GROWTH AND YIELD OF TOMATO UNDER ALTERNATE FURROW IRRIGATION IN KIBWEZI, AN "ASAL" AREA IN EASTERN KENYA

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Abstract

Water saving irrigation technologies are key for crop production in arid and semi-arid lands (ASALs) considering the scarcity of water in these regions. A study was set up to test one such a technology, the alternate furrow irrigation (AFI) on tomato at farm level. The experiment was conducted in a furrow irrigation scheme in Kibwezi, which is an ASAL in Kenya. The objective of the study was to determine the effect of AFI on growth, yield and water use of tomato vareity "Nuru" F1. Irrigation water was applied through furrows in two ways: Alternate Furrow irrigation (AFI) where two neighbouring furrows were alternately irrigated during consecutive watering, eliciting Partial Root Drying (PRD) and Conventional Furrow Irrigation (CFI), which was the farmer practice of filling each furrow with irrigation water at each watering. The experimental design was randomized complete block design with three replications. Irrigation water use, soil moisture, leaf relative water content, vegetative and reproductive growth were determined. The cummulative irrigation water supplied to the AFI treatment was 60-62% of that supplied to the CFI treatment. This amounted to water savings of 38-40%. Plants in the AFI row that received water and those in the CFI had higher leaf RWC, which was significant on limited sampling dates. Most parameters of growth both vegetative and reproductive were higher in CFI compared to AFI, but the difference was not significant. Implementation of AFI in the Kibwezi irrigation scheme can lead to water saving and enhance productivity. However, the declines in vegtative and reproductive growths observed emphasize the need to apply AFI carefully with soil moisture monitoring, to avoid developing severe water deficits, which can lead to significant reductions in both growth and yield.

Key words: Conventional Furrow Irrigation, Dry matter, Partial Root Drying, Plant growth, Plant height, Relative Water Content.

1ntroduction

Tomato (*Solanum lycopersicum L*) is an important horticulture crop worldwide for its use as a fruit vegetable alongside other solanaceae crops (Salunkhe and Kadam, 1998). In Kibwezi, tomato is produced through furrow irrigation in smallholder schemes. This is an arid and semi-arid (ASAL) region, prone to drought stress (GoK, 2009). Adoption of water-saving irrigation strategies may result in water saving, which could be used to expand the smallholder irrigation schemes.

An important adaptation of furrow irrigation is Alternate Furrow Irrigation (AFI) in which furrows are irrigated alternately rather than consecutively during irrigation water application. This is a form of partial root-zone drying (PRD) system which has been found to increase the production of various vegetables in the ASAL areas (Fereres et al., 2007; Jones, 2004) as well as saving irrigation water. Partial root drying is a water saving technology presently being investigated in many countries. There is now considerable evidence in literature that growth in many plants is limited by water deficit (Weele et al., 2000; Liu et al., 2006). Plants develop adaptive growth and development changes as a result of chemical signals from roots in a drying soil e.g limited shoot growth (Shinozaki et al., 2007; Weele et al., 2000). It is again certain that inadequate supply of water from the soil results to limited shoot growth and functioning. A portion af a plant root system in contact with drying soil has been shown to be a source of stimulants for production of growth inhibiting hormones which are also antitranspirants in the plant e.g ABA and ethylene (Davies et al., 2005). Morphological and phenological changes in plants growing in drying soils are attributed to root to shoot signalling (Davies et al., 2000). The core of PRD is alternating irrigation in space and time (Sadras, 2009; Liu et al., 2006) because this ensures the roots are exposed to changing dry and wet soil conditions which is important for continous production of ABA (Davies et al., 2000; Dodd et al., 2006).

Research literature on the performance of the tomato crop under AFI (PRD) in Kenya is scarce and information on growth and fruit yield are not adequately available. In the ASAL areas of Eastern Kenya the tomato crop is grown scantly under irrigation at scattered sites at Kibwezi, Kiboko, Yatta and Mavoko areas. The average productivity ranges between 15-20 t/ha (MOA,2009). Under AFI growth in tomato plants has been shown to diminish without significant yield reduction (Weele et al., 2000; Liu et al., 2006; Fereres et al,. 2007; Jones, 2004). Plants faced with drought can undergo early flowering as a drought escape mechanism (Franks, 2011; Jones, 1992; Sherrard and Maherali, 2006). The objective of this study was to determine the effect of alternate furrow irrigation (AFI) on growth, yields, water status and water use of tomatoes in the Arid and Semi-Arid Lands of Kenya.

Materials and methods

The experimental site

The site at Kwakyai irrigation scheme in Kibwezi (2.5^{o}S, 37^{o}E) is an area in the southern part of the Eastern province of Kenya. It is a lowland area at 800 m above sea level which receives an average annual rainfall of 750 mm and has an average temperature of 28^{o}C (MoA 2009). The soil is classified as sandy-clay-loam with an average pH of 8.2 (FAO, 1988). The rains are unreliable. Irrigation water is available from nearby canal serving the irrigation scheme. Water to irrigate farms on the lower side of the canal is supplied using gravity flow through smaller channels. A one acre size of farm was obtained from a willing farmer for the research. The field experiments were conducted in June-August 2010 and January-March 2011.
Climatic data of the experimental site for the period June 2010 to 2011 and the last 20 years (1990-2009) was obtained from KEFRI weather station at Kibwezi. The soil physical and chemical properties were determined using standard laboratory methods at Jomo Kenyatta University of Agriculture and Technology.

Experimental design and treatment

Tomato (*Solanum lycopersicum L*) variety Nuru F1 was planted and subjected to Alternate Furrow Irrigation (AFI) and a Conventional Furrow Irrigation (CFI) in a randomized complete block design with three replications. The conventional furrow irrigation was adopted from the farmer practice of irrigating the furrows once every week. The alternate furrow irrigation consisted of skipping furrows alternately resulting in each furrow being irrigated once in two weeks. Thus different amounts of water were used for AFI and CFI. The crop for each treatment was planted in 6 m x 4 m plots consisting of seven rows 60 cm apart and plant spacing of 30 cm. There was a buffer zone of 2 m between the treatments.

Crop establishment and irrigation management

In the field the crop was sown in nursery beds of 1 m wide and 4 m long on 5th April 2010 and 16thDecember 2010 for the first and second seasons, respectively. The tomato variety “Nuru” used is a hardy high yielding

determinate hybrid variety with good shelf life and high demand in the market.
Standard nursery practices were done during the nursery period after which seedlings were transplanted to plots 4 m x 6 m in size at standard spacing. Planting fertilizer (17;17;0-N.P.K) was applied at 1.5 kg per plot (400kg/ha) and topdressing at 2.0 kg per plot (600kg/ha) with CAN (26% N) fertilizer after one month. All other standard field management activities were done.

During both seasons, a pre-irrigation of approximately 500 liters was applied to every plot (i.e. 200,000 l/ha once a week for a period of 30 Days After Transplanting (DAT) to encourage full establishment of the transplanted plants. Thereafter the prescribed irrigation treatment was administered until harvesting stage and the final day for tomato harvesting. The amount of water supplied to each plot was measured using calibrated standard Parshal flume (Armfield – made by Armfield Technical Education Co. Ltd, Hingwood Hampshire England)

Data collection

Irrigation water use

Irrigation water was applied by opening the inlet canals and letting water run into the furrows according to the treatment until the furrow was full of water.. The volume of water (Qm^3) supplied to each plot was estimated using the flume head on the basis of the flow rate (f) m^3/min and time (t) in minutes of watering. The computation was done using the following flume calibration equation;

$$Q = f\ x\ t \text{ .... (1)}$$
$$f = 4.9952h^{1.5919} \text{ .... (2)}$$

Where
h = flume head (m)

Soil Moisture Content

Soil moisture content (SMC) was determined gravimetrically one day before and after watering every week. Three soil samples, one from a randomly selected furrow of the CFI plot and two from the AFI plot were taken at a depth of 10 cm. The AFI samples were taken one from an alternate row 1 and another from an alternate row 2. The samples were immediately weighed. They were later dried at 105°C for 24 hours and weighed. The gravimetric water content on dry weight basis was calculated using formula (FAO-IAEA, 2008);

$$SMC\% = \frac{FW-DW}{DW}\ x\ 100 \text{ .... (3)}$$

Where:
FW – Fresh weight
DW= Dry weight

Plant Water Status

The Relative Water Content (RWC) was determined on young leaves. These were cut from the plants and weighed immediately to get fresh weight. The leaves were then floated on distilled water in a petri dish for 24 hrs and then their weights determined. They were then dried at 72°C for 48 hrs. Their dry weights were also obtained. The RWC% on weight basis was calculated using the formula by Jones, 2004 and Turner *et al*., 2006

$$RWC = \frac{FW-DW}{TW-DW} \times 100 \text{ ....(4)}$$

Where:
FW- Fresh weight
DW- Dry weight
TW- Turgid weight

Plant growth

Growth was quantified by measuring the plant height and the number of leaves at weekly intervals. Data on plant heights was collected weekly by measuring the randomly sampled plants from the base to the tallest tips of plant stem/branch using a ruler. The number of leaves were also counted and recorded weekly. The date of first flowering for the entire field were also recorded. The progression of flowering and number of flowers per branch and fruits per plant in tomatoes was recorded weekly for the sampled plants.

Data analysis

For soil moisture content (SMC) and relative water content (RWC) of leaves, Analysis of

Variance (ANOVA) was done using General Linear Models (GLM) in SAS mode of statistical analysis at 5% level of significance and means separation was done using LSD. For data on plant height, number of leaves, yield, water used and others analysis was done using non-paired t-Test procedure in SAS and means separation done using Confidence Intervals (CI).

Results

Site conditions

The site was relatively drier during the first season of June- August 2010 with no rain recieved compared to the second season of January-March 2011 (Table 1). The temperatures were relatively high in the first season, ranging between 26-33°C compared to 18-23°C (Table 1). The soils were clay loam (45% clay, 30% loam, 25% sand), with a bulk density of 1.35, field capacity of 32% (W/W) and permanent wilting point of 5% (W/W). The soils had moderate contents of N (0.19%), P (0.16%), K (3.5%) and soil pH of 8.5. Climatic data of the field experimental site for the period June 2010 to 2011 and the last 20 years (1990-2009) is presented below
.

Table 1. Climatic data of Kibwezi district for the year 2010, year 2011 and the last 10 yrs1999-2009

Period	Climatic data	Months												Annual
		J	F	M	A	M	J	J	A	S	O	N	D	
Year 2010	Temp(^{o}C)	21	15	19	25	35	34	32	35	34	32	27	24	
	Rainfall(mm)	36	47	330	73	0	0	0	0	0	0	154	73	714
Year 2011	Temp(^{o}C)	*23*	*18*	*20*	*26*	*32*	*33*	*28*	*26*	*35*	*30*	*28*	*22*	
	Rainfall(mm)	*14*	*24*	*86*	*19*	*7*	*0*	*0*	*0*	*0*	*8*	*53*	*172*	428
Long term	Temp(^{o}C)	*22*	*16*	*19*	*25*	*33*	*34*	*30*	*29*	*34*	*31*	*27*	*23*	
1990-2009 (averages)	Rainfall(mm)	*46*	*11*	*68*	*41*	*5*	*1.3*	*0*	*0*	*5*	*15*	*84*	*98*	

Rainfall days; 2010; May-July = 0,0,0 Nov & Dec= 9,7 2011; Feb-Mar =3,5
(Source; KEFRI Kibwezi)

Irrigation water use

During the June-August 2010 period, the AFI plots of 24 m^2 received 900-1150 liters of water per irrigation day while those of CFI with similar size received 1400-1650 liters per irrigation day (figure 1a). Thus the amounts were significantly different in most of the days for alternate furrow irrigation (AFI) and conventional furrow irrigation (CFI) except at 28 DAST. The cumulative irrigation water applied for AFI and CFI plots were 7651 L and 12292 L at 49 days after start of treatment (DAST).

During the January-March 2011 period, the AFI plots of 24m^2 received 400-750 liters of water per irrigation day while those of CFI with similar size received 900-1350 liters per irrigation day (figure 1b) below. Thus the amounts were significantly different in most of the days for AFI and CFI except at 21 DAST. The cumulative irrigation water applied for AFI and CFI plots were 5033 L and 8437 L at 49 DAST.

Soil Moisture Content

In both seasons, the soil moisture content (SMC) under AFI followed an alternate pattern with high levels in the watered furrow and low levels in the non-watered furrow (figure 2). In the 2010 experiment the SMC ranged 5.6-12.0% during the non-watered time and 15-20% in the watered furrows in the two seasons. The soil moisture pattern in this treatment followed a two week cycle. CFI plots on the other hand exhibited an increase and decrease in soil moisture pattern in a one week cycle in line with the weekly irrigation for both seasons. There was a higher soil moisture in the CFI plots than the AFI plots for most of the experimental period in both seasons. This was significant on 2, 15, 29 and 50 (DAST) in 2010 and 2, 8, 22, 36 and 50 DAST in 2011.

Relative Water Content

The relative water content of the leaves was increasing and decreasing in a weekly pattern in cycles in both AFI and CFI treated plants in both 2010 and 2011. The RWC oscillations generally revolved around 95% and 60% in the 2010 and 2011 respectively (figure 3). The RWC of plants under CFI was generally higher than plants under AFI for most of the periods in both periods. The lowest levels reached were 50% at 21 DAST in 2010 and 60% at14 and 42 DAST in 2011. The relative water content of plants under AFI and CFI prior to watering ranged between 75-88%. The range after watering was between 85-95%. Plants in the AFI row that received water hada significantly higher leaf RWC than plants in the CFI treatment row at 21 and 35 DAST in 2010. In 2011, plants in the CFI row always had higher RWC, which was significant at 7, 22, 49 and 50 DAST.

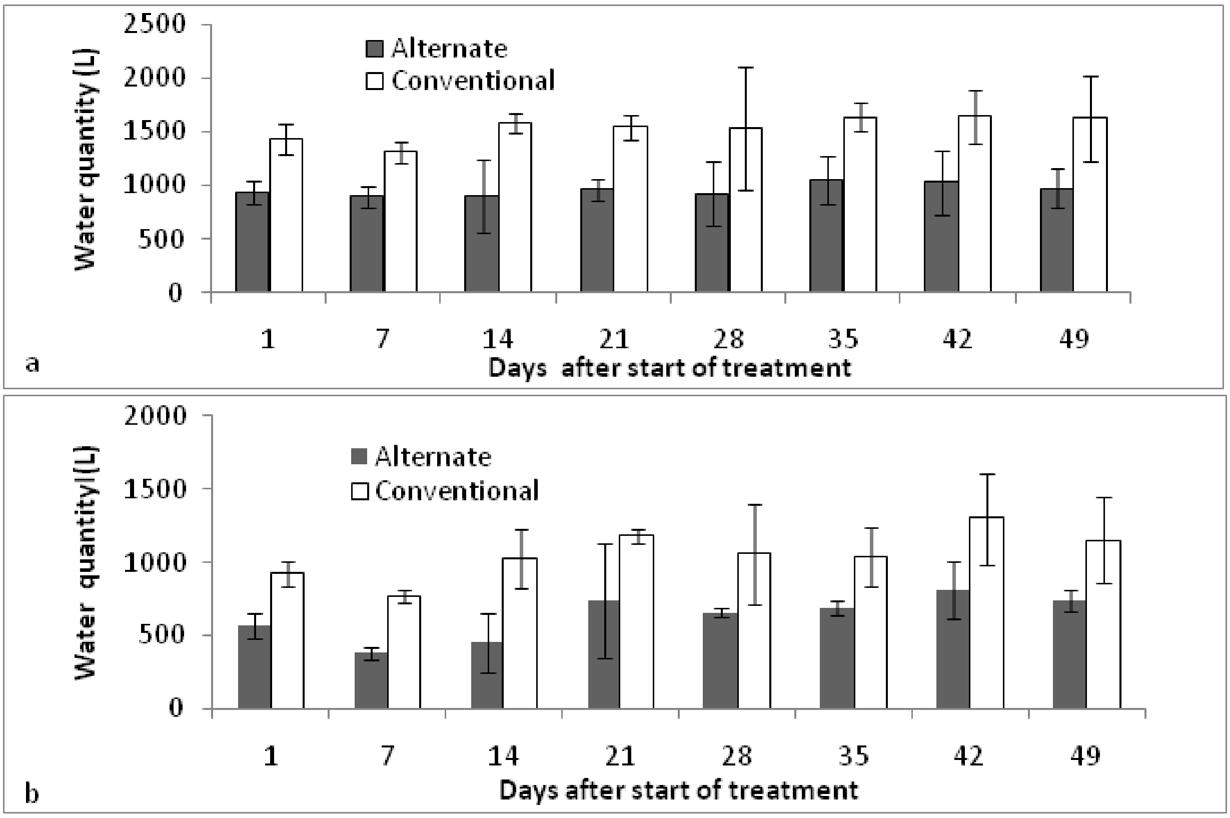


Figure 1. Irrigation water quantities applied in alternate furrow irrigation (alternate) and conventional furrow irrigation (conventional) treatments for tomato during June-August 2010 (a) and January - March 2011 (b) in Kibwezi (vertical bars show 95% CI).

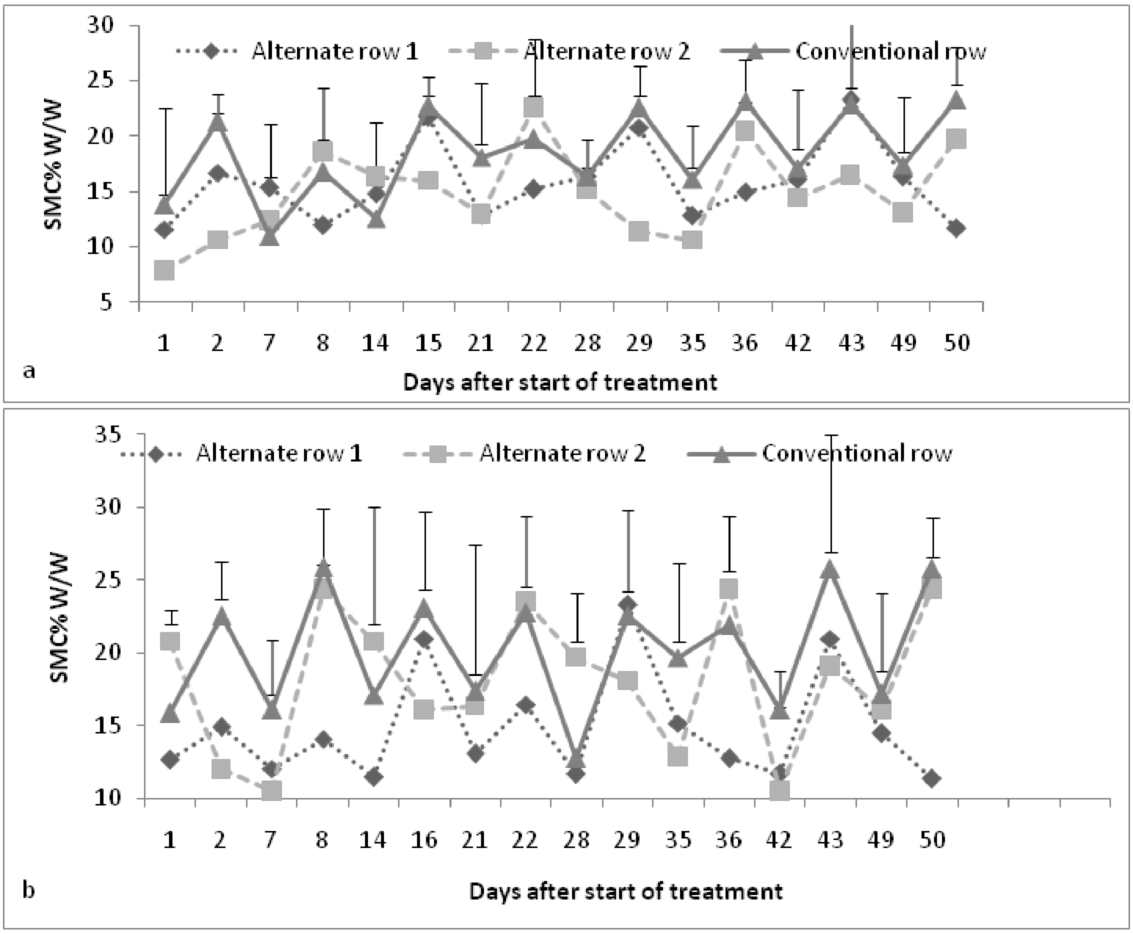


Figure 2. Soil moisture in alternate furrow irrigation (alternate) and conventional furrow irrigation (conventional) treatments for tomato during June-August 2010 (a) and January - March 2011 (b) in Kibwezi (vertical bars represent $LSD_{0.05}$).

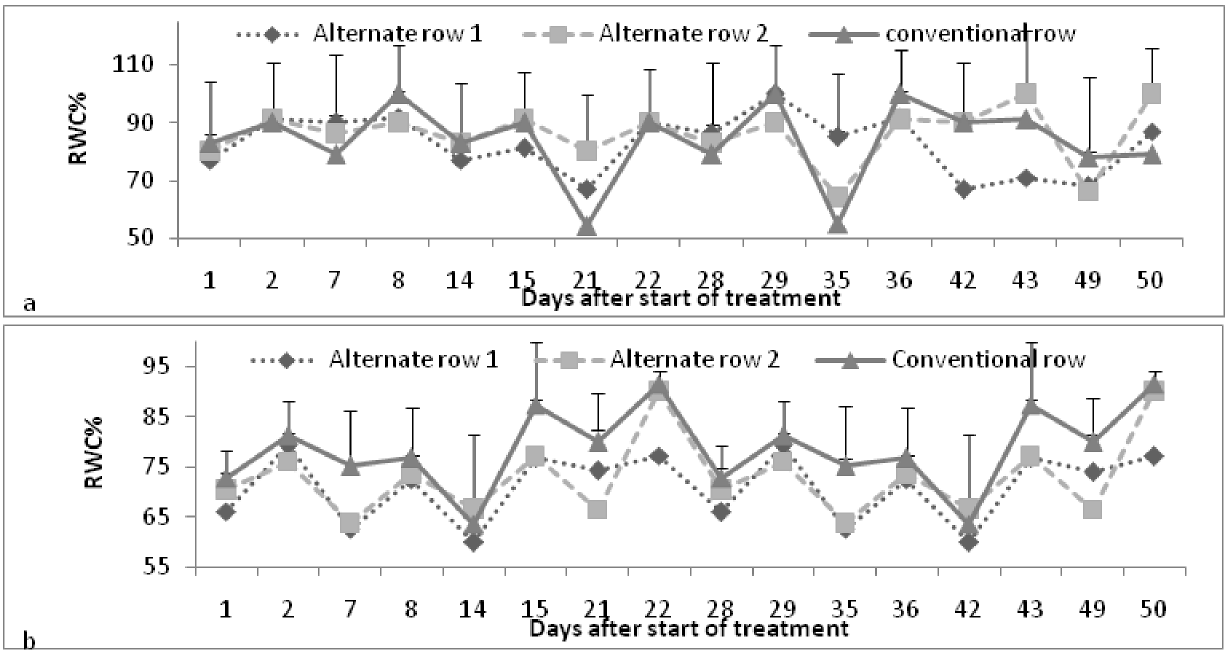


Figure 3. Leaf relative water content (RWC) for alternate furrow irrigation (alternate) and conventional furrow irrigation (conventional) treatments for tomato during June-August 2010 (a) and January - March 2011 (b) in Kibwezi (vertical bars represent $LSD_{0.05}$).

Plant growth

At the start of the treatments, plants had similar heights (figure 4). At the end of the season, CFI treated plants had an average height of 60 cm compared to 55 cm for plants in AFI in 2010. In 2011 the AFI and CFI plants were 49 cm and 50 cm tall respectively. However, the variations in plant height between the two treatments were not significantly different (P≤0.05) in both years.

There was no significant difference (P≤0.05) in the number of leaves between the CFI and AFI plants in both seasons (figure 5). In 2010 AFI and CFI plants had 48 and 47 leaves per plant at 49 DAST, respectively while in 2011 the plants had 49 and 51 leaves, respectively at 42 DAST. Similarly, the number of branches per plant showed no significant differences between control and AFI plants in both seasons (figure 6). The AFI had 5.2 and 7.6 in 2010 and 2011 respectively, while the CFI plants had 5.7 and 8 branches respectively in 2010 and 2011.

The AFI plants had higher number of trusses and fruits in 2010. However, there were no significant differences in number of trusses and fruits between the treatments in both 2010 and 2011 (figure 7 and 8). It was also noted that AFI plants took a shorter time to flowering and ripening. The start of ripening was observed at 35 DAST for AFI and 42 DAST for CFI. Shoot dry matter (DM) per plant was higher in CFI treated; plants than plants under AFI in both 2010 and 2011 (figure 9).

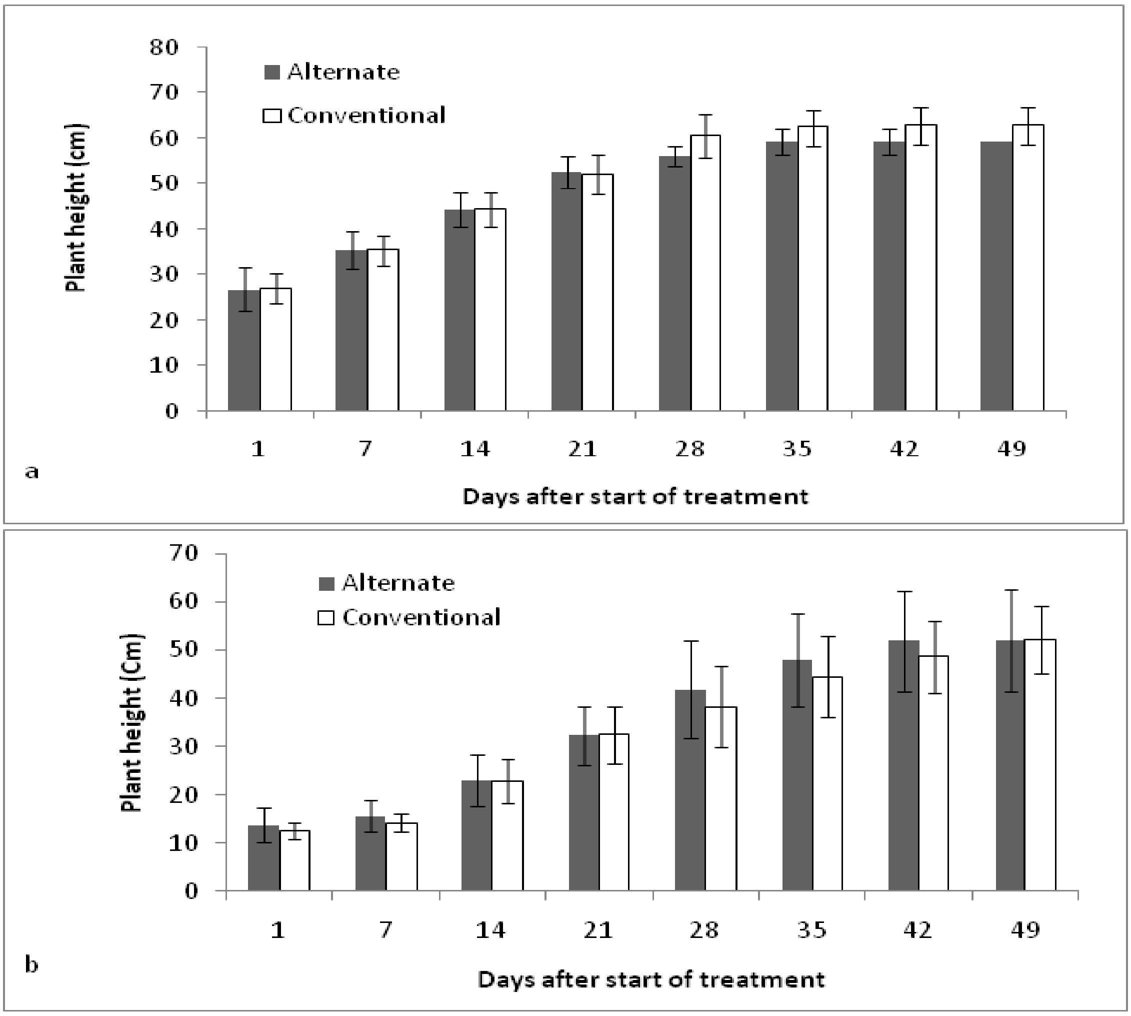


Figure 4. Plant height for alternate furrow irrigation (alternate) and conventional furrow irrigation (conventional) treatments for tomato during June-August 2010 (a) and January - March 2011 (b) in Kibwezi (vertical bars show 95% CI).

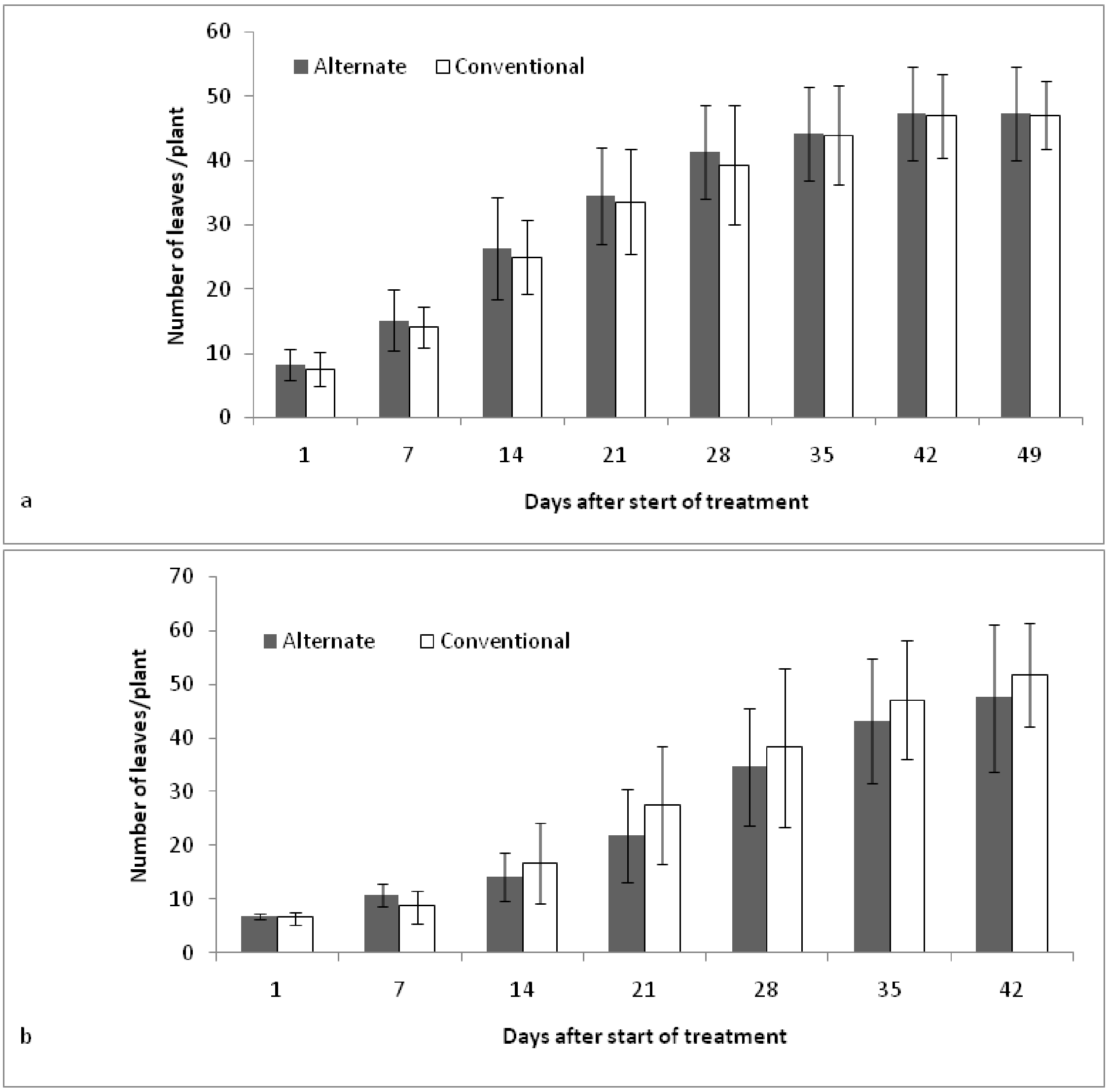
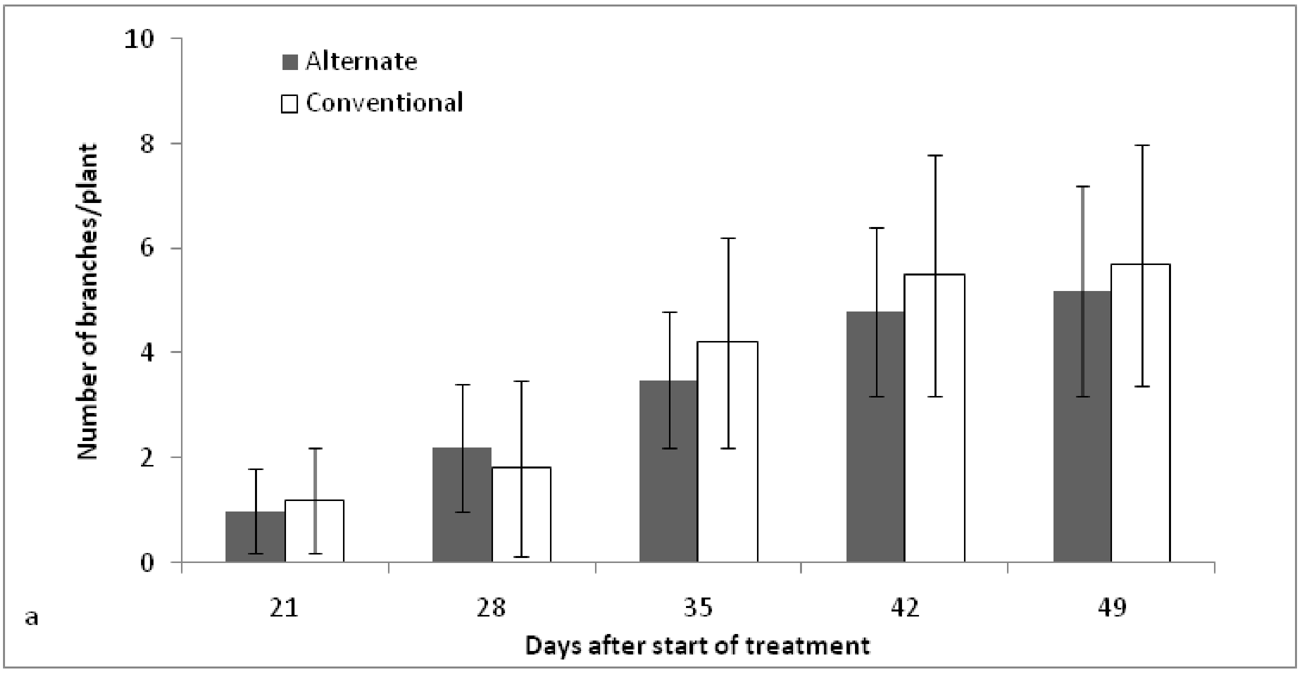


Figure 5. Number of leaves for alternate furrow irrigation (alternate) and conventional furrow irrigation (conventional) treatments for tomato during June-August 2010 (a) and January - March 2011 (b) in Kibwezi (vertical bars show 95% CI).



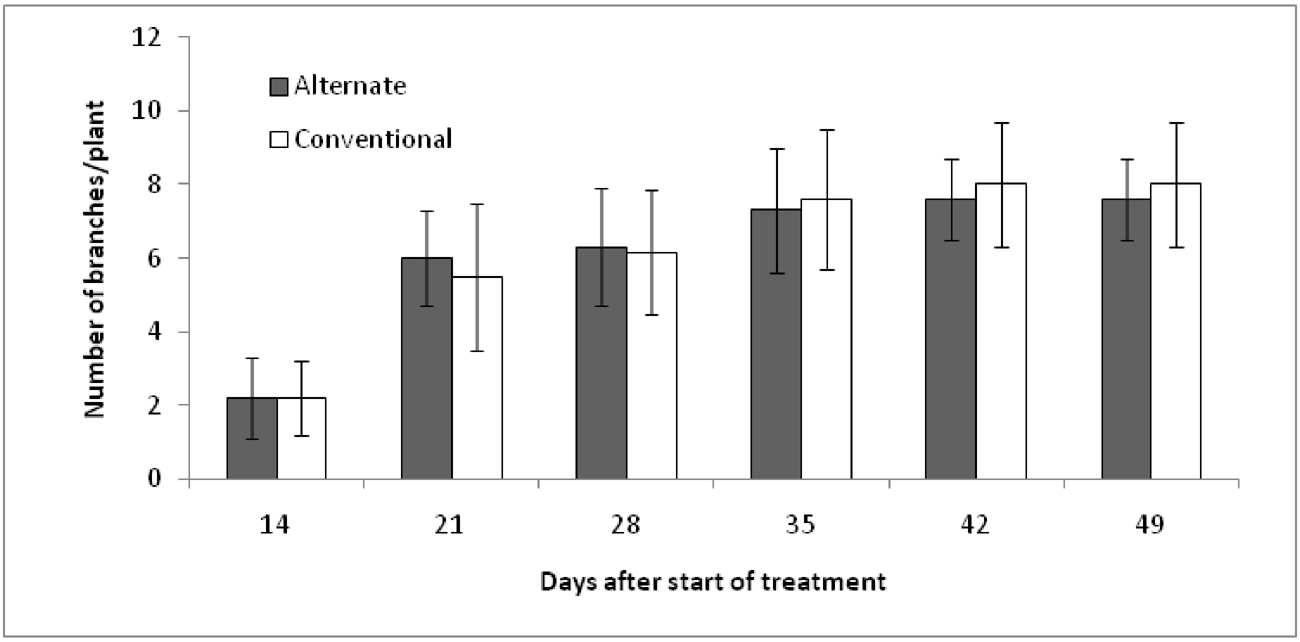


Figure 6. Number of branches for alternate furrow irrigation (alternate) and conventional furrow irrigation (conventional) treatments for tomato during June-August 2010 (a) and January - March 2011 (b) in Kibwezi (vertical bars show 95% CI).

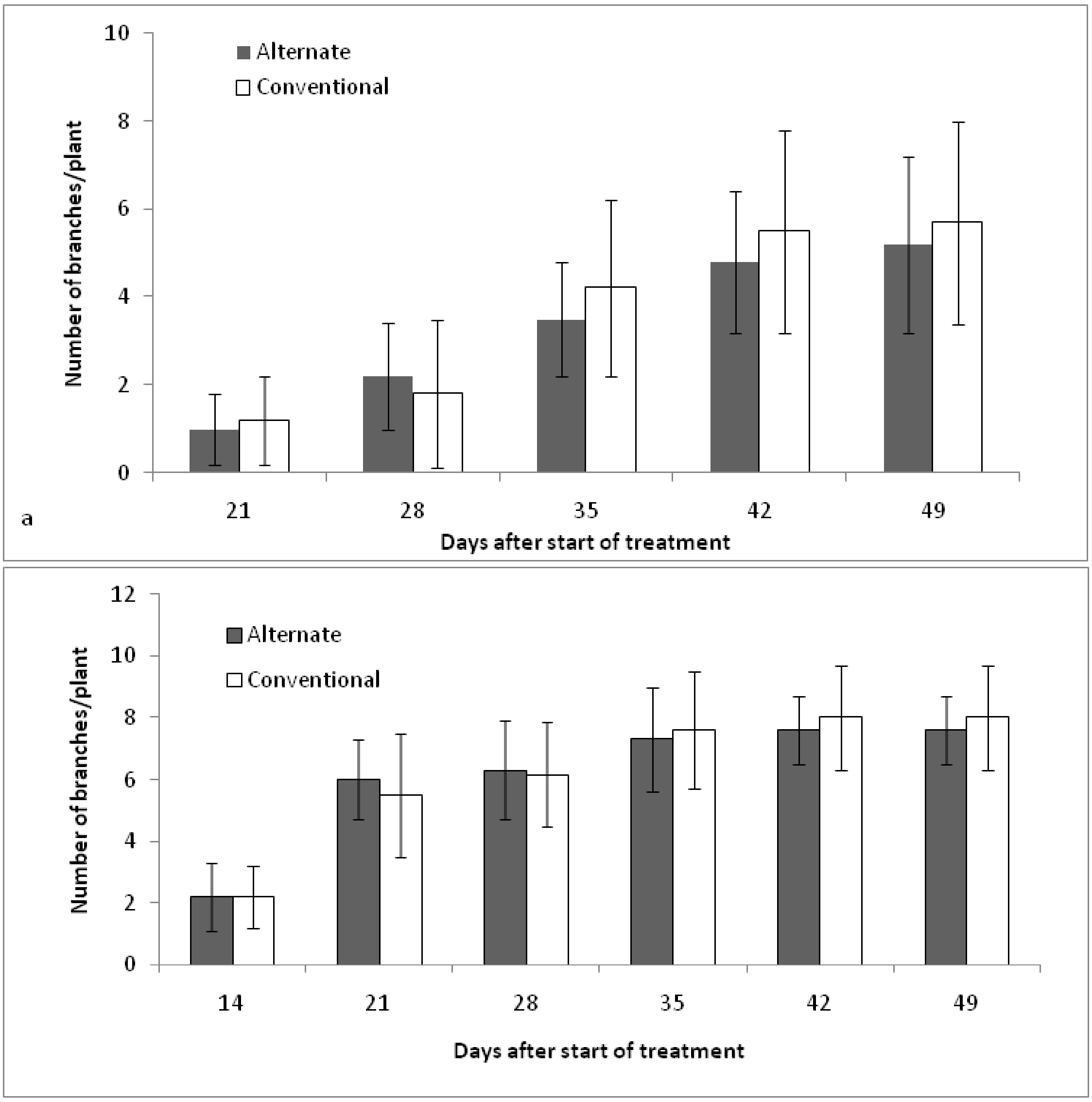


Figure 7. Number of trusses for alternate furrow irrigation (alternate) and conventional furrow irrigation (conventional) treatments for tomato during June-August 2010 (a) and January - March 2011 (b) in Kibwezi (vertical bars show 95% CI).

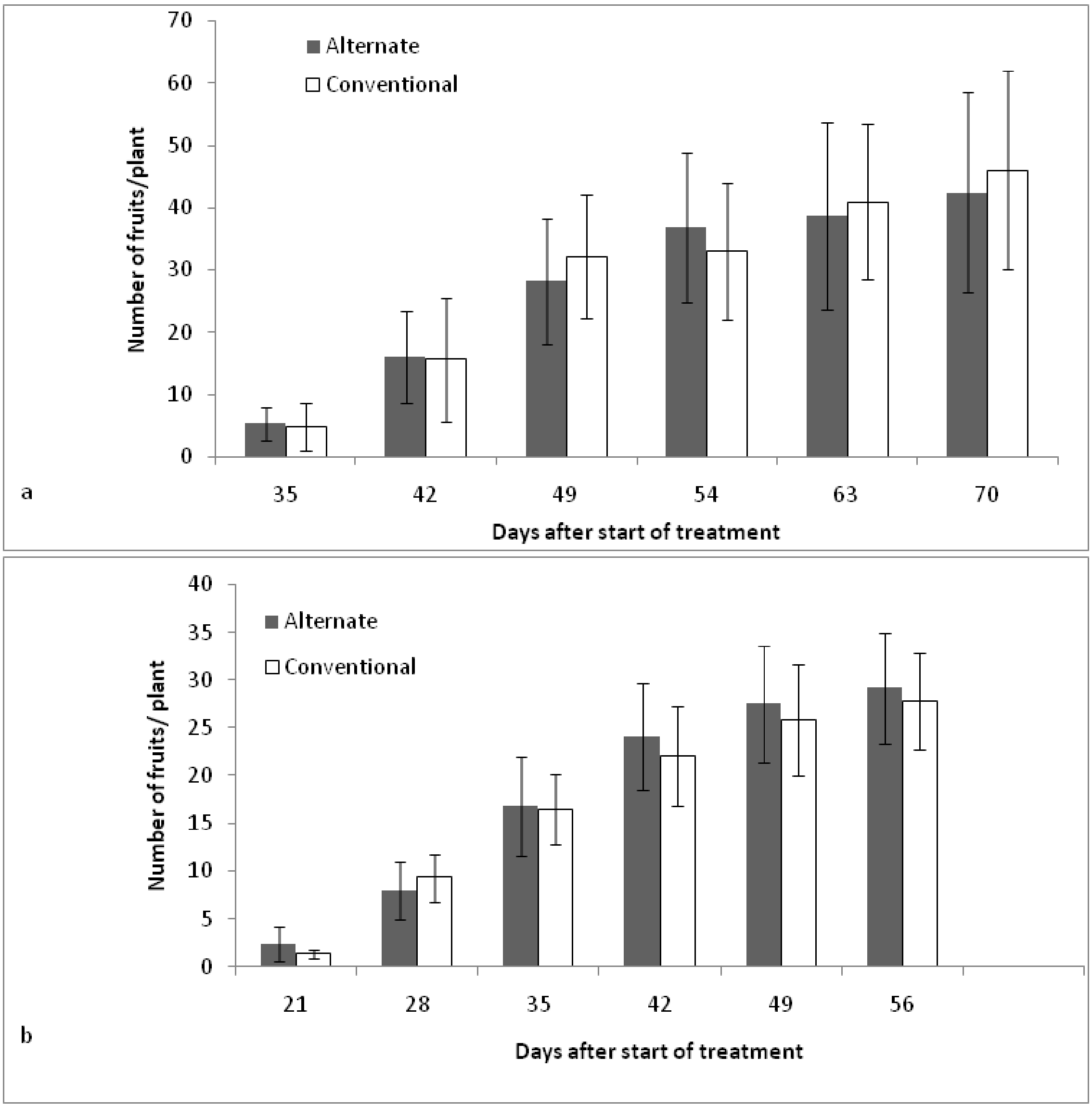


Figure 8. Number of fruits for alternate furrow irrigation (alternate) and conventional furrow irrigation (conventional) treatments for tomato during June-August 2010 (a) and January - March 2011 (b) in Kibwezi (vertical bars show 95% CI).

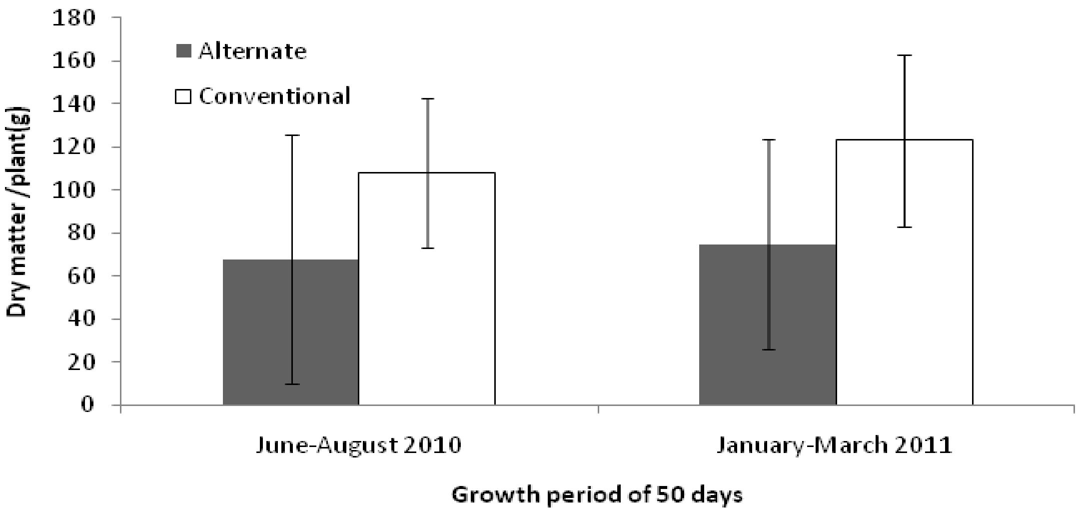


Figure 9. Shoot DM accumulation at 50 DAST for alternate furrow irrigation (alternate) and conventional furrow irrigation (conventional) treatments for tomato during June-August 2010 (a) and January - March 2011 (b) in Kibwezi (vertical bars show 95% CI).

Discussion

In both 2010 and 2011, less cummulative irrigation water was applied to the alternate furrow irrigation (AFI) treatment than the convential furrow irrigation (CFI). The AFI treatment was supplied with cummulative irrigation water which was 60-62% of that supplied to the CFI treatment. This amounted to water savings of 38-40%. The alternate furrow irrigation is a form of partial root drying (PRD), which has shown significant water savings in various crops. Sepashah and Ahmadi, 2010 have indicated in their review on PRD that irrigation water may be reduced by 30-50% with no significant yield reduction. Partial root drying caused a reduction in applied water ranging between 30-34% in sugar beet (*Beta vulgaris*), maize (*Zea mays*) and potato (*Solanum tuberosum* L.) without causing significant reductions in the yields (Sepashah and Ahmadi, 2010; Liu et al., 2006). The range of water saving reported in this study is therefore similar to that reported by other studies. Irrigation water saving through use of AFI can be crucial in expanding smallholder irrigation, which can lead to increased production.

The soil moisture content (SMC) in the alternate furrows of the alternate furrow irrigation (AFI) treatment varied in an alternate pattern during the irrigated and drying cycles i.e they alternately increased and decreased. SMC of the irrigated furrows was higher than that of drying furrows. The slight increase in SMC in the skipped furrow one day after irrigation was observed in several days. This could be attributed to lateral infiltration or redistribution of water through the soil (Kang et al., 2000). A similar pattern was reported for volumetric soil water content for a PRD trial on tomato (Zegbe et al., 2004).

The relative water content (RWC) followed a pattern similar to the changes in soil moisture on most of the sampling dates. Plants that received irrigation water in both AFI and CFI tended had higher leaf RWC and this was significant on several sampling dates. This suggests that moderate leaf water defecit developed in plants that did not recieve irrigation water in the AFI. Plants in the CFI treatment also developed moderate water defecit before watering for most of the sampling dates. Sepaskhah and Ahmadi (2010) have cited various authors who indicated that in AFI, roots in the watered side supply adequate water to the plant and this maintains a higher shoot water status. However, in this study, this was not the case for all sampling dates.

There was no significant variation in the vegetative growth in terms of plant height, number of leaves, number of branches and dry matter between plants in the AFI and CFI treatments. Similarly, at the reproductive stage, plants in both treatments had statistically similar number of trusses and number of fruits. However, at both growth stages, plants in the CFI showed more growth than those in AFI. This could be explained by the observation that plants in the AFI experienced moderate levels of water deficit as shown by lower leaf RWC. Reduction in growth under AFI is a physiological response to the periodic drought stress. This has been attributed to chemical root signals such as plant hormones, pH and ions as well as hydraulic signals in the root in a dryng soil (Bauerle at al., 2006; Liu et al., 2005; Stoll et al., 2000; Wilkinson, 1999). The signals are thought to limit gas exchange and hence reduce leaf expansion and vegetative growth (Sepaskhah and Ahmadi, 2010). Shahnazari et al. (2007) and Kirda et al. (2004) have reported marginals reductions in shoot growth and yields of potato and tomato, respectively. However, Wakrim et al. (2005) reported significant reductions in shoot and pod biomass of beans (*Phaseolus vulgaris* L.) under PRD compared to.

Conclusion

The results of this study show that AFI is a water saving irrigation method that can be suited to Kibwezi, a region in the ASAL part of Eastern Kenya. Implementation of AFI will lead to 38-40% more water being available to irrigate more land. However, the declines in vegtative growth observed point to the need to apply AFI carefully, to avoid developing severe water deficits, which can lead to significant reductions in both growth and yield.

References

Bauerle W.L., W.W. Inman and J.B. Dudley 2006. Leaf abscisic acid accumulation in response to substrate water content: Linking leaf gas exchange regulation with leaf abscisic acid concentration. Journal of American Society of Horticultural Science 131: 295-301.

Davies W., G. Kudoyarova and W. Harung 2005. Long distance ABA signalling and its relation to other siganaling pathways in the detection of soil drying and the mediation of plant's response to drought. Journal of Plant Grownth Regulation 24: 285- 295.

Davies W.J., M.A. Bacon, D.S. Thompson, W. Sobeigh, and L.G. Rodriguez 2000. Regulation of leaf and fruit growth in plants in drying soil: exploitation of the plant's chemical signaling system and hydraulic architecture to increase the efficiency of water use in agriculture. Journal of Experimental Botany 51: 1617-1622.

Dodd I.C., J.C. Theobald, M.A. Bacon and W.J. Davies 2006. Alternation of wet and dry sides during partial root zone drying irrigation alters root-to-shoot signaling of abscisic acid. Functional Plant Biology 33: 1081- 1089.

FAO 1988. World Soils Report No 60. FAA-UNESCO Soil Map of the world. Revised legend. Rome Italy.

FAO/IAEA 2008. Field Estimation of Soil Water Content - A practical guide to methods, instrumentation and sensor technology, IAEA, Vienna Austria pg 24.

Fereres E. and M.A. Soriano 2007. Deficit irrigation for reducing agriculture water use. Journal of Experimental Botany 58: 147-159.

Franks S.J. 2011. Plasticity and evolution in drought avoidance and escape in the annual plant Brassica rapa. New Phytologist 190: 249-257.

GoK 2009. Government of Kenya, Ministry of State for Development of Northern Kenya and other Arid Lands: National Policy for the Sustainable Development of Arid and Semi Arid Lands Of Kenya.

Jones H.G. 2004. Irrigation scheduling; advantages and pitfalls of plant based methods. Journal of Experimental Botany 55: 2427-2436.

Jones, H.G. 1992. Plants and Microclimate: A Quantitative Approach to Environmental Plant Physiology (2nd Edn), Cambridge University Press, Cambridge, 428 pp.

Kang S.Z., P. Shi, H.Y. Pan and Z.S. Liang 2000. Soil water distribution, uniformity and water use efficiency under alternate furrow irrigation in the arid areas. Irrigation Science 19: 181-190.

Kirda C., M. Cetin, Y. Dasgan, S. Topcu, H. Kaman, B. Ekici, M.R. Derici and A.I. Ozguven 2004. Yield response of greenhouse grown tomato to partial root drying and conventional deficit irrigation.

Agricultural Water Management 69: 191-201.

Liu F., A. Shahnazari, N.A. Mathias, J. Sven-Erik and R.J. Christian 2006. Physiological responses of potato (Solanum tuberosum L.) to PRD: ABA signaling, leaf gas exchange and WUE. Journal of Experimental Botany 57: 3727-3735.

Liu F., C.R. Jensen and M.N. Andersen 2005. A review of drought adaptation in crop plants:changes in vegetative and reproductive physiology induced by ABA-based chemical signals. Australian Journal of Agricultural Research 56: 1245-1252.

MOA 2009. Ministry of Agriculture, Annual report Kibwezi District.

Sadras V.O 2009. Does PRD improve irrigation water productivity? A meta-analysis. Irrigation Science 27: 183-190.

Salunkhe D.K. and S.S. Kadam 1998. Handbook of Vegetable Science and Technology: Production, Composition, Storage and Processing. Mercel Dekker Inc. pp. 171-202.

Sepaskhah A.R. and S.H. Ahmadi 2010. A review on partial root-zone drying irrigation. International Journal of Plant Production 4: 241-258.

Shahnazari A., F. Liu, M.N. Andersen, S.E. Jacobsen and C.R. Jensen 2007. Effects of partial root-zone drying on yield, tuber size and water use efficiency in potato under field conditions. Field Crops Research, 100: 117-124.

Sherrard M.E. and Maherali H. 2006. The Adaptive Significance of Drought Escape in Avena Barbata, an annual grass evolution 60: 2478-2489.

Shinozaki K. and S.K. Yamuguchi 2007. Gene networks involved in drought stress response and tolerance. Journal of Experimental Botany 58: 221-227.

Stoll M., B. Loveys and P. Dry 2000. Hormonal changes induced by PRD of irrigated grapevine. Journal of Experimental Botany 51: 1621- 1634.

Turner N.C., S. Abbo, J.D. Berger, J.D. Chateral, R.J. Few, J.C. Mannur, S.J. Sign and H.S. Yadawa 2006. Osmotic adjustments in chickpea under water stress conditions. Journal of Experimental Botany 58: 187-194.

Wakrim R., S. Wahbi, H. Tahi, B. Aganchich and R. Serraj 2005. Comparative effects of partial root drying (PRD) and regulated deficit irrigation (RDI) on water relations and water use efficiency in common bean (Phaseolus vulgaris L.). Agricultre Ecosystems & Environment 106: 275-287.

Weele C.M., G.W. Spollen, E.R. Sharp and I.T. Baskin 2000. Growth of Arabidopsis thaliana seedlings under water deficit studied by control of water potential in nutrient agar media. Journal of Experimental Botany 51: 1555-1662.

Wilkinson, S., 1999. PH as a stress signal. Plant Growth regulation 29: 87-99.

Zegbe J.A., M.H. Behboudian and B.E. Clothier 2004. Partial rootzone drying is a feasible option for irrigating processing tomatoes. Agri. Water Management 68: 195-206.