placed on one side of the trench, was first placed back into the pit to fill in the remaining 50% of the trench area. The sub-soil was then spread along the outer surface of the trench and covered with mulching materials before watering. Once and for all, the trenches were fully watered from the surface only immediately after planting of the seedlings and the installation of the pitchers. Pitchers were then continued to be filled in with water at intervals to feed the seedlings. During the main rainy season, the pots were kept empty but closed as the soil normally saturates from the rain water. However, the soil on the top surface of the trenches were constantly kept manured and mulched in order to regulate the soil temperature as well as supply nutrients to the seedlings. Stone bands were placed around the trenches just for demarcation purpose and the whole orchard yard was fenced with local materials in order to protect the plants from intruding domestic and wild animals. The system was generally found to be as much as 10 fold efficient, saving 70-90% of water, compared to the conventional surface irrigation method in that there was almost no evaporation loss and infiltration loss was so negligible.

The pots were purchased for Birr 10-12.00/piece from the organized village-level pot-makers (all females), as most of them culturally possess the knowledge of pot-making from selected soils available within their localities. As such, the system not only enabled each and every household to grow at least five grafted/budded nationally released high value fruit trees within their homesteads, but also provided ample employment and income generation opportunities to the local pot-makers. Moreover, the system had also enabled the Project to scale up the knowledge and skill of clay pot making to the other members of the intervention villages and beyond.

Figure 8. Millennium Village Project (MVP) truck distributing clay pot pitchers, manufactured by locally organized women clay pot-makers, across the intervention villages, Hawzen district, Tigray Regional State, Ethiopia

4. Summary and Conclusions

4.1. Comparative advantages of pitcher irrigation

Various studies, including the local experience acquired during the implementation period of the Millennium Village Project stated above, distinguished the following advantages of pitcher irrigation as compared to other systems.

- It is a sustainable and socially inclusive technology, which can be applied equally across all landscapes, climatic conditions (low, medium or highland) and topographic areas.
- It is proved useful for land restoration under sloppy areas and more reliable than the relatively high tech drip irrigation system, which usually is much more costly and requiring flat fields.
- It is ideal for small farmers trying to make a living out of marginal drylands; enabling them growing different crops in such areas where they otherwise could not do so.

- It is much less sophisticated and easy to install, operate, maintain and managed by individual smallholder farmer households. It is made with locally available materials and skills, and doesn't need a pump to work.
- The system is completely indigenous (readily available throughout the world, especially where they are traditionally used to keep drinking water), technically feasible, economically viable, socially acceptable, and environmentally friendly (minimize soil erosion by keeping the water underground, maintains good soil structure and aeration since water is not poured on to the soil, etc.) and low input system that enables sustainable crop production. The clay pots are relatively cheap in price in that they are manufactured locally by local pot-makers and from selected locally available soil types). Communal farmers, especially women, can manufacture the pots without having to develop special skills.
- Unlike other systems of irrigation, the system needs no water pressure and water filters.
- It is an efficient and low cost sub-surface micro irrigation system requiring less labor and delivers steady supply of water slowly directly to the root zones instead of to broader areas of the field. As such, various studies indicate that it saves about 90% of water that could be applied through the traditional furrow irrigation systems. Studies also indicate its cost is about 82 per cent cheaper both than the 'drip' and 'sprinkler' irrigation systems. Water loss from the pot is regulated by soil moisture content (i.e. when the soil reaches field capacity, water flow from the pots either stops or decreases significantly).
- It minimizes infiltration loss (enables demand-driven slow release of water below the ground). Deep percolation losses are negligible since water is released from smaller areas, and the rate of water loss can be controlled site to site by the amount of water put in each pitcher
- Evaporation loss is as well very negligible as the mouths of the pitchers are kept closed immediately after refilling.
- It minimizes the risk of salinity and by so doing enables farmers grow crops in areas with such problems. Normally salts are moved out of the root-zone to the edge of the wetted soil so that the water around the plant roots is less salty. Experiments in Kenya and India have shown that buried clay pots work better than usual irrigation methods in areas where the available water is salty.
- It controls weeds, i.e. water is applied at depth and the need for plowing and weeding is minimized as the water source is below the surface and does not allow for weeds to get out of control. In other words, when properly applied, the system needs less weeding to do in that the water in the pot is given to the crop, not to the weeds.
- Various studies indicate that it is ideal for growing high value crops under sandy to loamy soil with 40-60 per cent porosity.
- As shown in Table 1 above, the systems enables higher yields per unit area, i.e. 72-88%, 64-85% and 44-76% higher than with furrow (flood), sprinkler and drip irrigation systems respectively. Studies also indicate that the pitcher system is up to 10 times more efficient than watering plants from above with watering cans; hence less work for the farmer household as there will be less water to fetch and apply. Furthermore, since the system needs less water, it is so feasible to apply using rainwater catchment systems, spotted seasonal runoff mini-collection ponds and related cisterns as water sources. This also helps extend the growing season of crops over the whole period of the dry season.
- It creates job and business opportunities, especially for women, as those who make the pitchers can sell more clay pots along with clay made lids to cover the mouths.
- It is known to stabilize the effects of heavy winds and sand dunes in coastal areas by growing fruits, vegetables and shrubs
- Once the technology is installed and protected well, the system can be used for several seasons.

- It helps expand and integrate fruit production successfully into the existing homestead and mountain area crop and agro-forestry-based production systems and bring about ecological, aesthetical, and economical and nutrition benefits to rural communities.

4.2. Basic precautions required to overcome certain limitations of the pitcher irrigation system

As with any other system, pitcher irrigation is not as well a perfect solution that can be applied without any limitations. Consequently, some of the precautionary measures that need to be given due attention include:

- At times, some plants may become highly dependent on the pitchers as their only water source and therefore may not develop the actual deep-rooting systems to as much a level as their potentials. Under such circumstances, wicks of appropriate size may be used to improve the situation.
- During installation or removal of the pitchers, they need to be handled with care to avoid breakage
- The buried clay pots may clog up over time, especially if left dry for a long time. If this happens, they need to be removed from the soil and scrubbed, or soaked to clean out the pores
- The clay mixture, firing time and temperature and choice of clay need to be right and ascertained way ahead to be sure that the pitcher pot will be good enough for the purpose.
- If silty or muddy water is used, it may block the tiny holes in the clay pot and stop it from working efficiently. Hence the water should be clean enough, or else filtered using narrow meshed materials or cloths in advance of filling it into the pots.

5. Recommendations

With a vision to promote the production of fruit crops across all dryland parts of Ethiopia, the following interventions are prioritized and recommended.

- Clay pot pitcher irrigation can be made more useful to small-scale farmers when combined with small water harvesting techniques such rainwater catchment systems, use of treadle pumps attached to a hosepipes, spotted seasonal run-off mini-collection ponds and related cisterns as water sources.
- Further research needs to be undertaken to improve the design, durability and overall efficiency of the existing clay pot pitchers.
- Extension and agricultural research institutions should work more closely with the farming communities in order to identify, develop and smoothly promote a range of locally appropriate technological options such as the clay pot pitcher irrigation system.
- Extension services of all kind should make every effort necessary in good time to improve the entire livelihoods of the farming communities and conserve natural resources using the existing strategy to adopt and promote (scale up and scale out) the underlying success stories of the Millennium Village Projects that have been implemented all across Sub-Saharan Africa.
- The use of locally manufactured clay pot pitchers not only provides a sustainable source of inexpensive pots for irrigation purposes, but also offers an outlet for promoting income and skill development opportunities more inclusively across the rural communities (esp. women and rural youth).

6. Acknowledgements

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