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Effects of Deficit Irrigation on Yield and Quality of Onion Crop

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Abstract

The broad objective of this study was to test Deficit Irrigation (DI) as an appropriate irrigation management strategy to improve crop water productivity and give optimum onion crop yield. A field trial was conducted with drip irrigation system of six irrigation treatments replicated three times in a randomized complete block design. The crop was subjected to six water stress levels 100% ETc (T100), 90% ETc (T90), 80% ETc (T80), 70% ETc (T70), 60% ETc (T60) and 50% ETc (T50) at vegetative and late season growth stages. The onion yield and quality based on physical characteristics and irrigation water use efficiency were determined. The results indicated that the variation in yield ranged from 34.4 ton/ha to 18.9 ton/ha and the bulb size ranged from 64 mm to 35 mm in diameter for T100 and T50 respectively. Irrigation water use efficiency values decreased with increasing water application level with the highest of 16.2 kg/ha/mm at T50, and the lowest being13.1 kg/ha/mm at T100. It was concluded that DI at vegetative and late growth stages influence yields in a positive linear trend with increasing quantity of irrigation water and decreasing water stress reaching optimum yield of 32.0 ton/ha at 20% water stress (T80) thereby saving 10.7% irrigation water. Onion bulb production at this level optimizes water productivity without significantly affecting yields. DI influenced the size and size distribution of fresh onion bulbs, with low size variation of the fresh bulbs at T80.

Keywords: deficit irrigation, bulb size, colour, shape, water requirement

1. Introduction

The ever increasing world population and the demand for additional water supply by industrial, municipal, and agricultural sectors exert a lot of pressure on renewable water resources forcing the agricultural sector to use the available irrigation water efficiently to produce more food to meet the increasing demand (Andarzian et al., 2011; Valipour, 2014a). To achieve sustainable use of limited water resources available for agriculture, it is necessary to develop guidelines for irrigation applications to be used by extension service providers and farmers (Geerts, Raes, & Garcia, 2010).

This study was conducted in Nandi County, in the western part of Kenya which experiences water scarcity during the dry season from October to March, often resulting in conflicts. During this season vegetable supply is low while its demand is high. Therefore it is desirable to utilize the scarce water resource during this period to produce vegetables under irrigation for the ready market using an appropriate water saving technology. Deficit irrigation (DI) strategy was chosen for use in the study as it maximizes irrigation water productivity and optimizes crop yields (English & Nakamura, 1989; Zhang & Oweis, 1999; Fereres & Soriano, 2007; Geerts & Raes, 2009).

A certain level of water stress is applied to the crops in DI strategy either during specific growth stages or throughout the growing season, without necessarily causing significant yield reduction compared with the benefits achieved by diverting saved water to irrigate other crops (Kipkorir, Raes, & Labadie, 2001; Leskovar, 2010). Olalla, Padilla, and Lopez (2004) reported that the sizes of onion bulbs under DI were in direct relationship to quantity of water applied. Geerts and Raes (2009) reported that DI could be used to raise the crop yield to crop water consumption ratio where crops have growth stages in their development where they are tolerant to water stress. This takes place through either suppressing the water loss caused by unproductive evaporation, or by increasing the proportion of marketable yield to the overall produced biomass, or by increasing the ratio of total biomass production to transpiration due to hardening of the crop but due to the conservative relation between biomass production and crop transpiration whose effect is considered to be limited

(Steduto, Hsiao, & Fereres, 2007). In addition, crop yield could be improved through application of sufficient fertilizer (Steduto & Albrizio, 2005) or by avoiding bad agronomic practices during crop development (Pereira, Oweis, & Zairi, 2002).

Leskovar (2010) reported that results of onion trials indicated that DI at the 50% ETc had a significant effect on yield, while the yield from DI at 75% was not much different from 100% ETc and produced a similar bulb size. It was further concluded from the study that it would be possible to produce onion by water-conservation practices to a 75% ETc rate, as a means to target high-price bulb sizes without reducing quality. However, he advised that DI should be avoided during the yield formation stage for high yield to be achieved.

By practicing DI during vegetative development and late season stages, which are considered to be water stress tolerant stages of onion, some water would be saved (Kipkorir, Raes, & Massawe, 2002; Tesfaye, 1997). The specific objectives of this study were: (i) to determine onion yield in response to various water deficit application levels, during stress tolerant stages, (ii) to determine the effect of deficit irrigation on the quality of onion crop produced based on colour, shape and bulb size and (iii) to determine irrigation water use efficiency of the onion; by setting up on-farm field trials.

2. Method

2.1 Study Area Characteristics

2.1.1 Location

The study was conducted at Mosoriot Teachers College farm in Nandi County which is located in the western part of Kenya at 35°10′E longitude, 0°19′N latitude and an altitude of 2117 m above sea level. The soil texture at the site is sandy loam, deep red, well drained with good fertility.

2.1.2 Climate

The area experiences a bimodal type of rainfall with mean annual rainfall of 1365 mm. The mean annual minimum and maximum temperatures are 10 °C and 24 °C, respectively (Ralph & Helmut, 1983).Climatic data observed during the season were acquired from the nearby Eldoret International Airport (EIA) meteorological station. The station is approximately 5 km north of the field trial site. Rainfall received at the nearby EIA metrological station during the main growing season (March, 2013 to July, 2013) was 939 mm, and 365mm during the dry season from October, 2013 to March, 2014.

2.1.3 Soil

Soil physical properties were determined according to Lambe (1951) and Valipour (2014d). Soil moisture content at field capacity (θ_{FC}) and permanent wilting point (θ_{WP}) were determined in the laboratory before the start of the trial based on texture analysis and pedo-transfer function (Saxton, 2003; Saxton, Rawls, Romberger, & Papendick, 1986). Soil moisture content was determined every 10 days during the field trial period by volumetric method. The soil chemical properties obtained from laboratory tests determined the type and quantity of fertilizer and soil amendments applied. The bulk density was also determined using the procedures outlined by Okalebo, Gathua, and Woomer (2002).

Table 1. Soil physical properties of the study area

Depth (cm)	Sand (%)	Clay (%)	Loam (%)	Textural Class (USDA)	FC (vol %)	WP (vol %)	AWC (vol %)
0-15	70.4	5.0	24.6	Sandy Loam	17.0	6.8	10.2
16-30	70.0	6.0	24.0	Sandy Loam	18.5	6.9	11.6
31-60	65.0	10.0	25.0	Sandy Loam	20.0	7.0	13.0
Average	68.5	7.0	24.5		18.5	6.9	11.6

Note. FC = field capacity, WP = wilting point, AWC = available water holding capacity (FC-WP).

Table 2. Soil chemical properties of the study site

Laboratory	Parameter, unit	Symbol	Test results	
			Before correction	After correction
Crop Nutrition	pH	pH	4.63	5.10
	Phosphorus, ppm	P	5.16	9.14
	Potassium, ppm	K	318	401
	Calcium, ppm	Ca	540	1050
	Magnesium, ppm	Mg	140	217
	Nitrogen,%	N	0.25	-
	Sodium, ppm	Na	62.7	53.2
	C.E.C., meq/100g	C.E.C	12.5	-
	E.C.(salts),uS/cm	EC(S)	77.0	-
	ECw (dS/m)	ECw	0.4	
University of Eldoret	pH	pH	4.94	-
	Carbon,%	C	4.55	-
	Phosphorus, Mg/kg	P	4.19	-
	Nitrogen, %	N	0.54	-

Soil samples collected from the study site were analyzed to determine physical and chemical properties and gave the results in Table 1 and Table 2 respectively. The chemical properties of the soil in Table 2 determined the type and quantity of fertilizer and amendments applied during the study to meet crop nutrient requirement and create suitable environment for crop development.

2.2 Experimental Details

2.2.1 Field Trial Design

The field trials were carried out during the 2013 growing season in six plots replicated three times to give rise to 18 plots and six different treatments (Figure 1). The source of water for the experiment was a borehole near the site.

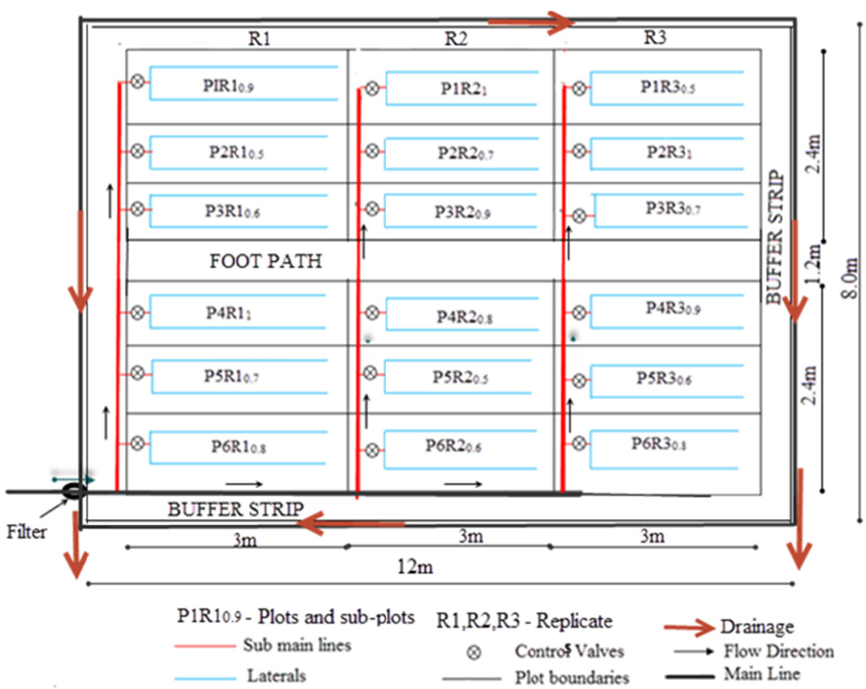

Figure 1. Design of trial plots showing irrigated plots and drip pipes

The field trial was laid out in a Randomized Complete Block Design (RCBD) with three replications under each treatment. There were six treatments in each block of varying water application levels consisting of T50 (50% ETc), T60 (60% ETc), T70 (70% ETc), T80 (80% ETc), T90 (90% ETc) and T100 (100% ETc) and applied at specific growth stages. The treatments consisted of full irrigation throughout the growing season, five treatments with 10%, 20%, 30%, 40% and 50% water deficit application at two different crop growth stages (development and late season) considered to be drought tolerant (Doorenbos & Kassam, 1979).

The blocks were named after the three replications designated as R1, R2, and R3 and plots in each replication as P1, P2, P3, P4, P5, and P6 giving rise to 18 (3 × 6 = 18) plots. DI levels were named according to a combination of the replicate position (R1, R2, R3) and plot number (P1, P2, P3, P4, and P5) together with a subscript denoting the quantity of water applied as a percentage of ETc. The six levels of application within block R1 appeared as: $R1P1_{0.9}$, $R1P2_{0.5}$, $R1P3_{0.6}$, $R1P4_{1.0}$, $R1P5_{0.7}$, and $R1P6_{0.8}$. The same applied to the second and third blocks of replications which were also named as: $R2P1_{1.0}$, $R2P2_{0.7}$, $R2P3_{0.9}$, $R2P4_{0.8}$, $R2P5_{0.5}$, $R2P6_{0.6}$; and $R3P1_{0.5}$, $R3P2_{1.0}$, $R3P3_{0.7}$, $R3P4_{0.9}$, $R3P5_{0.6}$, $R3P6_{0.8}$ respectively. The six levels of water application were randomly assigned to the plots in each block of replicates (Figure 1).

2.2.2 Rain Shelter

A rain shelter structure was constructed over the plots to prevent the crop from receiving additional water from rainfall (Figure 2). The structure measured 12 m long by 8 m wide with 1m buffer zone between the edge of the shelter and the boundary of the plots, all around the structure. A polythene sheet was used as a cover over the structure to keep off rainfall. The shelter cover was used only during a rain event. Drainage channels were excavated around the site to discharge rainwater away from the site. A polythene sheet was inserted into the soil all-round the trial site to prevent lateral water seepage from the drainage into the plots.

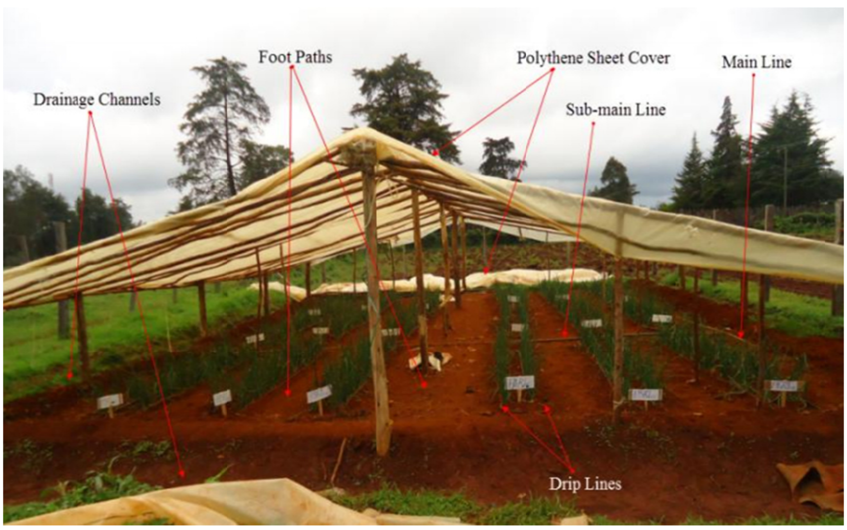

Figure 2. Rain shelter structure used in the field trials

2.2.3 Crop Management

The crop was transplanted one month after applying soil amendments to the soil in the trial plots. The type and rate of application was based on the results of soil analysis (Malakouti, 1999). The amendments and rates of application were Calcitic lime – 3300kg/ha, Dolomitic lime – 2500kg/ha, *Mijingu* rock phosphate – 240kg/ha, Manure/compost – 5000kg/ha, and Magnesium Sulphate – 40kg/ha.

Transplanting of 42 days old onion crop seedlings was done on 1st March, 2013 at a spacing of 10 cm by 30 cm. Before transplanting, water was applied to the plots to raise the soil moisture content to field capacity as the soil was very dry. Di-Ammonium Phosphate (DAP) fertilizer was applied at a rate of 160 kg/ha at transplanting. Crop management after transplanting involved: timely weed control, top dressing, pests and disease control and timely water application according to the irrigation schedule. The most common pests were thrips and onion fly.

Weeds were manually controlled through regular cultivation. Care was taken to avoid root damage which could slow plant growth. Weed control was particularly important during the first two months of growth when plants were growing slowly. Top dressing with Calcium Ammonium Nitrate (CAN) fertilizer at recommended rate was done after three weeks of transplanting (Ministry of Agriculture [MoA], 2012).

The crop was harvested 150 days after transplanting when bulb onions were mature and the leaves had collapsed or bent over and left to dry for 10-12 days. Mature bulb onions were manually uprooted from the soil and cured in the sun for 10-14 days before taking measurements of yield and quality parameters. Dried leaves were cut off at 3.5 cm from the bulb. During harvesting, two bulbs were left out in each row, one at each end. Off-types were removed together with small bulbs resulting from gap-ups. The remaining ranged from 35 to 45 bulbs per plot out of which 30 bulbs were randomly picked for determination of yield and quality.

2.2.4 Irrigation System

Water was pumped from the borehole and stored in a masonry tank situated next to the plots. The quality of water was obtained from the existing records and was found to be suitable for irrigation of onion crop (Ministry of Environment and Natural Resources [MENR], 2012). The water was tapped from the base of the tank and piped to the plots by gravity through a main line of 25 mm diameter. The main supply pipe branched into three sub-mains to supply 18 sets of laterals which separately served each of the 18 plots (Figure 1).

Flow from the sub-mains to the laterals (drip lines) was controlled using in-line control valves which regulated the supply of water to the crops during full and deficit water application to various plots. Drip pipes ran along the rows of onions which were spaced at 30 cm apart by 240 cm long. A filter was installed on the main line just before the sub-mains to guard the emitters against blockage by dirt and soil particles leading to non-uniformity of irrigation water application. Head losses in the pipeline distribution network were determined according to Valipour (2014b, 2014d & 2012). Details of the setup are presented in Figures 1 and 2.

After transplanting on 1st March 2013, specified irrigation schedules per plot were applied to each treatment. Irrigation water discharge from the drip system was regularly measured with transparent graduated cylinders to ascertain the accuracy of the drip system at regular intervals.

2.2.5 Irrigation Scheduling

The crop season length (150 days) of Red Creole onion variety considered in the trial was divided into four growth stages (initial, development, mid-season and late season) each with specific duration in days. Reference evapotranspiration (ETo) was calculated from climatic data from Kapsoya Meteorological Station (located approximately 20 km north of the site) using the FAO Penman Monteith equation (Allen, Pereira, Raes, & Smith, 1998 and Valipour, 2015).

The crop coefficient (Kc) was determined (Allen et al., 1998; Valipour, 2014c) for each of the 10 days during the growing season. The estimation was made from growth stages curve with an assumption that the humidity and wind speed were medium. With reference evapotranspiration (ETo) and crop coefficient known, crop evapotranspiration (ETc) was calculated using the expression

$$ETc = Kc \times ETo \quad (1)$$

The net and gross irrigation depths in mm/day were estimated (Gupta & Larson, 1979) and used to calculate the amount of water applied and application intervals.

The first to be determined was the Total Available Water (TAW), Equation 2.

$$TAW = 10 \times (\theta_{FC} - \theta_{WP}) \quad (2)$$

Where, θ_{FC} is the soil moisture content at field capacity and θ_{WP} is the soil moisture content permanent wilting point.

The equivalent depth of total available water, d, was then computed from the obtained total available water, bulk density, D_b of the soil and the root zone depth, Zr (FAO, 1986)

$$d = TAW \times Db \times Zr \quad (3)$$

Net irrigation application depth (Inet) was considered to be equivalent to readily available water which is the maximum allowable depletion based on the rooting characteristics of the crop and calculated thus.

$$Inet = TAW \times Db \times Zr \times p \quad (4)$$

Where p is allowable moisture depletion (p = 25%), (FAO, 1986).

Gross irrigation depth (Igross) was then computed from the obtained net irrigation and irrigation efficiency (Ea) of the system.

$$Igross = Inet/Ea \quad (5)$$

The application efficiency for drip system range between 70% and 95% (Howell, 2003). For this study, 85% was used. The irrigation interval (i), was also calculated from net irrigation application depth and the crop evapotranspiration (Valipour, 2014c)

$$i = Inet/ETc \tag{6}$$

The volume (V) of water applied to meet the demand of the crop was calculated from the ground wetted area (A) and gross irrigation application, Igross (Valipour, 2012).

$$V = A \times Igross \tag{7}$$

Irrigation time of application (T) was determined from volume (V) of water applied and the drip emitter discharge (Q) in litres per hour:

$$T = V/Q \tag{8}$$

The integrity of drip discharge was regularly checked by recording the time taken for the discharge to fill a vessel of known volume. The calculated irrigation schedule for zero effective rainfall for the field experiment during the entire growing period of the crop is given in Table 3.

Table 3. Irrigation schedule for the entire season

Month	March, 2013			April, 2013			May, 2013			June, 2013			July, 2013		
Decade	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
ETo (mm/day)	5.2	5.3	5.1	5.0	4.9	4.2	3.6	3.8	3.4	3.4	3.5	3.3	2.8	2.7	2.7
Kc	0.5	0.5	0.6	0.7	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9
ETc (mm/day)	2.6	2.7	3.0	3.3	3.8	3.9	3.6	3.8	3.4	3.4	3.5	3.3	3.2	2.5	2.4
Inet (mm)	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
Igross (mm)	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
Irrigation interval, I (days)															
%Etc	Initial (No stress)		Development (Stressed)			Mid-season (No stress)					Late season (Stressed)			Irrigation (Stop)	
100	5	4	4	3	3	3	3	3	3	3	3	4	4		
90	5	4	4	4	3	3	3	3	3	3	4	4	5		
80	5	4	5	4	4	3	3	3	3	3	4	5	6		
70	5	4	6	5	4	3	3	3	3	3	5	5	6		
60	5	4	7	6	5	3	3	3	3	3	6	6	8		
50	5	4	8	8	6	3	3	3	3	3	7	8	9		

Note. A decade is 10 days.

2.3 Onion Yield and Quality Characteristics

Onion bulbs were harvested 150 days after transplanting and cured for 10-14 days before yield and quality characteristics data were collected. This was after the bulbs had attained moisture content for storage.

2.3.1 Yield

Fresh bulb yield was estimated by weighing 30 randomly picked onion bulbs from each treatment harvested and converted to fresh yield in ton/ha.

For dry bulb yield, ten randomly selected bulbs from each treatment were weighed, chopped and dried in an oven at 70^{o} C until a constant weight was achieved and converted to dry yield in ton/ha.

2.3.2 Quality Properties

Thirty onion bulbs were randomly selected from each treatment to determine some quality parameters composed of size represented by the equatorial diameter, colour and texture, moisture content; and shape index. The equatorial diameter (mm) of onion bulbs were measured using a digital vernier caliper. The diameter measured was the maximum width of the onion in a plane perpendicular to the pole. Bulb diameter was determined as one of the parameters of crop quality (Murthy, 2007).

The colour and texture of onion bulbs vary according to varieties which are normally available in three colours namely yellow, red and white. The colour and texture of the skin and inner flesh of harvested onion bulbs were established through CIE colour system (Smith & Guild, 1931). Red Creole onion crop variety was used in the field trial.

Ten randomly selected bulbs at storage moisture content from each treatment were weighed, chopped and dried in an oven at 70 °C until a constant weight was achieved. Moisture content was calculated based on Equation 9.

$$MC(\%) = \frac{W_w - W_d}{W_w} \times 100 \tag{9}$$

Where, MC = moisture content; W_w = wet bulb weight and W_d = dry bulb weight.

The shape index is used to evaluate the shape of onion bulbs and was determined using Equation 10 (AbdAlla, 1993). A shape index greater than 1.5 indicates that the bulbs are oval while index lower than 1.5 means a spherical shape,

$$\text{Shape Index} = \frac{D_e}{\sqrt{D_p \times T}} \tag{10}$$

Where, D_e: Equatorial diameter, D_p: Polar diameter and T – Thickness.

2.4 Irrigation Water Use Efficiency

Irrigation water use efficiency (IWUE) was determined according to Jensen (1983) using Equation 11.

$$IWUE = \frac{DFY(\frac{ton}{ha})}{ETa(mm)} \times 100 \tag{11}$$

Where, DFY: Dry fibre yield, ETa: Actual reference evapotranspiration

Irrigation water use efficiency (kg/ha/mm) values were used to evaluate the effectiveness of the irrigation treatment practices on maximum water utilization by onion crops.

2.5 Data Analysis

Statistical analysis methods were used to analyse the data obtained from the trial for effect of water stress on yield and quality components of onions. Analysis tools used comprised Analysis of Variance (ANOVA) mean and standard deviation computed using Microsoft Excel, 2007. Analysis of variance for the yield and quality components was carried out to determine the significance of the impact of water stress on yields and quality according to the RCBD principle. The probability level for determination of significance was 5%.

3. Results and Discussion

3.1 Yield Response of Onion to Water Stress

The crop in this field trial was subjected to water stress at vegetative and late season stages with six different treatment levels, five of which were water stressed to different degrees (T90, T80, T70, T60, and T50) while one (T100) acted as control and was not stressed as given in Table 4. Water application depth in each irrigation event was 13 mm. Yield per unit area obtained from fresh onion in the experiment was found to increase with increasing irrigation water levels across the various treatments (Figure 3).

Yield from non-stressed treatments (T100) which acted as control was highest at 34.4 ton/ha while the most stressed treatment (T50) had the lowest yield of 18.9 ton/ha. The intermediate treatments T90, T80, T70 and T60 gave yields of 32.6, 31.9, 25.2, and 22.6 ton/ha respectively. The standard deviation varied between 0.6 and 1.7 ton/ha while the coefficient of variance ranged from 2% to 7.5% within the replications. The standard deviation within the treatments was low suggesting that yield was more clustered around the mean.

Analysis of variance across the treatments (at 5% probability) indicated that DI significantly affects yield, Table 4.

Table 4. Yield response (in ton/ha) of onion to different applied irrigation water stress levels

	Replicates	Treatments					
		T100	T90	T80	T70	T60	T50
	R1	34	32	32	26	24	20
	R2	36	33	31	27	22	19
	R3	33	32	32	23	21	18
Mean		34.4	32.6	31.9	25.2	22.6	18.9
SD		1.11	0.64	0.64	1.70	1.70	1.11
CV (%)		3.2	2.0	2.0	6.7	7.5	5.9
ANOVA for yield							
Fcalculated			6.25	12.25	62.5	102.4	294
Ftable			7.709	7.709	7.709	7.709	7.709
Comment			Insignificant	Significant	Significant	Significant	Significant

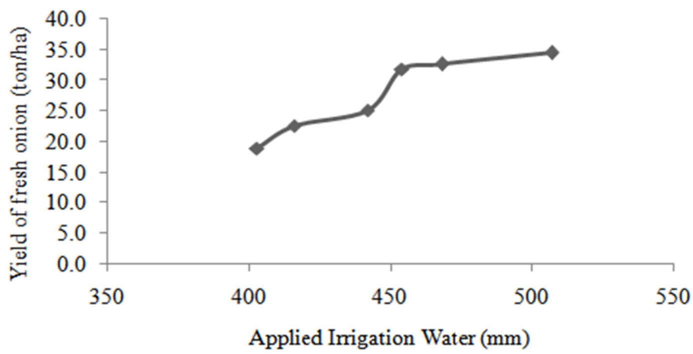

Figure 3. Yield of fresh onion for various applied irrigation water levels

From above yield reduction occurred significantly among the treatments which received minimum amounts of water (T80, T70, T60 and T50) as opposed to those which received higher quantities (T100 and T90). The effect of various treatments, influenced yields to different levels and the degree of recovery also varied according to the intensity of water stress applied. Yield decreased with increasing water stress signifying that the more stress the crop is subjected to, the slower it is for it to recover leading to progressively lower yields.

When a crop is subjected to water stress at the development and late growth stages at varying levels, soil moisture is depleted through absorption by the roots leading to reduced physiological activities which in turn affect root development. If timely replenishment is not provided, the crop wilts and may recover partially, resulting in reduced yield and its components (Kirda & Kanber, 1999). Results of trials conducted on vegetables and cereals showed that the lowest yield was obtained from the full stress treatment applied throughout the growing season (75% deficit). However, stressing the crops during the vegetative and late season stage of the growing season does not affect the crop yield significantly (Bazza & Tayaa, 1999; Leskovar, 2010).

This is because these growth stages are stress tolerant as opposed to initial and development stages which could result in significant drop in yield.

3.2 Quality Response of Onion to Water Stress

3.2.1 Onion Bulb Diameter

Onion bulb diameter was determined as an indicator of size and it was found to be significantly influenced by applied irrigation water stress levels at 5% probability (Tables 5 and 6). The largest mean diameter (64 mm) was from T100 which received maximum amount of water (494 mm) while treatment T50 gave the smallest diameter (35 mm) having received the least amount of water at 364 mm. Results indicated that bulb diameter varied proportionally with the quantity of irrigation water applied. There is therefore a linear relationship between bulb size and quantity of irrigation water applied. The coefficient of determination analysis between diameter and irrigation water applied was (R^2 = 0.927), indicating that the increase in bulb diameter in different treatments was attributed to increase in the quantity of water hence quantity of water applied influences onion size.

The distribution of bulb sizes showed that large (> 60 mm) formed 27 % of the total production, medium (45-60 mm) made 40% and the remaining 33% were small (< 45 mm) as shown in Table 6. Large size was largely produced under treatments T100, T90, and T80 which received water amounts of 494 mm, 468 mm and 441 mm respectively. On the other hand standard deviation for the treatments varied with the highest being from T50 and the lowest T80. The low size variation of the bulbs as indicated by low standard deviation under T80 was an indication that the onion bulb diameters were more clustered closely around the mean under T80 than in other treatments.

Table 5. Onion bulb size (in mm) as influenced by applied irrigation water stress levels

	Replicates	Treatments					
		T100	T90	T80	T70	T60	T50
	R1	64.5	63.8	60.4	56.6	52.4	44.3
	R2	65.4	66.1	59.3	53.2	47.5	40.0
	R3	67.7	64.6	62.6	55.4	49.7	43.0
Mean (mm)		64.0	60.0	58.0	53.0	40.0	35.0
SD		1.6	1.2	1.7	1.7	2.4	2.2
CV		2.56	1.95	2.90	3.24	6.09	6.30
ANOVA for bulb size							
Fcalculated			0.81	14.12	62.14	89.37	217.98
Ftable			7.709	7.709	7.709	7.709	7.709
Comment			Insignificant	Significant	Significant	Significant	Significant

Table 6. Onion bulb size frequency distribution in response to applied irrigation water stress levels

Onion diameter distribution	Treatments						Proportion of Total (%)
	T100	T90	T80	T70	T60	T50	
>60 mm (%)	80	57	27	0	0	0	27
45-60 mm (%)	20	43	73	100	3	0	40
<45 mm (%)	0	0	0	0	97	100	33

A similar effect of various irrigation water levels on size of onion bulb was observed by Olalla et al., (2004) under drip irrigation. Leskovar (2010) reported that it would be possible to adjust water conservation practices to a 75 percent ETc rate, as a means to targeting high-price bulb sizes without reducing quality. These results emphasize that adequate soil moisture content along the growing period encouraged the vegetative growth of the plant and enhanced the development of large and medium bulb size which is considered to be marketable.

3.2.2 Mass of Onion Bulbs

Fresh onion bulb mass across treatments was influenced significantly (at 5% probability) by DI (Table 7) with a coefficient of determination of 0.943 which suggests a direct relationship between DI and mass. The highest mean weight of bulbs (103 g) was obtained from treatment with the highest supply of water while the treatment with the lowest quantity produced the least mean bulb weight (57 g). There is a positive linear relationship between water stress and bulb mass. This means that water stress affects negatively the weight of individual bulbs.

Table 7. Mean mass (in g) of single fresh Onion bulbs

	Replicates	Treatments					
		T100	T90	T80	T70	T60	T50
	R1	103	97	97	77	73	60
	R2	107	100	93	80	67	57
	R3	100	97	97	70	63	53
Mean		103	98	96	76	68	57
SD		4	2	2	5	5	3
CV		3.4	2.0	2.1	6.7	7.6	5.9
ANOVA Analysis							
Fcalculated			5.76	11.02	60.72	98.52	277.04
Ftable			7.71	7.71	7.71	7.71	7.71
Comment			Insign	Significant	Significant	Significant	Significant

3.2.3 Moisture Content

The moisture content of onion bulbs as depicted in Table 8, do not vary with treatments and range from 84% to 89%. This means that the influence of water stress on onion moisture content was not significant.

Table 8. Moisture content (in %) of fresh onion bulbs under different treatments

	Replicates	Treatments					
		T100	T90	T80	T70	T60	T50
	R1	89	88	88	85	86	85
	R2	86	89	85	86	84	82
	R2	91	86	87	87	83	84
Mean		89	88	87	86	84	84
SD		2.0	1.0	1.5	1.5	1.0	0.6
CV		2.26	1.14	1.73	1.74	1.19	0.72
ANOVA Analysis							
Fcalculated			0.35	1.38	2.91	6.5	8.65
Ftable			7.71	7.71	7.71	7.71	7.71
Comment			Insignificant	Insignificant	Insignificant	Insignificant	Significant

3.2.4 Shape Index

The shape index data is presented in Table 9. The results indicate that water stress at vegetative and late stages of growth of onion do not significantly affect the shape of onion bulbs. All bulbs were oval as shape index is greater than 1.5 (Figure 4).

Table 9. Shape index of onion from the research trial

Treatment	D_e	D_p	T	SI
T100	63.69	42.02	21.63	2.11
T90	60.20	38.04	18.03	2.30
T80	57.79	36.46	15.31	2.45
T70	52.75	34.37	12.81	2.51
T60	39.52	33.81	9.81	2.17
T50	34.90	36.02	7.87	2.07

Note. D_e= equatorial diameter, D_p = Polar diameter, T = Thickness and SI = Shape Index.

Figure 4. Shape and colour of onion bulbs under different treatments

3.2.5 Colour and Texture

The colour and texture of the harvested crop of onion was red on the outer skin, purple white flesh and red inner scales (Figure 5). This description was determined using CIE colour system (Sahin & Sumnu, 2006) which indicated that the skin colour of the produced onion bulbs matched the description of red creole onion by the supplier. It was therefore apparent that water stress treatment on onion did not affect colour and texture of onion skin and flesh. The colour and texture remains attractive to the eye and is appealing to the consumer.

Figure 5. Colour and texture of onion bulbs as influenced by treatments

3.3 Irrigation Water Use Efficiency

Irrigation water use efficiency (IWUE) refers to the relationship between units of dry yield produced by a crop and the quantity of irrigation water applied (Steduto, 1996). Data on the amounts of applied irrigation water under different irrigation treatments are presented in Table 9. Full irrigation treatment (T100), was used as the reference point for comparison of irrigation treatments in saving water.

Table 9. Irrigation water use efficiency

Treatment	T100	T90	T80	T70	T60	T50
ETa (mm)	494	456	399	366	347	328
Total DFY (ton/ha)	7.2	6.5	6.3	5.6	5.1	4.3
IWUE (Kg/ha/mm)	14.6	14.7	15.8	16.1	15.9	16.2

The net saving of irrigation water from T90, T80, T70 T60, and T50 were 5.3%, 10.7%, 15.8%, 21.1% and 26.3% respectively. IWUE values decreased with increasing water application level. The highest IWUE was obtained from treatment T50, 16.2 kg/ha/mm while the lowest was T100, with 14.6 kg/ha/mm. The relative decrease in IWUE was initially low up to T70 and then it increased with increasing irrigation water application. Table 9 shows the IWUE values from the field trial expressed in kilograms of total dry bulb yield produced per mm of actual evapotranspiration from planting to harvesting.

IWUE for T80 and T70 were almost the same at 15.8 and 16.1 kg/ha/mm while the difference in dry bulb yield was 0.7 ton/ha .Water saving for these two treatments (T80 and T70) was 10.7% and 15.8 % respectively. Optimum yield is achieved by balancing between IWUE, yield reduction and water saving. These findings indicate that T80 results in 10.7% water saving without substantial negative effect on irrigation water use efficiency of the crop (Figure 6).

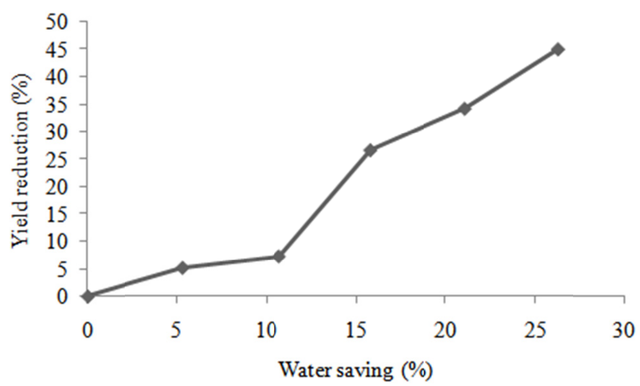

Figure 6. Optimum production based on water saving and yield reduction

From the results the water stress applied to onion crop through deficit irrigation at vegetative and late growth stages had an overall significant effect on both fresh and dry biomass yields. Onion bulb diameter was equally significantly affected by water stress giving rise to various respective bulb sizes. It is possible to predetermine the grades to produce for different market segments, by selecting appropriate water stress level to apply that does not compromise the yield per unit area.

Irrigation water use efficiency decreased with increasing water stress upto optimum point at T80 where a balance exists between water saving and yield reduction without substantial decline in water use efficiency. There is also low size variation of the bulbs at this point. Optimum production based on water saving and yield reduction indicated that producing at T80 saves 10.7% irrigation water but results in fresh bulb yield reduction of 2.5 ton/ha. The water saved is adequate to expand 0.12 ha of land and produce additional 3.8 tons of onions giving a total of 35.7 tons with the same quantity of water which could have yielded 34.4 tons/ha at full irrigation treatment. All the other treatments except T100 which acted as control gave rise to lower overall optimum yield even after utilising the saved water to produce more crop. Water stress affects yields negatively without substantially reducing yields at water stress level T80. Yield reduction resulting from DI was compensated for by utilizing saved water to produce more crops either by the same farmer or by other farmers relying on the same water resource (Table 10).

Table 10. Optimum production based on water saving and yield reduction

Treatment	T100	T90	T80	T70	T60	T50
Optimum yield, ton/ha	34.4	33	31.9	25.2	22.6	18.9
Water saving %	0.0	5.3	10.7	15.8	21.1	26.3
Yield reduction, %	0.0	5.2	7.3	26.7	34.3	45.1
Additional yield from water saving, ton	0.0	1.9	3.8	5.7	7.6	9.2
Total yield, ton	34.4	35	35.7	30.9	30.2	28.1

4. Conclusions

From the findings of the study it is concluded that deficit irrigation at vegetative and late growth stages of onions influence yields in a positive linear trend with increasing quantity of irrigation water and decreasing water stress reaching optimum crop yield of 32.0 ton/ha at 20% water stress thereby saving 10.7% irrigation water. It was further concluded that production at this level optimizes water productivity without significantly affecting crop yields.

Further, it was established that deficit irrigation influenced the size and size distribution of fresh onion bulbs, with low size variation of the fresh bulbs at 20% water stress (T80) as attested by low standard deviation of 1.0 as compared to other treatments. DI therefore can be used in deciding onion sizes to produce for a particular prevailing market. Deficit irrigation does not affect the shape of onion bulbs as depicted by the shape index of more than 1.5. The colour of bulbs was also not affected by DI thereby maintaining attractiveness of the product to the users.

The irrigation water use efficiency for onion yield was affected significantly by DI treatments with the highest values obtained under the most stressed (T50) treatment while the lowest values were obtained under full water supply (T100) treatment. However, highest yields and quality were recorded for lowest efficiencies and vice versa. It is concluded that optimum production occurred at optimum water use efficiency (T80).

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References

Abdalla, H. S. (1993). Effect of coating process on seeds viability and some physio-mechanical properties of Egyptian cotton. *J. Agric Sci. Mansoura Univ., 18*(8), 2384-2396.

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. *Irrigation and Drainage Paper no. 56* (p. 300). FAO, Rome, Italy.

Andarzian, B., Bannayan, M., Steduto, P., Mazraeh, H., Barati, M. E., Barati, M. A., & Rahnama, A. (2011). Validation and testing of the AquaCrop model under full and deficit irrigated wheat production in Iran. *Agricultural Water Management, 100*, 1-8. http://dx.doi.org/10.1016/j.agwat.2011.08.023

Bazza, M., & Tayaa, M. (1999). Contribution to improve sugar beet deficit-irrigation. In C. Kirda, P. Moutonnet, C. Hera, & D. R. Nielsen (Eds.), *Crop yield response to deficit irrigation*. Dordrecht, The Netherlands: Kluwer Academic Publishers. http://dx.doi.org/10.1007/978-94-011-4752-1_12

Doorenbos, J., & Kassam, A. H. (1979). Yield Response to Water. *Irrigation and Drainage Paper No. 33*. FAO, Rome, Italy.

English, M., & Nakamura, B. (1989). Effects of deficit irrigation and irrigation frequency on wheat yields. *Journal of Irrigation and Drainage Engineering, 115*(2), 172-884. http://dx.doi.org/10.1061/(ASCE)0733-9437(1989)115:2(172)

Fereres, E., & Soriano, M. A. (2007). Deficit irrigation for reducing agricultural water use. *J. Exp. Bot., 58*, 147-159. http://dx.doi.org/10.1093/jxb/erl165

Geerts, S., & Raes, D. (2009). Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. *Agric. Water Management, 96*, 1275-1284. http://dx.doi.org/10.1016/j.agwat.2009.04.009

Geerts, S., Raes, D., & Garcia, M. (2010). Using AquaCrop to derive deficit irrigation schedules. *Agricl. Water Management, 98*, 213-216. http://dx.doi.org/10.1016/j.agwat.2010.07.003

Gupta, S. C., & Larson, W. E. (1979). Estimating soil water retention characteristics from particle size distribution, organic matter content and bulk density. *Water Resource, 5*, 1633-1635. http://dx.doi.org/10.1029/WR015i006p01633

Howell, T. A. (2003). *Irrigation Efficiency. In Encyclopedia of Water Science* (p. 1076). Marcel Dekker, Inc. New York, New York.

Jensen, M. E. (1983). *Design and operation of farm irrigation systems*. ASAE. Michigan. USA.

Kipkorir, E. C., Raes, D., & Labadie, J. (2001). Optimal allocation of short-term irrigation supply. *Irrig. Drain Syst., 15*, 247-267. http://dx.doi.org/10.1023/A:1012731718882

Kipkorir, E. C., Raes, D., & Massawe, B. (2002). Seasonal Water Production Functions and Yield Response Factors for Maize and Onion in Perkerra, Kenya. *Agric. Water Management, 56*, 229-240. http://dx.doi.org/10.1016/S0378-3774(02)00034-3

Kirda, C., & Kanber, R. (1999). Water no longer a plentiful resource, should be used sparingly in irrigated agriculture. In C. Kirda, P. Moutonnet, C. Hera, & D. R. Nielsen (Eds.), *Crop yield response to deficit irrigation*. Dordrecht, The Netherlands: Kluwer Academic Publishers. http://dx.doi.org/10.1007/978-94-011-4752-1_1

Lambe, T. (1951). *Soil Testing for Engineers*. John Wiley & Sons, New York, USA

Leskovar, D. (2010). Scientists Complete Two-Year Study on Short-Day Onions. *Science Daily 2010.*

Malakouti, M. J. (1999). *Optimum use of chemical fertilizers in Iran*. Research Report, Soil and Water Research Institute (SWRI). Agricultural Publications, Tehran, Iran.

Ministry of Agriculture (MoA). (2012). *Uasin Gishu District Annual Agricultural Report*. Eldoret, Kenya.

Ministry of Environment and Natural Resources (MENR). (2012). *Uasin Gishu District Annual Environmental Report*. Eldoret, Kenya.

Murthy, C. (2007). Development of Grade Standards for Onion. *Karnataka J. Agric. Sci., 20*(2), 435-437.

Okalebo, J. R., Gathua, K. W., & Woomer, P. L. (2002). *Laboratory methods of soil analysis and plant analysis: A working manual*. TBSF UNESCO. EPZ Publishers, Nairobi, Kenya.

Olalla, F. S., Padilla, A. D., & Lopez, R. (2004). Production and quality of the onion crop (*Allium cepa* L.) cultivated under controlled deficit irrigation conditions in a semi-arid climate. *Agricultural Water Management, 68*, 77-89. http://dx.doi.org/10.1016/j.agwat.2004.02.011

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

Ralph, J., & Helmut, S. (1983). *Farm Management Handbook of Kenya* (Vol. II). Central Kenya.

Sahin, S., & Sumnu, S. G. (2006). *Physical Properties of Foods*. Springer Science+Business Media, LLC., New York, NY, USA.

Saxton, K. E. (2003). *Soil water characteristics hydraulic properties calculator*. Retrieved from http://wilkes.edu/boram/soilwatr.html

Saxton, K. E., Rawls, W. J., Romberger, J. S., & Papendick, R. I. (1986). Estimating generalized soil water characteristics from texture. *Soil Sci. Soc. Am. J., 50*, 1031-1036. http://dx.doi.org/10.2136/sssaj1986.03615995005000040054x

Smith, T., & Guild, J. (1931). The C.I.E. colorimetric standards and their use. *Transactions of the Optical Society, 33*(3), 73-134. http://dx.doi.org/10.1088/1475-4878/33/3/301

Steduto, P. (1996). Water use efficiency in Sustainability of Irrigated Agriculture. In L. S. Pereira, R. A. Feddes, J. R. Gilley, & B. Lesaffre (Eds.), *NATA ASI Series E* (Vol. 312). Applied Sciences, Kluwer Academic, London, UK.

Steduto, P., & Albrizio, R. (2005). Resource use efficiency of field-grown sunflower, sorghum, wheat and chickpea. II. Water use efficiency and comparison with radiation use efficiency. *Agric. Forest Meteorol., 130*, 269-281. http://dx.doi.org/10.1016/j.agrformet.2005.04.003

Steduto, P., Hsiao, T. C., & Fereres, E. (2007). On the conservative behavior of biomass water productivity. *Irrig.*

Sci., 25, 189-207. http://dx.doi.org/10.1007/s00271-007-0064-1

Tesfaye, K. (1997). *Influence of soil water deficit on the development, yield and yield components of haricot bean at different stages of growth* (MSc. Thesis, Alemaya University, Alemaya, Ethiopia).

Valipour, M. (2012). Determining possible optimal values of required flow, nozzle diameter, and wetted area for linear traveling laterals. *The International Journal of Engineering and Science, 1*(1), 37-43. Retrieved from http://www.theijes.com/papers/v1-i1/H011037043.pdf

Valipour, M. (2014a). Pressure on renewable water resources by irrigation to 2060. *Acta Advances in Agricultural Sciences 2*(8).

Valipour, M. (2014b). *Handbook of hydraulic engineering problems*. OMICS Group eBooks. www.esciencecentral.org/ebooks

Valipour, M. (2014c). *Handbook of irrigation engineering problems*. OMICS Group eBooks. www.esciencecentral.org/ebooks

Valipour, M. (2014d). *Handbook of water engineering problems*. OMICS Group eBooks. www.esciencecentral.org/ebooks

Valipour, M. (2015). Calibration of mass transfer-based models to predict reference crop evapotranspiration. *Appl Water Sci*. http://dx.doi.org/10.1007/s13201-015-0274-2.

Zhang, H., & Oweis, T. (1999). Water-yield relations and optimal irrigation scheduling of wheat in the Mediterranean region. *Agric. Water Management, 38*, 195-21. http://dx.doi.org/10.1016/S0378-3774(98)00069-9