Journal of Agriculture and Rural Development in the Tropics and Subtropics
Vol. 112 No. 1 (2011) 11–18

urn:nbn:de:hebis:34-2011101139325 ISSN: 1612-9830 – journal online: www.jarts.info

Clay pot irrigation for tomato (*Lycopersicon esculentum* Mill) production in the north east semiarid region of Ethiopia

Tibebu Tesfaye [a,*], Kindie Tesfaye [b], Kebede Woldetsadik [b]

[a]*Sekota Dryland Agricultural Research Center, Sekota, Ethiopia*
[b]*Haramaya University, Haramaya, P. O. Box 134, Ethiopia*

Abstract

Water shortage is one of the major constraints for production of horticultural crops in arid and semiarid regions. A field experiment was conducted to determine irrigation water and fertilizer use efficiency, growth and yield of tomato under clay pot irrigation at the experimental site of Sekota Dryland Agricultural Research Center, Lalibela, Ethiopia in 2009/10. The experiment comprised of five treatments including furrow irrigated control and clay pot irrigation with different plant population and fertilization methods, which were arranged in Randomized Complete Block Design with three replications. The highest total and marketable fruit yields were obtained from clay pot irrigation combined with application of nitrogen fertilizer with irrigation water irrespective of difference in plant population. The clay pot irrigation had seasonal water use of up to 143.71 mm, which resulted in significantly higher water use efficiency (33.62 kg m^{-3}) as compared to the furrow irrigation, which had a seasonal water use of 485.50 mm, and a water use efficiency of 6.67 kg m^{-3}. Application of nitrogen fertilizer with irrigation water in clay pots improved fertilizer use efficiency of tomato by up to 52% more than band application with furrow or clay pot irrigation. Thus, clay pot irrigation with 33,333 plants ha^{-1} and nitrogen fertilizer application with irrigation water in clay pots was the best method for increasing the yield of tomato while economizing the use of water and nitrogen fertilizer in a semiarid environment.

Keywords: clay pot irrigation, fertilization method, plant population, tomato

1 Introduction

Rainfed agriculture in arid and semiarid areas of Ethiopia is greatly influenced by water shortage due to rainfall failure or occurrence of successive dry spells during the crop growing seasons. The common characteristics of rainfed agriculture are low crop yields that are far below potential yields attainable and high on farm water losses (Rockstrom *et al.*, 2003). Therefore, increasing crop yield under these conditions strongly rests on the use of irrigation water and/or maximizing yield per unit of water applied (Pereira *et al.*, 2002).

Vegetables provide smallholder farmers with much higher income per hectare than staple crops (AVRDC, 1990). However, the growth and development of fleshy fruits of vegetable crops such as tomato is largely dependent on the net rate of water accumulation (Jones & Tardieu, 1998), and water greatly influences their yield, quality and market price as they are sold on the basis of freshness and weight (Amjad *et al.*, 2007). Irregular water supply during the critical crop growth stages of these crops can result in fewer flowers, fruit drop, reduced growth and fruit set, excessive vegetative growth, delayed ripening, blossom end rot and fruit cracking (Amjad *et al.*, 2007; LeBoeuf *et al.*, 2008). Hence, successful production of vegetable crops in arid and semiarid environment entails the use of full or supplementary irrigation.

Water can be applied to crop fields using either surface or subsurface methods. Among the subsurface methods, application of water using buried clay pots is one of the most efficient traditional methods of irrigation suited for small-scale irrigation in arid and semiarid areas (Bainbridge, 2001). It has been practiced in

* Corresponding author
E-mail: tibetes2005@yahoo.com ; Tel. +251 913005834
Fax +251 334400409; Sekota Dryland Agricultural Research Center, Sekota, P.O. Box 62, Ethiopia

dryland areas of India, Pakistan, Iran, Indonesia, Burkina Faso, Zimbabwe, Middle East and Latin America to irrigate various annual and perennial plants including vegetables and fruit trees (Batchelor *et al.*, 1996; Bainbridge, 2001; Daka, 2001). Clay pot irrigation is better than surface irrigation methods with respect to its higher irrigation efficiency, better fertilizer use efficiency and maintenance of favorable soil water around the crop root zone (SACCAR, 1996; Daka, 2001). The most commonly mentioned drawbacks of clay pot irrigation are decreased permeability of the clay pots to water over time, easily breakability of the clay pots, less flexible once the pots are installed and less applicable to large scale production (Bainbridge, 2001).

Despite its potential advantages, however, clay pot irrigation is not yet known in Ethiopia. Areas in North Eastern Ethiopia such as North Wello and Waghmira zones are well known semiarid areas where farmers practice furrow irrigation for vegetable production. The use of furrow irrigation depletes the water harvested in small ponds by individual farmers and even that diverted from irrigation schemes making water a limiting production factor in the region. The shortage of irrigation water in these zones usually results in a conflict among farmers and adversely affects crop production (personal observation). Therefore, adoption of irrigation method that save water, optimize fertilizer requirement and increase both the yield and area of irrigation are highly required in the semiarid areas of North Eastern Ethiopia. The method of clay pot irrigation has never been tried in Ethiopia. Moreover, it is necessary to evaluate the clay pot irrigation method in one of the semiarid areas of Ethiopia because of the fact that the efficiency of the method and the number of plants that can potentially be irrigated by the pots depend on the type and size of pots, soil characteristics, crop type and climate (Bainbridge, 2001). Therefore, the objective of this study was to determine the growth, yield, water use, water and fertilizer use efficiencies of tomato grown under clay pot irrigation with different plant population and fertilizer application methods.

2 Materials and Methods

2.1 Experimental site description

The study was carried out at Sekota Dryland Agricultural Research Center experiment station, Lalibela, North Eastern Ethiopia. The area is classified as semiarid and is characterized by land degradation, erratic and unreliable rainfall, water shortage and periodic famine (SDARC, 2005). The mean annual rainfall of the area is about 772 mm. The mean annual temperature generally ranges from 11.4 to 24.6 °C. The soil of the experimental site is clay in texture (Table 1). The experiment was conducted from October 2009 to February 2010, during the off-season. There was only 27.3 mm of rainfall during the experimental season.

Table 1: *Some soil physical and chemical properties of the experimental field*

Properties	*Depth (0-40 cm)*
Sand (%)	17.25
Silt (%)	32.62
Clay (%)	50.13
Total nitrogen (%)	0.12
Available phosphorus (ppm)	12.00
Organic carbon (%)	2.75
pH (1:1.25)	8.02

2.2 Treatments and experimental design

The experiment consisted of five treatments with different combinations of irrigation methods, plant population and fertilization methods (Table 2).

Table 2: *Treatment description*

No.	*Treatments*	*Acronym*
1	Furrow irrigation with recommended plant population (33,333 plants ha^{-1}) and nitrogen fertilization in band (control)	FRPPB
2	Clay pot irrigation with recommended plant population and nitrogen fertilization in band	CRPPB
3	Clay pot irrigation with recommended pant population and nitrogen fertilization with irrigation water (fertigation)	CRPPF
4	Clay pot irrigation with 25% additional plant population (41,667 plants ha^{-1}) and nitrogen fertilization in band	C25PPB
5	Clay pot irrigation with 25% additional plant population and nitrogen fertilization with irrigation water (fertigation)	C25PPF

The treatments were arranged in Randomized Complete Block Design with three replications. There were 15 experimental plots, each having a size of 5 m × 4.8 m (24 m^2). A spacing of 1.5 m was used between blocks and plots within a block.

2.3 Experimental materials and procedures

Locally made unglazed clay pots with a capacity of almost 8 liters each were installed by burying them neck deep, with the mouth openings left about 3 cm above the soil surface in well prepared bed. The clay pots were buried at a distance of 96 cm and 125 cm along the length and width of the experimental plots, respectively. Pots had an average maximum outside diameter of 26.45 cm with an average height of 33.17 cm. An area of 549.19 cm^2 was occupied by each clay pot. The average thickness of the pots was estimated by breaking up five randomly taken clay pots and measuring the thickness of fractured pieces with a Vernier caliper. The average thickness of the pots was 9.87 mm.

Melkasalsa which is an improved and well adapted tomato variety was used for the study. It has determinate growth habit and takes 100 to 110 days to final harvest (EIAR, 2002). Seedlings were transplanted to the experimental plots on 28th October 2009, 35 days after sowing. The tomato seedlings were planted in flat beds for clay pot irrigation and at the side of the ridges for furrow irrigation. All unestablished and weak plants were replaced within 5 days after transplanting to ensure the desired stand for each treatment. The recommended spacing for the variety (30 cm between plants and 100 cm between rows) was used for the control treatment (EIAR, 2002). Four and five plants were planted 3 cm around each clay pot for treatments with 33,333 plants and 41,667 plants ha^{-1}, respectively.

The pots filled with water were coved with clay lid to avoid evaporation of water from the pots. Graduated buckets and watering cans were used to measure the quantity of water required to replenish the pots and to water the furrow-irrigated plots. The clay pots were refilled to their initial level every 4 to 6 days, and the required volume of water was recorded. The irrigation interval for the furrow-irrigated plots was based on farmers‘ practice, which was every 5 and 7 days interval for about one month and the rest of the season, respectively. The amount of water applied to the furrow-irrigated plots was determined from the amount of water used by tomato-growing farmers in the study area. The average estimated amount of water applied at each irrigation interval by the farmers for tomato was about 21.8 mm.

All experimental plots were fertilized at a rate of 69 and 73 kg ha^{-1} P_2O_5 and N (nitrogen), respectively. Diammonium phosphate [$(NH_4)_2HPO_4$] was used as source of P_2O_5. In addition to the nitrogen obtained from DAP, the same nitrogen fertilizer source, urea [$CO(NH_2)_2$], was used for both fertigation and band application treatments. In all treatments, the whole amount of P_2O_5 and 37% of the total nitrogen was applied in to the soil at transplanting. For the band application treatments, 63% of the total N was applied into the soil 45 days after transplanting. In treatments receiving fertilizer with irrigation water, 63% of the total N was well diluted in a bucket and filled in the pots 45 days after transplanting.

2.4 Data collection and statistical analysis

Days to flowering and maturity of tomato were recorded as number of days from transplanting to the time when 50% of the plants in the plot developed flowers and matured, respectively. The total fruit yield was determined as the total weight of both marketable and unmarketable fruits produced. Marketable fruit yield is the yield of tomato, which is free from under sized, physiologically disordered, bird and pest-damaged fruits. Marketable and unmarketable fruits were collected from plants in the middle of the experimental plots (14.4 m^2) during successive harvestings. Then fruit yield ha^{-1} was obtained through conversion of the net plot yield. Irrigation water use efficiency was calculated as marketable fresh fruit weight (kg ha^{-1}) obtained per unit volume of irrigation water applied (m^3 ha^{-1}) (Kanber *et al.*, 1993). Fertilizer use efficiency was also calculated as marketable fruit yield produced (kg ha^{-1}) per unit of fertilizer applied (kg ha^{-1}) as described by Hebbar *et al.* (2004).

Analysis of variance for the parameters recorded was done by SAS statistical package (Version 10.0; SAS Institute, Cary, NC, USA) and treatment mean comparison was performed using Fisher's least significant difference test.

3 Results

3.1 Days to flowering and maturity

The number of days required to reach flowering by tomato plants was significantly ($P < 0.05$) affected by the treatments. Flowering of tomatoes grown under clay pot irrigation and nitrogen fertilization with irrigation water (CRPPF and C25PPF) was delayed by up to one week as compared to those under furrow irrigation with band application of fertilizer (FRPPB) (Table 3). Similarly, clay pot irrigated tomatoes with band application of fertilizer (CRPPB) reached flowering earlier than clay pot irrigated and nitrogen fertilized with irrigation water (Table 3).

The same as days to flowering, there was statistically significant difference ($P < 0.05$) among the treatments in number of days required to reach physiological maturity by tomato plants. The number of days to maturity of tomatoes under clay pot irrigation with 41,667 plants ha^{-1} and nitrogen fertilization with irrigation water (C25PPF) and clay pot irrigation with 33,333

Table 3: *Phenological and growth parameters of tomato as influenced by different combinations of plant population, irrigation and fertilization methods at Lalibela, Ethiopia*

Treatments	*Days to flowering*	*Days to maturity*	*Plant height (cm)*	*Plant dry weight (g plant^{-1})*
FRPPB	54.67 ^{b}	89.33 ^{c}	67.72 ^{b}	150.63 ^{b}
CRPPB	54.33 ^{b}	90.00 ^{c}	69.40 ^{b}	152.45 ^{b}
CRPPF	59.67 ^{a}	97.33 ^{ab}	81.67 ^{a}	227.08 ^{a}
C25PPB	57.33 ^{ab}	91.67 ^{bc}	70.87 ^{b}	146.06 ^{b}
C25PPF	61.33 ^{a}	99.00 ^{a}	83.73 ^{a}	198.16 ^{ab}
LSD (5%)	3.92	7.10	10.69	57.15
CV (%)	4.25	4.04	7.60	17.36

Values with the same superscript letter(s) in the same column are not significantly different ($P > 0.05$). FRPPB = furrow irrigation, 33,333 plants ha^{-1} and nitrogen fertilization in bands (control); CRPPB = clay pot irrigation, 33,333 plants ha^{-1} and nitrogen fertilization in bands; CRPPF = clay pot irrigation, 33,333 plants ha^{-1} and nitrogen fertilization with irrigation water; C25PPB = clay pot irrigation, 41,667 plants ha^{-1} and nitrogen fertilization in bands; C25PPF = clay pot irrigation, 41,667 plants ha^{-1} and nitrogen fertilization with irrigation water.

plants ha^{-1} and nitrogen fertilization with irrigation water (CRPPF) were longer than under furrow irrigation with 33,333 plants ha^{-1} and band application of fertilizer (control) (Table 3). Similarly, tomatoes grown under clay pot irrigation with band application of nitrogen fertilizer (CRPPB) matured earlier than under clay pot irrigation and nitrogen fertilization with irrigation water. However, tomatoes fertilized with irrigation water (CRPPF) remained statistically at par with plants of either band-fertilized with 41,667 plants ha^{-1} (C25PPB) or those fertilized with irrigation water (C25PPF) (Table 3).

3.2 *Plant height and above ground dry matter*

The height of tomato plants was significantly ($P < 0.05$) influenced by the treatments. Tomatoes grown under C25PPF and CRPPF had significantly higher plant height than the rest of the treatments (Table 3). The height of tomatoes grown under furrow irrigation with 33,333 plants ha^{-1} and band application of fertilizer were about 23.6% shorter than under clay pot irrigation with 41,667 plants ha^{-1} and fertilized with irrigation water. However, there was no significant plant height difference among treatments under the same fertilization method (Table 3).

There was also significant difference ($P < 0.05$) among the treatments in dry matter production per plant. Significantly higher dry matter accumulation per plant was obtained from clay pot irrigated tomatoes with 33,333 plants ha^{-1} and nitrogen fertilization with irrigation water (CRPPF) than furrow or clay pot irrigated with band application of fertilizer (FRPPB, CRPPB & C25PPB) (Table 3). However, treatments consisting of band application of fertilizer did not vary significantly among themselves and with C25PPF (Table 3).

3.3 *Number of marketable fruits per plant*

The treatments had highly significant ($P < 0.01$) influence on number of marketable fruits produced per plant. Application of nitrogen fertilizer with irrigation water through clay pots for a plant population of 33,333 plants ha^{-1} (CRPPF) increased the number of marketable fruits per plant over the rest of the treatments (Table 4). There was a trend of decreasing number of marketable fruits per plant with increasing plant population under the same irrigation and fertilization method. Under application of nitrogen fertilizer with irrigation water, clay pot irrigation with 25% additional plant population gave significantly lower number of marketable fruits per plant than with a plant population of 33,333 plants ha^{-1} (Table 4). Similarly, under band application of fertilizer, clay pot irrigation with 25% additional plant population gave significantly lower number of marketable fruits per plant than clay pot irrigation with 33,333 plants ha^{-1}.

3.4 *Total fruit yield ha^{-1}*

Treatments had significant ($P < 0.01$) effect on total yield of tomato. In this study, the highest total fruit yield was obtained from clay pot irrigation and nitrogen fertilization with irrigation water (Table 4). The increases in total yield with the use of clay pot irrigation with 33,333 plants ha^{-1} and nitrogen fertilization with irrigation water (CRPPF) and clay pot irrigation with 41,667 plants ha^{-1} and nitrogen fertilization with irrigation water (C25PPF) over the furrow irrigation with 33,333 plants ha^{-1} and band application of fertilizer (control) were 45.5 and 34.2%, respectively. Under the same fertilization method, treatments under clay pot irrigation with 33,333 plants ha^{-1} and 41,667 plants ha^{-1} did not vary significantly ($P > 0.05$) in total fruit yield.

Table 4: *Number of marketable fruits per plant, total, marketable and unmarketable yields of tomato as influenced by the treatments at Lalibela, Ethiopia*

Treatments	*Number of marketable fruits plant^{-1}*	*Total yield (t ha^{-1})*	*Marketable yield (t ha^{-1})*	*Unmarketable yield (t ha^{-1})*
FRPPB	25.91 ^{bc}	33.23 ^{b}	30.56 ^{b}	2.66
CRPPB	28.94 ^{b}	33.81 ^{b}	31.70 ^{b}	2.11
CRPPF	41.82 ^{a}	48.35 ^{a}	45.99 ^{a}	2.36
C25PPB	20.84 c	32.64 ^{b}	30.35 ^{b}	2.29
C25PPF	31.87 ^{b}	44.58 ^{a}	42.16 ^{a}	2.42
LSD (5%)	7.74	7.39	7.12	*ns*
CV (%)	13.77	10.20	10.44	15.32

Values with the same superscript letter(s) in the same column are not significantly different; *ns* = non significant;
FRPPB= furrow irrigation, 33,333 plants ha^{-1} and nitrogen fertilization in bands (control); CRPPB = clay pot irrigation, 33,333 plants ha^{-1} and nitrogen fertilization in bands; CRPPF = clay pot irrigation, 33,333 plants ha^{-1} and nitrogen fertilization with irrigation water; C25PPB = clay pot irrigation, 41,667 plants ha^{-1} and nitrogen fertilization in bands; C25PPF = clay pot irrigation, 41,667 plants ha^{-1} and nitrogen fertilization with irrigation water.

3.5 Marketable and unmarketable fruit yields ha^{-1}

Marketable fruit yield of tomato was significantly ($P < 0.01$) influenced by the treatments. Similar to that of total fruit yield, clay pot irrigation and nitrogen fertilization with irrigation water (CRPPF & C25PPF) gave higher marketable yield than furrow or clay pot irrigation with band application of nitrogen fertilizer (Table 4). However, there was no statistically significant ($P > 0.05$) difference in marketable fruit yield among treatments with the same fertilization method. Unlike marketable yield, unmarketable fruit yield of tomato was not significantly ($P > 0.05$) influenced by the treatments (Table 4).

3.6 Amount of water applied

Furrow irrigation resulted in significantly ($P < 0.001$) higher seasonal water use than clay pot irrigation (Table 5). However, there was no significant difference in amount of water applied among treatments with clay pot irrigation. It was possible to save 68.7% to 69.9% water by using clay pot than furrow irrigation method.

3.7 Irrigation water use efficiency

Irrigation water use efficiency of tomato was significantly ($P < 0.001$) affected by the treatments. Tomatoes grown under clay pot irrigation gave significantly higher irrigation water use efficiency than those under furrow irrigation method (Table 5). This means tomatoes grown under clay pot irrigation require less water than those under furrow irrigation to produce a unit of marketable fruit yield. As presented in Table 5, treatments with application of nitrogen fertilizer into clay pots (CRPPF & C25PPF) gave significantly higher irrigation water use efficiency than those with band method of fertilization.

3.8 Fertilizer use efficiency

Fertilizer use efficiency of tomato varied significantly ($P < 0.01$) among the treatments. Tomatoes grown under clay pot irrigation with application of nitrogen fertilizer along with the irrigation water (CRPPF & C25PPF) gave significantly higher fertilizer use efficiency than furrow or clay pot irrigated tomatoes with band application of nitrogen fertilizer (Table 5). Application of nitrogen fertilizer with irrigation water increased fertilizer use efficiency of tomato by up to 50.5, 31.07 and 52 % over FRPPB, CRPPB and C25PPB, respectively. However, fertilizer use efficiencies of tomatoes grown under treatments with the same fertilization method were similar.

4 Discussion

The prolonged flowering and physiological maturity of tomatoes grown under clay pot irrigation and nitrogen fertilization with irrigation water could be attributed to an extended vegetative growth and slow transition to reproductive stage because of continuous supply of water throughout the growing season and improved fertilizer use efficiency. This finding is in line with an investigation by Ramalan & Nwokeocha (2000), who reported delayed flowering and decreased percent yield earliness with increase in soil wetness. High evapotranspiration from the surface of the soil in the furrow-irrigated plots could cause moisture stress during the period between the irrigation intervals and thus could have resulted in earlier maturity (Scholberg *et al.*, 2000). The shorter days to maturity of tomatoes under clay pot irrigation with band application of fertilizer than clay pot irrigation and nitrogen fertilization with irrigation water could be due to inaccessibility of nitrogen to all roots uniformly.

Table 5: *Seasonal amount of water applied, irrigation water and fertilizer use efficiencies of tomato grown under different treatments at Lalibela, Ethiopia*

Treatments	*Seasonal amount of water applied (mm)*	*Irrigation water use efficiency (kg m^{-3})*	*Fertilizer use efficiency (kg yield kg^{-1} NP)*
FRPPB	458.50 a	6.67 c	296.4 b
CRPPB	140.13 b	22.96 b	307.4 b
CRPPF	138.24 b	33.62 a	445.94 a
C25PPB	140.65 b	21.99 b	294.3 b
C25PPF	143.71 b	29.47 a	408.81 a
LSD (5%)	11.92	6.10	68.93
CV (%)	3.10	14.11	10.44

Values with the same superscript letter(s) in the same column are not significantly different.
FRPPB = furrow irrigation, 33,333 plants ha^{-1} and nitrogen fertilization in bands (control); CRPPB = clay pot irrigation, 33,333 plants ha^{-1} and nitrogen fertilization in bands; CRPPF = clay pot irrigation, 33,333 plants ha^{-1} and nitrogen fertilization with irrigation water; C25PPB = clay pot irrigation, 41,667 plants ha^{-1} and nitrogen fertilization in bands; C25PPF = clay pot irrigation, 41,667 plants ha^{-1} and nitrogen fertilization with irrigation water.

The increase in plant height of tomatoes under clay pot irrigation and nitrogen fertilization with irrigation water is in agreement with previous reports by Daka (2001) and Bainbridge (2001) who reported faster growth and establishment of plants under clay pot than surface irrigation methods.

The highest number of marketable fruits obtained from CRPPF could be associated with more dry matter production per plant. Thus, higher vegetative growth could have resulted in higher number of flowers and then fruits produced per plant. Similarly, higher number of fruits per plant has been reported under drip fertigation than soil-applied fertilizer under furrow and drip irrigation methods (Hebbar *et al.*, 2004). The decrease in number of marketable fruits per plant with an increase in plant population could be attributed to competition for nutrients, light and physical space as they are all planted around the clay pot.

The higher total and marketable fruit yields of tomatoes under clay pot irrigation and nitrogen fertilization with irrigation water was in agreement with previous reports that showed crops grown under clay pot irrigation respond better to fertilization with irrigation water than broadcasting (SACCAR, 1996; Daka, 2001). The higher total and marketable yields of tomato under clay pot irrigation and fertilization with irrigation water (CRPPF & C25PPF) could be due to higher number of marketable fruits produced per plant.

Water saving by clay pot irrigation in this study is consistent with the observations made by SACCAR (1996) for tomatoes and by Bainbridge (2001) for corn. The greater amount of water saved by clay pot than furrow irrigation could be attributed to the supply of water below the soil surface directly to the root zone, which reduces the amount of water loss by evaporation and deep percolation (Daka, 2001). About 50% of the water applied as surface irrigation in traditional irrigated gardens can be lost as soil evaporation (Batchelor *et al.*, 1996). On the other hand, controlled water delivery by clay pots based on the external environment and uptake by plants (Bainbridge, 2001) could also result in lower tomato water use.

The improved irrigation water use efficiency of tomato in treatments under clay pot irrigation was mainly due to higher yield and lower seasonal amount of water applied under clay pot than furrow irrigation. On the other hand, formation of numerous fibrous roots with high surface area all around the clay pots could have increased water uptake by the plants and then irrigation water use efficiency. Daka (2001) reported that under clay pot irrigation, root development and distribution is within the wetted zone.

The improvement in fertilizer use efficiency by fertigation under clay pot irrigation could be due to higher marketable yield than band application under both furrow and clay pot irrigation. This in turn was due to efficient use of nitrogen fertilizer as it was applied with irrigation water directly to the maximum root zone activity. The result of this study is in agreement with the previous reports that clay pot irrigation improves fertilizer use efficiency when the fertilizer is applied with irrigation water (SACCAR, 1996; Daka, 2001).

5 Conclusion

The study showed that clay pot irrigation and nitrogen fertilizer application along with irrigation water prolonged flowering and maturity of tomatoes. Clay pot irrigation and nitrogen fertilization along with irrigation water increased the growth, total yield and marketable yields of tomato than furrow or clay pot irrigation with nitrogen fertilizer applied into the soil. Greater water saving of up to 69% was achieved with clay pot irrigation as compared to furrow irrigation under semi arid condition. The higher yield and lower seasonal water use under clay pot irrigation resulted in superior irrigation water use efficiency than furrow irrigation. Nitrogen fertilization with irrigation water in clay pots improved fertilizer use efficiency of tomato by up to 52% than band application with furrow or clay pot irrigation. Thus, clay pot irrigation with 33,333 plants ha^{-1} in combination with nitrogen fertilizer application with irrigation water is recommended for high yield of tomatoes while economizing water and nitrogen fertilizer use in arid and semiarid areas. Similarly, the slow and continuous supply of water by clay pots could be a complement to the growth habit of indeterminate tomatoes. Although it needs an investigation, the number of clay pots required to irrigate a unit of land could also be reduced by using indeterminate tomatoes due to its creeping growth habit. Irrigation water saving by clay pot irrigation can be further enhanced by altering the porosity of pots and hence, appropriate clay: sand composition, wall thickness and firing temperature for various vegetables should be further investigated.

References

Amjad, M., Jahangir, M. M. & Iqbal, Q. (2007). Drought stress in vegetable production. DAWN, Economic & Business Review. URL `http://archives.dawn.com/dawnftp/72.249.57.55/dawnftp/2007/07/02/ebr5.htm`.

AVRDC (1990). *Vegetable production Training Manual*. Asian Vegetable Research and Development Center (AVRDC), Shanhua, Taiwan, 447p.

Bainbridge, D. A. (2001). Buried clay pot irrigation: A little-known but very efficient traditional method of irrigation. *Agricultural Water Management*, 48 (2), 79–88. doi:10.1016/S0378-3774(00)00119-0.

Batchelor, C., Lovella, C. & Murata, M. (1996). Simple microirrigation techniques for improving irrigation efficiency on vegetable gardens. *Agricultural Water Management*, 32 (1), 37 – 48. doi: doi:10.1016/S0378-3774(96)01257-7.

Daka, A. E. (2001). *Development of a technological package for sustainable use of Dambos by small-scale farmers, Chapter 7: Clay pot irrigation as water saving technology for small-farmer irrigation*. Ph.D. thesis University of Pretoria, South Africa.

EIAR (2002). Tomato production manual. Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa, Ethiopia, pp. 1-13.

Hebbar, S. S., Ramachandrappa, B. K., Nanjappa, H. V. & Prabhakar, M. (2004). Studies on NPK drip fertigation in field grown tomato (Lycopersicon esculentum Mill.). *European Journal of Agronomy*, 21 (1), 117 – 127. doi:10.1016/S1161-0301(03)00091-1.

Jones, H. G. & Tardieu, F. (1998). Modeling water relations of horticultural crops: a review. *Scientia Horticulturae*, 74, 21 – 46.

Kanber, R., Yazar, A., Önder, S. & Köksal, H. (1993). Irrigation response of Pistachio (Pistacia vera L.). *Irrigation Science*, 14 (1), 7–14. doi: 10.1007/BF00195000.

LeBoeuf, J., Shortt, R., Tan, C. & Verhallen, A. (2008). Irrigation scheduling of tomatoes: An introduction. Ontario Minstry of Agriculture, Food and Rural Affairs. URL `http://www.omafra.gov.on.ca/english/crops/facts/08-011.pdf`.

Pereira, L. S., Oweis, T. & Zairi, A. (2002). Irrigation management under water scarcity. *Agricultural Water Management*, 57 (3), 175–206. doi:10.1016/S0378-3774(02)00075-6.

Ramalan, A. A. & Nwokeocha, C. U. (2000). Effects of furrow irrigation methods, mulching and soil water suction on the growth, yield and water use efficiency of tomato in the Nigerian Savanna. *Agricultural Water Management*, 45 (3), 317–330. doi: 10.1016/S0378-3774(99)00104-3.

Rockstrom, J., Barron, J. & Fox, P. (2003). Water productivity in rain-fed agriculture: challenges and opportunity for smallholder farmers in drought-prone tropical agro-ecosystems. In J. W. Kijne, R. Barker, & D. Molden (Eds.), *Water productivity in Agriculture: Limits and opportunities for Improvement* (pp. 145–162). CAB International.

SACCAR (1996). Indigenous low input clay pot subirrigation for sustainable crop production. SACCAR Newsletter, Southern Africa Center for Cooperation in Agricultural and Natural Resources Research and Training.

SAS (2002). *Statistical Analysis System*. SAS Institute Int., Cary, NC, USA.

Scholberg, J., McNeal, B. L., Jones, J. W., Boote, K. J., Stanley, C. D. & Obreza, T. A. (2000). Growth and Canopy Characteristics of Field-Grown Tomato. *Agronomy Journal*, 92 (1), 152–159. doi: 10.2134/agronj2000.921152x.

SDARC (2005). Bugna woreda farming system survey report. Sekota Dryland Agricultural Research Center, Sekota, Ethiopia, 6p.

Singandhupe, R. B., Rao, G. G. S. N., Patil, N. G. & Brahmanand, P. S. (2003). Fertigation studies and irrigation scheduling in drip irrigation system in tomato crop (Lycopersicon esculentum L.). *European Journal of Agronomy*, 19 (2), 327–340. doi: 10.1016/S1161-0301(02)00077-1.