



EFFECT OF DEFICIT IRRIGATION REGIMES ON GROWTH, YIELD, AND WATER USE EFFICIENCY OF MAIZE (*Zea mays*) IN THE SEMI-ARID AREA OF KIBOKO, KENYA †

[EFECTO DE LOS REGÍMENES RIEGO DEFICITARIOS SOBRE EL CRECIMIENTO, EL RENDIMIENTO Y LA EFICIENCIA DEL USO DEL AGUA DEL MAÍZ (*Zea mays*) EN LA ZONA SEMIÁRIDA DE KIBOKO, KENIA]

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SUMMARY

Background: Globally, more than 40% of annual food production comes from irrigated lands, and agriculture is the largest consumer of water, at 70% of all freshwater withdrawals. As water scarcity becomes more acute worldwide, increasing the effectiveness of agricultural water resources becomes a priority for enhanced food production. **Methodology:** A study was carried out for two seasons in Kiboko, Makindu Sub-County during 2018 and 2019 short and long rains, respectively to evaluate the response of maize growth, yield, and water use efficiency to deficit irrigation in the semi-arid area. The experiment was arranged in Randomized Complete Block Design with three replicates. The irrigation regimes were T1 (100 % field capacity), T2 (75 % field capacity), T3 (50% field capacity), T4 (25 % field capacity), and T5 (rain-fed) were evaluated. **Results:** In season I, there was a difference ($P \leq 0.05$) on Plant height, leaf area, and leaf area index, in T1 compared to T5. Plants in T1 were higher (308.1cm) than those in T5 (263cm) (control). Irrigation deficit showed an effect ($P \leq 0.05$) on maize growth in season II, with plant height of 270.3cm in T1 compared to 95.6cm in T5. The yield components showed a difference ($P \leq 0.05$) on cob-size, 100grains weight, aboveground biomass and harvest index in both seasons. The highest yield of 10.9 and 10.2 t ha⁻¹ was obtained in T1 in Season I and II, respectively and lowest in T5 (8.8 t ha⁻¹ and 3.0 t ha⁻¹) in the season I and season II, respectively. Higher aboveground biomass and yield were obtained under full irrigation, and declined under varied deficit irrigation regimes. Water use efficiency had no significant difference at the different treatments in the season I, since rains were moderately reliable, thus allowing pausing of irrigation with little water stress. However, in season II, a difference ($P \leq 0.05$) in water use efficiency (WUE) was observed. Generally, water use efficiency ranged from 19.6 to 22. kg ha⁻¹ mm⁻¹ in season I and 16.6 to 24.8 kg ha⁻¹ mm⁻¹ in season II. **Implication:** Irrigating maize at 50% water deficit increases the WUE with minimal yield decline, hence a better deficit irrigation strategy in water conservation under scarcity situation. **Conclusion:** Growth and yield of maize increased with increased amount of irrigation water and decreased under reduced irrigation while WUE increased with reduced irrigation and decreased under severe water stress.

Keywords: Regulated deficit irrigation; performance; water use efficiency; water stress.

RESUMEN

Antecedentes: A nivel mundial, más del 40% de la producción anual de alimentos proviene de tierras de regadío, y la agricultura es el mayor consumidor de agua, con el 70% de todas las extracciones de agua dulce. A medida que la escasez de agua se agudiza en todo el mundo, aumentar la eficacia de los recursos hídricos agrícolas se convierte en una prioridad para mejorar la producción de alimentos. **Metodología:** Se llevó a cabo un estudio durante dos temporadas en Kiboko, sub-condado de Makindu durante las lluvias cortas y largas de 2018 y 2019, respectivamente, para evaluar la respuesta del crecimiento del maíz, el rendimiento y la eficiencia del uso del agua al riego deficitario en el área semiárida. El experimento se organizó en diseño de bloques completos aleatorios con tres repeticiones. Los regímenes de riego fueron T1 (100% de capacidad de campo), T2 (75% de capacidad de campo), T3 (50% de capacidad de campo), T4 (25% de capacidad de campo) y T5 (de secano). **Resultados:** En la temporada I, hubo una diferencia ($P \leq 0.05$) en la altura de la planta, el área foliar y el índice de área foliar, en T1 en comparación con T5. Las plantas en T1 fueron más altas (308.1cm) que las de T5 (263cm) (control). El déficit mostró un efecto ($P \leq 0.05$) en el crecimiento del maíz en la temporada II, con una altura de planta de 270.3cm en T1

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en comparación con 95.6cm en T5. Los componentes del rendimiento mostraron una diferencia ($P \leq 0.05$) en el tamaño de la mazorca, 100 granos peso, biomasa aérea e índice de cosecha en ambas temporadas. El mayor rendimiento de 10.9 y 10.2 t ha⁻¹ se obtuvo en T1 en la Temporada I y II, respectivamente y el menor en T5 (8.8 t ha⁻¹ y 3.0 t ha⁻¹) en la temporada I y la temporada II, respectivamente. Se obtuvieron mayor biomasa aérea y rendimiento con riego total, y disminuyeron con diversos regímenes de riego deficitario. La eficiencia no tuvo diferencia significativa en los diferentes tratamientos en la temporada I, ya que las lluvias fueron moderadamente confiables, lo que permitió pausar el riego con poco estrés hídrico. Sin embargo, en la temporada II, se observó una diferencia ($P \leq 0.05$) en la eficiencia del uso del agua (WUE). En general, la eficiencia del uso del agua varió de 19.6 a 22 kg ha⁻¹ mm⁻¹ en la temporada I y de 16.6 a 24.8 kg ha⁻¹ mm⁻¹ en la temporada II. **Implicaciones:** El riego de maíz con un déficit de agua del 50% aumenta el WUE con una disminución mínima del rendimiento, por lo tanto, una mejor estrategia de riego deficitario en la conservación del agua en situaciones de escasez. **Conclusión:** El crecimiento y el rendimiento del maíz aumentaron con una mayor cantidad de agua de riego y disminuyeron con un riego reducido, mientras que la WUE aumentó con un riego reducido y disminuyó con un estrés hídrico severo. **Palabras clave.** Riego deficitario regulado; rendimiento; eficiencia en el uso del agua; estrés hídrico.

INTRODUCTION

Regulated deficit irrigation (RDI), a concept coined in the 1970s, controls soil water deficit at certain times in a season to reduce irrigation water requirements (Stewart and Steiner, 1990). This practice has shown grain yield substantially increased during the last decade. The rapid decline of water resources in recent years, however, has led to an urgent need for a reduction of irrigation to make agriculture sustainable in Kiboko semi-arid area (Kipkorir *et al.*, 2001).

Global cereal use is projected to increase by 14% by 2027, mainly due to higher food and feed use in developing countries OECD/FAO, (2018). Maize consumption is expected to increase by 16% by 2027, with maize used for animal feed increasing its overall share of total use to 58% in 2027, largely due fast expanding livestock sectors as well as rising incomes in most developing countries and the consequent growth in meat and poultry consumption. This would translate to an increase in maize demand as livestock feed especially for poultry and pigs (Locke *et al.*, 2013). Maize for human consumption will increase mainly in developing countries, especially those in Sub-Saharan Africa where populations are growing rapidly and white maize is an important staple for several countries OECD/FAO, (2018) as well as in fuel industries and breweries in the production of ethylic alcohol (Dabija *et al.*, 2021).

Deficit irrigation (DI) systems are among the management systems that have been successfully implemented in various crops (Tari, 2016; Afshar *et al.*, 2014; Zhang *et al.*, 2016). In DI, crops are exposed to a certain level of drought stress by withholding irrigation at specific growth stages or reducing the amount of irrigation water, either during a particular period or throughout the growing season. Therefore, crops under DI receive an amount of water below their full requirement, which, under optimal

conditions increases irrigation water use efficiency (IWUE) in exchange for an acceptable yield penalty (Chen *et al.*, 2018; Huang *et al.*, 2005). This yield penalty can be economically tolerable compared with the cost or value of water saved in water-limited environments. DI has been successfully implemented to maximize IWUE and increase yield per unit water used in various crops (Chuanjie *et al.*, 2015), including maize (Cakir 2004; Payero *et al.*, 2006; Aguilar *et al.*, 2007; Jahansouz *et al.*, 2014; Domínguez *et al.*, 2012).

In Kenya, DI has been brought about by the increase in population, migration into the Arid and Semi-Arid Lands (ASALs), and climate change (Kinama *et al.*, 2007) and variability. In the ASALs of Kenya, rainfall variability across and within seasons has resulted in moisture deficits. Climate change enhances soil evaporation and reduces water available to crops due to the expected temperature increases. Indeed, soil evaporation takes up to 50% of the total rainfall in the soil water balance in semi-arid areas (Kinama *et al.*, 2005).

This experiment was designed and conducted to evaluate maize crop response to regulated deficit irrigation in the Kiboko area.

MATERIALS AND METHODS

Study site

The study was carried out at KALRO Kiboko Research Centre, latitude 02° 127 S, longitude 37° 437 E, elevation 975 m above Sea level, and approximately 160 km southeast of Nairobi, the capital city of Kenya (Maingi *et al.*, 2001).

The soils of the area comprise of well-drained Fluvisols, Ferralsols, and Luvisols, according to the (USDA, 1997) soil classification. The soil texture is sandy loams that have very high drainage (Wiesman

et al., 2000). Rainfall is bimodal, with the short rain in October– December and long rains start from March–June (Wiesman *et al.*, 2000). The mean annual rainfall is less than 500 mm (Juma, 2012).

The relief of the area is flat to gently undulating linear with a slope of 2%. The land use is a research site with a border cultivated area and abandoned trial site. The land is cultivated for field crops such as sorghum (*Sorghum bicolor*), maize (*Zea mays*), beans (*Phaseolus vulgaris*), cowpea (*Vigna unguiculata*) and pigeon pea (*Cajanus cajan*).

Experimental Design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with five treatments replicated three times. Four soil water deficit irrigation regimes were applied throughout the

growing period, and rain-fed treatment acted as control. Irrigation water was applied at different regimes i.e. T1 (100% FC), T2 (75% FC), T3 (50% FC) T4 (25%FC) and T5 (rain-fed) only rain-fed with no irrigation. Duma 43 maize variety was used as a test.

The water was applied by drip irrigation system and amount applied at each treatment was calculated from the full irrigation treatment (100%) using the maize crop water requirement (CWR) at 100 cm rooting depth.

Treatments

The treatments were: **T1** (100% field capacity), **T2** (75 % field capacity), **T3** (50% field capacity), **T4** (25% field capacity), **T5** (Rain-fed condition).

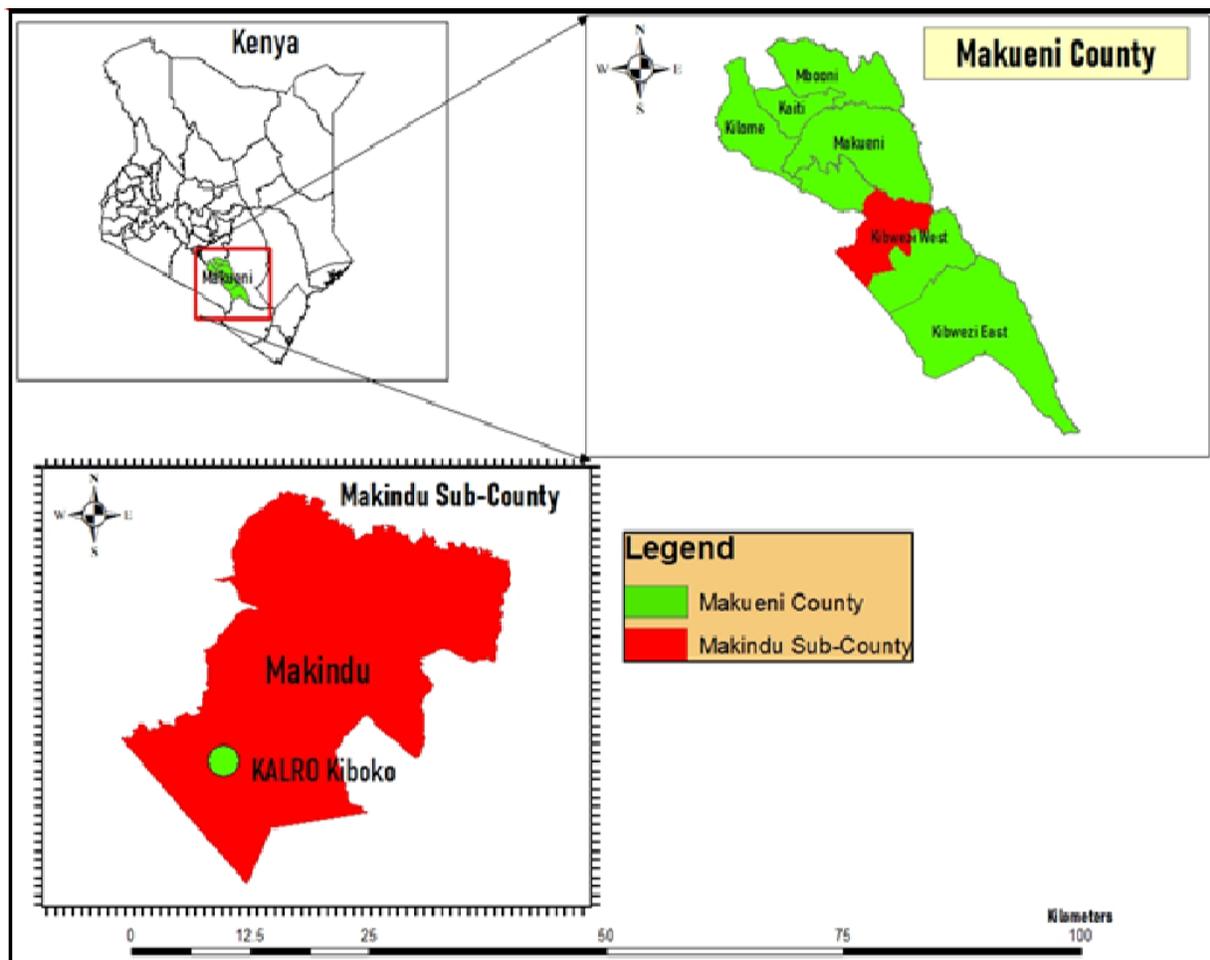


Figure 1. Map of Kenya showing the study site in Kiboko research station Makueni County; Source: Generated from ARC-GIS

Drip irrigation installation

The system consisted of one filter, seven valves, T-joints, start connectors, Polyvinyl chloride (PVC) pipes, drip lines, end lines, and L-bow. The treatments were irrigated individually and the water controlled by the use of valves in the system. The main valve controlled T1 since it was the last to go off during irrigation; while T2, T3, and T4 were controlled by individual valves. The duration of irrigation for each treatment was calculated from the system discharge per hour.

Christiansen's Coefficient of Uniformity (CCU)

Christiansen (1942) "defined" the coefficient of uniformity (CCU) as the ratio of absolute difference of each value from the mean and the mean of means. The Christiansen's Coefficient of Uniformity (CCU) can be expressed as in Eq. 1

$$CU = 100 \left(1 - \frac{\sum_{i=1}^n |x_i - \mu|}{\sum_{i=1}^n x_i} \right) \quad \text{_____} 1$$

Where, n – Number of the depth measurements of the water applied, each representing an equal irrigated area. x_i – measured application depth in liters (L). μ – mean application depths in liters (L). CU – coefficient of uniformity (%)

The uniformity test was taken from 12 plots after the complete installation of the drip irrigation system. Three drip laterals were selected in each plot from the edges and middle of the plot. Graded beakers in mm were placed in all the selected drip laterals in each plot to collect water during the testing process. The drip irrigation system was open to run for 10 minutes and stop, the water collected in the beaker was recorded, a mean value was obtained in each plot (x_i) and mean of means (μ) was obtained by the means ($\sum x_i/n$) got from the 12 plots.

The coefficient of uniformity (CCU) was 96% which indicates almost equal distribution of all discharges from the emitters. Ascough and Kiker (2002) reported that the CU values (in %) for various irrigation systems varied from 17.4 to 95.2 per cent.

Coefficient of variation (CV)

This is the ratio of actual emitter discharge to the design emitter discharge in litres per hour ($L h^{-1}$).

$$CV = Q_{act}/Q_{design} \quad \text{_____} 2$$

The coefficient of variation (CV) was 0.93 which indicate high accuracy of the emitters discharge efficiency, thus the variation between the system

discharge and actual emitters was 7%. Similar coefficient of variation has been reported (Solomon, 1984; Burt *et al.*, 1997; Ascough and Kiker, 2002).

Irrigation water

Irrigation amounts were calculated according to evaporation pan records (Allen *et al.* 1998), using the equation given below (Equ):

$$I = A \times E_p \times K_{pc} \quad \text{_____} 3$$

Where, I = amount of irrigation water, A = ratio of depth of irrigation water applied to the cumulative evaporation, E_p = the cumulative evaporation amount, and K_{pc} = coefficient (including crop coefficient, and application efficiency).

Irrigation time

It was calculated according to following equation;

$$t = (I \times A)/q \quad \text{_____} 4$$

Where, t = irrigation time (hrs), I = depth of applied irrigation water (mm) A = wetted area by emitters (m^2) and q = emitters discharge ($L h^{-1}$).

Measurements of soil moisture and evapotranspiration

Soil moisture content was monitored at a depth of 30, 45 60, 75, 90, 105, and 120 cm weekly using the gravimetric technique.

A soil sample was collected at each plot using a soil auger, and the sample was weighed before oven drying at 105 °C for 24 hours to constant weight.

Soil water balance equation was used to estimate the evapotranspiration (ET_o) (Miranzadeh *et al.*, 2011; Karuku *et al.*, 2011; Karuku *et al.*, 2014; Koech *et al.*, 2015).

$$ET = (P + I + SG) - (D + R) - \Delta S \quad \text{_____} 5$$

Where, ET= evapotranspiration (mm), P= precipitation (mm) taken from nearby meteorological station, I = Irrigation water (mm) applied, D = deep percolation (mm), ΔS = changes in soil moisture content (mm), R = runoff and SG = the groundwater contribution to plant available water (mm).

D, SG and R was found to be negligible during the experimental period, hence the equation was rewritten as below;

$$ET = P + I - \Delta S \quad \text{_____} 6$$

Agronomics Practices

Land preparation was done by ploughing and harrowing with a tractor and then subdivided into plots of 3m x 6m with a border spacing of 1m. Two maize seeds were planted per hole. After germination, one seedling was thinned to obtain plants per hole and a population of 44444 plants ha⁻¹. The spacing between rows was 75 cm and between plants was 30 cm.

Maize parameters measured during the growing period

Growth parameters collected included plant height (cm), leaf area index (LAI), grains weight per 100 seeds (g), grain yield (tha⁻¹), total dry matter weight (tha⁻¹), and harvest index, Hi (%).

Plant height (cm)

Plant height was recorded at 30, 60, and 90 days after emergency and at harvest for each treatment. The height readings were taken from the soil surface to the leave base of highest fully expanded leaf. Measurements were taken from five tagged plants per treatment using a meter ruler.

Leaf area index (LAI)

The leave length and width for the five tagged plants in each plot at the different water levels (T1, T2, T3, T4, and T5) was measured at the central part of the leaf at 50% heading, the leaf length and width were obtained for each plot, and the leaf area was calculated using Watson (1947).

$$LA = L \times W \times 0.75 \quad \text{7}$$

Where; LA= leaf area, L is the length 0.75 is the maize correction factor.

The leaf area index (LAI) was estimated from leaf area per plant (A) divided by land area per plant (p).

$$LAI = \frac{\text{Leaf area per plant}}{\text{Land area per plant}} = \frac{A}{p} \quad \text{8}$$

Where, LAI = leaf area index, A = leaf area per plant (cm²) and P = land area per plant (cm²).

Total dry matter weight (tha⁻¹)

Total dry matter weight was recorded at harvest from five randomly selected plants per plot. The plant was separated from the plant's root portion, and then it was labelled and partially dried in before oven drying it at 60°C.

Seed grain weight (g)

One hundred grains weight was recorded from each plot from five randomly selected plants, and an average for the treatments. This measurement was done using a weighing machine.

Grain yield (t ha⁻¹)

Grain yield in tha⁻¹ from each plot was recorded from air-dried cob, separated and cleaned before drying it to 14% moisture content. The grains were weighed and recorded in kilo grams (kg) before it was converted to tha⁻¹.

Harvest Index (%)

This refers to the crop's economic yield divided by total dry weight, as Donald (1992) described. He used the formula below to calculate the harvest index.

$$\text{Harvest index} = \frac{\text{Grain yield (kilo gram per hectare)}}{\text{Total dry weight (kilo gram per hectare)}} \quad \text{9}$$

Water Use Efficiency (WUE)

WUE was estimated from the yield in kilogram (kg) and actual crop evapotranspiration ET_c (mm) with the equation given below (Karuku *et al.*, 2014, Araya *et al.*, 2011, Song *et al.*, 2019).

$$WUE(\text{kg ha}^{-1} \text{mm}^{-1}) = \frac{\text{Yield}(\text{kg ha}^{-1})}{ET_c(\text{mm})} \quad \text{10}$$

Where, WUE is water use efficiency (kgm⁻³), Y is the yield (kg ha⁻¹), and ET_c is the crop reference evapotranspiration.

Data analysis

The data analysis was done with the aid of GenStat 19th edition (Lane and Payne, 1997) and subjected to analysis of variance (ANOVA) with means differences separated by Duncan's multiple range test at 95% confidence level (P≤0.05 level of significance).

RESULTS AND DISCUSSIONS

Soil characterization

Chemical soil properties

The soil chemical properties of the experimental site are presented in Table 1. The soil pH obtained was 7.15, which is within the required pH for effective maize growth that ranges from 5.0 to 7.0 (FAO, 2012).

Table 1. Chemical soil properties of the experimental site.

Parameters	Soil characterization	Very high	High	Medium	Low	Very Low
pH-H ₂ O (1:2.5)	7.45		>7	5.5-7	<5.5	-
CEC (me 100g-1)		>40	25-40	12 – 25	6 – 12	<6
OC (%)	1.1	-	>2.5	1.5-2.5	<1.5	-
TN (%)	0.1	-	>0.7	0.5-0.7	<0.5	-
P (ppm)	51	>46	26-45	16-25	10-5	<9
K (me 100g-1)	0.88	>1.2	0.6-1.2	0.3-0.6	0.2-0.3	<0.2
Ca (me 100g-1)	2.4	>20	10 -20	5 – 10	2 – 5	<2
Mg (me 100g-1)	3.3	>8	3 - 8	1 – 3	0.3-1	<0.3
Na (me 100g-1)	0.53	>2	0.7-2	0.3-0.7	0.1-0.3	<0.1

Legend: TN – Total Nitrogen, OC – Organic carbon, P – phosphorous, K – Potassium, Ca – Calcium, Mg – Magnesium, Na – Sodium, CEC – Cation Exchange Capacity,

Physical soil properties

The soil physical properties of the study site are shown in Table 2. The particle size distribution showed that sandy texture was dominant.

The sandy soil content was 68.5, clay 26.8 and the silt soil content shows low soil contain of 4.6%, thus the textural class of the soil was sandy clay loam according to the textural triangle.

The bulk density indicated a slight variation with depth and ranged from 1.30 g cm⁻³ at the depth of 0 – 15 cm to 1.55 gcm⁻³ at the depth of 90 – 105 cm. This could be because of decrease in organic matter content with depth and compaction due to the weight of the overlying soil layer (Brady and Weil, 2002). The soil moisture content at field capacity and permanent wilting point was at PF 4.2 and PF 2.0 respectively and the hydraulic conductivity (Ksat

mmday⁻¹) was high which indicated high permeability of the soil.

Climatic data

Climatic data are shown in Table 3. Maximum and minimum air temperature (°C), rainfall (mm), relative humidity (%), wind speed (ms⁻¹) at screen height (2m about the ground) and sunshine hours were obtained from Kiboko research station.

The mean air temperature recorded in season I (September – December 2018) was 30.8°C max and 17.2°C min. The hottest month was November with a mean air temperature of 31.5°C max and 18°C min. In season II (February – June 2019), the mean air temperature was 32°C max and 17.2 °C min with April as the hottest month with a mean temperature of 35 °C max and 19.1 °C min. The temperatures were within the range (21 to 27°C) for optimal maize

Table 2. Physical soil properties of the experimental site.

Soil depth (cm)	Texture				Bulk density (g/cc)	FC (Vol. %)	PW (Vol. %)	AWC (Vol. %)	Ksat (mmday ⁻¹)
	%Sand	%Clay	%Silt	Class					
0 – 15	70	24	2	SCL	1.30	22.13	10.54	11.59	71
15 – 30	70	24	2	SCL	1.35	22.85	11.12	11.73	63
30 – 45	68	28	4	SCL	1.41	23.01	11.22	11.79	68
45 – 60	68	28	4	SCL	1.42	23.42	11.41	12.01	62
60 – 75	68	28	4	SCL	1.43	23.51	10.86	12.65	58
75 – 90	68	28	8	SCL	1.43	23.62	11.24	12.38	63
90 – 105	68	28	8	SCL	1.55	22.73	11.42	11.31	60
Average	68.5	26.8	4.6	SCL	1.4	23.01	11.1	11.92	63.5

Legend: SCL – Sandy Clay Loam FC – Field Capacity, PWP – Permanent wilting Point, AWC – Available water content, Ksat – Saturated hydraulic conductivity.

Table 3. Mean climatic parameters during the two cropping seasons.

Cropping Season	Year	Month	Tmax (°C)	Tmin (°C)	Wind speed (m/s)	Sunshine (H/day)	RH (%)	Rainfall (mm)	ETo (mm)
Season I	2018	Sep	30.78	15.22	207	7.93	79.6	0.30	4.7
		Oct	30.53	17.27	216	7.23	82.6	1.43	4.9
		Nov	31.46	18.01	173	6.06	82.0	5.73	4.2
		Dec	29.93	17.98	229	6.07	85.3	10.4	3.7
		Jan	31.4	17.37	138	7.05	79.3	1.39	4.2
Season II	2019	Feb	33.13	17.13	155	7.46	82.8	0.00	4.8
		Mar	33.13	17.12	164	6.87	77.2	0.00	4.7
		Apr	35.1	19.13	219	6.59	72.4	1.36	4.1
		May	30.53	17.45	138	6.79	80.4	0.44	3.8
		Jun	29.3	15	138	6.92	79.3	0.06	3.5

Legend: T_{max} (°C) (maximum temperature), T_{min} (°C) (minimum temperature) RH (relative humidity), (%) percentage, (mm) millimetres, ms^{-1} (meters per second).

growth (Sanchez and porter, 2014). The average rainfall in season I was 3.9 mm with the highest rainfall of 10.4 mm recorded in December and the lowest of 1.4mm in October. Season II had 0.37mm as its average rainfall which indicate a low rainfall in both seasons though higher in season I than in season II. Rainfall occurrence depends greatly on the temperature and weather conditions (Trenberth, 2011, Mawonike and Mandonga, 2017). A high temperature increases the rate of potential evaporation which would deplete the soil moisture content (Nkuna and Odiyo, 2016). Relative humidity (RH) on average was 82 and 78% in season I and II, respectively which moderately high. Relative humidity (RH) directly influences the water relations of plant and indirectly affects leaf growth, photosynthesis, pollination, occurrence of diseases and finally economic yield (Hoogenboom, 2000). The dryness of the atmosphere as represented by saturation deficit (100-RH) reduces dry matter production through stomatal control and leaf water potential (Grange and Hand, 1987). The wind speed was 192 and 163 ms^{-1} in season I and II, respectively whereas sunshine recorded an average of 6.9 hours in both seasons.

Growth parameters of maize

Plant height (cm)

Maize height was not significantly affected by deficit irrigation (T1, T2, T3 and T4) in season I. However, there was a significant difference ($P \leq 0.005$) observed between T1 (100% FC) at 308 cm and T5 with 263 cm plant height at the maturity stage. The finding is in agreement with Rosadi *et al.* (2005) who found out that a small difference in moisture deficit levels did not affect plant height. In season II, plant height had

highly significantly ($P \leq 0.005$) difference between deficit irrigation regimes and rain-fed, with a maximum maize height of 306 cm obtained in T1 followed by 262 in T2, 225 cm in T3, 197cm in T4 and the least plant height of 96 cm was recorded under in T5. Water is an important component of plant cell and raw material for photosynthesis. Carbohydrates are manufactured from water combine with carbon dioxide (CO_2) in the presence of sunlight. Water keeps the plant turgid and erect; moisture deficiencies in plant result in cell flaccidity and the plant drops and wilt. Tari (2016) and Jia *et al.* (2017) found out that maize plant grown under sufficient moisture content produce high plant height while water stressed condition produces dwarf maize plant.

Leaf area and leaf area index

Leaf area and leaf area index was recorded during the growing period and the data obtained in season I revealed non-significant difference among the deficit irrigation treatments. However significant ($P \leq 0.005$) difference was noted between fully irrigated (T1) treatment that recorded 718 cm and 4.8 leaf area and leaf area index and 661cm and 4.4 obtained under T5. Pandey *et al.* (2000) recorded the highest value of leaf area index for corn that was obtained under the conditions of full irrigation (without stress). In season II deficit irrigation has high significant ($P \leq 0.005$) effect on the leaf area and leaf area index, a maximum leaf area and leaf area index of 700 and 4.6 recorded in T1 followed by 591 and 3.8 in T2, 540 and 3.3 in T3, 525 and 2.9 in T4 and the least leaf area and leaf area index of 242 and 1.2 was observed under rain-fed (T5). The findings agree with (Bouazzama *et al.*, 2010) who found out low

leaf area index in the treatments under more water stress.

Maize yield components

Yield attributes of maize measured during the harvesting time includes; cob size (cm), grain weight per 100 seeds, aboveground biomass, yield and harvest index (HI) are shown in Table 5.

Cob size (cm)

Cob size was recorded at the harvesting stage and data obtained in season I shown a significant effect of deficit irrigation on maize cob size. Among the deficit irrigation regimes, the maximum cob size of 19.6cm was observed in T1 which was no significantly ($P \leq 0.05$) difference from its immediate irrigation regimes of T2, T3 and T4. Whereas

Table 4. Effect of deficit irrigation regimes on growth parameters of maize.

Treatments	Season I			Season II		
	PH (cm)	LA (cm ²)	LAI	PH (cm)	LA (cm ²)	LAI
T1	308a	718a	4.8a	306a	700a	4.6a
T2	297a	707a	4.7a	262b	591ab	3.8b
T3	295a	673a	4.5a	225c	540b	3.3bc
T4	292a	667a	4.5a	197d	525b	2.9c
T5	263b	661a	4.4a	96e	242c	1.2d
S.E.D	11.52	40.1	0.32	9.23	76.9	0.54
L.S.D (5%)	11.52	92.4	0.75	21.97	117.4	1.25
CV%	4.80	7.0	7.90	4.60	11.4	9.00

Legend T1 (100 % field capacity), T2 (75 % field capacity), T3 (50 % field capacity), T4 (25 % field capacity), T5 (rain-fed) PH (plant height), LA (Leaf area) and LAI (leaf area index). Mean followed by the same letter in a column are not significantly different from each other at ($P \leq 0.05$) level.

Table 5. Effect of deficit irrigation regimes on Yield Components of maize.

Cropping season	Treatments	Cob size (cm)	g-w (g)	Bio mass (t ha ⁻¹)	Yield (t ha ⁻¹)	Harvest index
Season I	T1	19.6a	39.6a	35.2a	10.9a	0.31a
	T2	19.4ab	38.4a	33.9a	10.4a	0.30a
	T3	19.2ab	37.8ab	32.7ab	9.8ab	0.29ab
	T4	18.6ab	37.2ab	30.4b	9.0b	0.29ab
	T5	18.1b	33.6b	28.1c	8.4c	0.29ab
	S.E.D	0.38	1.71	12.6	0.51	0.03
	L.S.D (5%)	0.88	3.95	9.01	6.5	0.07
	CV%	2.50	5.60	3.90	1.18	13.7
Season II	T1	19.9a	41.3a	33.8a	10.2a	0.30a
	T2	17.1b	40.8a	30.3b	9.1b	0.30a
	T3	16.9bc	39.9a	27.6c	8.3bc	0.29ab
	T4	15.7c	35.1b	23.9d	6.0c	0.25b
	T5	13.2d	18.1c	14.8e	3.0d	0.20c
	S.E.D	2.23	2.84	0.88	0.54	0.02
	L.S.D (5%)	5.14	6.55	2.03	1.24	0.52
	CV%	7.50	7.80	6.60	4.90	2.00

Legend: T1 (100 % field capacity), T2 (75 % field capacity), T3 (50 % field capacity), T4 (25 % field capacity), (rain-fed) and g-w (grain weight). Means followed by the same letter in a column are not significantly different from each other at ($P \leq 0.05$) level.

the minimum cob size of 18.1cm was obtained in T5, this was significantly ($P \leq 0.05$) difference compare to the irrigated treatments. In season II deficit irrigation had a high significant effect on cob size, with highest cob size of 19.9cm obtained in full irrigated treatment (T1) followed by T2 (75% FC), T3 (50% FC) , T4 (25% FC) and least cob size of 13.2 cm was recorded under rain-fed (T5).

Grain weight per 100 seeds

A deficit irrigation regime had significant ($P \leq 0.05$) effect on grain weight (g). In season I, the maximum grain weight of 39.6g was recorded in T1 which has no significant effect from T2 while T3, T4 and the rain-fed that recorded the least grain weight of 33.6 g had a significant ($P \leq 0.05$) difference. In season II grain weight shown a high significance difference, among the deficit irrigation regimes, a maximum grain weight of 41.3g obtained under full irrigation (T1) which has no significance deference from T2 and T3, however there was a significance ($P \leq 0.05$) difference noted in T4 and T5 that obtained 35.1g and 18.1g respectively compared to full irrigated treatment. Grain filling stage requires adequate moisture content to facilitate the assimilation of dry matter to the grains, hence water stress at this stage will reduce the assimilation of dry matter to the grain as well as cause the production of sterile pollen grains thus low grain weight (Du *et al.*, 2015 and Li *et al.*, 2018) found that water stress in reproductive stage reduces grain weight of maize.

Above ground biomass (t/ha)

The above ground biomass (t/ha) was found to be linear with deficit irrigation. The data collected in season I, revealed a significant effect ($P \leq 0.05$) of deficit irrigation on above biomass, a maximum above ground biomass of 35.2 tha^{-1} was recorded in T1 which was no significance difference from to 33.9 tha^{-1} obtained from T2, but significance difference to T3, T4 and T5 that obtained the minimum above ground biomass of 28.1 tha^{-1} . In season II deficit irrigation had high significant effect on biomass accumulation, with a maximum of 33.8 tha^{-1} recorded in in T1 followed by T2, T3, T4 and T5 that obtained the least biomass of 14 tha^{-1} . Generally, accumulation of above ground biomass of maize depends on the level of deficit irrigation regime and it reduces significantly with decrease in deficit irrigation. The findings are in agreement with Igbadu *et al.* (2008) who reported that deficit irrigation at any growth stage resulted in decrease in both biomass and grain yield. Yazar *et al.* (1999) and Pandey *et al.* (2000), who reported that deficit irrigation definitely reduces yield of maize crop, and

that maize dry matter and grain yield increased significantly with irrigation.

Grain yield (t/ha)

Grain yield of maize was significantly ($P \leq 0.05$) affected by deficit irrigation regimes. In season I the data collected revealed a maximum grain yield of 10.9t/ha obtained in T1 which was no significantly difference from T2 but significantly ($P \leq 0.05$) different T3, T4 and T5 that record the lowest grain yield of 8.4 tha^{-1} . In season II maximum yield 10.2 tha^{-1} was obtained in full irrigation (T1), 9.1t ha^{-1} in T2, 8.5t ha^{-1} in T3, 6.0 t ha^{-1} in T4 and lowest yield of 3.0 tha^{-1} was obtained in rain-fed. Season I has low yield variation between deficit irrigation and rain-fed condition whereas season II has high yield variation between irrigated and rain-fed, these could be as result of rainfall pattern between the two seasons. Season I slightly moderate rainfall that had added significant moisture content to the soil compared to season II that received very little rainfall (Table 5), hence the crop was mostly depending on irrigation thus the effect of deficit irrigation and water stress cause the yield variation in season II. The result clearly shows that maize yield is linear with deficit irrigation regimes, and this agrees with the findings of (Naescu, 2000, Karam *et al.*, 2003; Farre *et al.*, 2006; Mengü and Ozgurel, 2008, Oktem, 2008, Golzardi *et al.*, 2017), who reported that deficit irrigation reduces the yield of maize crop, and maize dry matter increases significantly with irrigation. The findings are also agreeing with Rhoades and Bennett (1990) and Lamm *et al.* (1995), who reported that it is difficult to plan deficit irrigation for maize without causing yield reduction.

Harvest index (HI)

The harvest index of maize was almost the same in season I Table 6. However, in season II harvest index revealed high significant ($P \leq 0.05$) difference, with high harvest index obtained in T1 and T2 which was highly significant ($P \leq 0.05$) to 0.29 recorded in T3, 0.25 in T4 and 0.2 in T5 as the least harvest index. Yield and above ground biomass in season I were moderately high along with a small variation among all the treatment, which results to low variation in harvest index in season I. Golzardi *et al.* (2017), Mohammadi *et al.* (2018), and Xue *et al.* (2018) reported that maximum harvest index of maize was produced when filed was well irrigated. Bryant *et al.* (1992) indicated that water stress reduces yield by reducing accumulated biomass and the harvest index. However, (Traore *et al.*, 2000) found that the harvest index was affected by water deficit only when stress was imposed during anthesis.

Table 6. Effect of deficit irrigation regimes on maize water use efficiency (kg ha⁻¹mm⁻¹).

Treatment	Season I		Season II	
	ET _{maize} (mm)	WUE (kg ha ⁻¹ mm ⁻¹)	ET _{maize} (mm)	WUE (kg ha ⁻¹ mm ⁻¹)
T1	553a	19.7b	445a	23.0ab
T2	530a	19.6b	377b	23.7ab
T3	495b	19.8ab	334c	24.8a
T4	447c	20.6ab	303d	19.8bc
T5	401d	22.0a	180e	16.6.3c
S.E.D	11.5	0.90	24.4	1.40
L.S.D (5%)	26.5	2.10	56.2	3.30
CV%	2.90	5.50	9.10	8.10

Legend T1 (100 % field capacity), T2 (75 % field capacity), T3 (50 % field capacity), T4 (25 % field capacity), and T5 (rain-fed). Means followed by the same letter in a column are not significantly different from each other at ($P \leq 0.05$) level.

Maize water use efficiency (WUE)

The effects of deficit irrigation on water use efficiency of maize are shown in Table 6. Water use efficiency of maize was found to be significantly ($P \leq 0.05$) different and varies with seasons and irrigation level. The values recorded for water use efficiency of maize ranges from 16.6 to 24 kg ha⁻¹mm⁻¹. In season I, the maximum water use efficiency of 22 kg ha⁻¹mm⁻¹ obtained under rain-fed (T5), which was significantly ($P \leq 0.05$) difference compare to 19.7 and 19.6 kg ha⁻¹mm⁻¹ obtained in T1 and T2 respectively.

In season II, water use efficiency was highly significantly ($P \leq 0.05$) difference, with a maximum WUE of 24.8 kg ha⁻¹mm⁻¹ obtained in T3 followed by T1 and T2 that recorded the same water use efficiency of 23.7 kg ha⁻¹mm⁻¹, 19.8 obtained in T4 and lowest was 16.6 kg ha⁻¹mm⁻¹ recorded under rain-fed (T5).

Rainfalls were insufficient and unreliable in season II; as a result, the crops was entirely dependent on irrigation, which results in high water use efficiency. Regulated deficit irrigation (RDI), as described and used by Rawson and Turner, (1983), and Fabeiro *et al.*, (2002), can further improve WUE. The RDI maintains crop plants under water deficit stress during some of the growth stages by controlling irrigation amounts. Fully irrigated plants usually have widely opened stomata. Plants open their stomata for CO₂ uptake and carbon gain but will lose significant quantities of water at the same time (Kang and Zhang, 2004). A small narrowing of the stomatal opening can reduce water loss substantially with little effect on the photosynthesis rate. Earlier research predicted that plants generally should have the capability to increase their WUE in this way, thereby

maximizing their chance of surviving a period of drought, potentially without a great reduction in carbon gain and biomass accumulation; however, this may occur only when crops are aerodynamically well coupled to the atmosphere (Grieu *et al.*, 1988). However, during critical growth stages, it is particularly important to maintain plant water supply and status (McLaughlin and Boyer, 2004).

CONCLUSIONS

Generally, irrigating maize (*Zea mays*) under deficit irrigation in the study area will have the following effect on its productivity;

- Irrigating maize at 50% water deficit would improve water use efficiency without much reduction in yield in the study area.
- High maize yield performance along all the treatments in season I was due to moderate rainfall received, while yield variations in season II were due low and unreliable rainfall hence crops were entirely grown under irrigation as such deficit irrigation effect were observed all the treatments.
- Deficit irrigation under 25% field capacity (FC) reduces yield and water use efficiency with 41% and 14%, respectively.

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Author contribution statement (CRediT). **L. Bosco Wani** – conceptualization, data curation, formal analysis, funding acquisition, methodology, Investigation, Project administration, visualization, resources, software, Writing – original draft., **George N. Karuku** – Supervision, validation, writing – review & editing.

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