EVALUATION OF DRIP IRRIGATION AND GREENHOUSE SYSTEMS IN PRODUCTION OF TOMATOES IN ARID AND SEMI-ARID LANDS, KENYA

RAPHAEL M. WAMBUA[1*] AND BENEDICT M. MUTUA[1]

[1]Department of Agricultural Engineering,
Egerton University, P.O Box 536-20115,
Egerton-Kenya

[*]Corresponding author email: wambuarm@gmail.com

Abstract

An evaluation of on-farm performance of drip irrigation system within a greenhouse in arid and semi-arid lands (ASALs) environment was conducted. Field experiment was conducted at South Eastern Kenya University, Kenya. Sample emitter discharge was monitored using a measuring can inserted in sub-soil at each emitter, and timer. Above-ground biomass was estimated by weighing sampled tomato plants. Data on drip-deficit irrigation parameters was assessed using standard equations. Results show cumulative average water use efficiency of 2.2 kg/m^3, maximum total biomass of 600 g/plant, emitter variation 7, application depth of 12 cm, and Gross irrigation requirement of 17.2 mm and drip system capacity of 4117 litres. Emitter discharge declined linearly with distance from the elevated tank with an average discharge of 679 ml/hr. Although the theoretical irrigation interval is four days, it is recommended that the a practical value of three days be adopted for tomato growing due to erratic evapo-traspiration rates is which is accelerated by wind, and extreme sun's radiation in the dry land conditions. Research on on-farm performance of evaporative cooling on crop production within a greenhouse is recommended. Application of integrated rainwater harvesting and drip system-optimization water requirement of different crops should be investigated.

Key words: Drip-deficit irrigation, Cumulative Water Use Efficiency, Total Biomass, emitter variation, drip system-optimization

Introduction

Tomato (*Lycopersicon esculentum*) is classified as a vegetable crop, and like numerous other crops, it has recently received new outlook in technological production. This is as a result of invention, application and development of precision irrigation technology such as drip irrigation system (Asher and Phene, 1993; Ben-Gal and Shani, 2003) and greenhouse. The combination of the two approaches ensures water availability in any growing season of the crop. Water deficit reduces total tomato dry matter accumulation over time. This deficit which is also referred to as water stress inhibits crop growth and development (Unlu *et al*., 2011). During the vegetative and flowering stage both biomass and fruit yield are reduced (Liu *et al*., 2010). However, drip-deficit irrigation which allows crop to sustain some degree of water scarcity in order to reduce cost of production and at the same time potentially increase crop yield (Sekyere *et al*., 2010). During drip irrigation, soil water content must never fall to or below permanent wilting point so the plant tissue can thrive once soil water becomes available.

Drip irrigation which is also called trickle irrigation is an irrigation system in which water is delivered at the root-zone of the plant at low quantities and pressure. It is thus the only method that has an advantage of applying water where it is needed (Asher and Phene, 1993), allowing it to infiltrate into soil in a small area, distributing the water in three dimensional manner and leaves the soil between rows of crops un-irrigated. Drip lines allow an irrigation system to water the root zone that lies directly under plants, efficiently watering each plant without over-application of other areas minimizing water wastage (Naika *et al*., 2005). The other advantage is saving in the quantity of water used. . Drip lines place water directly on the root zone, allowing it to saturate the soil underneath each plant. They allow a gardener to water specific plants without wasting water by over-spraying onto sidewalks and uncultivated areas. Drip lines reduce the amount of total runoff, saving water resources as well as homeowners money on their water bill.

Drip irrigation systems are relatively cheap, and can be installed easily in conjunction with traditional irrigation systems. Drip lines can be run to specific areas of the garden, and then affixed with a variety of specialty tips creating an infinite number of delivery options. Drip systems are expandable, so when you add new plants to your garden it is easy to tap into existing drip lines and get water and fertilizer to where it is needed (Soussa, 2010). Two-way and three-way splitters can be installed anywhere on the drip line, allowing water to be re-directed and placed where plants need it. The maintenance cost of drip system is low. Once a drip irrigation system is installed it requires very little maintenance. Simply adjust your watering times and duration to match the season, and let the drip system do all the work.

Greenhouse farming finds different applications in farming. It has been has been used for research, training, and commercial purpose. Using the green house technology a number of horticultural crops may be grown. These include tomatoes, onion, green and garlic. There are a number of benefits of using this technology: it leads to increased income and poverty eradication, it is appropriate in water scarcity areas due to its high water use efficiency, it leads to increased per unit area production, it is easy to control pests and diseases within the system using low quantities of pesticides, crop rotation is possible for disease and pest control, high value crops can be grown, it is possible to dispense and apply organic manure (for organic farming and inorganic fertilizer) through the ferttigation technique and it can lead to increased food security especially under climatic change scenarios of Arid and Semi-Arid Lands (ASALs) .

Figure 1. A section of the greenhouse with elevated tank, drip laterals and young tomato plants growing in the green house at the SEKU Green Farm

Although it requires high initial capital, green houses are cost effective and enable a farmer to be a business by making greater outputs than the inputs. In combination with drip irrigation, greenhouse can be used in ASALs as a strategy to alleviate poverty (Keskin *et al.*, 2010) . With sufficient on-farm research and field data, the technology can transform rural households to own knowledge based greenhouse enterprises. Control of diseases with a greenhouse may use chemical and bio-control techniques. The bio-control method involves keeping an environment clean and healthy for crops. In this, living organisms that suppress or inhibit disease causing agents are used in a farming environment (Gvrerosca and Ziberoski, 2011).

The combination greenhouse farming with drip irrigation system technology has some challenges such as the need to have high initial capital which is a limitation to numerous rural farmers. Replication of the projects especially at household level remains a challenge due the lack of both the capital and management skills. Thus adoption rate in most rural areas is yet to be fully explored. However, the system has long term returns and should be encouraged in irrigated agriculture for poverty alleviation. Information on how crops perform under different conditions may be assessed by field use of filed measurents or application of crop production models.

The crop production models are of paramount importance in the assessment of crop research and for commercial crop production. To develop accurate and reliable crop models, long term data on crop growth and development such as biomass accumulation may be used as an indicator of the level of crop yield. Although tomato is a commonly grown vegetable crop worldwide, precise studies on its dynamic biomass accumulation for crop under drip irrigation within green house for arid and semi-arid (ASALs) environment is scarce. The effect of climate, plant density and water application on tomato plant growth parameters and its biomass accumulation has not fully been explored.

Objective

The objective of this research was to assess the performance of drip irrigation system installed in a greenhouse for production of tomatoes on sandy-clay soils located on arid and semi-arid (ASALs) environment.

Material and methods

Study Area

The research was conducted within South Eastern Kenya University (SEKU), Farm. The SEKU greenhouse farm lies within a larger Land which is located approximately between longitudes 37˚44′ and 37˚48′ E and latitudes 1˚17′ and 1˚21′ S, at an elevation of 1204 m above sea level. The land is characterized by soils which are generally rhodic FERRALSOLS in nature. The soil consist of well-drained, deep to very deep dark-red to dark reddish brown friable sandy-clay. The land receives an annual average rainfall of 600 mm which is bi-modal in nature. Due to low rainfall, seasonal and food demand variation, drip irrigation was explored to study its performance in the tomato production. The lateral set up adopted for the assessment was applied on the field (Figure 2)

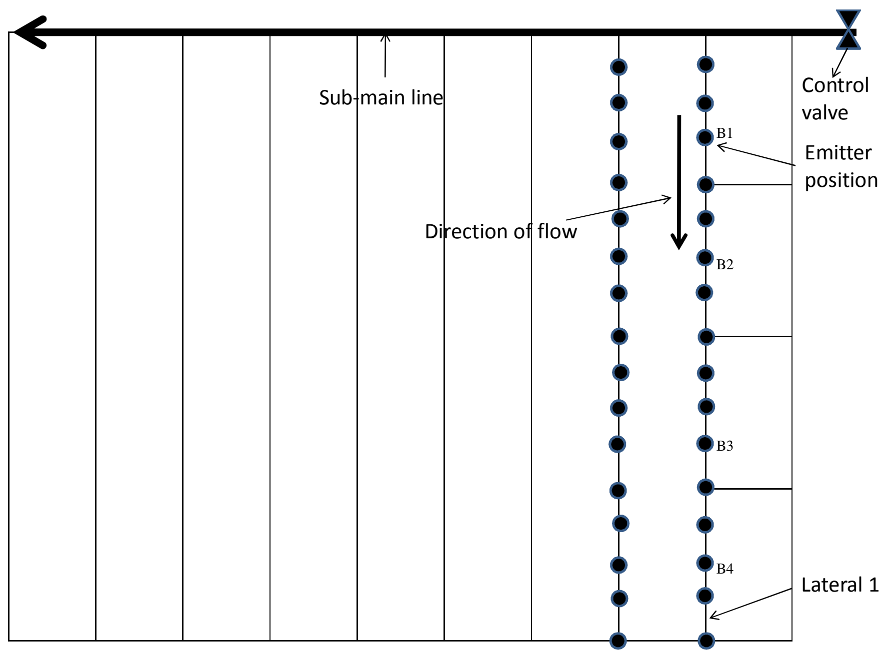

Figure 2: The on-farm drip system layout representing part of laterals with emitters

The laterals were laid along rows of tomato crop planted with plant density of 2.5 Plants/m^2. Then, measuring cans were placed under each monitoring emitter and volume readings taken at the beginning and end of each irrigation time. The volumes of the water were recorded at the end of one hour. Then above-ground biomass monitoring was done by taking the weight of the wet tomato plant at two week intervals. The Important drip system parameters estimated using standard irrigation functions. The above layout consisted of a total of laterals twelve lateral for a green house of dimensions 30 m by 8 m. Each lateral had 96 emitters and this translates to an average of 1,152 emitters in total per green house. From the experiment, average emitter discharge was found to be 0.679 l/hr which means that for one hour of irrigation, the total discharge per house is 782 litres.

Distribution Uniformity (Du)

The D_u was determined by measuring the flow rate from the sample emitters and using the D_u equation (USDA-ARS, 1997)

$$D_u = \frac{(Q_e)_{at\,25\%}}{\bar{Q}_e} \times 100\% \qquad (1.1)$$

Where D_u is the distribution uniformity, (%), Q_e at 25% is the average flow rate from the sample emitters in the lowest quarter of all the flow rates measurements (l min^{-1}) and Q_e is the average flow rate.

Uniformity of application

The emitter uniformity of application of drip irrigation system may be determined from a standard equation as shown below

$$U_e = \left(1.00 - \frac{1.27\,C_v}{n}\right) \times \frac{q_{\min}}{q_{avge}} \times 100\% \qquad (1.2)$$

Where U_e is the emission uniformity (%), n is the number of emitters per plant/on permanent crop mostly $n=1$, c_v is the manufacturer's coefficient of variation, q_{min} is the minimum emitter discharge l/hr, q_{avge} is the average or design emitter discharge (l /hr). However, the above function utilizes manufacturers coefficient *cv* which was not available at the time of on-farm studies. Therefore, a the following method was adopted to determine emitter uniformity by calculating emitter variation

$$q_{\mathrm{var}} = \left(1.00 - \frac{q_{\min}}{q_{\max}}\right) \times 100\% \qquad (1.3)$$

The value of emitter variation q_{va}, was used to categorize the drip irrigation performance into most desirable (table 1) and other variables for tomato cultivation were adopted for this study (table 2), which are developed for tomato farming.

Table 1. Criteria for coefficientof emitter variation (q_{va}) assessment

Range of qvar (%)	Level
Less than 10	Most Desirable
10-20	Desirable
More than 20	Un-acceptable

Source: [15]

Table 2. The estimated values for variables used in the drip irrigation system

	Drip system and crop parameter						
S.No	η_s	p_s	MAD	D_{rz}	F.C	PWP	E_t
Value	80%-90%	20%- 40%	0.5	0.9 m	11.8%	3.7%	7.6 mm/day

Source , [15]

In which η_s is system efficiency (%), p_s is the percentage of area wetted during the irrigation, MAD is the management allowable depletion, D_{rz} is the average root zone (m), F.C is field capacity (%), PWP is the permanent wilting point (%) and E_t is the consumptive use of tomato (mm/day)

Water use efficiency

For every week the cumulative water use efficiency WUE_c is determined from the modified efficiency function

$$WUE_c = \frac{Bio_T}{I_w} \qquad (1.5)$$

Where *WUEc* is the cumulative water use efficiency (kg of biomass /m^3 of water), Bio_T is the total plant biomass (kg) after *t* weeks of transplanting, while I_w is the total cumulative irrigation water. (m^3) at the time *t*. Different crops respond differently to water availability and water stress. For instance according to Misra and Misra,2010, it was noted that WUE, photosynthesis and photochemical efficiency decreased with increase in water stress for a Jatropa (*Jatropha curcas*) plant.

The average application depth

In micro-irrigation, average depth applied per irrigation to the wetted area, d_{aw}, is usually used for estimating the Management Allowed Depletion (*MAD*). The d_{aw} in centimeters is calculated from the average cubic meters per hour (q_{av}) at each emitter, the number of emitters per plant, the number of hours of operation per irrigation, and the wetted area per tree in square meters. The following is the function adopted for this assessment:

$$d_{aw} = \frac{q_{av} \times t}{A_p} \times 100 \qquad (1.4)$$

Where d_{aw} is the average depth of application, q_{av} is the average emitter discharge (m^3/hr), t is the duration in time of irrigation (hours) and A_p is the average wetted area per plant. The average wetted area was calculated as 24% of the total area of 30 m by 8 m since not all land is irrigated during drip irrigation. This gave 0.5658 m^2/plant and the duration of drip-deficit irrigation duration was one hour and q_{av} was 0.00679 m^3/hr as per lateral emitter discharges (tables 3 to 6). These values were used as input data into various functions as described below and the result tabulated (table 7)

The consumptive use of tomatoes

Various parameters of the on-farm drip irrigation and tomato plant were evaluated as described below and their values calculated (Table 7). Net irrigation requirement of the tomatoes was determined from readily available moisture. The net irrigation is the quantity of water required to increase the moisture content in the effective root zone to field capacity. Readily available water (RAW) was calculated using the functions:

$$RAW = MAD \times AW \qquad (1.5)$$

Where RAW is readily available water (mm), MAD is the maximum allowable moisture depletion (mm) and AW is the available water to the crop (mm). The AW is a function of root zone, field capacity, permanent wilting point and percentage area wetted by the irrigation system. If these variables are incorporated in equation 1.5 above, it becomes

$$RAW = MAD \times Drz \times (F.C - PWP) \times \frac{P_s}{10} \qquad (1.6)$$

Where Drz is the effective root zone (m), $F.C$ is the field capacity (percent), PWP is the permanent wilting point (percent) and P_s is the wetted area as a percent of the total area under drip irrigation (table 1). The gross irrigation requirement which is the total amount of water applied throughout the irrigation was computed from the relation:

$$GIR = \frac{RAW}{\eta_s} \qquad (1.7)$$

Where GIR is the gross irrigation requirement (mm), RAW is the readily available water also called net irrigation requirement (mm) and η_s is the average efficiency of the drip irrigation system in the field as quoted from the table 2 above. The number of days between two consecutive irrigations for periods without rainfall is also referred to as irrigation interval or frequency. It is calculated as a ratio of net depth of irrigation to the transpiration rate of crop on being irrigated. The following equation was applied:

$$I_t = \frac{RAW}{T} \qquad (1.8)$$

Where I_t is the irrigation interval (days) and T is the average transpiration rate of tomatoes (mm/day) computed from

$$T = E_t \times \frac{P_s}{85} \qquad (1.9)$$

Where E_t is the conventional accepted consumptive use of tomatoes (mm/day) as adopted from table 1. The amount of water required per irrigation is commonly referred to as drip set capacity. This was estimated as the product of the area under irrigation and the gross irrigation depth

$$q_c = A \times GIR \times 10^3 \quad (1.10)$$

Where q_c is the drip system capacity (litres), A is the area under drip irrigation (m^2).the above computed results were recorded (table 7)

Results and Discussions

Data on the on-farm measured sample emitter discharge per lateral was recorded (Tables 3, 4, 5 and 6)

Table 3: Emitter discharge at different locations along lateral 1

Date	Discharge (ml/hr) per emitter								
	1	2	3	4	5	6	7	8	9
22/12/2010	700	700	700	700	699	666	665	664	662
24/12/2010	700	700	700	700	699	666	666	668	660
26/12/2010	700	700	700	700	700	665	665	667	660
27/12/2010	700	700	700	700	699	666	666	666	663
29/12/2010	700	700	700	700	688	667	665	666	665
Average	700	700	700	700	699	666	665.4	666.2	662

Table 4: Emitter discharge at different locations along lateral 2

Date	Discharge (ml/hr) per emitter								
	1	2	3	4	5	6	7	8	9
22/12/2010	700	700	692	690	667	664	662	658	655
24/12/2010	700	697	696	694	676	665	658	650	650
26/12/2010	700	700	698	680	680	672	660	654	650
27/12/2010	700	700	685	685	680	670	668	660	656
29/12/2010	700	688	676	670	680	676	670	668	659
Average	700	697	689.4	684	676.6	669	664	658	654

Table 5: Emitter discharge at different locations along lateral 3

Date	Discharge (ml/hr) per emitter								
	1	2	3	4	5	6	7	8	9
22/12/2010	699	687	675	669	666	663	661	657	654
24/12/2010	699	699	684	679	675	664	657	649	649
26/12/2010	699	699	695	689	679	671	659	653	649
27/12/2010	699	699	697	693	679	669	667	659	655
29/12/2010	699	696	691	684	679	675	669	667	658
Average	699	696	688.4	682.8	675.6	668.4	662.6	657	653

Table 6: Emitter discharge at different locations along lateral 4

Date	Discharge (ml/hr) per emitter								
	1	2	3	4	5	6	7	8	9
22/12/2010	698	686	674	668	664	661	659	655	652
24/12/2010	697	697	682	677	673	663	656	648	648
26/12/2010	697	698	694	688	677	669	657	651	647
27/12/2010	698	698	696	692	678	668	666	658	654
29/12/2010	697	694	689	682	677	674	668	666	657
Average	697.4	694.6	687	681.4	673.8	667	661.2	655.6	651.6

The maximum average emitter discharges for lateral the first, second, third and fourth lateral are 700, 700, 699 and 651.6 ml/hr. on the other hand, the minimum values are 662, 654, and 651.6 ml/hr. from these figures, and there is a general decline trend in both maximum and minimum emitter discharge. This is attributed to the frictional loss along the lateral which increases with length of the pipe. Since the discharge is directly proportional to the operating pressure at the emitter, it is also expected to decrease with length of the lateral. To get a clear picture of the trend, the average emitter discharge down the lateral was correlated with the lateral length (Figure 1)

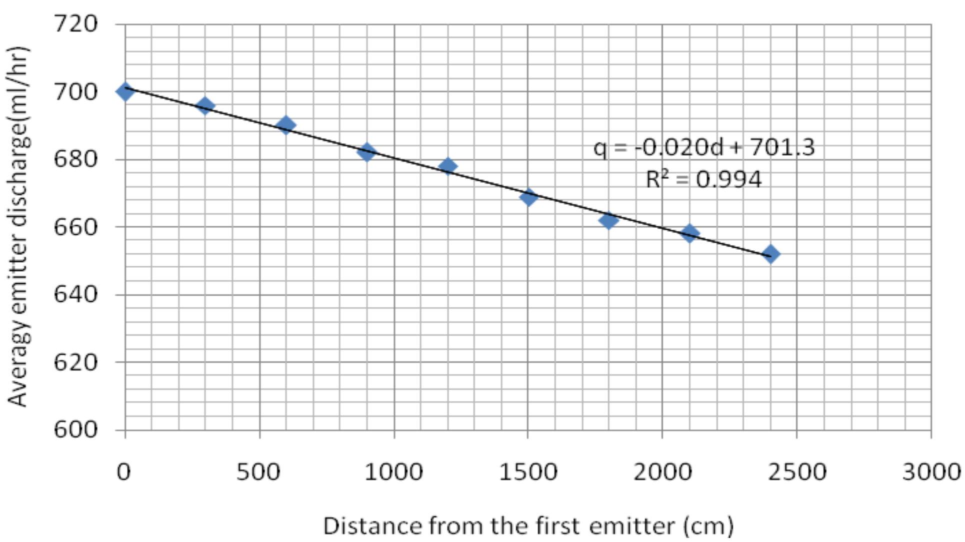

Figure 3: Variation of emitter discharge with length from the first emitter

There is linear correlation between average emitter discharge with the distance down the lateral with a coefficient of determination of 0.994, maximum and minimum discharges being 701.3 ml/hr and 652 ml/hr. The average rate of discharge-depletion rate along the lateral is determined from the gradient of the linear curve and is estimated as 0.02 ml/hr. cm (Figure 3). This means that if the discharge on the first emitter is known, then the discharge at any other emitter location down the lateral can be estimated by this gradient.

The cumulative water use efficiency (WUE_c) which gives the efficacy of water utilization in crop biomass production was estimated for different weeks and results plotted (Figure 4)

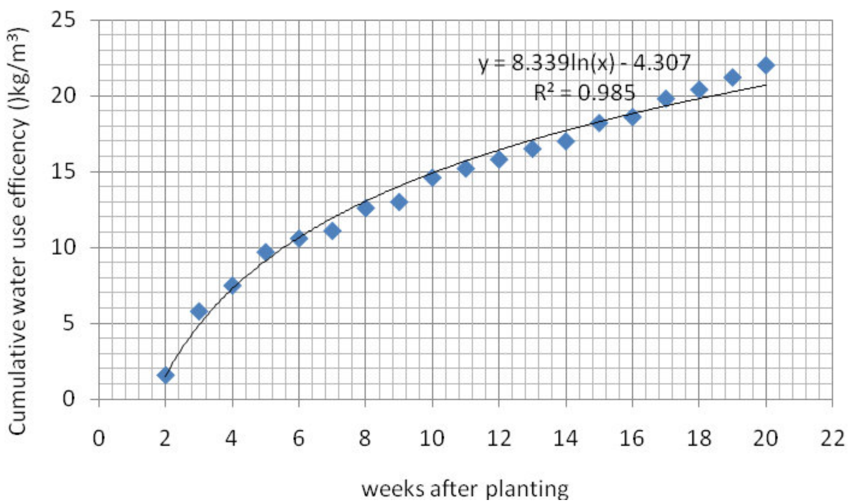

Figure 4. Variation of water use efficiency (WUE) with period in weeks

Results indicate that the cumulative water use efficiency varied logarithmically with period in weeks with a coefficient of determination being 0.985. During the time of assessment, the lowest and highest cumulative water use efficiencies were 1.5 $kg/m^3$and 22 kg/m^3 respectively. This means that on average one cubic meter of water was used to produce 22 kg of biomass within the study period. The WUE is comparable with values from other studies. For instance, a *WUE* drip-irrigated tomato has been found to be 19-25 kg/m^3 (Hanson *et al*., 2006). The approximate value for studies conducted in Israel was 25 kg/m^3[2] . The biomass composition was partitioned and results presented (figure 5)

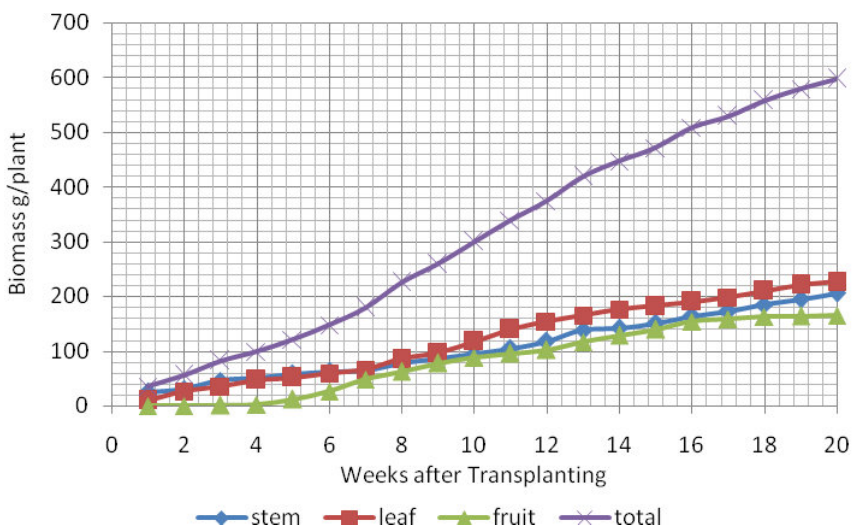

Figure 5. The cumulative partitioned biomass of the tomato plants within the greenhouse

From the above diagram, within the first four weeks of transplanting, cumulative biomass for leaf and stem had a gradual linear development while that of the fruit remained at zero since flowering had not yet started. After the fourth week, the trend changed. The leaf, stem and total show a significant growth in cumulative biomass. It is during this period when the fruit biomass begins to show a substantial growth

(Schwarz and Klaring, 2001). This trend continue up to the end of the 20^{th} week evaluation period when the fruit, leaf, stem and total cumulative biomass are at 160 g/plant, 200 g/plant, 240 g/plant and 600 g/plant respectively. At the end of the assessment period, the total biomass was partitioned (figure 5)

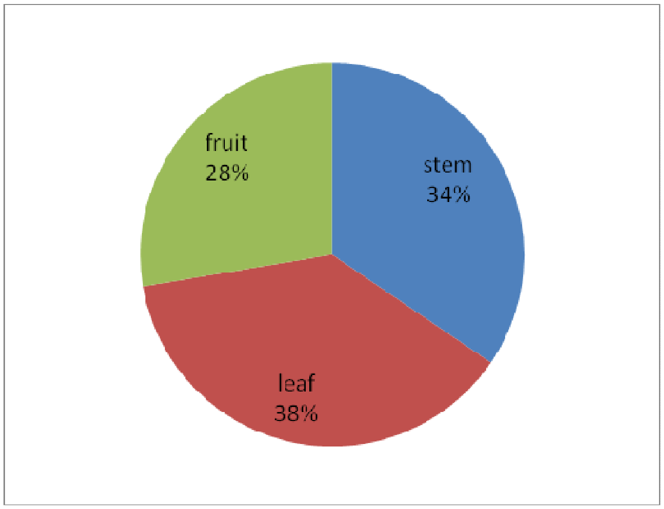

Figure 6. The average proportions of biomass composition of tomato plant within the greenhouse

It was noted that on average, the biomass tomato distribution in descending order is leaf, stem and fruit represented by 38%, 34% and 28% respectively (figure 6) .

Table 7. the computed results of drip system performance parameters based on conventional variables

Parameter	Computed Value
Readily Available Water (RAW)	14.6 mm
Gross Irrigation Requirement (GIR)	17.2 mm
Irrigation Interval (I_t)	4 days
Drip system Capacity (q_c)	4117 litres
Emitter variation, (q_{var})	7
Average depth of application	12 cm

Based on the assessment from the above, the computed values for Readily Available Water, Gross Irrigarion Requirement, Irrigation Interval, Drip system capacity and emitter variation were 14.6 mm, 17.2 mm, 4 days, 4117 litres and 7 respectively. The readily available water is a measure of the amount of water which can be accessed by the crop without stress or exertion of high pressure.

Conclusion and recommendation

The findings show that that the drip system capacity was approximately 4117 liters per hour, with an average single emitter discharge of 0.679 liters per hour. The level of water consumption was assessed using the Water Use Efficiency (WUE). Its value was computed based on cumulative domain reaching 22 kg of tomato yield per cubic meter of water applied using the drip system, for the monitoring period of twenty weeks. Although the computed irrigation interval from the data is four days, it is recommended that the actual value be reduced to three days since the field is located in dryland where evapo-traspiration is accelerated by wind, and extreme radiation penetrating into the greenhouse.

It is recommended that more research be conducted explore the on-farm performance of evaporative cooling on crop production within a greenhouse. In this, the possibility of applying integrated rainwater harvesting system-optimization and trend of stage-wise water requirement of different crops and seasons should be investigated. The optimization should be geared towards increasing drip-deficit water-use efficiency to allow adoption of the technology to curb food security within water scarce regions.

References

Asher, J. B. and Phene, C. J. (1993). The effect of surface drip irrigation on soil water regime evaporation and transpiration, 6th International conference on irrigation proceedings, Tel-Aviv, Israel, May 3-4), 1993.

Ben-Gal and Shani, A. U. (2003). Water use and yield of tomatoes under limited water and excess boron, *J. Plant and soil sci.*, 256: 179-186

Gvrerosca, B. and Ziberoski, J.(2011). The influence of Trichoderma harzianum on reducing root rots, *International Journal of Pure and Applied Sciences and Technology*, 2(2): 1-11

Hanson, B. R., Hutmacher, R. B. and May, D. M. (2006). Drip irrigation of tomato and cotton under shallow saline ground water conditions, *Journal of irrigation and drainage systems*, 20 pp 155-175

Misra, M. and Misra, A. N (2010). Jatropha: The Biodiesel Plant Biology, Tissue Culture and Genetic Transformation, *International Journal of Pure and Applied Sciences and Technology* 1(1) (2010): 11-24

Keskin, G., Tatlidil, F. F. and Dellal, I. (2010). An analysis of tomato production cost and labour force production, in Turkey, Bulgarian journal of agricultural sciences, 16 (6): 692-699

Liu, H., Sun, J. S., Duan, A., Lian, Y. (2010). Effect of water stress on tomato growth and physiological characteristics under drip irrigation in green house, *Journal of Irrigation and Drainage* http://en.cnk.com.cn/Article_en/CJFDTOTAL.GGPS201003013.htm

Naika, S., Jeude, J. L., Goffau, M. and Hilmi, B. (2005). Cultivation of tomato production, processing and marketing, Agromisa Foundation and CTA, Wageningen, the Netherlands

Schulbach, K., Tjosvold, S., Kasapligi, D., 1999. Improving irrigation systems conserves water in greenhousegrown cut flowers. Calif. Agric., 53 (2): 44–48.

Schwarz, D. and Klaring, H. P. (2001). Allometry to estimate leaf area of tomato, *J. of plant Nutr.* Vol 24, pp 1291-1309

Sekyere, J. D. O., Asante, P. and Bonsu, P. O. (2010). Water requirements, deficit irrigation and crop coefficient of hot pepper (*Caspicum fruitscens*) using irrigation interval of 4 days, ARPN Journal of agricultural and biological science, 5.(5): 72-78

Shrivastava, P.,Rajput, G. S. and Nayak, S. (2011). Soil moisture distribution as influenced by drip irrigation supply and planting pattern in heavy soils of Madhya Pradesh, *Journal of agricultural technology*,7(4): 1177-1186

Soussa,H. K. (2010). Effect of drip irrigation water amount on crop yield, productivity and efficiency of water use in desert regions of Egypt, Nile basin *water science and engineering journal* ,. 3 (2): 96-109

Unlu, M., Kanber, R., Kanpur, B., Tekin, S. and Koc, D. L. (2011). The crop water stress index of drip irrigated cotton in a semi-arid region of Turkey, *African journal of biotechnology* 10(12): 2258-2273

USDA-NRCS (1997). National Engineering handbook, Irrigation Guide, Washington, DC, USA.