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Determining the water use efficiency (WUE) of drought tolerant common bean varieties

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Abstract

In semi-arid regions, like Machakos, crops use only a small fraction of total rainfall received in many agricultural systems. An experiment was set up to evaluate initial soil characteristics, determine moisture retention using pF-curve as early warning for irrigation scheduling, determine moisture trends during phenological stages, determine water use efficiency (WUE) of grain and above ground biomass production of four selected bean varieties. The experiment was laid out in randomized complete block design with 4×3 Split-plot arrangement and replicated four times for two seasons of 2016 and 2017. The treatments were Conventional tillage, Minimum tillage and zero tillage replicated four times. The bean varieties were four in the order of GLPX92, KAT/B1, KATX56 and KATRAM replicated four times in a 4×3 Split-plot arrangement. Soil moisture was taken using neutron probe at different depths. The result shows that GLPX92 had the highest WUE followed by KAT/B1, KATX56 and KATRAM the least performing.

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Introduction

Common bean (*Phaseolus vulgaris* L.) in sub-Saharan Africa is a frontline crop in fighting hunger, malnutrition and poverty. The crop is a food secure and nutritious crop especially in this region (Namugwanya *et al.*, 2014). In Kenya, the greatest challenge is to grow enough food to feed the increasing population, which is increasing at 2.5% per annum (Mwehia, 2015). Katungi *et al.* (2011) argued that common bean is a leading legume in both production and consumption in Kenya. Namugwanya *et al.* (2014) estimated that the crop meet 50% of dietary protein requirement of household in SSA. Production of this crop has drop dramatically due to biotic and abiotic factors mostly in semi-arid areas of Kenya. However, soils of the study area has poor infiltration, surface capping, and ceiling with degraded land poor in major nutrients like N, P, and K. The pF curve is used as an early warning sign to soil moisture retention characteristics which is basically dependent on soil structure, texture and the crop under cultivation (Alphen *et al.*, 2000). Soils in the study area are difficult to till during cropping season due to extreme dryness and animals used to plough are very weak because of the lack of feed. Moreover, farmers without Ox and implements have to rent from their colleagues to plough hence causing delay and low yields. According to Kwena *et al.* (2017), any delays in planting, particularly at the start of the wet season bring risks of significant yield losses almost proportional to the time delay. In Tanzania, Bucheyeki and Mmbaga, (2013) attributed the low yield of the crop to the use of unimproved varieties with low yield potential.

This study aimed at evaluating the water use efficiency (WUE) of four varieties of common bean (GLPX92, KAT/B1, KATRAM AND KATX56) to bridge the production gap in the study area faced by moisture challenge due to climatic variability caused by drought hence crop failures in many semi-arid areas of Kenya. Koech *et al.* (2015), reported that under water deficient environments, WUE is a critical consideration of plant productivity hence, for semi-arid the study area, WUE will be refer to as rain water used by plants during the long rains (LR) and short rains (SR) seasons with higher value resulting in "more yield per drop" of rain water. However, other researchers like Sinclair *et al.* (1984) referred to WUE as the amount of dry matter per unit of water lost in both transpiration and evaporation. Under field condition, crop transpiration is difficult to determine (Mwehia, 2015). However, other researchers have measured transpiration by separating E from ETo since not all water received from rainfall goes to production shown in (Kinama *et al.*, 2005). Moreover, most of the water received is transpired by crop during greater atmospheric demand, and soil evaporation, runoff Kinama *et al.* (2007) and deep percolation. WUE was estimated using Transpiration (T) obtained from soil water balance in semi-arid Kenya. Soil evaporation was estimated at over 40% of the total rainfall and runoff as 10% of the total rainfall in monocrop maize under control treatment maize plot (Kinama *et al.*, 2005). However, Rost *et al.* (2009) explained that the main focus of arid and semi-arid areas on crop production is the efficiency with which water is used.

This study used ETO to determine the effect of drought tolerant common bean varieties on WUE, grain and biomass yields as a way of enhancing farmers' capacity in increasing yield with the available water using crops that are tolerant to drought under rainfed agriculture especially in arid and semi- arid areas of Kenya.

Materials and methods

Site Description

Katumani dryland Research Centre is located in Machakos County at latitude 01^o 34' S, longitude 37^o 14' E, and an altitude 1600 m above sea level and 80 km southeast of Nairobi. Rainfall is bimodal with annual mean rainfall as 711mm whilst the average seasonal rainfall is 301 mm for the long rains (March-May) and 283 mm for the short rains (October-December). The short rains tend to be more reliable for crop production than the long rains (Kwena *et al.*, 2017). Temperature range between 17 and 24°C (Jaetzold *et al.*, 2006). The mean potential evaporation is in the range of 1820 mm to 1840 mm per year (Gicheru and Ita, 2000).

However, the semi-arid eastern Kenya, rainfalls are unpredictable with coefficients of variation in seasonal rainfall often exceeding 50% (Kwena *et al.*, 2017).

Katumani is covered by Lixisols soils derived from granitoid gneiss of the Basement System Complex. They are deep to very deep, well drained, dark red to reddish brown, weakly structured and friable, with sandy and sandy loam near the surface (Gicheru and Ita, 2000). In semi-arid Eastern Kenya, soils are faced with fertility and slightly acidic in reaction.

The cation exchange capacity (CEC) of these soils is generally low to very low (e.g. 7.8 cmol kg^{-1}), (Composition *et al.*, 2016 and Itabari *et al.*, 2013). The soil also exhibits high erodibility, surface capping under raindrop impact resulting in poor infiltration of rain water hence high runoff, serious erosion, and lose of nutrients on many of the steeper cropland sites (Simpjol and Luhllfwa, 1996). The landscape of Katumani consists of flat to hilly elevations with a relief variation of 10 - 20 m. The slopes are straight to gradient range between 2% and 20% (Kutu, 2012).

Experimental Design and Layout

The experiment comprised of 12 treatments in a 4×3 split plot Randomized Completely Block Design (RCBD) and replicated four times. The sub-plots included four drought tolerant common bean varieties KAT/B1, KATX56, GLPX92 and KATRAM. The major plots comprised of three tillage systems: conventional tillage Ox-drift (CT), minimum tillage hand hoe (MT) and zero tillage (ZT) combined as follows: KAT/B1 in combination with CT, KAT/B1 in combination with MT, KAT/B1 in combination with ZT, KATX56 in combination with CT, KATX56 in combination with MT, KATX56 in combination with ZT, GLPX92 in combination with CT, GLPX92 in combination with MT, GLPX92 in combination with ZT, KATRAM in combination with CT, KATRAM in combination with MT, KATRAM in combination with ZT. The varieties were selected by farmers through a survey conducted in the study area through the assistance of local leaders within the three locations as well as with the extension liaison officers from Kenya Agricultural and Livestock Research Organization (KALRO), Katumani. However, the basis of selection according to the farmers was due to High WUE and grain yield and high selling rate.

The experimental plots measured 2 m × 8 m. Common beans were planted at a spacing of 50 cm between and 10cm within rows. Three seeds were planted per hole but were later thinned to two after germination to reduce competition for nutrients and increase proper growth within varieties. In the conventional tillage, the land was plowed using a chisel and tow oxen to pull the draft to till the soil a month before commencing of planting seeds in the field. The treatments were arranged in a 4 × 3 split-plot arrangement in Randomized Completely Block Design (RCBD). The land size of the experimental area was 61 m × 18 m. Plot size was 2 m × 8 m and rows between plots were 0.75 m.

The sub-plots were separated by a 1m path-way and the four blocks horizontally and vertically were separated by 3 m × 2 m path-ways respectively. There was a total sum of 48 plots with 48 access tubes for moisture reading drilled with auger, one in each plot excluding the 2 access tubes drilled out of the experiment plots for calibration of the 503 DR Hydro probe. However, weeding in the experimental plots and site area were done with hand hoe and spread on the soil surface beneath the crop to reduce soil moisture evaporation, thereby giving rise to soil moisture conservation for crop use. A map of the experimental site is shown in Fig. 1.

Data collection

Soil sampling and analysis

This was carried out on total N, available P, and soil pH, total K, Ca, Mg, Mn and Al before planting. These were done to establish the initial nutrients status of the soil before conducting the experiment. Total N was determined by Kjedhal method (Bremner, 1996), while available P was determine using and Olsen method (Olsen *et al.*, 1954). Soil pH was done in the ratio 1:2.5 soil to water. Total cations were analyzed using Mehlich method and determined using Atomic Absorption Spectrophotometer (Mehlich *et al.*, 1962 and Hinga *et al.,* 1980).

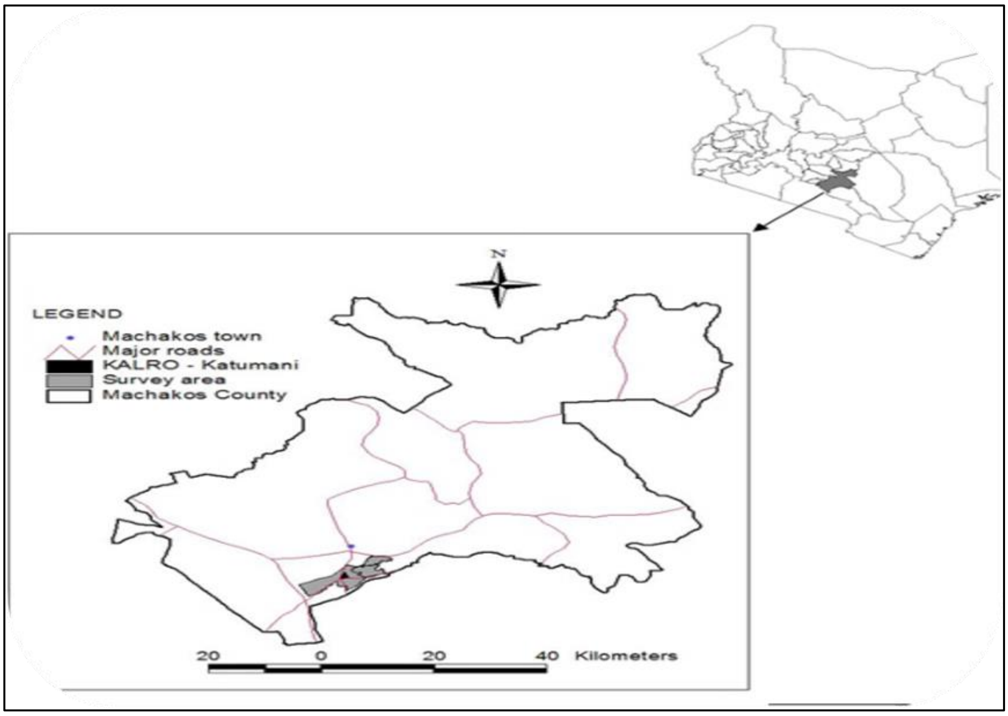


Fig. 1. Shows experimental site of the study area**.**

Soil Field Capacity and Permanent Wilting Point

These were determined from soil samples collected in the field from the Katumani Research station using core rings sealed with lid and taken to Kenya Agriculture Research and livestock Organization Laboratory Westland branch where the soil was analyzed at various points as follows: pF 0, 2.0, 2.3, 2.5, 3.7 and 4.2 pressures (N/m^2) to determine the retention of soil moisture (m^{-3}.m^{-3}) by pressure plate method (Klute, 1986).

Total Available Water Content (TAWC) (M^{-3}.M^{-3})

This was taken bi-weekly throughout the phenological stages of plant using a neutron probe (503DR Hydro probe) lowered down into the access tubes installed in every sampling unit in the experimental area. A total of 50 tubes were installed, one each in every plot. A total of 48 tubes were used for the experimental units while two tubes were used for calibration at every sampling time of which probe is lowered down the tubes to collect moisture readings from 20cm up to 80cm depth.

Calibration of the neutron probe

The probe was calibrated using the gravimetric water content (g/100g soil) by plotting a graph of the ratio of neutron counts and standard count against gravimetric water content. A line of best fit was developed with y = mx + c equation. Where y - gravimetric water content, m - gradient, x - is the neutron counts and C is the y interception in this case zero interception. All the neutron probe readings were converted into gravimetric readings by multiplying with m gradient of the line of best fit. Finally, the gravimetric water readings were converted into volumetric water content using the equation below (Lal and Shukla, 2004);

$$\Theta = \omega\rho_b \div \rho_w \quad [1]$$

Where: $\boldsymbol{\rho}_b$ - soil bulk density, $\boldsymbol{\rho}_w$ - water density (g.cm^3), Θ - volumetric water content, ω -gravimetric water content.

Climate Data

Climatic data were recorded daily using an automatic agrometeorological weather station at KARLO Katumani. Data comprised of solar radiation (Rs), air temperature, minimum and maximum temperatures (Tmin and Tmax), rainfall (P), relative humidity (HR) and wind speed). Minimum and maximum thermometers, gun ballani, hygrometer and anemometer were used for measurement of air temperatures, solar radiation, humidity and wind speed respectively.

The weather data were used for computation of ETo of common bean using the FAO Pennman-Monteith Formula (Allen *et al.*, 1998 and Hsiao *et al.*, 2012). Illustrated below

$$ET_{\circ} = \frac{0.408Sa\ (R_n - G) + \gamma \frac{900}{T+273} U_{2m}(e_s - e_a)}{Sa + \gamma(1 + 0.34U_{2m})} \quad [2]$$

Where: ET_O - Reference evapotranspiration, R_n - Net radiation at the crop surface in ($MJ.m^2.d^{-1}$), G -Soil heat flux density ($MJ.m^2.d^{-1}$), T - Mean daily temperatures at 2m height (°C), U_{2m} - wind speed at 2 m height (m/sec), e_s - saturation vapor pressure (kPa), e_a - Actual Vapor Pressure (kPa), e_s-e_a - Saturation vapor pressure deficit (kPa),Sa -Slope saturation vapor pressure curve at temperature T (kPa/°C), γ - Psychrometric constant (kPa/°C)

Water Use Efficiency (WUE)

This was computed using data on grain yields, biomass yields express over ET of common bean obtained from computation of climate data using the Penman Monteith formula. WUE was computed using the formula below.

$$WUE = \frac{Grain\ yields}{ET\ common\ beans} \quad [3]$$

Grain Yields

These were harvested at crop maturity from the inner rows after discarding the outer two rows from all four sides of each experimental plot where fresh weights of pods and biomass were taken and later sun dried for a week and dry weights were taken and divided by the effective harvested area and these were converted to grain yield ha^{-1} using the following formula;

$$\frac{Grain\ yield}{ha} = \frac{Grain\ yield\ (kg)}{harvested\ effective\ area\ m^2} \times 10{,}000\ m^2 \quad [4]$$

Data Analysis

All data on bean yield and WUE were subjected to a two-way analysis of variance (ANOVA) using Genstat 14th edition software statistical package at alpha 0.05. Mean separation was carried out using Duncan Multiple Range Test (DMRT) based on treatment size. The experiment model was as follow 4 × 3 split- plot (RCBD) (Model).

Results and discussions

Soil Characteristics

During the experiment under the two cropping season (SR and LR) rains season in 2016 to 2017, the initial soil characteristic suggest that the soil of the study area had an acidic pH and low organic carbon to nitrogen ratio and had phosphorus in low to medium quantities for both LR and SR season (Table 1.0), which indicate the characteristic of luvisols in the study area (Karuku and Mochoge, 2016). However, rating for phosphorus levels in the study area range from 20 - 200 as medium to very high while 0 - 20 as low to very low (Gicheru and Ita, 2000).

The texture of the soil is sandy clay loam with a slow hydraulic conductivity and a high bulk density indicating compaction either due to previous tillage practices or by grazing animals' base on the mixed cropping system and human induced activities. Initial soil moisture content (Table 1) for both season were 1.83 $m^{-3}.m^{-3}$ and 1.21 $m.^{-3}m^{-3}$ this moisture content (table 1.0) is as a result of rainfall before planting.

These results implies that the initial moisture content for the SR season was higher than that of the LR due to precipitation received during the onset of the cropping seasons. In this experiment, it was prudent to evaluate the soil nutrient status to understand other factors hampering WUE and grain yield given the fact that the two work together to enhance agricultural productivity.

As a result of the wider scope of agricultural WUE, the use of agronomic and biological solution must be considered on a broader level (*Deng et al.*, 2006). However, in arid and semi-arid areas, nitrogen plays a vital role in improving agriculture WUE while phosphorus assist plants in deep extraction of water from soil layers (Zhong and Shangguan, 2014). From the initials soil characteristic (Table 1), di-ammonium phosphate (DAP) 80 kg/ha and rhizobium inoculant (USDA 2667) at the rate of 150g/15kg legume seeds, were used as soil amendments to improve the soil before planting during both seasons (SR and LR).

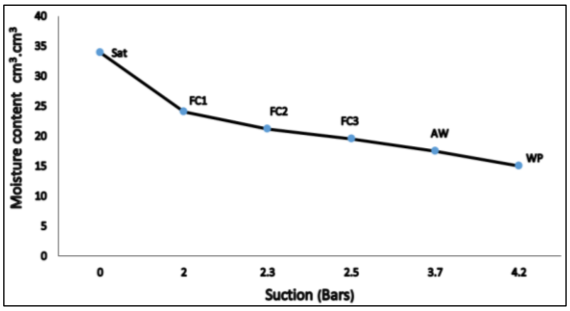
Table 1. Shows initial soil characteristic of the study site (Data are mean across experimental plots)

Parameters Short rain Long rain		
pH	5.21	5.06
%OC	1.11	1.16
%N	0.08	0.12
P (ppm)	18.43	23.4
K (Cmol/kg)	1.2	1.7
Ca (Cmol/kg)	5.88	4
Mg (Cmol/kg)	1.69	1
CEC (Cmol/kg)	12.24	12
Mn	51.5	65.1
Fe	64.14	50.58
Zn	11.95	12.5
Al Cmol/kg	1.98	2
Ksat-hydraulic-conductivity (cm/hr^{-1})	1.18	1.18
% sand, silt, clay (sandy clay loam)	69,5, 26	69, 5, 26
Bulk density	1.40	1.40
Soil moisture content at planting ($m^3.m^{-3}$)	1.83	1.21

The WUE biomass results for both seasons were as followed: SR – under conventional tillage (CT) GLPX92 (27.5), KAT/B1 (23.9), KATRAM (23.5), KATX56 (25.4); minimum tillage (MT) GLPX92 (23.9), KAT/B1 (24.2), KATRAM (18.9), KATX56 (20.4); no-till (NT) GLPX92 (20.7), KAT/B1 (18.3), KATRAM (17.8) and KATX56 (19.4) while for the LR, WUE was as followed: (CT) GLPX92 (92.8), KAT/B1 (77.3), KATRAM (89.5), KATX56 (94.6); (MT) GLPX92 (85.5), KAT/B1 (85), KATRAM (62.9), KATX56 (74.9); (NT) GLPX92 (98.6), KAT/B1 (116.3), KATRAM (108.2) and KATX56 (95.9). During the drought period (SR), GLPX92 had the highest WUE under CT system while during favorable season (LR), KAT/B1 had the highest WUE under (NT) followed by KATRAM. These results, agrees with Sharma, Molden, and Cook, (2015) and Turner, (2004) and Wang *et al.* (2016), that increased use of chemical fertilizer in dryland farming double grain yields and WUE. Table 1.0 shows initial soil characteristic of the study site (data are means across study site).

Soil moisture retention curve

The potential failure curve (pF) illustrates the moisture retention for the soil in the experimental site for the two cropping season (Fig 1.1) However it has being research that not all plant have the same wilting point because roots distribution are not uniform in soil as such, moisture absorption from the soil by plant roots differ (Çakir, 2004 and Chen *et al.*, 2014). Moreover, depending on the soil textural class, the pF curve shows tremendous value as early warning tool reminding of critical point in moisture levels during plants phenological stages under rainfed environment. This curve helps field managers take preventive measures to avoid crop failures during production. However, water management during crop production will not only be able to increase WUE but can facilitate the structural adjustment needed by agriculture (Deng *et al.*, 2006). Soil of the study area read field capacity as pF 2 to pF 2.5 and relative available water (RAW) at pF 3.7 or 5.0bar and wilting point at pF 4.2 or 15.0 bar (Fig. 1.1). Due to high evapotranspiration rates in East Africa and high stress factor on crops, pF 2.3 to 3.7 can be suspected to give more accurate value of the actual available soil moisture in the experimental area. Fig. 1.1: shows moisture retention curve for early warning sign



Sat-saturation, FC–field capacity, RAW – readily available water, WP–wilting point.

Fig. 1.1. Moisture retention curve for early warning sign.

Soil moisture trend at different phenological stages during the two cropping season (SR and LR) rains

Soil moisture trend was high during the LR as compared to SR (Fig. 1.2), and decreased towards the flowering stage (28 DAP) days after planting and later increased to podding stage (42 DAP) and decreased towards harvesting stage (70 DAP). Moisture trend intercepted at 42 DAP (podding) and increase at 56 DAP (maturity) with the SR and decreased at 56 DAP (maturity) with the LR and finally decrease at 70 DAP (harvest) with both (LR and SR) season. Moisture trend in the growth stages of crop is very important to yields and WUE of crops. During this study, results of crop moisture trends showed variations during various phenological stages. This could be as a result of erratic rainfall variability experienced during both seasons due to high temperatures, water loss through evaporation and drought effects during the SR season.

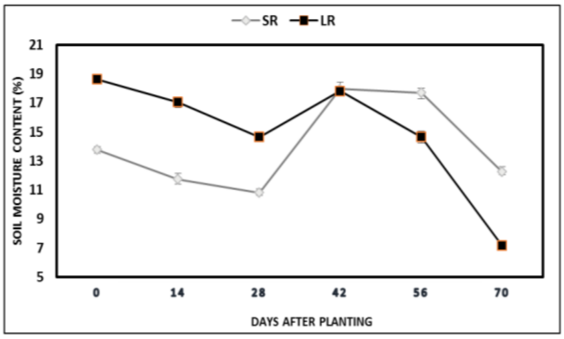


Fig. 1.2 Soil moisture trend during the phenological stages from planting to 70 DAP during the Short and Long (SR and LR) rain season 2016 and 201**.**

However, varieties did not influence moisture trend at the various growth stages but tillage influence moisture trend at the various stages of crop growth. This could be as a result of climatic effects due to drought causing rainfall variation and increased temperature experienced in semi-arid areas or could either be as a result of deep infiltration in the conventional tillage and runoff in the conservation tillage systems due to surface capping, compaction as obstruction due to hard pan. In the study area, rainfall drop from 283mm to 184mm for the SR below the average rainfall of 283 mm while the LR was above average from 301mm to 380mm. However, yield losses associated with drought at different crop growth stages of plant development have been looked at by many studies (Farooq *et al.*, 2012 and Aslam *et al.*, 2015). This could be one of the causes of low yield and WUE during the both season. Negassa *et al.* (2012) showed that crown root initiation and anthesis as the two stages in which losses from drought stress can be more critical in wheat.

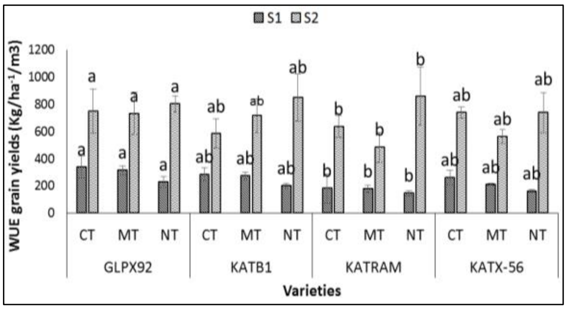
Moreover, Vaghasia *et al.* (2010) reported increase in moisture supply leads to increase in water use. This could be the cause of the variation in biomass and grain yields during the LR season as a result of higher rainfall compare to the SR season. Çakir, (2004) reported that between two moisture stress treatment, stress given at flowering stage cause reduction in pod yield while reduction in grain due to moisture stress imposed at pod development stage. During this study, similar trend was observed at various phenological stages especially during flowering and podding stages for both season (SR and LR) rains (Fig. 1.2), where crops experience moisture stress before reaching the podding stage and there on to maturity.

This could probably be one of the many causes of low production in many semi-arid areas of Kenya as a result of moisture variation due to the effects of climate. Fig. 1.2: shows soil moisture trend during the phenological stages during the SR and LR rain season 2016 and 2017.

Effect of varieties on grain yield and WUE biomass

From this study, it was observed that season influenced grain yield WUE ($P < 0.001$) and there was also variations observed among the treatments declining with GLPX92, KAT/B1, KATX56 and KATRAM as well as with tillage NT, CT and MT (Fig.1.3). Moreover, among these varieties, GLPX92, differed in grain yield WUE with KATRAM and not with KAT/B1, KAT56 under the same tillage systems and seasons (Fig. 1.3). However, lower and higher WUE of grain yield was observed during the SR and LR season as followed GLPX92 (27.5 $ton.ha^{-1}$), KATB1 (23.9 $ton.ha^{-1}$), KATRAM (22.5 ton $.ha^{-1}$) and KATX-56 (25.4 $ton.ha^{-1}$) and GLPX92 (92.8 $ton.ha^{-1}$), KATB1 (77.8 $ton.ha^{-1}$), KATRAM (89.5 $ton.ha^{-1}$) and KATX-56 (94.6 $ton.ha^{-1}$) respectively with the LR yielding higher as compared to the SR. This increased in WUE grain yield during the LR season is as a result of increased soil moisture content received by increased precipitation as compared to the SR season marked by intense drought with increase in temperature (Fig. 1.3). However, crop performed better in NT followed by CT and MT respectively during the LR while CT was the highest performing tillage system followed by MT and NT during the SR season. This is due to the loosing of the soil and breaking apart any obstacles beneath the soil surface for easy moisture infiltration and easy access of moisture in the rooting zone for moisture uplift as reported by (Sun *et al.,* 2014 and Whitmore *et al.,* 2009).

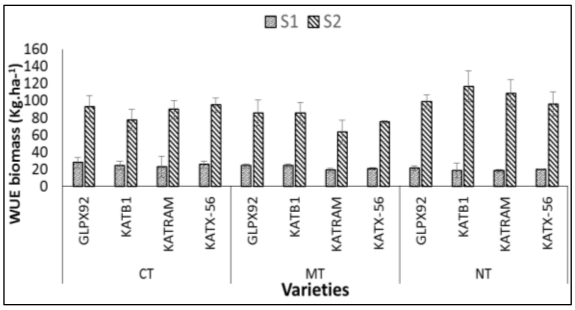
However, varieties had no influence on grain yields WUE ($P = 0.151$, Fig. 1.3) while interaction between varieties × tillage did not influence grain yield WUE ($P = 0.631$). Krutt, (2001) reported the dominance of one varieties over another to be due to genetic characteristic like grain yields, hydraulic lift and resistance. According to Ruggiero *et al.* (2017), these responses strongly impact (WUE). This could be the level of supremacy GLPX92 exhibited over KATRAM during the two cropping season LR and SR) that were so fair and harsh for crop production in semi-arid terrains like Machakos County.



Bars with the same lower case letters are not significantly different at $P < 0.05$. Whereas bars with different lower case letters are significantly different at $P < 0.05$. CT – conventional tillage, MT – minimum tillage, NT – no-till, S1- season one, S2- season two

Fig. 1.3 Effects of varieties on grain yield WUE.

Under the two cropping season (SR and LR) rains, varieties had no significant difference on biomass WUE (P = 0.604, Fig. 1.4). Tillage also did not influence biomass WUE (P = 0.320, Fig. 1.4), neither did interaction between tillage × varieties influence biomass WUE. However, season had influence on biomass WUE ($P < 0.001$, Fig. 1.4) with higher biomass among varieties during the LR as compared to the SR season decreasing with GLPX92, KATX56, KATRAM and KAT/B1 under (CT), GLPX92, KAT/B1, KATX56 and KATRAM under (MT) and KAT/B1, KATRAM, GLPX92 and KATX56 under (NT) respectively. The interactions between tillage × season also influenced biomass WUE (P = 0.010) as is shown in (Fig. 1.4).



S1- season one; S2- season two, CT- conventional tillage, MT- minimum tillage, NT- no-till

Fig. 1.4 Effects of varieties on above- ground biomass WUE.

Moreover, the interactions between varieties × season had no influenced on biomass WUE but there was variations among treatments in biomass WUE. The aboveground biomass WUE was generally higher than that of the grain yield WUE for both cropping season in 2016 and 2017.

This could be as a result of higher evapotranspiration due to drought caused by climatic variations during the two cropping season.

Moisture stress also cause reduction in biomass yield during intense drought during the SR season 2016. Polania *et al.* (2016) reported drought stress reduction in both biomass and grain yield WUE. Beebe *et al.* (2014) said that harvest index can be reduced by terminal drought stress. Results of crop failures and reduction in crop yields due to drought during the SR season, agrees with Beebe *et al.* (2014) and disagree with Ruttanaprasert *et al.* (2016) that drought increase harvest index in some cases. However, from this study, GLPX92 prove dominant over KATRAM and not with KAT/B1 and KATX56 during the both season (SR and LR). This indicate that KATRAM was the least performing varieties during the both season. However, in other research, "Economic models of biomass production for bioenergy generation, (Davis *et al.*, 2014), identified biomass yield as the most important factor to determine economic viability. Fig. 1.3 and Fig. 1.4: shows Effects of varieties on grain yield WUE and Effects of varieties on above- ground biomass WUE.

Conclusion

Seasons had influence on grain yield and above ground biomass WUE and these influences were as a result of moisture stress due to drought and higher temperatures and rainfall variation. The difference observed among GLPX92, KATB1 and KATX56 were not significant and does not justified the supremacy of GLPX92 above KATB1 and KATX56 but conversely, it proved supreme over KATRAM.

The increased grain yield and biomass WUE could be attributed to some environmental, physiological and morphological factors of which further research needs to be conducted. However, it was observe that GLPX92 during both season had higher grain yield and above ground biomass WUE than KATRAM which was hypothesized to be due to genetic characteristics which needs further research. Moreover, it was generally understood by this study that drought is the prime factor of moisture stress in crop production during cropping seasons, hence, reduces grain yield and above ground biomass WUE based on the region. Finally, selection of varieties for production in these regions should be based on the season and tillage practices apart from soil infertility that can be remediated with chemical fertilizers and agronomic practices.

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