

Comparative Efficiency Evaluation of Different Clay Pots Versus Bucket Irrigation System Under Swiss Chard (*Beta vulgaris* subsp. *cicla*) Growers Condition in Northern Ethiopia

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ABSTRACT

Rain-fed agriculture shares the largest crop production system in Tigray region. However, due to erratic nature of rainfall, crop production is always at a risk. For this reason crop production in the arid and semi arid regions of northern Ethiopia usually requires supplemental irrigation. In an effort to assist agricultural production under smallholder farmers, the Regional Bureau of Agriculture and Natural Resources has been looking for efficient and less costly irrigation methods. Although drip irrigation technology has been well known for its higher efficiency, its adoption was too slow due to its high initial cost and inadequate technical knowhow. At the moment, in some areas of Tigray farmers have started practicing locally made low cost clay pot irrigation technology. However, the water use efficiency and its economic viability under smallholder farmers were not adequately understood. The objectives of this study were thus to examine the economical viability and estimate the water use efficiency of clay pot irrigation technology and to evaluate the performance of different clay pot design for irrigating Swiss chard (the most common leafy vegetable crop in this region). In this research traditional pot maker was instructed to manufacture four different clay pot designs (imperforated bar type, imperforated round shape type, perforated bar type and perforated round types) which were used for assessing performance of clay pot for irrigating swiss chard. Performance tests were carried out based on economic and biomass water use efficiencies and cost benefit ratios under two groups of farmers (with and without land). The result showed that the imperforated bar shaped clay pots were found to be suited to grow Swiss chard. The water seeps out through the micro pores of the clay pots with relatively slow leaks and long surface wetting time and large area converge around the roots of plants. Contrarily, perforated clay pots leak the water fast through the macro and micro pores and have relatively short wetting time and small area coverage. On the other hand, the difference between imperforated bar and round types were simply the shapes of the pots which is to do with the area coverage along with the rows of the Swiss chard plant. Round types were not as suitable as bar type of the same capacity for row Swiss chard crops due to their small wetting area coverage compared to a similar volume with imperforated bar shaped clay pots type. The economic and biomass water use efficiency for the imperforated bar clay pot design was higher than that of the bucket irrigation system as well as other tested clay pots. The other advantages with imperforated bar clay pots over the bucket type is that the water source is inside the soil thus evaporation is almost nil and there is also less probability of occurrence of leaf disease due to watering and ultimately improving the biomass and economical water use efficiency. However, the technology was not as profitable as the bucket irrigation technique when considering the benefit-cost ratio (BCR) due to costs incurred for purchase of clay pots.

Keywords: Climate change adaptation, Clay pot irrigation, Swiss chard, Water use efficiency

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INTRODUCTION

Ethiopia is one of the sub-Saharan Africa countries that have been affected by climate variability and change. Climate variability and change distorts the hydrological cycle (change in temporal and spatial distribution and intensity of rainfall; increased evapotranspiration and a reduced soil moisture) (Goudie, 2006), and increase the frequency of extreme climate related hazards which consequently affect food security.

Rainfall over the northern Ethiopia is often characterized by convective storms with very high intensity and spatial and temporal variability. The onset and cessation of rain as well as the length of growing season vary from season to season which makes it difficult to rely on rainfed agriculture (Araya and Stroosnijder, 2011). In addition, substantial amount of rainfall is lost through direct evaporation, runoff and deep drainage indicating crop water stress occurs because the available soil water over the growing season is not enough to compensate the crop water requirement. Consequently, drought stress has been one of the most frequent climatic hazards causing severe food shortages in the region. Small-scale water harvesting techniques such as ponds, dams and hand dug wells have been constructed for mitigating long dry spells, especially in rural and drought-prone areas of Ethiopia. However, mismanagement of water has been one of the major existing challenges due to poor access to efficient irrigation application system. Therefore, there needs a better approach to improve water security in order to meet the growing water and food demands on a sustainable basis. Locally made affordable technologies that improve the efficiency of existing small-scale irrigation schemes are required. Such practices could have an impact on climate change adaptation, food security and sustainability of the livelihood. Low cost porous clay pots were tested for irrigating various fruits and vegetable crops in many part of the world and reported to significantly reduce field application losses (evaporation and drainage) (Bainbidge, 2001; Daka, 2001; Okalebo et al., 1995; Wolde-Georgis, 2010). Reports indicated that the advantages of using clay pot irrigation technologies are many among others: very efficient, manufactured locally, affordable, require less labour and less skill, can be used in mountainous and rugged topography like in northern Ethiopia, and materials are environmentally friendly and maintains good soil structure and hence are useful for peasant farmers to successfully grow fruit trees and vegetables and reduce impacts of climate change and variability on crop production (Bainbidge, 2001; Daka, 2001; Okalebo et al., 1995; Wolde-Georgis, 2010). Using clay pots irrigation technology was also reported to be many times more efficient than using other water saving technologies (Bainbidge, 2001).

However, the clay pot technology has not been promoted and used due lack of adequate information and lack of crop specific suitable standard design. According to Siyal and Skaggs (2009), enhancing the performance of clay pot irrigation technology needs developing better operational guides and technical standards. There have been knowledge gaps on the technical use of buried porous clay pots for irrigating high value crops such as vegetables and fruit crops under smallholder farmers in the dry land areas. In addition, there has been little quantitative information on the efficiency and economic viability of the technology under farmer's condition. Therefore, the objectives of this research were:

- To study the biomass and economic water use efficiency of clay pot irrigation designs for growing small scale Swiss chard crop under with and without land owner conditions.
- To analyze the benefit cost ratio and to evaluate clay pot design in comparison with the bucket irrigation system for growing Swiss chard under small scale farmers condition.

MATERIALS AND METHODS

Study site

The study site is located 777 km north of Addis Ababa found in the regional state of Tigray. The experiment was carried out at Mekelle University experimental site (lat. 13.28° N and long. 39.6° E) with an elevation of 2212 meters above sea level. The long term (1980 - 2012) daily climate data that includes daily temperature (min. and max.) and rainfall data were obtained from the national meteorological agency (NMA). The mean annual rainfall and evapotranspiration for the site were about 600 mm and 1700 mm, respectively. According to Araya et al. (2010) the climate of the site is categorized as semi-arid. About 70 - 80% of the rainfall is received during the main rain season (June to September). The soil is categorized as Cambisol with silt clay loam (0 to 40 cm) and sandy loam (40 - 60 cm). The physical characteristics of the experimental site are shown in Table 1.

Table 1: Soil physical characteristics of experiment site

Soil depth cm	FC (Vol %)	PWP (Vol %)	Sand (%)	Silt (%)	Clay (%)	Soil texture
0-20	32.04	14.28	55	24	21	Silt clay loam
20-40	37.45	19.33	50	26	24	Silty clay loam
40-60	30.62	19.01	64	20	16	Sandy loam

FC, field capacity; PWP, permanent wilting point.

Treatments and experimental setup

The treatments were four clay pot designs having equal water holding capacity: imperforated bar type (width = 0.1m and height 0.1m and length 0.5m, total capacity = 5 litres); perforated bar type (width = 0.1m and height 0.1m and length 0.5m, total capacity = 5 litres); imperforated round type (capacity = 5 litres); perforated round type (capacity = 5 litres); control (direct water application method). Each treatment was repeated three times. There were 15 plots each of which had an area of 2 m². Pots were installed in the plots at intervals of 0.3 m between rows as treatment and were arranged in randomized complete block design. Swiss chard (*Beta vulgaris* subsp. *cicla*) was planted from seeds. Seeds were sown in a wet soil then thinned to a recommended spacing of 0.3 m between rows and 0.1 m between plants. Each plot was made to have 48 Swiss chard plants. The control was bucket irrigation system which is the application of irrigation water directly into the plants along sides of the rows in the plots (with out pot).

Crop management

Swiss chard was fertilized with N and P of 110 and 138 kg/ha, respectively. Nitrogen was applied twice in split (half at sowing and the other half 45 days after planting) whereas phosphorus was applied once at sowing. Irrigation was carried out from sowing to final harvest depending on the distribution of rainfall. Irrigation was done by refilling with five liters of water per pot (40 liters per plot) over seven days interval after the cessation of rain. During the rainy period the frequency depend on occurrence of dry spell. The total amount of supplementary irrigation applied per treatment was equivalent to 1800 m³/ha (Table 2).

Table 2: Rainfall received and irrigation water applied over the growing season (June- September)

Rain received (mm)	Applied Irrigation (mm)	Sum total irrigation applied & rain received (mm)	Total water (m ³ /ha)
299.8	180	479.8	4798

Data collection and analysis

Rainfall data was measured using rain gauge installed on the site. Irrigation water was measured and applied using a gauged watering bucket. Fresh biomass weight of Swiss chard was first harvested 45 days after planting. The biomass was then sequentially harvested five times every 10 days from an area of 2 m² (Table 3). The marketable fresh weight and market prices were recorded every 10 days, and the gross income was calculated from the sales of fresh biomass per season (Table 4). Biomass Water Use Efficiency (BWUE) was estimated as the amount of fresh marketable biomass (kg) of Swiss chard per amount of water applied (m³). Economic Water Use Efficiency (EWUE) was calculated as the net return from the sales of fresh biomass (kg) divided by the amount of water applied (m³). Benefit Cost Ratio (BCR) was calculated as the present value of total net income divided by the present value of total cost. In general, a benefit cost ratio higher than 1 indicates that the project is economical. Thus the higher the BCR, the more economic the project is, conversely, with the BCR of less than one a project would be uneconomical. With a BCR closer to one a project would be marginal.

Table 3: Swiss chard fresh biomass harvest in 10 days interval

Treatment	1st kg/ha	2nd kg/ha	3rd kg/ha	4th kg/ha	5th kg/ha	Total kg/ha
A	10700	14000	12600	14000	20000	71200
B	13700	9100	10900	9700	5200	48600
C	8600	9000	8900	10300	6200	42900
D	12000	9200	9400	8900	5300	44700
E	11800	11100	11900	8600	6400	49700

The first biomass was harvested 45 days after planting. A = imperforated bar type; C = perforated bar type; B = imperforated round type; D = perforated round type; E = control.

Table 4: Gross income from sale of Swiss chard under the different treatments

Treatment	Six season's gross income (birr/ha) from sales of Swiss chard			
	Rep 1	Rep 2	Rep 3	Mean (birr/ha)
A	480569	433390	509758	474572a
B	322389	293100	367286	327592bc
C	283540	272518	304331	286797c
D	250263	301945	351813	301340bc
E	327743	283427	397890	336353b

A = imperforated bar type; C = perforated bar type; B = imperforated round type; D = perforated round type; E = control.

Scenarios and assumptions

Our scenario analysis for clay pot performance evaluation was based on two groups of farmers: the first group has farm land and the second group of farmer is landless. The second groups of farmers are assumed to rent land from farmers with extra land. We assumed that both groups of farmers also have access to irrigation. Clay pot functioning life span was estimated to be two years. Based on the present research growing Swiss chard took about four month from sowing to final harvest during which five fresh biomass harvests were carried out. As there were no other constraints except water, three growing season per year were assumed. The income obtained per season was multiplied by six seasons during which clay pot irrigation systems was expected to be operational. Production cost and market prices were assumed constant over the projected two years period. The profitability of the scenarios was then assessed based on benefit cost ratio, economic and biomass water use efficiency.

RESULTS AND DISCUSSION

EWUE and BWUE

In scenario - I of this study, the biomass water use efficiency (BWUE) for Swiss chard ranged from 8.9 kg/m³ for treatment with perforated bar type clay pot design to 14.8 kg/m³ for treatment with imperforated bar type clay pot design (Table 5 and 6). The relatively higher BWUE in imperforated clay pot design was attributed to the better and uniform water distribution both in time (slow leak saves water and maintains uniform distribution) and area coverage. In scenario – I, the Economic Water Use Efficiency (EWUE) under imperforated bar type (68.7 birr/m³) was also higher than the other treatments for similar reasons mentioned above. Bucket irrigation has shown higher EWUE compared clay pot irrigation designs with the exceptions of imperforated bar type. The major reasons for higher performance of the bucket irrigation (control) were due to direct and controlled application of irrigation water into the plants (minimal field application and conveyance water loss). In addition, the prescheduled irrigation water was calculated considering bucket irrigation practice for Swiss chard.

However, the EWUE in control (bucket irrigation) was slightly lower than the imperforated bar type which could be attributed to the evaporation losses as the water is applied on the surface unlike the subsurface water delivery by the imperforated clay pot. In addition, in bucket irrigation, some of the water applied directly into the plants might flow below the rooting zone through the cracks in the soil. Like in scenario – I, BWUE and EWUE in scenario – II were higher in treatments with imperforated bar type clay pot designs followed by control (bucket irrigation) (Table 6). The difference between the bucket and imperforated clay pot irrigation treatment was not big but the EWUE for the other treatments were by far lower than both bucket and imperforated clay pot. The gross income obtained from imperforated clay pots was also significantly higher than the other treatments (Table 4).

Table 5: Total projected biomass, net income, BWUE, EWUE, BCR from Swiss chard projected based on six season clay pot operational life under Scenario-I

Tr	Biomass (kg/ha)	Gross income birr/ha)	Total cost birr/ha)	Net Income (birr/ha)	Water requirement (m ³ /ha)	BCR ()	BWUE kg/m ³	EWUE birr/m ³
A	427200	2847434	869840	1977594	28788	3.27	14.8	68.7
B	291600	1965550	869840	1095710	28788	2.26	10.1	38.1
C	257400	1720779	869840	850939	28788	1.98	8.9	29.6
D	268200	1808042	869840	938202	28788	2.08	9.3	32.6
E	298200	2018119	69840	1948279	28788	28.9	10.4	67.7

Where, Tr, is treatment; BCR, is benefit cost ratio; BWUE, biomass water use efficiency; EWUE, economic water use efficiency; A = imperforated bar type; C = perforated bar type; B = imperforated round type; D = perforated round type; E = control.

Table 6: Total projected biomass, net income, BWUE, EWUE, BCR from Swiss chard projected based on six season clay pot operational life under Scenario –II

Tr	Biomass (kg/ha)	Gross income birr/ha)	Total cost birr/ha)	Net Income (birr/ha)	Water requirement (m ³ /ha)	BCR ()	BWUE kg/m ³	EWUE birr/m ³
A	427200	2847434	911840	1977594	28788	2.1	14.8	67.24
B	291600	1965550	911840	1095710	28788	1.2	10.1	36.6
C	257400	1720779	911840	850939	28788	0.9	8.9	28.1
D	268200	1808042	911840	938202	28788	1	9.3	31.13
E	298200	2018119	111840	1948279	28788	17	10.4	66.22

Where, BCR, is benefit cost ratio; BWUE, biomass water use efficiency; EWUE, economic water use efficiency; A = imperforated bar type; C = perforated bar type; B = imperforated round type; D = perforated round type; E = control.

Benefit Cost Ratio (BCR)

Of the clay pot irrigation designs, highest and lowest BCR were recorded for imperforated and perforated bar type design with a value of 3.27 and 1.98 under scenario – I and 2.1 and 0.9 under scenario – II, respectively. According to the BCR analysis, most of the tested clay pots types were economically viable with the exceptions of perforated bar type under scenario - II. The benefit cost ratio for scenario I are generally higher than that of scenario II for because land costs are not considered under scenario – I (Table 5 and 6). Generally, most of the clay pot treatments under scenario I and II were economically viable because the income from the total sales of fresh Swiss chard were higher than the cost of production. On the other hand, bucket irrigation (control) was more profitable than the clay pot irrigation technology because the investment cost was almost zero. The bucket irrigation is one of the most common irrigation methods used for fruit with home garden growers in northern Ethiopia.

Performance evaluation of clay pot irrigation system

Clay pot irrigation system was reported to improve irrigation uniformity and water use efficiency for different crops through its self regulated irrigation system (Sheikh and Shah, 1983; Power, 1985; Batchelor et al. 1996, Hagazi, 1998; Bainbridge, 2001; Ashrafi et al., 2002).

According to this study, pots with moderately slow leaks (as in imperforated clay pot type) were desirable for irrigating shallow rooted crops like Swiss chard. Reports showed that the water outflow from clay pots depend on many pot's characteristics including wall thickness, firing temperature, sand to clay ratio from which the pot is made (Abu-Zreigand Atoum, 2004; Tesfaye et al., 2011). Furthermore, water flow from the pores of pots was also reported to be regulated by external factors among others by the water needs of neighbouring plants, evapotranspiration demand of the atmosphere and osmotic status of the soil (Daka, 2001; Bainbridge, 2001). Some reports also showed that water leak from porous pots could be affected by saturated hydraulic conductivity of the clay pot, surface area, soil texture and crop type (Abu-Zreigand Atoum, 2004; Siyal and Skaggs 2009).

Results of this study showed that clay pot design determine the water distribution around the roots of the experimental plant and hence determine the crop water productivity. Pots with round shape were not as efficient as those bar types because Swiss chard is a shallow rooted crop grown in rows whose water demand might be met by using a bar pots buried closely in parallel along the rows of Swiss chard plant.

On the other hand, the imperforated (naturally with micro pores) clay pots were more efficient than the perforated types. In imperforated clay pots, water outflow was slow and most likely regulated by water needs of the plant and maintain uniform water distribution for relatively longer period of time. However this was not the case with those artificially perforated clay pot designs which have macro holes to pass water more rapidly and freely. In this case, the water outflow was not regulated by the water need of the surrounding plants.

Imperforated types are self regulated which depends on the availability of soil water in the rooting zone. The water outflow from the clay pot stops when the when the soil becomes wet and water outflow slowly starts again when the soil becomes dry. The imperforated clay pot types have achieved relatively higher water and economic water use efficiency with relatively higher benefit cost ratio and productivity.

CONCLUSION

Of all clay pot types, the bar shaped imperforated clay pots were identified as superior for irrigating Swiss chard. However farmers may not be interested because: the high investment cost of clay pot; clay pots may sometimes hinder farm operation and are fragile; making the required shape/design could be difficult and time taking for traditional pot makers. Therefore, we recommend that small scale clay pot manufacturing industries should be introduced to support the efforts of saving available water for agriculture. Clay pot may be used potentially to irrigate small scale home garden vegetables or fruit crops which could enable farmers supplement additional household income (Bainbridge, 2001). In this study, the technology was found to be economically viable under small scale Swiss chard home garden growers condition although was much lower than the bucket irrigation technology. The benefit cost ratio for bucket irrigation was found to be very attractive compared to clay pot designs. Therefore, farmers should consider the cost of and benefits when they consider purchasing irrigation technology.

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