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Evaluating maize performance under varying water depletion levels in bura irrigation scheme, Kenya

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Key words: Above ground biomass, Canopy cover, Water depletion levels, Yield

Abstract

Sufficient soil moisture in the root zone is critical for optimal crop development. Excess or deficit water leads to reduced crop growth and yields. A field study was done to determine the effect of available water on performance of PH4 maize variety on sandy clay loam soil at Bura Irrigation Scheme, eastern Kenya. Three water depletion level treatments T75, T50 and T25 laid in Randomized Complete Block Design (RCBD) were used during 2015 long rain (March to June) and 2016 short rain (October to December) seasons. Irrigation was undertaken when 25% (T75), 50% (T50) and 75% (T25) of available water capacity (AWC) was depleted, respectively. Canopy cover, above ground biomass and grain yield was used as indicators of maize performance. Treatments T75 and T50 had no significance difference among them but both had significantly ($P \leq 0.05$) higher above ground biomass, canopy cover, stover and grain yield compared to T25. Maize performance showed a positive linear relationship with the quantity of irrigation water applied up to a certain optimal quantity. Additional irrigation water used in T75 treatment gave slightly higher yields though statistically insignificant compared to T50 treatment. Higher Water Use Efficiency (WUE) was recorded in T75 than T50. Supplemental irrigation at 50% AWC is recommended for the scheme as it gives high yields and is safe on water compared to T75.

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Introduction

Globally, irrigation provides 60% of cereal produced and uses over 70% of global fresh water (FAO, 2003). With the expected future global increase in food and fibre demands and water scarcity, more pressure will be put on the available fresh water resources. Every available drop of water therefore needs to be prudently used to increase crop production (UN, 2016). The potential for increasing maize production in SSA is huge but unfortunately, maize production has been on the decline, getting as low as 1.5 Tonha^{-1} (You *et al.*, 2012). One of the major contributing factors to this poor performance is water. Challenges in its availability and efficient use especially at farm level have immensely contributed to the low yields. This is the situation replicated in the study area and in many other irrigation schemes in Kenya (Ali, 2012; Koech, 2014). For instance, irrigation land in the Scheme totals 5,360ha though only 3,340ha are currently under irrigation due to inadequate water supply (Scheme Management-2015). Improvement of WUE in the scheme would mean possible use of less water or the same amount of available water to produce more food by irrigating more land. Maize production in the scheme currently stands at 3.5Mgha^{-1} for commercial farm and 4.4Mgha^{-1} for seed maize. This falls below the global average of 4.9Mgha^{-1} (Edgerton, 2009). It is also well below the attainable yield of 6Mgha^{-1} or more with hybrid maize varieties and application of recommended fertilizer rates (Kang'ethe, 2004; Republic of Kenya, 1997; 2004).

To change this trend and produce more food with less water, increased attention to water management comprising monitoring and measurement at all stages of the irrigation value chain is key. This means that water conservation practices will become the focus of renewed research to maximize on irrigation water. Sustainable water management practices may in future reduce the irrigation demand for water and spare some for use in expansion of irrigated land and other competing sectors. It is in this light that this study was carried out to improve Kenya's agricultural water resource management through understanding yield potentials and exploiting gaps in present irrigated maize (*Zea mays* L.) production.

Materials and methods

Study Site

Bura Irrigation Scheme is located in the Tana River Basin, Tana River County (Fig. 1.), 50km North of Hola town and approximately 400 km North of Mombasa city; latitude 10^{o}8'S, longitude 39^{o}45' E and elevation of 110m asl. The scheme lies in agro-ecological zone V (semi-arid to arid) and experiences a bimodal mean annual rainfall of about 400 mm. Long rains occur in March to June while short rains occur in October to December (Jaetzold *et al.*, 2009). High Temperatures are experienced all year round with little seasonal variation. Mean maximum temperatures never fall below 31°C and average minimum temperatures are above 20°C. February and March are the hottest months where temperature ranges between 29.2 and 30.5^{o}C (Muchena, 1987). The mean measured annual evaporation using US Weather Bureau Class A evaporation pan for Garissa and Hola is 2,712 and 2,490 mm, respectively. The scheme is situated between the Garissa and Hola meteorological stations and on average records a daily evaporation of about 6.4 mmday^{-1} giving an r/ETo of 0.15. The soils are a combination of Vertisols and Vertic-fluvisols (WRB, 2014) according to Wamicha *et al.* (2000), which are characterized with swelling and ponding during wet seasons, and low infiltration rates due to sealing of pores (Koech *et al.*, 2014). The scheme has shallow sandy clay loams and heavy cracking clays overlying saline and alkaline sub-soils of low permeability (Mwatha *et al.*, 2000). Land suitability evaluation indicates that the soils are marginally suitable to not suitable for arable farming. The land is best suited for livestock, pasture and forages (Muchena, 1987).

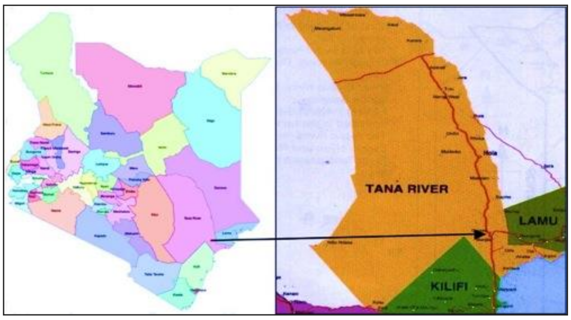

Fig. 1. Location of Tana River County and Bura in Kenya

Source: Department of Geography University of Nairobi.

Experimental Layout and Design

The experiment had three water depletion levels as treatments replicated five times in a 4m x 4.5m plots, giving a total of 15 experiments laid out in a RCBD. The study was carried out during 2015 October - December and 2016 long rains (March-June) cropping seasons. At 90% maize seed germination, three water depletion levels treatments were applied, namely:

- T75 - treatment, where water was applied when 25% of AWC was depleted,
- T50- treatment, where water was applied when 50% of AWC was depleted and
- T25 - treatment, where water was applied when 75% of AWC was depleted

All plots were irrigated to just near/or field capacity during each irrigation exercise.

No irrigation was done after effective rain until AWC fell to the intended level as per each treatment. Soil AWC was monitored using an Extech Soil Moisture Meter with an 8-inch Stainless steel probe to determine moisture deficit. Effective rain was considered to be that part of the total rain that replaced, or potentially reduced, a corresponding net quantity of required irrigation water and was taken to be 75% of rain over 5mm.

Effective Precipitation (mm) = (RAIN - 5) x 0.75

Soil Characterization

A 600cm^3 Soil auger was used to collect undisturbed core samples for physical and chemical analysis. Saturated hydraulic conductivity (Ksat) and soil water content at saturation (θs), field capacity (θf) and permanent wilting point (θpwp) were determined based on the method described by Hinga *et al.* (1980). Soil pH was determined with a pH meter in a ratio of 1:2.5 soil/water suspension while electrical conductivity (EC) was determined on a soil paste using an EC meter. Soil texture was by hydrometer method as described by Glendon and Doni (2002). Cation exchange capacity was determined in an ammonium acetate (NH_4OAc) solution at pH7 and NH_4-N concentration in the extracted solution determined by micro-Kjeldhal distillation followed by titration with hydrochloric acid. Exchangeable bases (Ca,Mg, Na and K) were extracted from the soil - NH_4OAc leachate and determined using Atomic Absorption Spectrometry (AAS) by use of atomic absorption spectrophotometer. Organic carbon in soil and manure samples was determined following the Walkley and Black (1934) method as described by Nelson and Sommers (1996). Total N was determined by micro-Kjeldhal distillation method as described by Bremner (1996). The Bray II method was used to determine available P according to Bartlett *et al.* (1994).

Agronomic Practices

The land was ploughed using a disc plough and furrows made in the entire block before dividing it into plots for uniformity. The furrows ran parallel to the shorter side of the plot on an east-west orientation. Maize seeds, variety PH4 were treated with Thiamethoxam at a rate of 10g per kg of seed prior to planting to protect them from insect pests. Planting was done at a depth of about 5cm by hand at a spacing of 25cm between plant and 75cm between rows to give a density of 53,333 plants ha^{-1}. Diammonium Phosphate (DAP) fertilizer was incorporated into the soil during planting at the recommended rate of 175 kg ha^{-1}. All plots were irrigated to near field capacity after planting to enhance maize seed germination. A pre-emergent weed killer, Atrazine and S-Metolachlor (Primagram) were applied after the first irrigation at a rate of 2500 ml ha^{-1}. Weeds that sprouted thereafter were uprooted by hand or weeded by hand hoe. Top dressing at the recommended rate of 250 kg ha^{-1} urea was done 40 days after seedling emergence. Spraying with Deltamethrin at 1000 ml ha^{-1} 60 days after emergence was used to control pests such as stalk borer. No mulch was added in order to replicate farmers' practice.

Crop Data

Above ground biomass

Above ground biomass (AGB) was determined bi-weekly by destructively harvesting two randomly selected plants from each of the four middle rows for all the 5 plots of each treatment. The harvested plants were dried in an oven at 60^{o}C for 72 hours, and then weighed on a digital balance with precision of ±0.002 grams. The obtained weights were averaged and extrapolated to biomass inMgha^{-1} at a cropping density of 53,333 plants ha^{-1}.

Canopy Cover

Maize canopy cover (CC) was determined using the meter stick method (Miller, 1969) between 11.30am and 12.30pm every two weeks starting after 90% maize emergence. Three sites were selected at random and marked in each plot. The CC was determined from these specific points throughout the experimental period. The meter rule was placed on flat ground at midday and the% CC estimated by taking the sum of centimeters covered by the canopy shade on the meter rule. The meter rule was then rotated and the procedure repeated over an angle of 45°, 90° and 135°. The four readings were averaged to get the percentage CC for that spot. The readings obtained from the three spots in a plot were averaged to get the percentage CC for the plot.

Grain Yield

Grain yield (GY) was determined by harvesting all cobs from three randomly selected plants in each of the six rows after crop attained physiological maturity. The average number of ears per plant, the average number of rows per ear and the average number of grains per row from each plot were determined. The cobs were shelled and units of 1000 grains weighed to obtain the average weight of grain at 13.5% moisture content. The data obtained was used to estimate GY per hectare using Equations 1 and 2.

Grains per ear = Rows of grains x number of gains per row..........Eq. 1

Mass of grain per hectare = Number of ears per hectare x grains per ear x average mass of grain....... Eq 2

Statistical Analysis

Data collected was summarized in Microsoft Excel spreadsheets and subjected to analysis of variance (ANOVA) using Statistical Analysis System (SAS) version 9.1. Post hoc analysis to separate the means was carried out using LSD ($P \leq 0.05$) to determine the sources of differences.

Results and discussion

Soil characterization of the study site

The amount of clay in the soil increased with depth from 30% at 0-30cm to 35% at 31-60cm and 44% at 61-120cm depths (table 1). This could probably be due to leaching of the fine clay particles by water down the profile because clay is considered a mobile component in the soil (Charles 1977), a phenomenon known as eluviation.

This leaves the coarse sand particles at the top. Gul *et al.* (2011) and Adugna *et al.* (2011) reported similar findings. According to FAO World Soil Resources Reports (2001), eluviation will occur when water percolates through the soil carrying with it clay as well as metals, humus and other colloidal or dissolved substances and deposit them in lower depths through illuviation process (Gemma *et al.*, 2017).

Table 1. Salient soil characteristics of the study site.

Thickness of profile	Soil texture			Texture class	PWP	FC	AWC	Ksat
cm	Sand (%)	Silt (%)	Clay (%)	(USDA)	--------- Vol.% --------			cm hr^{-1}
0-30	50	20	30	Sandy clay loam	25.1	36.85	11.75	2.27
31-60	40	25	35	Clay loam	14.74	32.85	18.11	0.882
61-120	38	28	44	Clay	25.61	39.47	14.86	0.461

Legend: PWP - permanent wilting point, FC - field capacity, AWC - available water capacity, Ksat - saturated hydraulic conductivity.

Amount of water that can be held in the soil profile is of great importance because soil is a major water reservoir. Water retention of the top horizon (0-30cm) was lowest compared to the horizons below. It was highest in the middle horizon (31-60cm), which then decreased in the 61-120cm horizon (Table 1). The low available water capacity in the topsoil probably was due to high sand content that reduced available water capacity because water in sand's large pores is subject to free drainage under gravity.

As the soil particles size decrease, the pores become finer and hold more water against free drainage, increasing water-holding capacity as was seen with the second profile. A fine textured soil therefore holds more water than a coarse textured one because small pores have higher matrix potential than large pores (Jon, 2015). The bottom layer (61-120cm) had the highest clay content (44%) in comparison to the horizons above but in contrast, available water capacity of this horizon was found to be lower. This could be because clay creates a complex soil matrix of much smaller pores, which makes it hold more water, but the water is held at greater suction pressure leading to increased permanent wilting point, hence reducing the amount of available water. According to Nathalie *et al.* (2001), although clay soils can hold 280 mm of water per metre depth, only 70 mm of it is available to plants. The rest of water is held so tightly and unavailable for use by crops. This is also in agreement with findings by Jeff (2001), O'Geen (2013), Ministry of Agriculture - British Columbia (2015) and Zachary (2016).

The observed high Ksat values in the study indicate high rate of water movement. These Ksat values were found to decrease with depth, as the amount of clay content increased (table 1). This is an indication of increasing resistance to water movement down the profile. Ksat is important in the study of soil infiltration and drainage, aspects that are vital in irrigation water management (Tayfun, 2005) and in the study of nutrient movement in the soil (Philip *et al.*, 2014). The value is also important as it dictates the plant type to be grown in a soil, spacing and erosion control. Behzad (2015) also says that Ksat is important in modeling flow and contaminant transport in the soil. Others such as Lin (2003) and West *et al.* (2008) talk of importance of Ksat in modeling and determination of water budget, soil leaching potential and its suitability for agriculture. The notable drop in Ksat value between the surface 0-30cm and the horizons below could be an indicator of compaction. This low Ksat in the lower horizon will cause resistance to plant root penetration and water percolation, which is likely to cause ponding and runoff during rain or irrigation. Ponding indicates saturated soils and most crops don't do well in waterlogged soils due to anaerobic conditions. Since Ksat in agricultural lands is influenced by, among other factors, cropping and tillage practices (Das *et al.*, 2010), farmers can correct this by using better farming methods such as deep tillage to loosen the soil and application of manure that will improve soil structure.

Effect of water depletion on maize performance

Treatments T75 and T50 had no significance difference between them on above ground biomass (15.6 and 15.5Mgha^{-1}, respectively), canopy cover (67.6% and 64.7%, respectively) and grain yield (6.3 and 6.2Mgha^{-1}, respectively). The two treatments however had statistically ($P \leq 0.05$) higher above ground biomass, canopy cover and grain yield as compared to T25 (6.5Mgha^{-1}, 50.5% and 2.74Mgha^{-1}, respectively) (Table 2). The good performance of treatments T75 and T50 was probably because the two treatments didn't suffer moisture stress because the available water capacity (AWC) didn't fall below 50%, the critical point for crops such as maize (Thomas *et al.*, 2019).

Table 2. Means of above ground biomass, canopy cover, harvest index, stover and grain yield.

Treat ments	AGB (Mgha^{-1})	CC (%)	HI (%)	STY (Mgha^{-1})	GY (Mgha^{-1})
T75	15.6^a	67^a	40.6^b	9.2^a	6.29^a
T50	15.5^a	64.7^a	40.3^b	9.2^a	6.188^a
T25	6.5^b	50.5^b	42.0^a	3.8^b	2.74^b
P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
LSD	0.42	4.62	1.13	0.391	0.136
R^2	0.997	0.917	0.768	0.99	0.99
CV	2.3	5.2	1.89	3.63	1.84

Legend: T75 - irrigation to or near field capacity when 25% of available water capacity (AWC) is depleted, T50 - irrigation to or near field capacity when 50% of AWC is depleted, T25 - irrigation to or near field capacity when 75% of AWC is depleted, ABM-above ground biomass, CC-canopy cover, HI-harvest index, SY-stover yield and GY-grain yield.

'Water engine' model (Yang *et al.*, 2004) suggests that there is a linear relationship between yield to amount of water transpired and that enough water led to high rate of photosynthesis hence higher vegetative growth. Treatment T25 received 305mm of supplemental irrigation water against an evaporative demand of 523mm for the growing season (Table 4), giving an r/ETo ration of 0.58 while that of T50 and T75 were 0.83 and 1.05, respectively; this is an indication that treatments T75 and T50 received enough water for crop growth while water supplied to T25 could not meet the crop water requirement. Consequently, the treatment gave significantly ($P \leq 0.05$) low grain yield, canopy cover and aboveground biomass as compared to T50 and T75 (Table 4).

Grain yield for treatment T25 was 55 and 56% lower compared to that attained in T50 and T75 treatments, respectively (table 3). When moisture fell to 25% of AWC, plants showed signs of moisture stress such as curling of leaves (fig. 2) probably because it became harder for plant roots to extract water because it was held at higher pressure in the soil matrix.

Fig. 2. Curled maize leaves as an indicator of moisture stress.

Water shortage is a major abiotic factor that limits agricultural crop production (Geoff, 2002; Nemeth *et al.*, 2002; Chaves and Oliveria, 2004; Lea *et al.*, 2004; Ramachandra *et al.*, 2004; Seghatoleslami *et al.*, 2008; Jaleel *et al.*, 2009 and Golbashy *et al.*, 2010). Inadequate water to crops leads to inhibited cell expansion and reduced dry matter accumulation due to decrease in chlorophyll content, which reduces the amount of food produced in the plant (Lack *et al.*, 2014, Libing *et al.*, 2016, Jain *et al.*, 2019).

As irrigation water increased, crop production also increased significantly. For instance, grain yield increased from 2.8 in T25 to 6.2 and 6.3Mgha^{-1} in T50 and T75, respectively (Table 3) as irrigation water increased from 305 mm in T25 to 435 and 549 mm in T50 and T75, respectively (Table 4) during the growing period. Hayrettin *et al.* (2013) observed that, as seasonal ET increased from 305mm for the non-irrigated treatment to 1133mm of irrigation water, grain yield also increased. For most crops grown under irrigated conditions, the allowable soil moisture deficit is 50% of the available moisture during critical growth stages, and up to 65% during stages of anthesis and grain filling (Thomas *et al.*, 2019; Zhandong *et al.*, 2014).

Below 50% AWC, the crop is considered in danger of undergoing enough stress to suffer a reduction in yield. Yenesew and Tilahun (2009) had similar findings where they observed that, stressing crop by 75% resulted in the highest yield reduction. According to Cakir (2004), water stress leads to reduced leaf area, lower crop growth rate, and reduced plant height and shoot dry matter. Farshad *et al.* (2008) showed that silking stage is the most sensitive.

Further, Westgate (1994) observed that water shortages may prolong the time from silking to pollen shed and limit the grain filling period severely, lowering grain yield. Pandey *et al.* (2000) observed yield reduction of 22 to 26% caused by decrease in leaf area as a result of water stress. Decreased leaf area reduces the fraction of photosynthetic active radiation (PAR) absorbed by the green vegetation hence decreasing net primary production. The result is reduction in grain number and weight.

Table 3. Grain yield, biomass and Water Use Efficiency.

Treatment	Grain yield (Mgha^{-1})	Water use efficiency (kgm^{-3})
T75	6.3[a]	1.4[a]
T50	6.2[a]	1.3[b]
T25	2.8[b]	0.6[c]
Means	5.11	1.1
P-value	<0.0001	<0.0001
LSD (0.05)	0.40	0.08
CV (%)	5.01	4.96

Legend: T75 - irrigation to or near field capacity when 25% of available water capacity (AWC) is depleted, T50 - irrigation to or near field capacity when 50% of AWC is depleted and T25 - irrigation to or near field capacity when 75% of AWC is depleted.

Table 4. maize yield in season II (long rain).

Treatment	GDD °C.day	Irri (mm)	Infil. (mm)	Runoff (mm)	Drain (mm)	Biomass $Mgha^{-1}$	HI %	Yield $Mgha^{-1}$	WPet Kgm^{-3}
T25	1726	305	337	0	0	6.5	43.1	2.8	0.6
T50	1726	435	459	0	111	15.5	40.0	6.2	1.4
T75	1726	549	708	0	0	15.6	40.4	6.3	1.3

Legend: T75 - irrigation to field capacity when 75% of PAW is depleted, T50 - irrigation to field capacity when 50% of PAW is depleted, T25 - irrigation to field capacity when 25% of PAW is depleted, Td - daily irrigation treatment, Tw - 7 days interval irrigation treatment, Tbw - 14 days interval irrigation treatment, Ttw - 21 days interval irrigation treatment

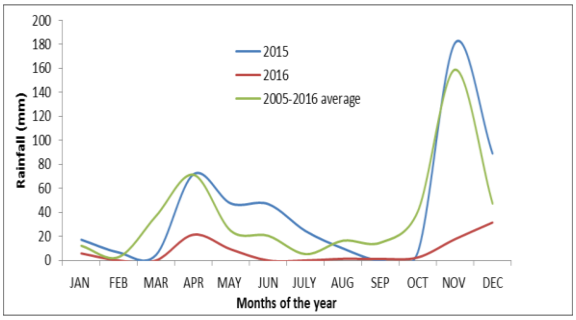

Fig. 3. 2005 - 2016 average rain and 2015 and 2016 rain.

Effect of water depletion on water use efficiency

The water use efficiency (WUE) for all treatments were significantly ($P \leq 0.05$) different with the highest recorded in T75 (1.4 Kgm-3) while the lowest (0.6 Kgm^{-3}) was recorded in T25. Treatment T50 recorded 1.3 Kgm^{-3} (Table 3) though it used less irrigation water (435 mm) compared to T75 (549 mm). Stress caused by a 25% and 50% reduction in applied water in treatments T50 and T25, respectively could have caused reduction in yield and WUE significantly. Mahdi *et al.* (2004) obtained the highest WUE for maize irrigated at 85% while Kannan *et al.* (2009) obtained at 70% of crop water application, which had no significant difference with treatments receiving 85% of crop water.

Shammout *et al.* (2016) obtained highest WUE when irrigating at 80% AWC and recommended irrigation at 80%. Hailu *et al.* (2015) obtained highest WUE with 100% irrigation, though the treatment used 39.75% more water than treatment irrigated at 75% ET.

Supplemental irrigation water for optimal growth for T50 treatment was estimated to be 420 mm for the growing season (planting to physiological maturity), though the fig. may vary depending on seasonal rain received. This gave a mean daily crop evapotranspiration (ETc) of 4.6mm against a daily ETo of 5.2mm, obtained from the weather station in the research center. The average evapotranspiration of the crop rose from $1.085mmday^{-1}$ for the initial stage to 8.4mm during the middle stage when the crop had highest evaporative demand due to fully established canopy. Irrigation and rainfall were the only source of crop water because underground water was found to be below 2m. Variation in soil water content was presumed to be due to evapotranspiration because it was assumed that deep percolation below 1m depths of soil was negligible and, no water was lost through runoff either.

Conclusion

The results of this study show that the quantity of irrigation water used has a positive impact on maize output in the scheme. The impact is significant at 95% confidence level and there was sufficient evidence to reject the null hypothesis.

Supplemental irrigation is important in ASAL regions where rain received during the growing season is not sufficient to support a healthy crop. However, due to serious water shortage and high cost of abstraction, where either diesel or electricity are used to pump, water saving farming and improvement of its efficient use at farm level are crucial. The researchers found that supplemental irrigation at 50% saved on irrigation water and didn't lead to significant reduction in yields.

Recommendations

- Supplemental irrigation at 50% AWC is recommended for the scheme. It uses less water and yet yields have no significant difference with irrigation at 75% AWC, which uses more water. T25 should not be recommended for adoption in the study area.

- Grain yield of over 6.0Mgha^{-1} is attainable in the scheme with proper irrigation practices. The experiment attained 6.3 and 6.2Mgha^{-1} for T75 and T50 treatments, respectively.
- Short rain is the recommended cropping season as opposed to long rain. The season receives much of the rain in the year. This is based on the 2005-2016 average (fig. 3). Cropping during this season will mean that less irrigation water will be needed for deficit irrigation.

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