International Journal of Engineering Innovation & Research
Volume 3, Issue 3, ISSN: 2277 – 5668

Effect of Water Application Levels on Growth Characteristics and Soil Water Balance of Tomatoes in Greenhouse

Luvai A. K.
kioko.allois@gmail.com

Gitau A. N.
gitauan@yahoo.co.uk

Njoroge B. N. K.
bnknjoroge@uonbi.ac.ke

Obiero J. P. O.
pobiero2003@yahoo.com

Abstract - **The effect of water application levels on growth characteristics and soil water balance of tomato grown in greenhouse were investigated. The study was conducted in two greenhouses located at Matinyani Secondary School and Kyondoni Location in Kitui County, Kenya. The variation of growth characteristics (plant height, stem diameter, fruit diameter and fruit weight) and extraction of soil water with time were monitored. Four irrigation water application levels namely T_1-1.2, T_2-1.0, T_3-0.8 and T_4-0.6 served as treatments. These were 120, 100, 80 and 60 % of crop water requirements computed using Piestley-Taylor model. The irrigation frequencies were daily and 1-day respectively at Matinyani and Kyondoni greenhouses. For the daily and 1-day irrigation frequencies respectively, applied irrigation water varied from 548 to 274 mm and from 255 to 128 mm while actual evapotranspiration varied from 537 to 246 mm and from 227 to 108 mm in T_1 to T_4 treatments. This study revealed that different water application levels had significant effect on growth characteristics, soil water balance and yield of tomato crop. Low water application levels as well as less irrigation frequencies reduced crop growth and yield and also led to low soil water content. Daily irrigated treatments produced the best growth characteristics, the best fruit quality and the highest yield. In particular, T_1 treatment produced the best stem diameter, plant height, fruit weight, fruit diameter and yield as 16.74 mm, 2.31 m, 129 g, 62 mm and 4.44 kg m^{-2} respectively. In terms of water use and irrigation water use efficiencies, T_4 treatment produced the highest as 11.90 and 13.26 kg m^{-3} respectively. Under scarce water resources, T_3 treatment (80 % ETc) under daily irrigation frequency was considered the most suitable water application level for tomato crop grown inside a greenhouse and therefore recommended.**

Keywords – **Evapotranspiration, Greenhouse Farming, Irrigation Frequency, Protected Cultivation, Water Resources.**

I. INTRODUCTION

The availability of water is the most important factor that limits development of agriculture in arid and semi-arid [1]. Competition for water resources has become stiffer due to the rapid growth of population, industrialization and urbanization. The current population growth has caused the per capita share of water fall below 1000 (approximately 700 cubic meters per capita) which according to international standards is considered the "water poverty limit" [2]. Further, it is projected that by the year 2025 the per capita share of water is expected to drop to 584 m^3 [2].

Nevertheless, water remains an important resource for the economy, health and welfare for the growing world population. In this regard, the need for the development of materials and methods for conservation of water on the three main scales namely field, watershed and regional has intensified. The needs of the growing population in third world countries have increased tremendously and therefore as a means of ensuring higher agricultural production per unit volume of water resources, per unit area of land per unit time, irrigation has been adopted [3]. Further, irrigation is the backbone of modern agriculture in arid and semi-arid regions [4]. Statistically, about 70% of the global fresh water resources are used for irrigation and this calls for intervention in order to find options to replace traditional farming and irrigation practices [5].

Protected cultivation is the current development in the horticultural sector which entails the growth of crops inside a greenhouse covered with glass or plastic films [6]. The use of this technology has been accelerated by the need to provide fresh and quality products throughout the year in addition to optimizing water use under varying climatic conditions [7] [8]. Greenhouse farming creates and maintains a controlled environment which fosters optimum crop production [9]. Most importantly, greenhouse cultivation increases irrigation water use efficiency and produces yields that are about five to ten times greater than in the field [10] [11]. Similarly, if crop production in a greenhouse is managed appropriately, better yield of improved quality is obtained because the inside microclimate and irrigation are easily controlled to favour the growth and development [9] [12]. Further, due to effective control of land, water, pesticide and fertilizer, cleaner crops are produced when compared to open field cultivation. Lastly, greenhouses offer an opportunity to farmers in arid and semi-arid regions to harvest water during rain events.

It has been observed that both quality and quantity of horticultural yield is directly affected by the availability of water [10]. In this regard therefore, in order to ensure sustainable and profitable production in greenhouses, water must be applied in adequate amounts and at appropriate times. In connection with this, drip irrigation system has been commonly used in greenhouses because it exercises control over water application by enabling accurate application of irrigation amounts alongside reducing water losses by soil evaporation and drainage when properly managed. Thus, water productivity in greenhouses can be improved in two main ways [13]: 1).Maintaining the degree of water production at current level along with reducing the consumption of water. 2). Increasing yield (including product weight, product

Copyright © 2014 IJEIR, All right reserved

diameter, stem diameter, and leaf area index) for every unit of water consumed. In general, by having a proper protection network for the available water resources, the degree of production in a greenhouse may be greatly improved.

Irrigation water requirements in a greenhouse vary depending on the season and the size of the crop cultivated [9]. In this regard, transplanted tomato plants require about 0.05 litres per plant per day while at maturity and especially on sunny days, plant water requirement may rise to 2.7 litres per plant per day [9]. A similar study on lettuce crop showed that different irrigation levels had effects on yield, quality and water use characteristics [1].

Greenhouses have become very popular in Kitui County with most companies citing them as goldmines that offer the most profitable business opportunities which no farmer ought not to miss. This follows a very aggressive promotion that takes advantage of the fact that farmers are desperate to get more profit from farming but in reality they lack relevant experience in this technology. Farmers have devised their own system of management for their greenhouse irrigation systems and this has resulted in a variety of performance levels. For these reasons, the objectives of the study were to: 1). Assess the effect of selected irrigation water application levels and frequencies on plant growth characteristics, soil water balance and yield during crop growth period. 2). Establish the optimum irrigation water requirement and water use efficiencies under greenhouse conditions.

II Materials and Methods

A. Experimental Site

The experiment was carried out in two greenhouses located at Matinyani secondary school and Kyondoni village, Kitui County, Kenya from May to October 2013. The location for Matinyani corresponds to latitude 1° 19′ 16″ S, longitude 37° 58′ 09″ E and altitude 1186 m above sea level while Kyondoni corresponds to latitude 1° 18′ 45.20″ S, longitude 37° 58′ 04.54″ E and altitude 1187 m above sea level. The climate of Kitui County is arid and semi-arid with very erratic and unreliable rainfall. Rainfall ranges from 500 to 1050 mm per annum while temperatures range from 14 °C to 34 °C. The long rains occur in April/May and the short rains in November/December. The soils within the county are reddish sandy clay loam with good infiltration and loose structure.

B. Experimental Set Up

The greenhouses measured 8 m by 15 m and the roofs were covered with a 200 micron transparent plastic paper. Drip irrigation system was used for the experiment. Laterals were laid for each plant row and inline emitters with discharge rates 1.188 and 0.55 liters per hour respectively at Matinyani and Kyondoni were spaced at 20 cm intervals on the lateral line. The main and sub-main pipelines for drip irrigation were made of polyethylene pipes of 25 mm diameter while linear low density polyethylene pipes of 12 mm and 8 mm diameter were used for the laterals at Matinyani and Kyondoni respectively. The control unit of the drip system consisted of a 500 liters tank, screen filter, main, sub-mains, laterals, drippers, flow meters, control valves and other accessories required for drip irrigation. The system was operated by the water head created by the 500 liter tank which was placed on a 2.4 m high stand above ground level. The experiment used tomato hybrid Anna F1 variety as the test crop. Four irrigation water application levels served as treatments: full irrigation (T_2) which corresponded to 100 % of ETc, 120 % of ETc (T_1; 20 % excessive), 80 % of ETc (T_3; 20 % deficit), 60 % of ETc (T_4; 40 % deficit). Table 1 describes the source, electrical conductivity and pH of irrigation water used at the experimental sites. Some of the chemical and physical properties of the soils in the experimental sites are given in tables 2 and 3 respectively.

Table 1: Description of irrigation water

Greenhouse	Source	Category	Ec (dS m^{-1})	pH
Kyondoni	Water pan	Surface	0.75	5.7
Matinyani	Borehole	Subsurface	0.80	7.5

Ec – Electrical conductivity; pH – soil reaction

Table 2: Chemical properties of the experimental soils

Greenhouse	Level	Ec (dSm^{-1})	pH
Kyondoni	S	0.45	6.72
	SS	0.6	6.60
Matinyani	S	0.4	7.40
	SS	0.3	7.01

S – Surface (0 – 30 cm); SS – Sub-surface (30-60 cm);
Ec – Electrical conductivity; pH – Soil reaction

Table 3: Soil Properties in the Greenhouses under Experiment

D(cm)	Sa (%)	C (%)	S (%)	Type	FC (%)	PWP (%)	BD (gcm^{-3})
Kyondoni							
0-20	50.44	37.95	11.61	SC	20.00	14.71	1.21
20-40	52.44	40.61	6.95	SC	19.47	13.58	1.26
40-60	50.44	37.28	12.28	SC	14.95	12.94	1.27
Matinyani							
0-20	69.69	24.38	5.93	SCL	11.90	8.02	1.14
20-40	62.03	32.05	5.93	SCL	13.90	10.67	1.42
40-60	61.36	33.05	5.59	SCL	13.40	10.26	1.43

FC – Field capacity; PWP – Permanent wilting point;
BD – Bulk density; Sa – Sand; C – Clay; S – Silt;
D – Soil Depth

C. Planting Procedure

At Matinyani and Kyondoni respectively, tomato seeds were sown on 21st May and 9th July, 2013 and transplanted on 30th June and 6th August, 2013. Tomato seedlings were transplanted onto raised beds measuring 0.9 m by 15 m and each having double rows with plant spacing of 60 cm along rows and 40 cm between rows. Irrigation was uniformly applied to all treatments at the beginning of

Copyright © 2014 IJEIR, All right reserved

International Journal of Engineering Innovation & Research
Volume 3, Issue 3, ISSN: 2277 – 5668

transplanting until 9th July and 16th August, 2013 at Matinyani and Kyondoni respectively for establishment of plants. Thereafter, a fixed irrigation frequency was applied in all treatments with irrigation being applied daily and after every one day until harvest at Matinyani and Kyondoni respectively. A recommended fertilization program was followed in the experiment with all the treatment plots receiving the same amounts of fertilizer which consisted 150 kg ha^{-1} DAP, 200 kg ha^{-1} CAN and 200 kg ha^{-1} NPK. Occurrence of the different growth stages and harvesting time were recorded as days after transplanting (DAT) accordingly.

D. Determination of Reference Crop Evapotranspiration

Potential evapotranspiration (ETo) was computed using Priestley-Taylor model (1).

$$\mathrm{ETo} = \frac{1}{\lambda}\,\alpha\frac{\Delta}{\Delta+\gamma}(\mathrm{Rn}-\mathrm{G}) \qquad (1)$$

Where, α is empirical coefficient, λ is Latent heat of vaporization, Δ is slope of saturation vapor pressure curve; γ is psychrometric constant, *Rn* is net radiation and *G* is soil heat flux. According to studies conducted by Pereira and Villa Nova cited in [1], α has a value of 1.12 and it depends on vegetation hence it can be related to sensible heat flux and vapor pressure. Further, the value of G is negligible in the daily calculation of potential evapotranspiration because it is small on daily basis [14]. Data for this model was obtained from meteorological measurements in the greenhouse comprising air temperature, wet bulb and dry bulb temperatures, estimates of net radiation, slope of the saturation vapor pressure curve and psychrometric constant. The parameters were estimated based on empirical relationships developed by [14].

E. Estimation of Crop water requirement

The crop water requirement in liters per plant per day under drip irrigation was computed using (2) proposed by [3].

$$\mathrm{Q} = \mathrm{A \times B \times C \times D} \qquad (2)$$

Where, *Q* is quantity of water per plant per day, *A* is gross area per plant (m^2), *B* is the amount of area covered with foliage (fraction), *C* is the crop coefficient, (fraction) and *D* is the reference evapotranspiration (mm). In this study, the experiments were carried out during the crop development, middle and late growth stages and the crop coefficient (Kc) used were 0.75, 1.15 and 0.75 respectively [14].

F. Determination of Actual Evapotranspiration

The actual evapotranspiration (ET) under different water applications was computed using the soil water balance equation [1][15][16]. This water balance (equation 3) did not consider surface runoff because drip irrigation system was used. In addition, due to the small variation in soil water contents below 30 cm depth, deep percolation was considered negligible.

$$\mathrm{ET} = \mathrm{I} + \Delta\mathrm{S} - \mathrm{D} - \mathrm{R} \qquad (3)$$

Where, *R* is run-off, ΔS is change in soil water storage, *D* is water net flux at deeper layer and I is quantity of irrigation water.

G. Measurement of Soil Water Content

Soil water content was measured using gravimetric method at 0.3 m increments down to 0.6 m before irrigation. Soil samples were collected from each treatment at three sampling points using a soil auger. In order to prevent preferential flow of irrigation water, holes which resulted from gravimetric sampling were refilled with soil and re-compacted.

H. Crop Physiological Measurements

The main crop physiological measurements done on tomato plants were plant height, stem diameter, fruit diameter and fruit weight. The measurements of plant height and stem diameter were made during the growth stages of the crop while fruit weight and diameter were done at the time of harvesting.

I. Tomato Harvesting

Harvesting of tomato fruits was done manually from 70 to 80 days after transplanting. An electronic balance (Sartorius) which had an accuracy of ±0.01 g was used to weigh the harvested tomatoes. In order to quantify the quality of harvested tomato fruits, the two main parameters used were fruit diameter and fruit weight.

J. Determination of Water Use Efficiencies

Water use efficiency (WUE, kg m^{-3}) was calculated as the ratio of yield (kg m^{-2}) to crop evapotranspiration while irrigation water use efficiency (IWUE, kg m^{-3}) was calculated as the ratio of yield (kg m^{-2}) to the applied irrigation water [15].

III. RESULTS AND DISCUSSIONS

A. Water Applied and Water Used

The average crop water requirement per plant per day was 1.35 and 1.28 liters per plant per respectively at Matinyani and Kyondoni greenhouses. These values lie between 0.05 and 2.7 litres per plant per day as outlined in [9]. The results show clearly that the crop water requirement varies from region to region. In this regard, determination of crop water requirements becomes an important activity for any water conservation study in crop production especially in arid and semi-arid regions where water is increasingly becoming scarce. In greenhouses in particular, ETc is an important aspect especially for planning water management. This is not only important from physical and biological dimensions but also from the applied engineering angle since the hydraulic design should factor in ETc.

The maximum amount of water applied to treatments irrigated daily was 548 mm in T_1 treatment while the minimum amount was 273 mm in T_4 treatment. Similarly, for treatments under 1-day frequency, the maximum amount of applied water was 255 mm in T_1 treatment while the minimum amount was 128 mm in T_4 treatment. The actual evapotranspiration varied from 537 to 246 mm in daily irrigated treatments and from 227 to 108 mm in 1-day irrigation treatments, (table 4).

Copyright © 2014 IJEIR, All right reserved

Table 4: Summary of water balance within the greenhouses

Matinyani			
I.T	***I (mm)***	***ΔS (mm)***	***ET (mm)***
T_1	548	-11	537
T_2	457	-14	443
T_3	365	-17	348
T_4	273	-28	245
Kyondoni			
I.T	***I (mm)***	***ΔS (mm)***	***ET (mm)***
T1	255	-28	227
T2	213	-18	195
T3	170	-18	152
T4	128	-20	108

I.T – Irrigation treatment; I – Irrigation water;
ΔS – Change in soil water; ETc – Evapotranspiration

B. Effect of Water Application Levels and Frequencies

Water application levels and frequencies affected tomato crop growth characteristics. The results indicated that daily irrigated treatments resulted in better crop growth characteristics and the best yield, (table 5).

Positive linear relations were found between plant height and irrigation water and between stem diameter and irrigation, (fig. 1, 2, 3 and 4). Fruit diameter and fruit weight had a similar response to water application levels same as that found in growth parameters and yield.

Table 5: Tomato growth characteristics and yield

Matinyani	*T*	*H (m)*	*S (mm)*	*F (mm)*	*W (g)*	*Y (kgm^{-2})*
	T1	2.31	16.72	62	129	4.44
	T2	2.3	16.48	60	126	4.15
	T3	2.25	16.35	55	122	3.93
	T4	1.85	14.38	53	111	3.26
Kyondoni	T1	1.64	16.74	59	124	2.74
	T2	1.54	16.07	55	115	1.85
	T3	1.47	15.36	49	104	1.4
	T4	1.36	14.24	45	98	1.04

T – Irrigation treatment; H – plant height; S – stem diameter; F – fruit diameter; W – fruit weight; Y – yield

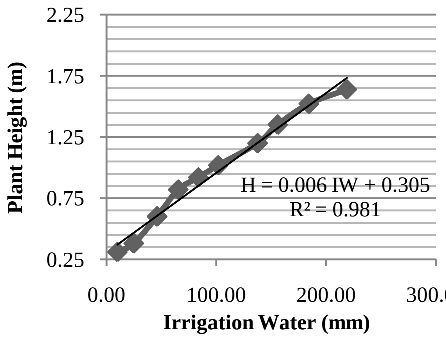

Fig.1(a): Relationship between applied irrigation water and plant height in treatment T_1 at Kyondoni greenhouse

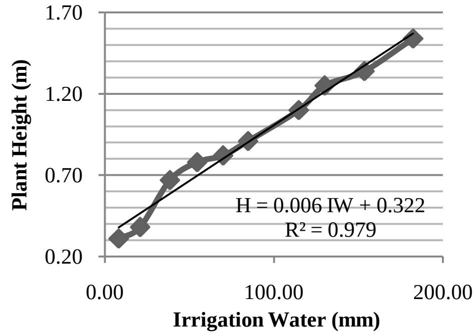

Fig.1(b): Relationship between applied irrigation water and plant height in treatment T_2 at Kyondoni greenhouse

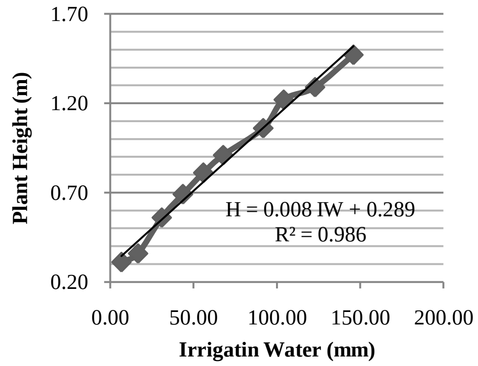

Fig.1(c): Relationship between applied irrigation water and plant height in treatment T_3 at Kyondoni greenhouse

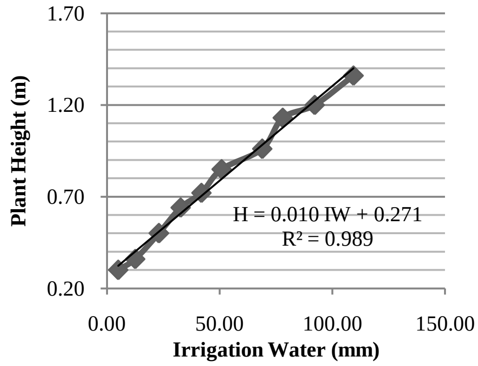

Fig.1(d): Relationship between applied irrigation water and plant height in treatment T_4 at Kyondoni greenhouse

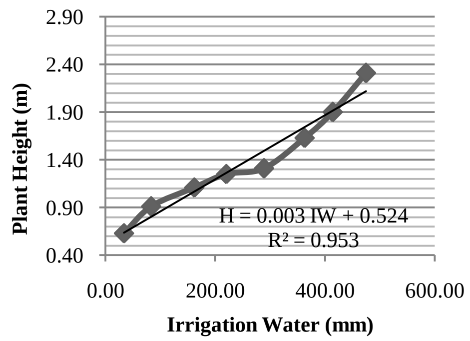

Fig.2(a): Relationship between applied irrigation water and plant height in treatment T_1 at Matinyani greenhouse

Copyright © 2014 IJEIR, All right reserved

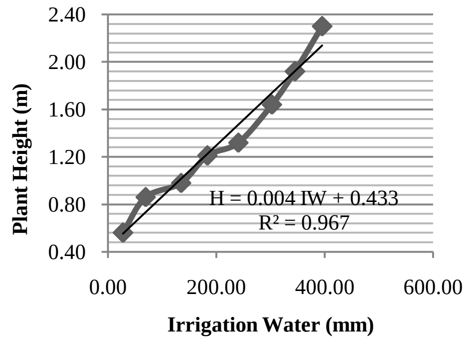

Fig.2(b): Relationship between applied irrigation water and plant height in treatment T_1 at Matinyani greenhouse

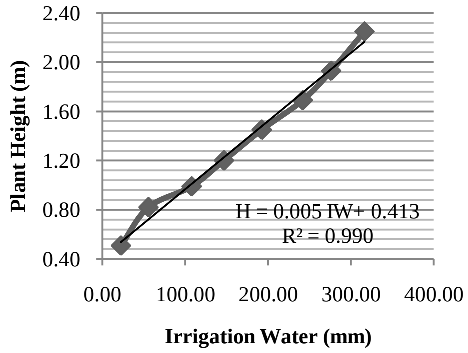

Fig.2(c): Relationship between applied irrigation water and plant height in treatment T_3 at Matinyani greenhouse

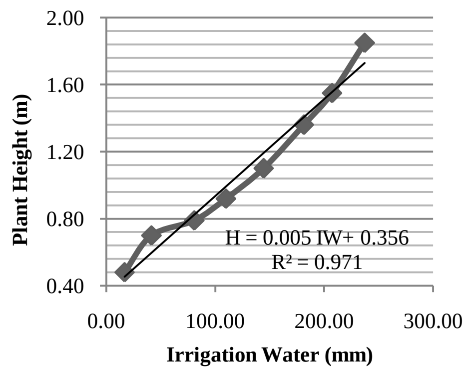

Fig.2(d): Relationship between applied irrigation water and plant height in treatment T_4 at Matinyani greenhouse

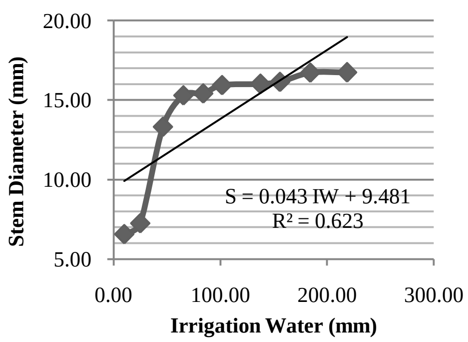

Fig.3(a): Relationship between applied irrigation water and stem diameter in treatment T_1 at Kyondoni greenhouse

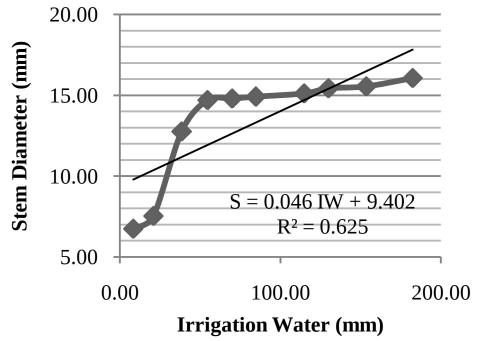

Fig.3(b): Relationship between applied irrigation water and stem diameter in treatments T_2 at Kyondoni greenhouse

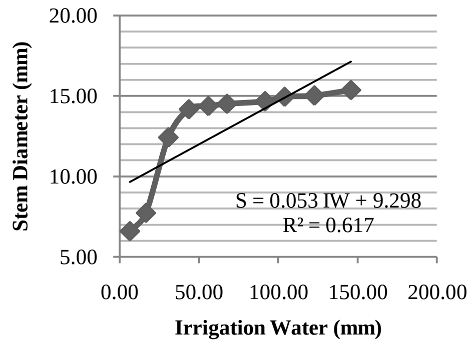

Fig.3(c): Relationship between applied irrigation water and stem diameter in treatment T_3 at Kyondoni greenhouse

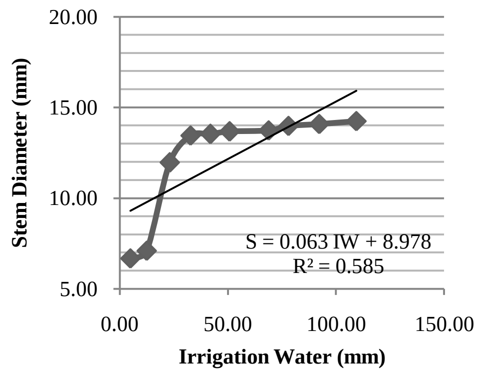

Fig.3(d): Relationship between applied irrigation water and stem diameter in treatment T_4 at Kyondoni greenhouse

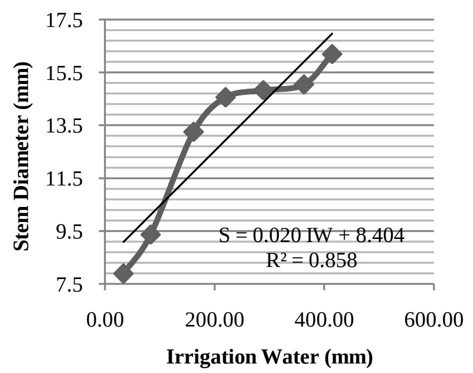

Fig.4(a): Relationship between applied irrigation water and stem diameter in treatment T_1 at Matinyani greenhouse

Copyright © 2014 IJEIR, All right reserved

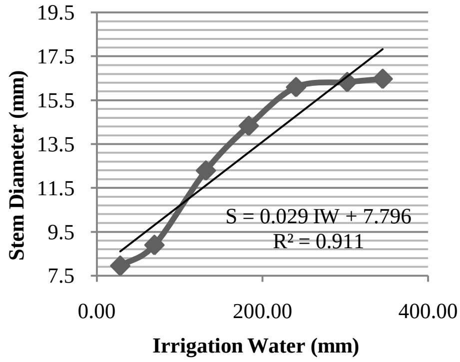

Fig.4(b): Relationship between applied irrigation water and stem diameter in treatment T_2 at Matinyani greenhouse

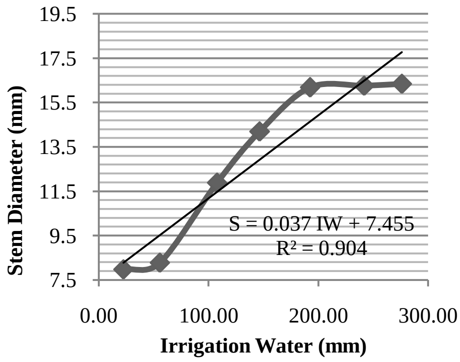

Fig.4(c): Relationship between applied irrigation water and stem diameter in treatment T_3 at Matinyani greenhouse

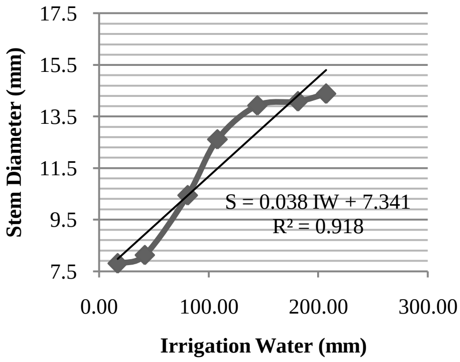

Fig.4(d): Relationship between applied irrigation water and stem diameter in treatment T_4 at Matinyani greenhouse

The highest tomato yields were obtained from daily irrigated treatments. For both irrigation frequencies, T_1 treatments gave the highest yield while T_4 treatments gave the least. Tomato yield varied from 4.44 kg m^{-2} to 3.26 kg m^{-2} for daily irrigated treatments and from 2.74 kg m^{-2} to 1.04 kg m^{-2} for 1-day irrigation treatments in T_1 to T_4 treatments. For treatments under 1-day irrigation frequency, the highest IWUE and WUE were obtained from T_1 treatment as 11.90 kg m^{-3} and 13.26 kg m^{-3}. Likewise, under daily irrigation frequency, T_4 treatment gave the highest IWUE and WUE as 10.74 kg m^{-3} and 12.07 kg m^{-3}.

Table 6: Summary of Yield, Water use Efficiencies (WUE) and Irrigation Water use Efficiencies (IWUE)

Irrigation treatment	*Yield (kg m^{-2})*	*IWUE (kg m^{-3})*	*WUE (kg m^{-3})*
Matinyani			
T_1	4.44	8.1	8.27
T_2	4.15	9.09	9.38
T_3	3.96	10.84	11.37
T_4	3.26	11.9	13.26
Kyondoni			
T_1	2.74	10.74	12.07
T_2	1.85	8.70	9.53
T_3	1.40	8.23	9.50
T_4	1.04	8.15	9.62

In both greenhouses, soil water content remained fairly high in T_1 treatments because they received more irrigation water. At about 30 days after transplanting, treatments in both greenhouses showed high levels of soil water content in the 0-30 cm soil profile but later considerable differences were noted. In connection with this, treatments under a 1-day irrigation frequency showed very little soil water content especially deep in the profile compared to daily irrigated treatments. This implied that irrigation frequency had an effect on soil water content.

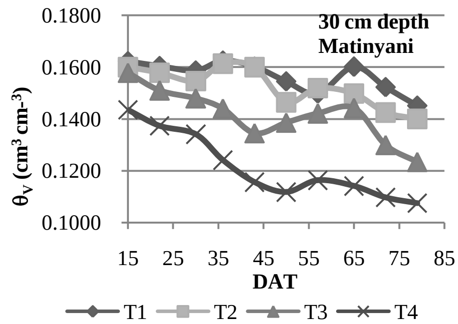

Fig.5(a): Variation of volumetric soil water content (θ_V) with days after transplanting (DAT) in treatments T_1 to T_4 within 30 cm depth at Matinyani greenhouse

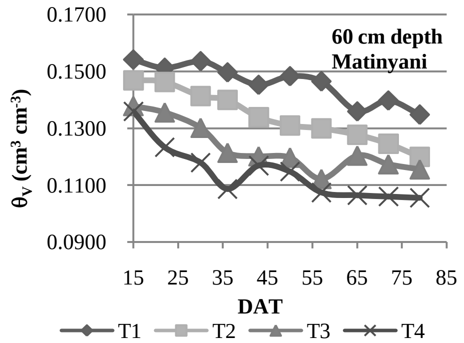

Fig.5(b): Variation of volumetric soil water content (θ_V) with days after transplanting (DAT) in treatments T_1 to T_4 within the 60 cm depth at Matinyani greenhouse

Copyright © 2014 IJEIR, All right reserved

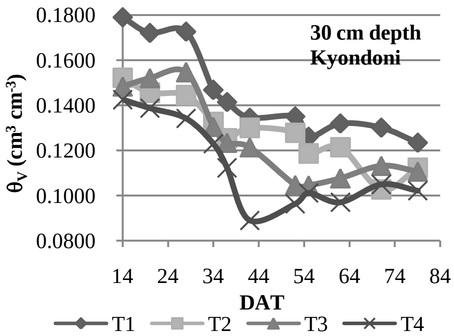

Fig.5(c): Variation of volumetric soil water content (θ_V) with days after transplanting (DAT) in treatments T_1 to T_4 within the 30 cm depth at Kyondoni greenhouse

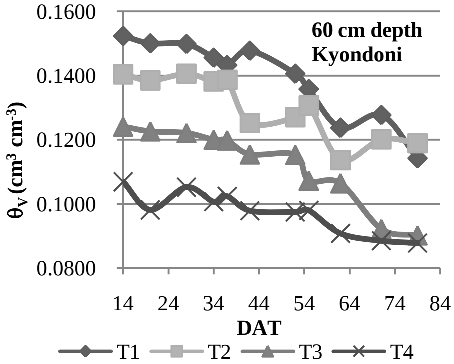

Fig. 5(d): Variation of volumetric soil water content (θ_V) with days after transplanting (DAT) in treatments T_1 to T_4 within the 60 cm depth at Kyondoni greenhouse.

Fig.5 shows that the depletion of soil water over time reflected an undulating profile with a number of peaks and troughs dispersed throughout the treatments. This was attributed to the variation of crop water use at various stages of growth and therefore it could be inferred that soil water content was directly related to the amount of irrigation water applied.

Throughout the entire cycle of the crop, proper distribution of water and maintenance of optimal levels of soil moisture reduces water losses by drainage as well as the water stress period of the crop thus resulting in increases in water use efficiency. This is attainable with water applications at a high frequency and small amounts

IV. Conclusions

In this study, different water application levels and irrigation frequencies had significant effect on crop growth characteristics, crop yield, water use efficiencies and soil water balance. It was found out that crop growth characteristics, crop yield and soil water content were significantly reduced when the amount of irrigation water and irrigation frequency were decreased. The optimum water requirement for Anna F_1 variety of tomato grown in a greenhouse was around 80 % of the crop evapotranspiration (ETc) calculated based on the microclimate inside the greenhouse. Irrigation applied with 80 % of crop evapotranspiration (ETc) was found to be the optimum irrigation amount for a greenhouse located in a semi-arid environment and therefore recommended.

Acknowledgments

The authors are grateful to the University of Nairobi for providing the funds to carry out this research work. We wish to acknowledge the support given by the staff of the department of Environmental and Biosystems Engineering, University of Nairobi who provided useful academic inputs and ideas that enriched this document. Sincere gratitude to goes to the members of WHENFS (Water Harvesting for Enhanced Nutrition and Food Security) research project team (Ms. K. Hannah, Dr. J.C. Mugachia, Ms. J. Wambua, Dr. R.M. Ocharo and Prof. W.K. Makau) who provided the two greenhouses and logistical support for this research work. Lastly, we wish to acknowledge the support given by the management of Matinyani Secondary School and Kamboo Youth Group, Kitui County during this research work.

References

[1] S. Bozkurt and S.G. Mansuroglu, "The effects of drip line depths and irrigation levels on yield, quality and water use characteristics of lettuce under greenhouse condition", African Journal of Biotechnology vol. 10 issue 17, pp 3370-3379, 2011.

[2] G. Abd El-Rahman, ''Water use efficiency of wheat under drip irrigation systems at Al-Maghara Area, North Sinai, Egypt". American-Eurasian J. Agric. & Environ. Sci. vol. 5 issue 5 pp 664-670, 2009

[3] V.S. Dunage, P, Balakrishnan and M.G. Patil, "Water use efficiency and economics of tomato using drip irrigation under netthouse conditions", Karnataka J. Agric. Sci. vol 22 issue 1 pp 133-136, 2009.

[4] M. Moller and S. Assouline, "Effects of a shading screen on microclimate and crop water requirements", Irrig Sci. vol. 25 issue, 171–181, 2007.

[5] S. Kulkarni, "Innovative technologies for water saving in irrigated agriculture", International journal of water resources and arid environments vol. 1 issue 3 pp226-231, 2011.

[6] F.M. Simba, "A flexible plant based irrigation control for greenhouse crops". M.Sc. Thesis, Physics Department, University of Zimbabwe, 2010.

[7] P.M. Casanova, I. Messing, A. Joel and A.M. Canete, "Methods to estimate lettuce evapotranspiration in greenhouse conditions in the central zone of Chile", Chilean Journal of Agricultural Research vol. 69 issue 1 pp 60-70, 2009.

[8] I. Impron, "A greenhouse crop production system for tropical lowland conditions". Ph.D Dissertation, Wageningnen University, Wageningen, The Netherlands, 2011.

[9] A. Harmanto, V.M. Salokhe, M.S. Babel and H.J. Tantau, H.J, "Water requirement of drip irrigated tomatoes grown in greenhouse in tropical environment", Agricultural Water Management vol. 71 pp 225-242, 2005.

[10] N.C. Sabeh, "Evaluating and minimizing water use by greenhouse evaporative cooling systems in a semi-arid climate", Ph.D Dissertation, Department of Agricultural and Biosystems Engineering, University of Arizona, 2007.

[11] G.Vox, M. Teitel, M. Pardossi, A. Minuto, F. Tinivella and E. Schettini, "Sustainable greenhouse systems" in Sustainable Agriculture, Salazar, A., Rios, I. (Eds), Italy: Nova Science Publishers, 2010 pp 1 – 70.

[12] F. Orgaz, M.D. Fernandez, S. Bonanchela, M. Gallardo, and E. Fereres, "Evapotranspiration of horticultural crops in unheated plastic greenhouse", Agricultural water management vol. 72, 81-96, 2005.

Copyright © 2014 IJEIR, All right reserved

[13] S.H. Tabatabaei, S, Moslehi, S. Najafi and T. Raiesi, “Management of water content of soil in cultivation of greenhouse cucumber (Cucumis sativus L, Nasim variety) in Isfahan-Iran”, African Journal of Biotechnology vol. 10 issue 54 pp 11157-11164, 2011.

[14] R.G. Allen, L.S. Pereira, D. Raes and Smith, “Crop evapotranspiration: Guidelines for computing crop water requirements”. FAO Irrigation and Drainage Paper 56. UN-FAO, Rome, Italy, 1998.

[15] C. Demirtas and S. Ayas, “Deficit irrigation effects on pepper (Capsicum annuum L. Demre) yield in unheated greenhouse condition”, Journal of Food, Agriculture & Environment vol. 7 issue 3&4 pp 989 – 993, 2009.

[16] V.G. Héctor, S.F. Ortega, and M. Argote, “Evaluation of water requirements for a greenhouse tomato crop using the Priestley-Taylor method”, Chilean Journal of Agricultural Research vol. 69 issue 1 pp 3 – 11, 2009.

AUTHOR’S PROFILE

Mr. Luvai Allois Kioko

obtained a B.Sc. degree in Environmental and Biosystems Engineering from University of Nairobi, Kenya in 2010. He is presently at University of Nairobi, Kenya where he is working towards M.Sc. degree in Environmental and Biosystems Engineering. His research interests include water resources engineering, irrigation engineering and structures.

Eng. Dr. Ayub N. Gitau

did his B.Sc. Studies at Egerton University, Kenya and obtained a degree in Agricultural Engineering. He obtained his M.Sc and Ph.D degrees from University of Nairobi, Kenya. His research interests are in agricultural mechanization development, renewable energies, conservation agriculture technologies and power and machinery engineering.

Eng. Prof. Njoroge B.N.K

obtained a B.Sc. degree in Civil Engineering from University of Nairobi, Kenya. He obtained his M.Sc. degree in Environmental Engineering from The University of Newcastle upon Tyne, United Kingdom and the degree of Doctor of Philosophy (Ph.D.) in Civil Engineering from Duke University, Durham, North Carolina, USA. His research interests include water resources engineering, hydraulics, public health engineering, wastewater engineering and water quality modeling.

Dr. John P. O. Obiero

obtained his B.Sc degree in Agricultural Engineering from Egerton University, Kenya. He obtained his M.Sc. and Ph.D. degrees from University of Nairobi, Kenya. He has conducted research in areas that include soil hydrology, hydrology and water resources with special emphasis on watershed modeling.

Copyright © 2014 IJEIR, All right reserved