# Evaluating water productivity of tomato, pepper and Swiss chard under clay pot and furrow irrigation technologies in semi-arid areas of northern Ethiopia

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**Abstract:** Managing irrigation water is among the critical issues to address food insecurity under climate change and variability conditions. Irrigation is suggested as one of the adaptation practices commonly implemented to reduce climate related risks. However, there is scarcity of water in many drylands and identifying an efficient and effective irrigation system is crucial. A comparative study was undertaken between bar-shaped clay pot and furrow irrigation on tomato, pepper and Swiss chard crops in northern Ethiopia during the cropping season of 2014/2015. Results were compared on the basis of yield, water productivity and economic performance. The yields of Swiss chard, tomato and pepper were increased by up to 51, 32 and 30%, respectively, in bar-shaped clay pot irrigation system as compared to the control. Water saving was also considerably increased by 40.6, 41.2 and 41.7% for the respective crops as compared to the control. Similarly, the water productivities of Swiss chard, tomato and pepper were 10.9, 4.2, and 1.8 kg $m^{-3}$, respectively. Further research on the suitability of bar-shaped clay pot irrigation on various soils and crops is recommended.

**Keywords:** bar-shaped clay pot; furrow irrigation; water productivity; yield response.

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## 1 Introduction

In the last four decades, occurrence of meteorological droughts and mismanagement of natural resources such as rainfall have been identified as the most frequently observed problems in Africa (Daka, 2001). Climate variability and non-climate factors have often led to food insecurity. As a result, there is a need to increase the land productivity using climate-smart agricultural interventions (Mintesinot et al., 2004).

Yield under rainfed agriculture is expected to decline due to climate change and variability (Parry, 2007). Africa will be one of the regions that is most affected by climate variability. A slight change in precipitation could significantly affect the livelihoods of many African communities due to low adaptive capacity (Ngigi, 2009).

Agriculture is a means of survival for most Ethiopians, however, agricultural productivity has been challenged mainly by moisture stress as majority of Ethiopians depend on seasonal rainfall. Yet, the country is endowed with adequate land and water resources to realise the great potential of developing irrigation (Girma and Awulachew, 2007). However, developing the water resources requires huge investment (Carter, 2006). In the last two decades, irrigation development has mainly targeted the construction of various water harvesting schemes such as surface storage in micro dams, river diversions, hand dug wells, ponds locally called 'Horeye' and others. Investment in developing access to irrigation by small scale farmers could greatly contribute to reduce moisture stress and improve crop production (MOFED, 2006; Kaur et al., 2010; Diao et al., 2010). Despite its benefits, the issue of water management at field and scheme level to ensure efficient water use has got little consideration (Mintesinot et al., 2004).

One of the leading constraints for achieving sustainable food production in the dry-lands has been lack of access to efficient irrigation technology. Even though there are efficient irrigation technologies such as drip irrigation that ensure efficient use of water, they are expensive and require highly trained manpower to manage (Ward et al., 2008). Alternative technologies such as the water filled buried clay pots have been used in many dry-lands of the world for thousands of years (Bainbridge, 2001). Employing locally made clay pots was found to be appropriatly efficient for small scale horticultural crop production (Bainbridge, 2001; Wolde-Georgis, 2010; Araya et al., 2014). The system is useful because it can be used in diverse slopes as well as saline soils (Bainbridge, 2001).

The plants with clay pot irrigation utilise the water efficiently based on the need of the plant (Bainbridge, 2002). The technique is reported to have very little adverse effect on the soil such as salt accumulation (Bainbridge, 2002; Daka, 2001). The technique has some other agronomic benefits such as the suppression of weeds (Bainbridge, 2002). Bainbridge (2001) has confirmed that a household having 400 $m^2$ land irrigated by clay pots can produce grain to feed a family sustainably throughout the year rather than waiting for unreliable rainfall.

Clay pot technology was reported to be efficient for growing tomato by Daka (2001) and fruit crops. However, there have been debates on the design of the clay pot for an ideal water distribution outcome. Until recently, the round clay pot has been the dominant design. For example, Wolde-Georgis (2010) successfully used the locally available round clay pot to grow apples in the Atebes village of northern Ethiopia. In drought prone areas such as Tigray region, clay pot irrigation technology was found to be best in water productivity of Swiss chard (Negash et al., 2009). However, this bar-shaped clay pot technology was not tested for other crops such as pepper and tomato. Therefore, the objective of this experiment was to make a comparative evaluation of the bar-shaped clay pot design in terms of water and economic productivity for tomato, pepper and Swiss chard and contribute to the knowledge and understanding of farmers and policy makers.

## 2 Methods

### 2.1 *Study site description and experimental design*

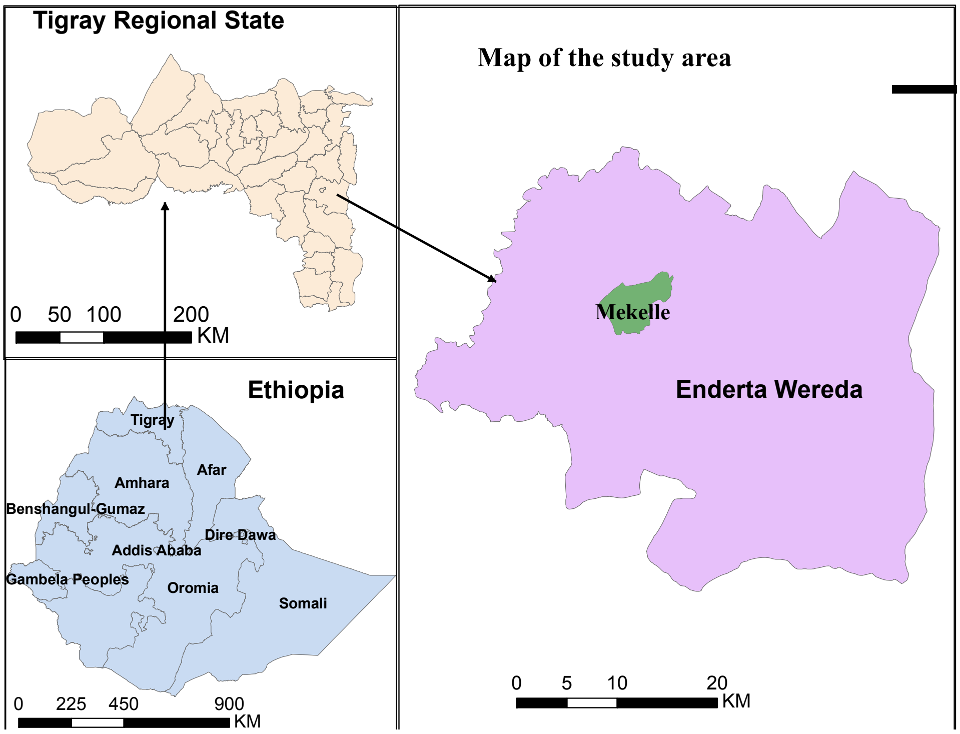
#### 2.1.1 *Study site description*

This research was carried out at Mekelle University (MU), Endayesus campus (Figure 1) during the cropping season in 2014/2015. MU is situated in Tigray, northern Ethiopia located at 13 28’47” N latitude and 39 29’10” E longitude and at an elevation of 2,212 metres above sea level. The average annual rainfall of the area is 600 mm from both long (80% June–September) and short (20%, February–May) rainy seasons respectively (Araya et al., 2011). Its average maximum and minimum temperatures are 26.5°C and 11.9°C, respectively (Negash et al., 2009). The dominant soil type in the research site is cambisol soil having a texture of sandy clay loam (Araya et al., 2014). Horticultural crops such as apple (*Malus domostica*), Swiss chard (*Beta vulgaris*), tomato (*Lycopersicum esculantum*), etc. and field crops namely wheat (*Triticum aestivum L.*), barley (*Hordeum vulgare L.*), ‘hanfets’ and mixed (*Triticum aestivum* + *Hordeum vulgare*), etc. are among the commonly cultivated in the site.

#### 2.1.2 *Experimental design*

The experiment consisted of three crops namely pepper (*Capsicum annuum*), tomato (*Lycopersicum esculantum*) and Swiss chard (*Beta vulgaris*). There were two irrigation method treatments: bar-shaped clay pot and furrow. The plot sizes for tomato, pepper and Swiss chard were 2.80 $m^2$ (2.14 m length × 1.31 m width), 2.59 $m^2$ (2.14 m × 1.21 m) and 2.18 $m^2$ (2.14 m × 1.02 m), respectively. The experimental setup required a total land area of 212.5 $m^2$. The treatments were arranged in a randomised complete block design and replicated three times.

**Figure 1** Study area location (see online version for colours)




## *2.2 Experimental materials and procedures*

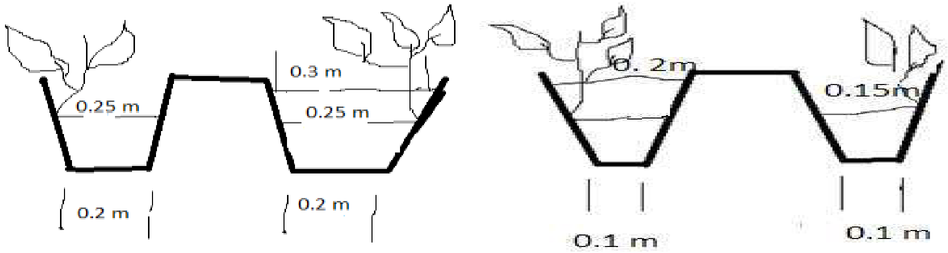
A bar-shaped clay pot (here after clay pot) with the capacity of approximately 5.0 litres, (0.50 m length × 0.10 m height and 0.10 m width) was used (Araya et al., 2014). The pots were buried up to the neck. The space between blocks and treatments was 1.5 m.

For tomato and pepper, seedlings were raised in seed beds and transplanted to the permanent fields when the seedlings produced five leaves. For Swiss chard seeds were planted directly in the field at a rate of two per pit to avoid a risk of germination failure. Thinning was conducted for Swiss chard after assuring survival of the plants. Planting was done at intra-row spacing of 0.3 m and inter-row spacing of 0.7 m for pepper as described in Negash et al. (2012) and 0.8 m inter-row spacing and 0.5 m intra-row spacing for tomato. For Swiss chard, the spacing between plants was 0.15 m and 0.30 m between rows (Negash et al., 2009).

The furrow dimension for tomato and pepper was 0.2 m at base and 0.3 m at upper part. So the seedling was planted at 0.25 m height of the furrow (middle of the slope). The furrow for Swiss chard was 0.1 m at lower bed and 0.2 m at upper width and the seeds were sown at 0.15 m height of the furrow from base and width of 0.15 m as in Figure 2.

Seedlings and seeds were planted and sown near each clay pot based on their corresponding spacing at a distance of 0.05m from the clay pot. Fertiliser was applied (for tomato and pepper) based on the national recommendation [128 kg of N (Nitrogen) and 96 kg P (phosphors) $ha^{-1}$]. About 55 kg and 23 kg of N and P $ha^{-1}$ were also applied for Swiss chard. The major sources of N and P were urea and di ammonium phosphate (DAP), respectively. N was applied in two splits: at planting and six weeks after planting for both tomato and pepper. For Swiss chard, P was applied at sowing while N was applied in two splits: at sowing and 45 days after sowing (Araya et al., 2014).

**Figure 2** Furrow spacing of tomato, pepper and Swiss chard respectively




## 2.3 *Irrigation scheduling*

Long-term (1959 to 2014) climate data for Mekelle including daily rainfall, maximum and minimum temperature, relative humidity, sunshine hours and wind speed data were collected from National Meteorology Agency (NMA). Then, CROPWAT version 8 software program was used to estimate the reference evapotranspiration (ETO, mm/days) based on Penman-Monteith method (Negash et al., 2012) and to work out the irrigation scheduling.

Irrigation water was applied both in furrows and clay pots based on calculated irrigation requirements by considering field application efficiency of 50% (Kifle et al., 2007) and 90% (Von Westarp et al., 2004), respectively.

Initially, the plots were irrigated uniformly to bring the soil to field capacity level before 24 hrs of planting. Rain gauge was installed in the middle of the experimental plots. Clay pots were refilled and irrigation was applied in furrows every four days during all the growing stages. In this study, water productivity was calculated as the ratio of the amount of harvested (fresh) crop yield to the amount of water applied (kg $m^{-3}$). The total amount of irrigation applied and rainfall amount and the amount total water application are presented on Table 1.

**Table 1** Irrigation water supply, rainfall amount and total water application during the cropping season in 2014/2015

| *No.* | *Source* | *Swiss chard* | | *Tomato* | | *Pepper* | |
|---|---|---|---|---|---|---|---|
| | | *Furrow* | *Clay pot* | *Furrow* | *Clay pot* | *Furrow* | *Clay pot* |
| 1 | Supplied Irrigation (mm) | 538.9 | 299.7 | 774.4 | 429.9 | 642.8 | 357.1 |
| 2 | Received rainfall (mm) | 51 | 51 | 51 | 51 | 51 | 51 |
| | Total water applied (mm) | 589.9 | 350.7 | 825.4 | 480.9 | 693.8 | 408.1 |
| | Total water applied ($m^3$ $ha^{-1}$) | 5,899 | 3,507 | 8,254 | 4,809 | 6,938 | 4,081 |

### 2.4 Data collection and sampling

#### 2.4.1 Agronomic data

Plant height for both tomato and pepper was measured every week using ruler starting from 30 days of transplanting till maturity. Number of fruits per plant and yield were measured during the cropping season. There were five successive harvests of tomato and Swiss chard whereas there were only two harvests from pepper crop.

#### 2.4.2 Statistical analysis

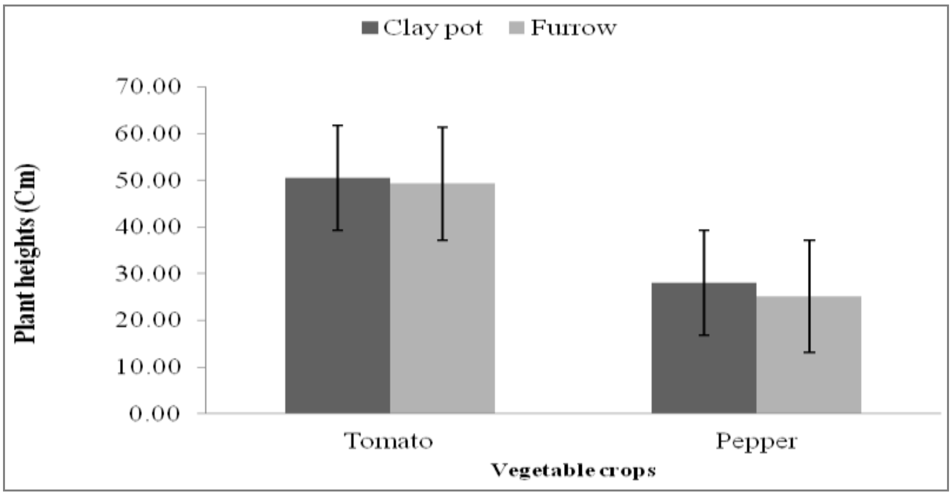
Yield and yield components (plant height, number of fruits per plot, fruit weight) of the crops were analysed using Genstat software.

## 3 Results

### 3.1 Plant height

Tomato and pepper have shown better performance in clay pot irrigation compared to furrow irrigation treatments in all of the four growth stages. However, there was no significant difference among the irrigation technologies. The highest plant height for both tomato and pepper was recorded at the 97th day after transplanting. Height of pepper was 28.1 and 25.1 cm in the clay pot and furrow irrigation methods, respectively; whereas the height of tomato was 50.5 cm in clay pot and 49.3 cm in furrow irrigation methods. In both crops plant height did not show statistical significance difference (Figure 3). The effect of clay pot irrigation practice on plant height in this study is in agreement with other findings (Araya et al., 2014).

**Figure 3** Measured plant height for pepper and tomato crops on clay pot and furrow irrigation technologies at Mekelle during the cropping season in 2014/2015



### *3.2 Fruits number per plot and average fruit weight*

Fruit number and average fresh fruit weight of tomato and pepper have shown variability on the two irrigation methods. Among the agronomic parameters for pepper, the numbers of pods per plot were found statistically significant ($p < 0.05$) in treatment in clay pot compared to in furrow irrigation method. In this study there were higher numbers of pods in furrow (177) compared to clay pot (158) during the first harvest but not statistically different. However, the trend changed during the second harvest, there were more pods per plot (160) in clay pot irrigation (which is significantly different ($p < 0.05$) than the conventional furrow irrigation practice (121) Table 2. Similarly, the average weight of green pepper in the clay pot irrigation has shown statistically significant difference ($p < 0.05$) as compared to the average pod weight of green pepper in the furrow irrigation method. The average fruit weight of green pepper pod was 6.1 g in clay pot and 5.4 g in furrow irrigation practice indicating that the use of clay pot irrigation system was also superior in terms of pod weight.

**Table 2** Mean comparison (analysis of variance) of green pepper yield and yield components as affected by irrigation method at Mekelle during the cropping season in 2014/2015

| *Irrigation method* | *Plant height (cm)* | *Fruit number* $plot^{-1}$ | *Average fruit weight (g)* | *Yield* $(t\ ha^{-1})$ |
|---|---|---|---|---|
| Furrow | 20.2 | $273^{b}$ | $5.413^{b}$ | $5.716^{b}$ |
| clay pot | 20 | $319^{a}$ | $6.06^{a}$ | $7.454^{a}$ |
| CV | 6 | 0.4 | 2.4 | 6.2 |
| LSD | 8.83 | 37.95 | 0.4515 | 0.3984 |
| Grand mean | 20.1 | 295.8 | 5.737 | 6.585 |

Notes: LSD, least significant difference; CV, coefficient of variance.
Letters a and b indicates to show statistically significant at 5% level.
$^{a}(p<0.05)$ and $^{b}(>0.05)$.

The average number of tomato fruits per plot was (127) and (120) in clay pot and furrow irrigation systems, respectively (Table 3). This implies that the number of fruits in clay pot was not significantly different from the furrow irrigation method. Whereas, the average fruit weights of tomato in clay pot irrigation (44.2 g) was significantly different ($p < 0.05$) from that of furrow irrigation method (35.5 g) Table 3.

**Table 3** Mean comparison (analysis of variance) of tomato yield and yield components as affected by irrigation method at Mekelle during the cropping season in 2014/2015

| *Treatment* | *Plant height (cm)* | *Fruit number* $plot^{-1}$ | *Average fruit weight (g)* | *Yield* $(t\ ha^{-1})$ |
|---|---|---|---|---|
| Furrow | 37.5 | 120 | $35.5^{b}$ | $15.18^{b}$ |
| clay pot | 38.5 | 127 | $44.34^{a}$ | $20.06^{a}$ |
| CV | 2.3 | 5.7 | 9.4 | 3.3 |
| LSD | 19.9 | 17.5 | 5.1 | 1.4 |
| Grand mean | 38 | 123.7 | 39.92 | 17.62 |

Notes: LSD, least significant difference; CV, coefficient of variance.
Letters a and b indicates to show statistically significant at 5% level.
$^{a}(p<0.05)$ and $^{b}(>0.05)$.

## 3.3 Yields of pepper, tomato and Swiss chard

Green pepper yield showed variable results during the first and second harvests. The first harvest of green pepper yield in furrow irrigation was superior but substantially reduced in the second harvest. Generally, yield was much higher with the clay pot irrigation (7.5 t $ha^{-1}$) compared to the use of conventional (furrow) irrigation (5.7 t $ha^{-1}$) as Table 2 shows. The total weight of tomato fruits in clay pots was significantly ($p < 0.05$) higher than the furrow irrigation system (Table 3) and this is in line with Tesfaye et al. (2012). The total tomato yields in the clay pot irrigation and the conventional furrow irrigation were 20.1 and 15.2 t $ha^{-1}$, respectively.

Swiss chard yield was significantly influenced by the irrigation methods. The biomass yield in treatment with the clay pot irrigation practices was significantly higher ($p < 0.05$) than the furrow irrigation practices. The average biomass yields in clay pot irrigation and furrow irrigation from five harvests were 36.1 t $ha^{-1}$ and 23.9 t $ha^{-1}$, respectively (Table 4).

**Table 4** Mean comparison (analysis of variance) of Swiss chard yield at Mekelle during the cropping season in 2014/2015

| *Irrigation method* | *Yield (t $ha^{-1}$)* |
|---|---|
| Furrow | $23.9^{b}$ |
| Clay pot | $36.1^{a}$ |
| CV | 4.6 |
| LSD | 3.524 |
| Grand mean | 29.99 |

Notes: LSD, least significant difference; CV, coefficient of variance.
Letters a and b indicates to show statistically significant at 5% level.
$^{a}$($p<0.05$) and $^{b}$($>0.05$).

## 3.4 Water productivity

The total yield obtained from the three vegetable crops and total applied irrigation water are presented in Table 5. The water productivity for Swiss chard was relatively higher as compared to the tomato and pepper (Table 5). The water productivity values for Swiss chard in clay pot (10.9 kg $m^{-3}$) were higher than that of furrow (4.1 kg $m^{-3}$) irrigation method.

**Table 5** Mean yield, total water used and water productivity of Swiss chard, tomato and paper crops during the cropping season in 2014/2015 in northern Ethiopia

| *Irrigation methods* | *Crops* | *Yield (kg $ha^{-1}$)* | *Total water applied ($m^3$ $ha^{-1}$)* | *Water productivity (kg $m^{-3}$)* |
|---|---|---|---|---|
| Clay pot | Swiss chard | 36,070 | 3,307 | 10.9 |
| | Tomato | 20,060 | 4,809 | 4.2 |
| | Pepper | 7,450 | 4,081 | 1.8 |
| Furrow | Swiss chard | 23,910 | 5,899 | 4.1 |
| | Tomato | 15,180 | 8,254 | 1.8 |
| | Pepper | 5,720 | 6,938 | 0.8 |

## 4 Discussions and conclusions

Fruit number per plot and average fruit weight of pepper showed variable results during the first and second harvests. It was superior in clay pot technology than furrow irrigation method. This could be due to the leaf burn observed in the furrow irrigation probably as consequence of salt accumulation in the root zone. Fruit weight of tomato in clay pots irrigation method was significantly different ($p < 0.05$) from that of tomato in furrow irrigation. This might be due to the adequate and uniform water availability in clay pot when compared to the irregular availability of soil water in the furrow irrigation systems.

Cumulative yield of the three vegetable crops in treatment with clay pot irrigation practices was significantly higher ($p < 0.05$) than the furrow irrigation practices. There was a 30% yield increase in clay pot irrigation system when compared to the furrow irrigation system in green pepper crop. The significantly ($p < 0.05$) higher green pepper yield in clay pot irrigation practices was in line with the work of Setiawan et al. (1998). This might be due to the salinity effect of the irrigation water (water salinity ranged between 0.7–3 $dsm^{-1}$) and as pepper is relatively sensitive to saline water (Setiawan et al., 1998). Therefore, this shows that clay pot irrigation technology could be used even under saline water conditions. The continuous sub-surface supply of water through the micro pores of the clay pots reduces salt accumulation in the root zone (Bainbridge, 2001). The yield increment in tomato was superior in clay pot technology than in furrow irrigation methods. There was a 32% increase in tomato yield in clay pot irrigation practice compared to furrow irrigation Table 6. The yield reduction in furrow irrigation could be as a result of decrease in number and weight of fruits per plant when compared to that of clay pot irrigation. Similarly, Swiss chard yield has shown yield difference between the treatments. There was an increase in biomass by 51% in clay pot irrigation relative to furrow irrigation practice. One of the possible reasons for relatively higher yield in clay pot irrigation could be due to the fact that Swiss chard has shallow root depth that enables the crop to easily and efficiently access water in clay pot irrigation practices as the pot diameter is very narrow compared to the furrow irrigation practice (Araya et al., 2014).

**Table 6** Mean yield comparison of vegetable crops in response to irrigation method treatments

| *Crops* | *Types of irrigation* | | *Yield* | | *Remarks* |
|---|---|---|---|---|---|
| | | | *Increments compared to furrow* | | |
| | *Clay pot ($t\ ha^{-1}$)* | *Furrow ($t\ ha^{-1}$)* | *(%)* | *LSD* | |
| Swiss chard | 36.07 | 23.91 | 51 | 3.52 | |
| Pepper | 7.45 | 5.72 | 30 | 0.4 | |
| Tomato | 20.06 | 15.18 | 32 | 1.41 | |

Water productivity of the vegetable crops indicated that there was a difference among the crops and treatments (Table 5). Therefore, this result indicated each unit of water applied resulted in more output of Swiss chard as compared to tomato or pepper. Besides, the water productivity for the three vegetables was superior in clay pot irrigation compared to that of furrow irrigation practice. The result was in line with other previous findings (Araya et al., 2014; Bainbridge, 2002; Mondal, 1974; Anonymous, 1978; Okalebo et al., 1995; Kefa et al., 2013).

This study showed there were a significantly higher fruit number, weight and yield per plot under clay pot irrigation practices than under the conventional furrow irrigation systems. Yields of Swiss chard, tomato and pepper with clay pot irrigation system increased by 51, 32 and 30%, respectively, as compared to furrow irrigation. This indicates use of clay pot irrigation technology could contribute to enhance food security in dry land areas where water is limited for vegetable production.

The crop water productivity in clay pot irrigation technology was better than furrow irrigation. The crop water productivity in clay pot was 10.9, 4.2 and 1.8 kg $m^{-3}$ for Swiss chard, tomato and pepper, respectively, whereas crop water productivity in furrow irrigation for the corresponding crops was 4.1, 1.8 and 0.8 kg $m^{-3}$, respectively. Thus, in areas with moisture scarcity, introducing clay pot irrigation could play a big role in minimising water constraint and contribute to water equity among beneficiaries. Clay pot was also found to be environmentally friendly. In the future the feasibility of the clay pot technology in time and spatial scale needs to be studied.

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