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Effect of Drip Irrigation Regimes on the Growth and Yield of Tomatoes in Central Uganda

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Abstract: Tomatoes rank first among rainy season vegetables produced for cash within the Lake Victoria Crescent Agro-Ecological zone of Uganda. Vegetable farmers are shifting to dry season production to improve market prices. The challenge to the tomato growers is how to manage irrigation for maximum yields. A 3-year field experiment was carried out on medium soils to determine the most appropriate irrigation schedule for tomato (Solanum lycopersicum) production under drip irrigation in the zone. Randomized Complete Block Design (RCBD) in three replicates was adapted for experimental design. A tomato variety MT56 was studied for three seasons under three treatments (T1= daily, T2=2 day T3= 5 day) irrigation intervals compared with rain fed crop (T0=control). Fifteen plants per treatment were used for monitoring stem elongation and estimating yield at harvest. FAO Cropwat 8.0 model was used for simulating the seasonal crop water requirements using a timing of 100% depletion of readily available moisture (RAM).

The yield of the two-day irrigation interval was the highest at 18.8t/ha for season 1 and 36.9t/ha for season 3.The equivalent irrigation water used for both seasons was 540mm and 720 mm for season 1 and season 3 respectively. The respective simulated irrigation water requirement for the two seasons was 438 mm and 601 mm. The two-day fixed time irrigation schedule corresponded with model timing of about 80% of critical depletion. Stem elongation was driven by mean air temperature and was not significantly ($p \leq 0.05$) modified by drip irrigation frequency.

Daily irrigation reduced marketable tomato yield by 28.2% in the relatively wet year 2013 in which seasonal rain amounted to 245.2 mm in 20 events, but improved it by 31.7 % in the dry year 2015 where 80.4 mm of rain were received in 8 events. Season 3 on the overall was a typical meteorological dry season of the zone. Lack of significant yield difference between treatments in season 1 points to the irrelevance of full irrigation in seasons where good amount of precipitation is anticipated.

Keywords: drip irrigation; scheduling; tomato yield; Uganda

I. INTRODUCTION

Globally, tomato (*Lycopersicon esculentum*) is the second most important vegetable crop next to potato [8]. By the year 2010, Uganda was the second largest producer of Fresh Fruit and Vegetables in sub-Saharan Africa, after Nigeria, producing about 1.1 million tonnes per year, [6]. Within the Lake Victoria Crescent Agro-Ecological zone of Uganda, tomatoes rank first among vegetables produced for cash [13]. The major challenge for farmers is low prices during glut production of tomatoes following the rainy seasons. Farmers are therefore trying to improve markets of fresh vegetables through off-season production. Constraints associated with dry season production include limited access to the water resource and soil moisture stress, which also limits growth and yield of tomatoes [11]. In this regard, informal small-scale irrigation has been increasing, especially for vegetable and fruit production [8].

Information on farm level irrigation management options in Uganda is still limited. There is need to identify appropriate irrigation regimes for communication to the farmers to avoid losses due to over or under irrigation. Research has demonstrated that poor irrigation management causes significant yield reduction in tomatoes [11]; [16] and that prolonged exposure of crops to water deficits result in yield reduction. Over-irrigation increases production costs and may result in soil nutrient leaching bellow the root zone and wastage of water [11]. Improper scheduling of irrigation results in wastage of water and in decreasing crop growth and yield [12].

Although irrigation schedule based on soil moisture monitoring improves irrigation water use efficiency [12], it requires use of expensive equipment, technical skill and is labour intensive. Most farmers in developing countries cannot afford more water saving irrigation scheduling equipment (moisture sensors) and even for the few who could afford; these tools are not readily available. Simple schedules that are easily adaptable to farmers' conditions would reduce the pressure on water resources while improving yields. It is permissible that interventions to increase water productivity focus more on improving yield than on decreasing water consumption [4]. This study therefore aimed at determining optimal irrigation schedule for yield improvement.

II. MATERIALS AND METHODS

1. SITE LOCATION

The study was carried out at two sites, Mukono Zonal Agricultural Research and Development Institute (MUZARDI) and Kamenyamiggo research (satellite) station using the fixed-time scheduling method. Mukono is located approximately 16 km east of Kampala along Kampala-Jinja- highway at Latitude; 0.37450613 and Longitude; 32.73084372 at 1157 m ASL. Kamenyamiggo research station is located in Lwengo district along Latitude; -0.30413 and Longitude; 31.67015 at 1228 m ASL. Soil samples were picked and analysed for major cations, Organic matter content, pH and soil texture. The soil at the study sites were medium textured and generally indicated acidic reaction at 5.2 at Mukono and 4.5 at Kamenyamiggo. Other major soil chemical properties at the site were described by [7].

2. EXPERIMENTAL DESIGN

Field experiments were carried out for three seasons from September to December 2013, June to September 2014 and June to September 2015. The seasonal adjustment was made following observation that September to December is within the normal rainy season. A Randomized Complete Block Design (RCBD) was used with three irrigation intervals (T1= daily, T2=2 day T3= 5 day) compared against the rain fed crop (T0=control) in three replicates. Twelve fifteen-meter long double row beds were planted with 25-day old seedlings of tomato MT56 at spacing of 0.6x0.6 m and irrigated under surface drip. Season three crop was direct planted using same spacing at 3 seeds per hole which was thinned to one plant per hole one week after germination. The plants were mulched with a layer of 2.5cm (1 Inch) dry grass.

3. FIELD MEASUREMENT OF IRRIGATION WATER

The seedlings were watered daily for 1 week to allow establishment before imposing the treatments. Irrigation was stopped on rainy days of one mm and above and resumed on average two days after the event. A water tank (1000 ltrs) was elevated at 1 m above the highest point on a 0.25 acre field, giving an operating pressure of 100cm. The supply lines were half open and the water emitted into 25ml plastic measuring cylinders previously installed bellow the emitters was recorded. A stop watch was used to time the flow. Other details on this method can be retrieved from [3]. Readings were taken from the uppermost bed and the lowest bed and an average reading was derived. The upper beds gave an average emission of 8.3ml/minute/emitter and the lowest bed tapes were emitting 9.76 ml/minute/emitter. An overall application rate, Q, of 540ml/hour/plant was adopted for the calculation of water used at average irrigation time of 45 minutes per day. The number of irrigation applications per treatment for the growing season were also noted and used in calculating the seasonal water requirement. The irrigator's equation $Q \times t = d \times A$ (1), where t is irrigation application time, d is irrigation depth and A is irrigated area (bed area), was used for calculation of irrigation depth determined as 30mm. The plants were generally irrigated for 30 minutes during the vegetative stage and for 1hr during flowering and fruiting.

4.DATA COLLECTION

For data collection, 5 plants per replicate were randomly selected and labeled. Plant height of 15 plants per treatment was recorded daily at Mukono station, and weekly at Kamenyamiggo until no further change in height was observed. These same plants were used in determining marketable yield at harvest. Damaged fruits (blossom end rots, radial and concentric cracks), were considered culls. Growth rate was calculated as the difference in main stem height recorded on two consecutive days. The important dates of field activities and observations are summarized in (Table 1). The weather data at Mukono site was recorded on daily basis using an automatic weather station located about 100M from the research plot. At Kamenyamiggo site, only rainfall data was recorded and other weather data was retrieved from www.accuweather.com and climate-data.org for use in modeling. Irrigation Water Use Efficiency (IWUE) was calculated as the ratio of observed yield to applied irrigation water which also equates water productivity.

Table 1 summary of field activities and observations

Activity/ observation	Date 2013 (season 1)	Date 2015 (Season 3)
Transplanting	25th Sept	25th June Direct seed planting
Flowering	10th Oct.	2nd Aug.
Pruning and weeding	18th Oct.	19th July
Fruiting	2nd Nov.	1st Sept
Fertilizer application	4th Nov. (NPK)	7th Sept. (MoP)
Spraying with fungicide	25th Oct. 1st , 8th , 11th Nov	15th ,22nd ,30th July and 17th Sept
1st Harvest	7th Dec.	29th Sept
2nd Harvest	11th Dec.	8th October
3rd Harvest	17th Dec.	15th October

5.DATA ANALYSIS

ANOVA were performed for evaluation of difference in yield and correlation between growths (stem elongation), irrigation frequency, and mean air temperature, and between yield and irrigation frequency using spss 10 and Microsoft excel 2007.

III. RESULTS AND DISCUSSION

6.SEASON AND SITE CHARACTERIZATION

During season 1, 20 events amounting to 245.2 mm of rain was received compared with 8 events amounting to 80.4 mm of rain in the third season. The longest period of consecutive dry days for season 1 was 13 days from 13th to 26th October equivalent to 19-32 DAT, which also coincided with the rapid growth period (Fig.1). Season two data is not included in this article due to damage resulting from field operations. The third season experienced 6 short droughts of average 11.3 days (SD=4.033) evenly distributed across the growth stages.

Mean daily air temperature in season one (Mukono) was 23^0C (SD=0.892) with seasonal evapotranspiration of 428.7mm and relative humidity value of 82 % (SD=5.9) while season three (Kamenyamiggo) had mean daily air temperature of 20.2^0C (SD=0.299) with seasonal evapotranspiration of 575.4 mm and relative humidity averaging 62 %. Season three on the overall was a typical meteorological dry season of the zone.

7.SEASONAL WATER REQUIREMENT

The two day irrigation interval resulted in 540 mm and 720 mm of irrigation water for season one and three, respectively. The respective simulated irrigation water requirement for the two seasons was 438 mm and 601 mm. The two scheduling methods compared, irrigating every after two days corresponded with a timing of about 80% of critical, readily available moisture (RAM), depletion using the model. The simulated irrigation schedule for 100% moisture depletion, refilling to field capacity at each application, for season 1 and 3 is presented in Fig.1and 2. Using the model would result in saving approximately 19% irrigation water indicating fair estimation of irrigation water using fixed depth and frequency. While significant linear relationship,
$Y = 0.0043x + 27.97; (R^2 = 0.53)$ (2) between applied water and yield existed as also observed by [9] polynomial relation gave better fit to the data.

The irrigation water use efficiency (IWUE) (Table 2) improved as the irrigation interval increased up to the five-day interval studied. The five day irrigation interval had the highest water use efficiency in both seasons. The improvement was solely as a result of reduced amount of water applied. This strategy does not appear very helpful in determining the optimal amount of irrigation water, as the calculated values linearly increase with reduced levels of applied water; this confirms similar findings by [5]. He observed that farmers wishing to maximize net revenue or the amount of output they generate for household consumption would not choose the irrigation depths that maximize water productivity.

By increasing yield from 18.79t/ha to 33.3t/ha with 540mm of irrigation water, productivity would improve by 44.9%. While reducing irrigation water from 540 to 270mm in season 1 improved productivity by 20.7% with 36.9 % reduction in yield. This implies that tomato water productivity strategies can be focused more on yield improvement than minimizing water application. The major concern should however be at what cost is that improvement attained.

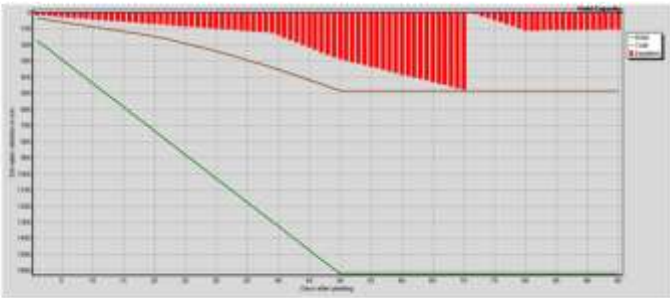

Figure 1. Season one irrigation water requirement as simulated using Cropwat model.

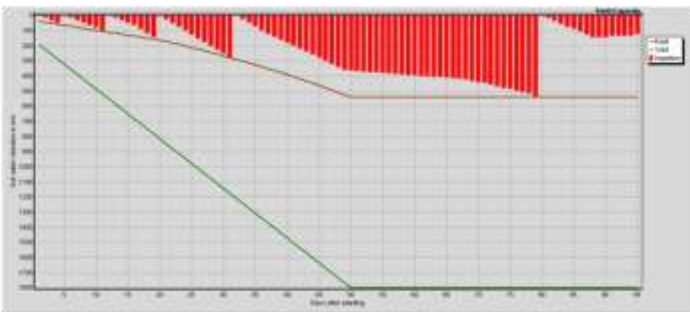

Figure 2. Season three irrigation water requirement as simulated using Cropwat model.

There is need for regulation of the flow of water, opening the lines fully would drain the 1000 liter tank in just a few minutes with high emitter pressure which might cause infiltration problems in soils with high porosity.

8.EFFECT OF IRRIGATION FREQUENCY ON STEM ELONGATION (GROWTH)

There was no significant effect of irrigation frequency on daily stem elongation. The plants showed similar growth rate patterns (Fig.3) with lows and highs occurring at the same time along the growth curve and exhibited determinate characteristics. The daily stem elongation was driven by mean air temperature (R^2=0.82) and was not significantly ($p \leq 0.01$) modified by drip irrigation frequency. This could stem from the fact that soil temperature is affected by irrigation timing and not irrigation frequency [13] and that temperature in the surface soil responds to changes in air temperature [15].Cooling of roots if attained inhibits shoot and leaf elongation rates [15]. This information could be useful in developing a strategy where cooling of plants is required. Tomato growth exhibited a linear function as daily mean air temperature across treatments for all seasons. The plants with more frequent irrigation; daily and two day interval however reached maximum average height of 53cm (7.76) and those on once in 5 days and non-irrigated reached 57cm (11.78). This observation collaborated [10] findings. They observed increasing shoot length with increased water stress in some tomato cultivars.

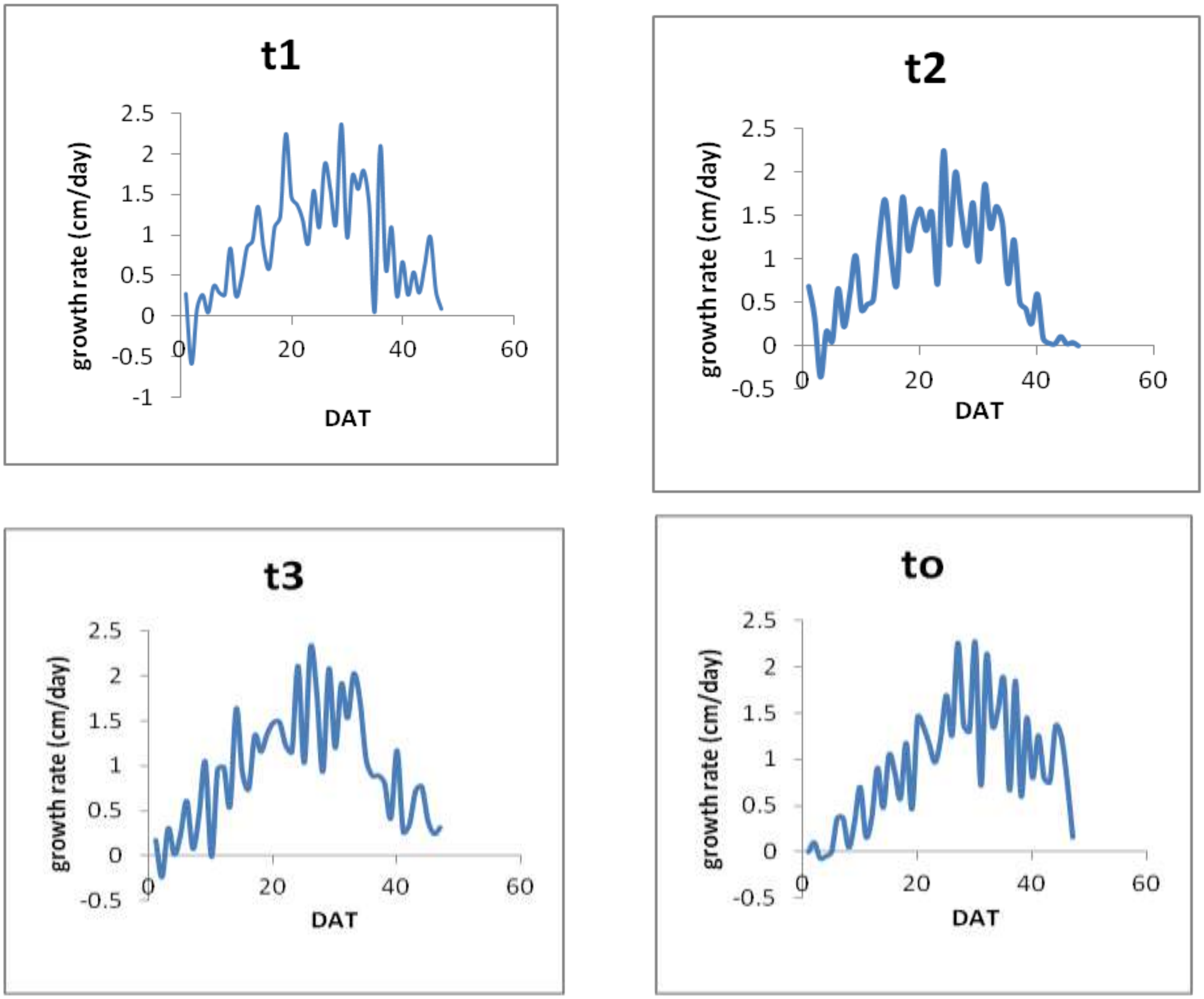

Figure 3. Growth rate of tomatoes for T1: Daily irrigation; T2: Two-day irrigation interval; T3: Five-day interval and T0: Rain fed crop up to 47 Days after Transplanting (DAT).

9.TOMATO YIELD AT HARVEST

The yield obtained from the different treatments during the first and third season is presented in Table 3. The treatment which received daily irrigation had the least yield in the first season. This was partly due to blossom/bloom drop. A number of flowers fell off before fruiting in plants where the field was irrigated daily. The fruits also had a lot of blossom end rot compared to those in other treatments causing a marketable yield reduction of 28.2% compared with the control. Some research has evidenced that wet soil conditions reduce oxygen concentration which causes stomata closure [16]. This reduces transpiration and yield ultimately. [8] Associated flower drop with water deficit during the flowering stage but from our observation, the flower drop could be due to over watering, indicating yield loss from poor irrigation management.

The best yield was observed in the two_ day interval treatment for all the seasons. First season yield was 39.6% higher than the control while the third season two_ day interval yield was 32.8% higher than the control. [14] Observed the highest tomato yield in 3_ day irrigation interval 10% higher than 1 day interval after a study of one_day, three_ day and five_ day irrigation frequencies. This confirms the recommendation that soil should somewhat dry out between watering of tomatoes for maximum yields [18] and indicates that tomato variety MT56 could be sensitive to poor soil aeration.

There was however no significant difference between yields obtained across irrigation treatments in season 1 (Table. 4). Lack of significant yield difference between treatments in season 1 shows the irrelevance of full irrigation in seasons where good amount of precipitation is anticipated.

Kamenyamiggo site had 32% higher water productivity than Mukono site due to the higher yield observed in the former site. This conforms to the observation that in many cases low water productivity is associated with low yield [4].

Table 2 Irrigation water, yield and Irrigation water use efficiency for season 1 and 3 across treatments

Treatment						
	2013			2015		
	Ir(mm)	Yield (t/ha)	IWUE (t/mm)	Ir (mm)	Yield (t/ha)	IWUE (t/mm)
T1	2100	8.52	0.00406	2370	36.31	0.01532
T2	540	18.79	0.03480	720	36.9	0.05125
T3	270	11.85	0.043889	300	28.5	0.09500
T0	245.2	11.34	0.046248	80.4	24.8	0.308458

Table 3. ANOVA for Season 3 observed yield data between treatments

ANOVA						
Source of Variation	***SS***	***Df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	53.060	3	17.687	11.389	0.02	6.591
Within Groups	6.212	4	1.553			
Total	59.273	7				

Table 44. ANOVA for season 1 observed yield data across treatments

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	28.6	3	9.5	0.606	0.645	6.591
Within Groups	62.8	4	15.7			
Total	91.4	7				

There was a marginal yield advantage of 4.5% between the 5day treatment and the control in the first season which improved to 13% in the third season. This could have resulted from the rains which were received almost once every week during evaluation season 1 but a relatively dry season 3 as earlier discussed. The five day irrigation interval would offer no much benefit than not irrigating at all.

Table 5 ANOVA of Seasonal yield data comparison

ANOVA						
Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	722	1	722	26	0.002	5.9
Within Groups	163	6	27			
Total	885	7				

Nonetheless, the growth period from seed to first harvest in both seasons was 96 days. The higher yield recorded in season three led to higher crop water productivity at Kamenyamiggo compared to the crop grown at MuZARDI. One of the reasons could be because the soils at Kamenyamiggo were generally more fertile.

10. CONCLUSIONS

The results suggest that daily irrigation of tomatoes is not necessary. The findings from the study indicated that where special irrigation scheduling tools are lacking, watering at 2 day interval for 1 hour can achieve irrigation water requirements for tomato growing in central Uganda.

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