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MORE CROP PER DROP: THE MAGIC OF SWEET POTATO
(*Ipomoea batatas* L.) †

[MÁS CULTIVO POR GOTA: LA MAGIA DE LA PATATA DULCE
(*Ipomoea batatas* L.)]

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SUMMARY

Background: Water is the most valuable resource in agriculture. Agricultural development in semi-arid eastern Kenya is essentially dependent on intermittent rainfall. An accurate estimate of sweet potato water usage and productivity is considered a significant feature of conservation agriculture under such climatic conditions. **Methodology:** The research was conducted for two seasons, from December 2018 to April 2019 and October 2019 to March 2020, with the aim of quantifying the water use efficiencies of two sweet potato varieties, Kabode and Bungoma. Assuming that there were no variations in water-use efficiency between the two varieties. The experiment was established as RCBD for the two seasons. Treatments comprised of sole sweet potato varieties of Kabode and Bungoma, together with their intercrops with common beans. **Results:** Seasonal effective rainfall values were 302 and 639.2 mm, whereas the mean saturation pressure deficit recorded was 2.5 and 2.4 Kpa for S (I) and S (II), respectively. This presented S(I) with 815.1 mm ET_{crop} demanding 622.1 mm irrigation water, whereas S(II) envisaged a 3.3% decrease in ET_{crop} values; 788 mm and requiring 427.6 mm of supplemental irrigation water to attain optimal sweet potato yields. Similarly, the test crops paraded WUE values of 39.8 and 30.0 kg ha⁻¹ mm⁻¹ and water productivity indices based on rain water were 1.11 and 0.95 kg m⁻³ for Kabode and Bungoma varieties, respectively. HI for S (I) were 40.8 and 35.4% whilst 54.2 and 46.8 % for Kabode and Bungoma varieties, respectively. **Implications:** WUE values of the sweet potato crop increased from warm-dry season S (I) to the warm-wet season S (II), as Kabode portrayed a higher adaptability. These results provide an acumen for decision making in the setting of climate change. **Conclusions:** Kabode variety differed significantly with Bungoma variety in their abilities to efficiently use water, thus portraying its adaptability in such a peculiar environment. The climatic environment: dew point temperatures and saturation pressure deficit had no significant impact on sweet potato water use efficiency.

Key words: Water use efficiency; crop water productivity; climate change; sweet potato production.

RESUMEN

Antecedentes: El agua es el recurso más valioso en la agricultura. El desarrollo agrícola en la semi árida región este de Kenia depende esencialmente de lluvias intermitentes. Una estimación precisa del uso de agua y la productividad de la batata se considera una característica importante de la agricultura de conservación en tales condiciones climáticas. **Metodología:** La investigación se realizó durante dos temporadas, de diciembre de 2018 a abril de 2019 y de octubre de 2019 a marzo de 2020, con el objetivo de cuantificar las eficiencias en el uso de agua de dos variedades de boniato, Kabode y Bungoma. Suponiendo que no hubo variaciones en la eficiencia del uso del agua entre las dos variedades. El experimento se estableció como RCBD para las dos temporadas. Tratamientos compuestos por variedades de boniato Kabode y Bungoma, junto con sus cultivos intercalados con frijol común. **Resultados:** Los valores de precipitación efectiva estacional fueron 302 y 639.2 mm, mientras que el déficit de presión de saturación promedio registrado fue de 2.5 y 2.4 Kpa para S (I) y S (II), respectivamente. Esto presentó S (I) con 815.1 mm de ET_{crop} demandando 622.1 mm de agua de riego, mientras que S (II) preveía una disminución de 3.3% en los valores de ET_{crop} ; 788 mm y requiere 427.6 mm de agua de riego suplementaria para lograr rendimientos óptimos de camote. De manera similar, los cultivos de prueba mostraron valores de WUE de 39.8 y 30.0 kg ha⁻¹ mm⁻¹ y los índices de productividad del agua basados en el agua de lluvia fueron 1.11 y 0.95 kg m⁻³ para las variedades Kabode y Bungoma, respectivamente. Los HI para S (I) fueron 40.8 y 35.4% mientras que fueron 54.2 y 46.8% para las variedades Kabode y Bungoma, respectivamente. **Implicaciones:** Los valores de WUE del cultivo de camote aumentaron de la estación cálida-seca S (I) a la estación cálida-húmeda S (II), ya que Kabode describió una mayor adaptabilidad. Estos resultados proporcionan una visión para la toma de

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decisiones en el contexto del cambio climático. **Conclusiones:** La variedad Kabode difería significativamente de la variedad Bungoma en sus habilidades para usar el agua de manera eficiente, lo que refleja su adaptabilidad en un entorno tan peculiar. El entorno climático: las temperaturas del punto de rocío y el déficit de presión de saturación no tuvieron un impacto significativo en la eficiencia del uso del agua de la batata.

Palabras clave: Eficiencia en el uso del agua; productividad del agua de los cultivos; cambio climático; producción de batata.

INTRODUCTION

Plants actively re-program their growth in response to abiotic pressures by modulating both cell division and expansion (Skirycz and Inzé, 2010). Growth decreases rapidly upon stress onset but it recovers and adapts once stress conditions become stable. To minimize the deleterious effects of stress and to complete their life cycle under adverse conditions, plants have evolved different adaptive responses that are summarized in the avoidance/tolerance model (Hashem and Mohamed, 2020). For example, during drought, plants close their stomata and accumulate compatible solutes to maintain a low water potential and to avoid dehydration. Exposure of plants to mild stress reduces cell number (Chmielowska-Bąk and Deckert, 2021). This decrease in cell number might result from either a longer duration of single cell division cycle and/or a shorter developmental window for cell proliferation. A more promising strategy will be to optimize plant growth so as to minimize its inhibition by mild stress (Ul Hassan, *et al.*, 2021). As long as the stress is moderate under mild climates, such plants would accumulate a maximum of biomass during their life cycle (Chaudhry and Sidhu, 2021). For this reason, an understanding on the mechanisms underlying growth regulation is essential and some important pre-requisites have to be fulfilled.

WUE, which indicates the quantity of dry matter created per unit of water used up in evapotranspiration, is used to quantify agricultural productivity in water-stressed areas (Molden, 1997). WUE is the functional physiological mechanism that allows crops to tolerate low soil moisture content and perform well under water stress conditions, defined as total biomass produced per unit area to evapotranspiration (Shao *et al.*, 2008). It creates a trade-off between carbon fixation and water depletion, which occurs in crops grown in ASALs due to evaporation of water from interstitial tissues of leaves as stomata open for CO₂ acquisition (Bramley *et al.*, 2013).

Experiments on WUE have been conducted throughout the world especially on cereals and legumes involving monocrop and intercrop, providing significant data with regards to the crops WUE and aiding in identifying drought adaptation traits (Juma, 2012). Such traits are critical for breeding of improved WUE crops under drought conditions. Agronomic interventions that aim at minimizing the amount of water losses and accurately transmitting water to the crop roots tend

to upsurge WUE. Likewise, any agronomic management activity that increases yields ultimately increases WUE. Besides, measures to increasing WUE entails controlling physiological processes that distress crops transpiration activities and yields (Hsiao and Bradford, 1983).

Studies by Masango (2014) in South Africa postulated that WUE increased by lessening the amount of water used up by sweet potato. WUE values ranged between 64.8 -97.5 kg mm ha⁻¹ under irrigation, whereas Onder *et al.* (2005) had values ranging from 33.2-75.9 kg ha⁻¹ mm⁻¹. This symbolises that crops parade higher WUE values under low or limited water supply. Gomes and Carr (2003) on the other hand in Mozambique deduced that under irrigated conditions, sweet potato had WUE of 85 kg mm ha⁻¹. In such cases, supplemental irrigation practices are beneficial to improving WUE, especially the most sensitive phenological growth stages of sweet potato such as tuber bulking (Dalla Costa and Giovanardi, 2000). Water supply is a prerequisite to meeting the ET_c demand and a major tool for increasing WUE. Li *et al.* (2010) pointed out that alternative fractional root irrigation had optimistic effects on WUE and leaf relative water content in maize plants. Generally, increasing WUE calls for the correct scheduling of irrigation and application based on the crop water needs, which can be realized through soil moisture measurements or monitoring differences in soil water storage (De Pascale *et al.*, 2011).

CWR are a vital constituent to warrant better scheduling of irrigation a factor that has been studied all over the world on various crops. However, variation in climate, differences in crop varieties and crop growth conditions have brought about difficulties in application of the various research findings from outside Katumani. Thus, information on sweet potato water needs specifically for the semi-arid part of Machakos is lacking. Hence the study was geared towards quantifying sweet potato water use and efficiency as an early warning and mitigation towards climate change.

MATERIALS AND METHODS

Study site

The research was carried out at the Katumani Research Centre in Machakos County, agro-ecological zone IV (Jaetzold *et al.* 2006). The elevation is 1624 meters above sea level, and the centre coordinates are -1.585543 and 37.240090.

Katumani experiences a bimodal rainfall distribution, with long rains beginning in March and ending in May, and short rains in November to mid-December. The mean daily maximum and minimum temperature are 24.7 and 13.7 °C, respectively with mean annual rainfall approximately 450-600 mm (Jaetzold *et al.*, 2006). The soils have a sandy clay

loam texture (Gicheru and Ita, 1987; Deckers *et al.*, 2003; Mwendia *et al.*, 2017). The site is suitable for Katumani maize (*Zea mays*) variety, sweet potato (*Ipomoea batatas*), beans (*Phaseolus vulgaris*), pigeon peas (*Cajanus cajan*) and mangoes (*Mangifera indica*).

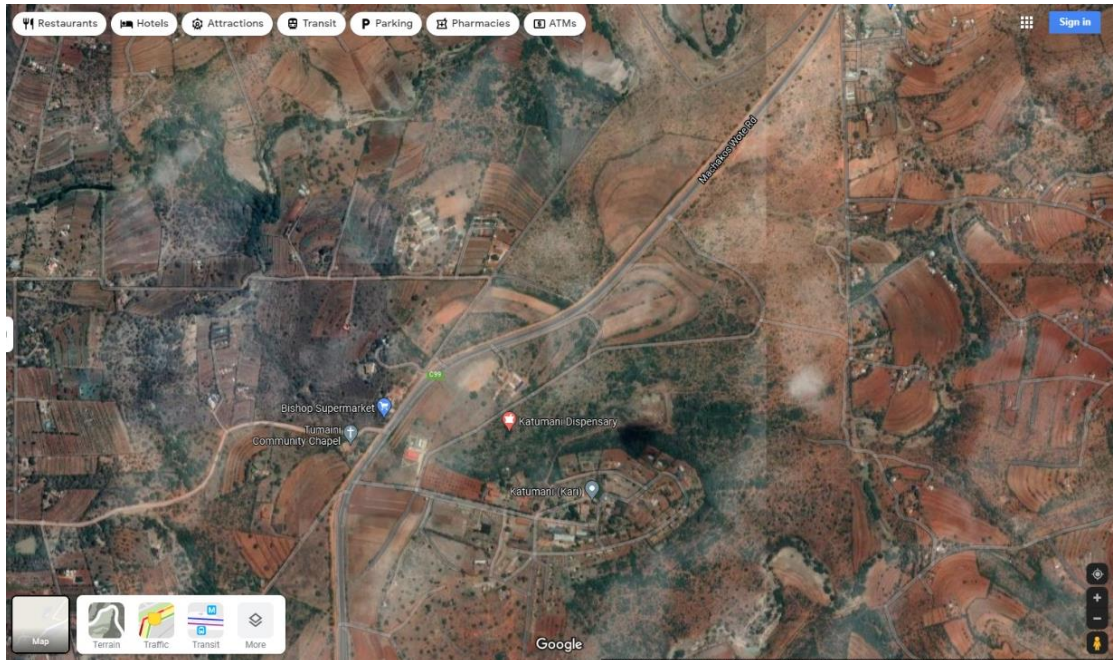


Figure 1. Experimental site. (Source Google earth).



Figure 2. Experimental layout and treatments.

Experimental design layout and treatments

A total of 15 pots were laid out from South East to North West direction in a RCBD, with each block having 5 treatments replicated 3 times. The experimental plots were 4m wide and 5m long. Spaces separating the plots and the blocks were 0.5 m and 1m, respectively. The plots were laid out on a 5% natural slope between two *Fanya-chini* terraces. *Fanya-chini* terraces are created by digging and heaping the soil upwards, creating bunds at the upper sides of the ditches. A narrow ledge between the ditch and the bund prevents the soil from fading away (Tenge *et al.*, 2011). Treatment combinations comprised of; **V1**: Monocropped Kabode (orange-fleshed), **V2**: Monocropped Bungoma (white-fleshed), **B**: Monocropped common beans (*mwezi mbili*), **V1M**: Kabode + common beans intercrop and **V2M**: Bungoma + common beans intercrop.

Agronomic practices on the experimental plots

The land was manually cleared using a hand hoe and ridges constructed 1m apart. Sowing was done at the onset of the rains. Season (I) commenced in November 2018-April 2019, whereas Season (II) from October 2019-March 2020. Sweet potato vines were planted at a spacing of 25 cm × 60 cm in each plot whereas common beans (*mwezi mbili*) were planted on top of the ridges at 5 cm depth and 25cm spacing within the row. Hand weeding was done with the aid of a hoe soon as weeds emerged throughout the cropping period. Pests and diseases were controlled upon incidence. Emamectine Benzoate 19g/L to control caterpillars and Lambda Cyhalothrin 50g/L was sprayed on beans to control bean fly. Earthing up sweet potato ridges with soil was done as the need arose. Harvesting of sweet potato was done 160 days after sowing at the point when the end of the vines had started yellowing. This was done by hand digging with a hoe up the ridges and uprooting the whole plant and removing the tubers.

Data collection

Weather data

Rainfall (mm), relative humidity, saturation pressure deficit (Kpa), and dew point temperatures (°C) were recorded daily from the site meteorological weather station.

Dew point temperatures and saturation water vapour pressure was computed using the dew point calculator (<https://www.calculator.net/dew-point-calculator.html>) (Logan and Nordstrom, 1985).

Effective rainfall was computed based on the United States Department of Agriculture, Soil Conservation Service (USDA-SCS) method as described in FAO publication by Dastane (1978) Eqn 1.

$$eff = \frac{tot \times 125 - 0.2 tot}{125} \quad (1)$$

Where, eff = effective rainfall (mm) and tot = total rainfall (mm).

Crop water requirements

In order to estimate sweet potato water needs, the Penman-Monteith (1948) equation utilized as described by Allen *et al.* (2006) in calculating crop evapotranspiration, Eqn 2.

$$\gamma ET_o = \frac{\Delta(Rn - G) + \rho_a C_p \frac{es - ea}{ra}}{\Delta + \gamma(1 + \frac{rs}{ra})} \quad (2)$$

Where: Rn - net radiation, G - soil heat flux, $(es - ea)$ - air vapour pressure deficit, ρ_a - mean air density under constant pressure, C_p - specific heat capacity of the air, Δ - slope of the relationship between saturation vapour pressure and temperature, γ is the psychrometric constant, and rs and ra are the (bulk) surface and aerodynamic resistances.

Sweet potato water needs were computed with the aid of CROPWAT model adopting equation 3; (Gomes and Carr, 2003), based on the growth stage, crop coefficient values and the sites reference evapotranspiration.

$$ET \text{ sweet potato} = ET_o \times Kc \quad (3)$$

Water use efficiency (WUE)

Since it was not practical to distinguish WUE for each component crop in the intercrop systems, it was only computed for the sweet potato based on the attained yield and evapotranspiration as to using the water balance approach which happens to be a bit cumbersome.

As a result, water productivity of a single cropping was calculated based on seasonal crop consumptive use. (Koech *et al.*, 2016; Djaman *et al.*, 2018) Eqn 4:

$$WUE \text{ (kg /ha/mm)} = \frac{\text{Economic Yields}}{\text{Evapotranspiration (mm)}} \quad (4)$$

Crop water productivity under rain fed was computed based seasonal crop consumptive use (SWU) (Igbadun *et al.*, 2006) Eqn 5:

$$CWP = \frac{\text{price} \times \text{crop yield}}{\text{(seasonal evapotranspiration)}} \quad (5)$$

The harvest index was also determined using Eqn 6:

$$HI = \frac{\text{tuber yield (kg)}}{\text{weight of total biomass(kg)}} \times 100\% \quad (6)$$

Statistical analysis

This was accomplished using of GenStat 19th edition (Lane and Payne, 1997). A two-way ANOVA was used to determine effects of treatments and seasons on the measured response variables. A Bonferroni test of significance was performed at $P \leq 0.05$ and used in comparing means of the measured variables.

RESULTS AND DISCUSSION

Climatic environment as a factor of crop water use and efficiency

Table 1 presents the effective rainfall, dew point temperatures and saturation pressure deficit during the growth stages.

Effective rainfall

Lower effective rainfall values were recorded in season (I) throughout the tuber bulking and harvesting stages; 18.5 and 8.4 mm dec⁻¹, respectively. Similarly, higher ER were observed at initiation and vegetative development stage yielding 91.6 and 183.7 mmdec⁻¹, respectively. On the contrary, season (II) at the tuber bulking stage, sweet potato encountered a significantly ($p < 0.05$) higher ER such that; tuber bulking, vegetative, initiation and harvesting were reported at 164.5, 185.1, 159 and 130.4 mmdec⁻¹, respectively, yielding a higher amount of soil water recharge relative to the atmospheric demand. In semi-arid regions effective rainfall illustrates in totality of rain water available in the crop root zone. It necessitates soil water recharge and enables a crop to meet its evapotranspiration demand (Karuku *et al.*, 2014; Mbayaki and Karuku, 2021a). Effective rainfall is mainly influenced by the land, soil, groundwater, rainfall and crop characteristics (Athar, 2020). In this regard, un-even distribution of rainfall decreases the ER, whereas a higher ET in crops creates a larger moisture depletion, hence the ER becomes indirectly proportional to the rate of water uptake by crops (Dastane, 1974; Croke and Jakeman, 2004). Low rainfall meant little recharge of the soil, decreasing the available water and increasing the soil matric potential, thus, decreasing plant water uptake and

productivity (Kendy *et al.*, 2003). In critical growth stages of sweet potatoes, low ER reported in the tuber bulking stage may decrease in leaf area index (LAI), vine length and an increase in the concentration of Absciscic acid (ABA) in roots and shoots, increasing its metabolic toxicity and subsequent yield affected (Obidiegwu *et al.*, 2015). These conditions are consistent with the results of (Picotte *et al.*, 2007), which suggest that most crops have higher water use under drought conditions, thus prompting them to strengthen their competitiveness due to low available moisture. Related to findings of (Karuku *et al.*, 2014), demonstrating the effects of low rainfall on soil water as a precursor to low crop yields. These differences in ER between the two seasons (I) and (II) may be referred to as a warm-dry season with maximum water use (ETc) and a minimal water use warm-wet season.

Dew point temperatures

Dew point temperatures recorded in season (I) ranged from 10-15 °C with lower values recorded at harvesting and tuber bulking as 10.4 and 12.8 °C, respectively. Higher dew temperatures were recorded at planting and during the vegetative growth recording 14.1 and 14.5 °C, respectively. Season (II) had significantly ($p < 0.05$) higher dew point temperatures across all the growth stages. These were: 14.9, 15.9, 15.1 and 15.6 °C at planting, development, tuber bulking and upon full crop maturity, respectively. Among other agro-climatic factors, agricultural sweet potato production is also influenced by frost or dew point temperatures (Raymundo *et al.*, 2014). Dew point temperature below 0°C are referred to as the frost point (Shank *et al.*, 2008). The low dew point temperatures recorded in the critical crop's growth stage (tuber bulking) may have impacted negatively on sweet potato survival since it experienced a low vapour condensation, hence a low soil moisture recharge thus raising crop water use in such a stage. Presence of dew creates temporary humid conditions, replenishing soil moisture and thus reducing soil water loss in ASALs (Mott and Parkhurst, 1991). Such dew point temperatures are consistent with the findings of (Spence and Humphries, 1971), who stated that sweet potato growth is mainly affected by

Table 1. Climatic data during the sweet potato phenological growth stages.

Season	Growth stage	Growth days	ER (mm/dec)	Dew point (°C)	SVP (Kpa)
Season (I)	Initial	40	91.6	14.11	2.4
	Vegetative and tuber initiation	42	183.7	14.54	2.3
	Tuber bulking	39	18.5	12.78	2.5
	Harvest	39	8.4	10.44	2.6
Season (II)	Initial	40	159.2	14.92	2.3
	Vegetative and tuber initiation	42	185.1	15.86	2.3
	Tuber bulking	39	164.5	15.09	2.4
	Harvest	39	130.4	15.55	2.5

Key: ER; effective rainfall, SVP; saturated water vapour pressure

dew temperatures ranging from below 10 °C and damaged at 1 °C. Thus, dew point temperature together with wet-bulb temperature can be vital in determining a crops critical-damage air hence, helpful in predicting impacts of climate variation in crop production especially in warm-dry areas (ASALs) (Snyder and de Melo-Abreu, 2005).

Saturated water vapour pressure

From the study, the observed saturated water vapour pressure deficit in season (I) was; 2.4, 2.3, 2.5 and 2.6 Kpa at initiation, vegetative development, tuber bulking and harvesting stages, respectively. In season (II), the observed SVP increased as the crop approached harvesting. SVP recorded were; 2.3, 2.3, 2.4 and 2.5 Kpa at planting, vegetative development, tuber bulking and upon the crop's maturity, respectively. In the changing climate regimes, saturated vapour pressure plays a hidden role especially in producing drought-resistant crops (Hsiao *et al.*, 2019). The lowest deficit in vapour pressure experienced was during the stage of vegetative growth and higher at tuber bulking and harvesting stages. Under high SVP conditions, transpiration increases in most terrestrial crops, hence reducing photosynthesis and carbon uptake, crop growth and thus a low water use efficiency (McDowell *et al.*, 2008). At a higher SVP, most plants close their stomata thus decreasing CO₂ hence a reduction in photosynthesis, biomass production and the resultant yield. Similarly, Howell and Dusek (1995) reported a vapour pressure deficit of approximately 1.8 Kpa which resulted in a higher WUE in most crops. Similarly, these results are in collaboration with the optimum range of SVP (0.5 to

2.5 Kpa) described by Wang *et al.* (2004). Therefore, higher SVP at harvesting (2.6 Kpa) had no significant effect on water use since the vegetative parts had withered thus posing a unique transpiration pattern (Tambussi *et al.*, 2007). In general, season (II) was a warm-wet season marked by a lower SVP relative to the season (I). In conditions with a lower SVP, crops undergo a reduced transpiration rate that does not reflect water-saving capacity (Fletcher *et al.*, 2017). Saturation vapor pressure deficits govern air dryness, and thus an increase in saturation vapor pressure may lead to a subsequent decrease in dew point temperature, especially in semi-arid areas, which explains the differences between season (I) and (II). Therefore, considering the effects of vapour pressure deficits on crop water use and yields is a vital aspect for future projections under rain fed agriculture with the rising levels of CO₂.

Crop and irrigation water requirements

Table 2 presents the crop and irrigation water needs for sweet potato throughout the experimental period.

The cumulative seasonal ET sweet potato in S (I) was 815.1 mm and 788 mm in S(II) recording a 3.3% decrease, necessitating 622.1 and 427.6 mm of irrigation water. Similarly, across both seasons, the highest water use was recorded during the reproductive stage in S(I) and S(II) totalling to 346.9 and 333.4mm, respectively, depicting a 3.9% decrease in ET sweet potato. Similarly, these reproductive stages demanded more irrigation water; 328.8 and 170.6mm in S(I) and S(II), respectively.

Table 2. Sweet potato water requirements.

Month	Stage	Kc coeff	S (I)		S (II)	
			ETc mm/dec	Irr. Req. mm/dec	ETc mm/dec	Irr. Req. mm/dec
Oct	Init	0.4	0	0	0	0
Oct	Init	0.4	0	0	0	0
Nov	Init	0.4	0	0	0	0
Nov	Init	0.4	76.3	35.3	75.6	27.6
Nov	Deve	0.41	57.1	14	56.5	9.2
Dec	Deve	0.54	22.4	0	21.7	0
Dec	Deve	0.74	29.7	0	28.9	0
Dec	Deve	0.94	43.4	5.5	42	0
Jan	Mid	1.14	49.8	34	48.2	0
Jan	Mid	1.21	54.9	54.7	53.1	1.2
Jan	Mid	1.21	62.6	62.1	59.5	19.1
Feb	Mid	1.21	179.6	177.5	172.6	150.3
Feb	Late	1.19	239.5	239	230	220.3
Feb	Late	1.05	0	0	0	0
Mar	Late	0.87	0	0	0	0
Mar	Late	0.66	0	0	0	0
Mar	Late		0	0	0	0
Cumulative (mm)			815.1	622.1	788	427.6

Key: Init; initiation; Dev; development, Mid; reproductive, late; maturity, Kc; crop coefficient, ETc: sweet potato crop evapotranspiration.; Source: CROPWAT output.

Table 3. Water Use Efficiency (WUE) and productivity.

	Season (I)			Season (II)		
	WUE	HI %	CWP	WUE	HI %	CWP
Kabode	6.56	40.8	0.22	73.08	54.2	2
Bungoma	6.44	35.4	0.21	53.48	46.8	1.7
LSD (5%)	4.268	18.8	0.1408	9.81	8.1	0.3237
SED	1.744	7.71	0.0576	2.83	3.31	0.1323
F pr.	0.603	0.237	0.603	0.001	0.036	0.001
CV %	37.5	28.5	37.5	8.6	7.8	8.6

Key: WUE (tuber); water use efficiency ($\text{kg ha}^{-1}\text{mm}^{-1}$), HI: harvest index, CWP: crop water productivity (Kgm^{-3})

Most regions in the ASALs are characterised by warm-dry climatic scenarios, crops parade a maximum water use (ET_{crop}) whereas the warm-wet ones have a low water usage. Such scenarios could have been aggravated by the low amount effective rainfall received in S(I), creating minimal soil water recharges, low aridity indices and eventually shortening the humid period. Such water supply deficits have been caused by an erratic distribution of rainfall, which may have created a significant imbalance in the soil water budget, creating a faster rate of aging in crops and thus a shorter life span hence, the discrepancies in the rates of water use in the two seasons (Thorne-Miller *et al.*, 1983). The low (ET_{crop}) observed in S (II) may have been created by a longer wet seasons which may have created a balance between rainfall and evaporation (ET_a=ET_m); root supply and leaf demand thus minimal ET sweet potato and this probably could lead to a high-water use efficiency (Zelitch, 1975; Monteith, 1977).

Water use efficiency, productivity and Harvest index

Table 3 presents the Water Use Efficiency (WUE) and Harvest Index (HI) of sweet potato throughout the experimental period.

Water use efficiency

Water use efficiency was expressed on a fresh tuber mass basis in both experimental seasons. In season (I), WUE values for Kabode and Bungoma varieties were 6.56 and 6.44 $\text{kg ha}^{-1}\text{mm}^{-1}$, respectively. On the contrary, season (II) recorded the highest WUE as Kabode and Bungoma variety yielded 73.08 and 53.48 $\text{kg ha}^{-1}\text{mm}^{-1}$, respectively. WUE describes the ratio of carbon assimilated during photosynthesis relative to transpiration in most terrestrial biomes (Niu *et al.*, 2011). Water use efficiency depicts the economic yield produced per the unit amount of water consumed by a crop. In this regard, most crops parade lower WUE values under low or limited water supply scenarios (Jones, 2004). Lower WUE values in season (I) could have alluded to the high amount of water use (ET_c) influenced by high SVP and low dew point temperatures compared to season (II) (Zhang *et al.*, 2015). Furthermore, low WUE might occur since most crop growth phases are very

long due to low-slung metabolic rates. Higher WUE values recorded in season (II) resulted from a decrease in the amount of water used up by sweet potato. This shows that in the production of sweet potato, a continuous supply of water throughout the season is needed and more interested should be taken at the tuber bulking stage (Mbayaki and Karuku 2021b). Similarly, the study observed that; an increase in water use efficiency corresponded with a decrease in sweet potato water use (ET_c). This is in contrast with the findings of Jones (2004) who observed that plants tend to experience a higher water use efficiency with a low supply of water based on environmental conditions. Thus, most crops within the semi-arid experience a short humid period (warm-dry season) within their production phased and thus much water is lost to the atmosphere via transpiration and very little is actually utilized for construction of carbohydrates and composition of plant tissues (Karuku *et al.*, 2014; Mbayaki and Karuku 2021).

Harvest index

In season (I) the HI of the two varieties was 40.8 and 35.4% for Kabode and Bungoma, respectively. Whereas in season (II) an increase in the HI was observed. A such, Kabode variety had 54.2 % whereas the Bungoma variety recorded a 46.8 % harvest index. The harvest index (HI) points to the efficiency in converting of photosynthates into an economic yield (Masango, 2015). The differences in HI values between the two seasons may have resulted from the difference in watering during the growing period (ER). Similarly, Rodiyati *et al.* (2005) showed that prolonged water stress reduced the rate of producing biomass and may end up changing its partitioning to the storage parts thereby impacting the economic yield.

Crop water productivity

The Crop water productivity (CWP) indices in season (I) were 0.22 and 0.21 kgm^{-3} for Kabode and Bungoma varieties, respectively. Whereas in season (II) higher CWP values were recorded compared to season (I) as Kabode had CWP indices of 2.0 kgm^{-3} while Bungoma variety had 1.7 kgm^{-3} . Crop water productivity (CWP) is a measure of how much crop is produced per volume of water used (Kang *et*

al.,2017). Climate, irrigation water management, and soil nutrient status can all be accounted for differences in CWP indices (Zwart and Bastiaanssen, 2004). Studies by Dong *et al.* (2001) in China found that the maximum CWP may go up to 2.20 kgm⁻³ upon application of manure and mulch improved soil water and temperature. Similarly, Karuku *et al.* (2014) indicated that incorporating residue in a cropping system may optimize on increasing soil water storage and thereby increasing crop economic yields as well as crop water productivity.

CONCLUSION

The present study investigated the impacts of environmental conditions on water use efficiency and productivity of sweet potatoes. Kabode variety differed significantly with Bungoma variety in their abilities to efficiently use water, thus portraying its adaptability in such a peculiar environment. The climatic environment: dew point temperatures and saturation pressure deficit had no significant impact on sweet potato water use efficiency. There's still a discrepancy of unexplained causes of variation in sweet potato WUE which may have been attributed to other factors not considered in this study. These findings may provide acumens for decision making in the setting of climate change and also for decision making at the beginning of the season, since the difference among variety's CWP might not be known to everybody.

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