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Effects of Tillage Practices on Water Use Efficiency and Yield of Different Drought Tolerant Common Bean Varieties in Machakos County, Eastern Kenya

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Abstract

As world population increases, the need to feed this increasing population by the year 2050 is rising with marginal areas been cultivated to address these needs. This study seeks to compare effects of tillage on water use efficiencies (WUEs) and yields of drought tolerant bean varieties in Machakos County using three tillage systems: conventional tillage (CT) done with chisel mounted on oxen for ploughing while minimum tillage (MT) and no-till (NT) were done using hoes to dig directly where seeds of four varieties were planted in 4 × 3 Split-plot randomized completely block design replicated four times. Erosion was negligible due to land slope flatness while actual ET crop was derived using meteorological data from 2016 and 2017 cropping seasons. Aboveground biomass and grain yield were harvested from the inner rows after discarding the outer two rows from all size of each experimental plot and weighed for total biomass and grain yield. Data were subjected to two-way analysis of variance (ANOVA) using Genstat 14th edition software statistical package at alpha 0.05. Duncan Multiple Range Test (DMRT) was used to separate means.

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Results indicate that interaction between tillage and seasons significantly influenced biomass and grain yield WUEs with GLPX92 yielding the highest in CT, MT and ZT though insignificant under the SR drought event, but under the LR favorable season GLPX92 yield decline with NT, CT and MT. These results, suggest interactions of conservation tillage and seasons the best option for production during favorable seasons and conventional tillage during drought events.

Keywords: water use efficiency (WUE); erodibility; Conventional tillage; Minimum tillage; No-till; short and long rains; climate change and drought.

1. Introduction

There is a growing concern of the increasing world population and the need to secure food security through a proper soil management strategy, which demands identification of an environmental friendly and crop yield sustainable system of tillage [1,2]. Tillage, being defined as the mechanical manipulation of the soil for the purpose of crop production [3]. However, tillage process significantly affects the soil characteristics such as soil water conservation, soil temperature, infiltration and evapotranspiration processes [1]. The art of tillage, can also be used as a soil management practice, to enhance cropping systems, influence Water use efficiency (WUE) of crop in semi-arid environments as well as plant population in temperate and humid environments and nutrients management practices and water availability [4 , 5] .

As the world is experiencing increasing population, so is the increasing demand for food hence, the need to open more lands arises. This must be done in such a way that soil degradation is avoided in that, the soil is prepared to serve as a sink rather than a source of atmospheric impurities. However, it is based upon the avoidance of the soil being a source of atmospheric pollutants that conservation tillage along with some complimentary practices such as soil cover and crop diversity [6], argues that conservation tillage is a component of conservation agriculture (CA) [4], propended that conservation tillage system can increase water use efficiency by 25-40%. However, little information on how conservation tillage influences the water use efficiency (WUE) of drought tolerant crops with short maturation period, such as beans is limiting our understanding on the importance of such practices in improving the production of drought tolerant common bean varieties. Despite these limitations, conservation tillage is still efficient in the maintenance of surface soil cover through retention of crop residues achievable by practicing zero tillage and minimal mechanical soil disturbance [6]. This study seeks to compare effects of tillage practices on WUEs and yields of drought tolerant bean varieties in Machakos County using three tillage systems CT, MT and ZT along with four varieties GLPX92, KATX56, KAT/B1 and KATRAM.

2. Materials and Methods

2.1. Description of Study Site

Katumani is a dryland Research Centre located in Machakos County on latitude 01º 35' S, longitude 37º 14' E, and an altitude of 1600m above sea level. It is located 8km south-west of Machakos town and 80 km south-east of Nairobi. Katumani occupies a total area of 489 ha. Ecologically it falls under agro-climatic zone IV, which is described as medium to marginal [9]. Rainfall is bimodal with annual mean rainfall as 711mm whilst the average seasonal rainfall is 301mm for the long rains (March-May) and 283mm for the short rains (October-December). However, the short rains tend to be more reliable for crop production than the long rains [8,13]. Temperature range between 17 and 24^{o}C [9]. The mean potential evaporation is in the range of 1820 to 1840 mm per year [10].

However, like other areas of the semi-arid eastern Kenya, rainfall occurs in events of unpredictable intensity, with coefficients of variation in seasonal rainfall often exceeding 50% [13,12]. Therefore, the timing and relative lengths of each growing period vary substantially such that any delays in planting, particularly at the start of the wet season bring risks of significant losses in yield almost proportional to the time delay [12,14,33]. The first rains occur from March to May with a peak in April. These are referred to as the long rains. The second season falls in October to December with a peak in November and is also known as the short rains.

Predominantly, Katumani is covered by Lixisols derived from granitoid gneiss of the Basement System Complex. Unlike other areas of semi-arid Eastern Kenya, soils in Katumani are deep to very deep, well drained, dark red to reddish brown, weakly structured and friable, with sandy and sandy loam near the surface [15]. 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}), [17,16]. The soils are often deep and well structured, allowing deep penetration of plant roots and a moderately good capacity to hold available water [10].

The soil also exhibit 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 [10].

The landscapes of Katumani consists of flat to hilly elevations with relief variation of 10-20m. The slopes are straight with gradient range between 2% and 20% [11].

The main agricultural production enterprise in the surrounding area is mixed crop-livestock production systems with varying degrees of integration. Main crops are maize, beans, pigeon pea, cowpea, and sorghum.

2.2. Experimental Design, Layout and Agronomic Activities

The main plot contain three tillage practices in a completely randomized block design (RCBD) and replicated four times while the sub-plots contain 4 drought tolerant bean varieties. Each sub-plots containing the tillage practices (CT, MT and ZT), were separated by 1 m path way and 0.75 m row and each block was separated by 3 m × 2 m horizontal and vertical path ways respectively and plot numbers were 48. The plots sizes were 2 m × 8 m respectively.

The experiment comprised of 12 treatments in a 4 × 3 Split plot RCBD replicated four times. They included four drought tolerant common bean varieties (X, Y, M and W) and three tillage systems; conventional tillage (CT), minimum tillage (MT) and zero tillage (ZT) combined as follows:

Table 1: Varieties arrangement in the three tillage practices in the experimental area

Varieties	Tillage
M	CT
M	MT
M	ZT
W	CT
W	MT
W	ZT
Y	CT
Y	MT
Y	ZT
Z	CT
Z	MT
Z	ZT

Each alphabetical letter represent a single variety combine with different tillage practices, CT- conventional tillage, MT- minimum tillage, ZT- zero tillage

The varieties were selected by breeders first then farmers through a survey conducted in the study area through assistance of local leaders and extension officers.

In the conventional tillage system, the entire field was ploughed before planting while in minimum tillage (MT), the entire field was not ploughed but only the rows where seeds were planted were ploughed. In the No-till (NT), holes were dug only in areas were seeds were planted thereby maintaining soil cover in both MT and NT while CT was bare.

Common beans were planted at a spacing of 50 cm between and 10 cm within rows.

Seeds planted per hole were three and later thinned to two after germination to reduce competition for nutrients and increase proper growth.

In the conventional tillage, the land were ploughed using chisel mounted on oxen a month before planting.

In these plots, 48 plastic pipe access tubes were installed firmly in the soil using an auger to a depth of 1 m or whichever shallower for the purpose of moisture reading.

Additionally, two plastic pipe access tubes were installed outside the experimental plots for neutron probe calibration purposes making the total access tubes to 50 pieces. The field slope was virtually even thereby making erosion negligible.

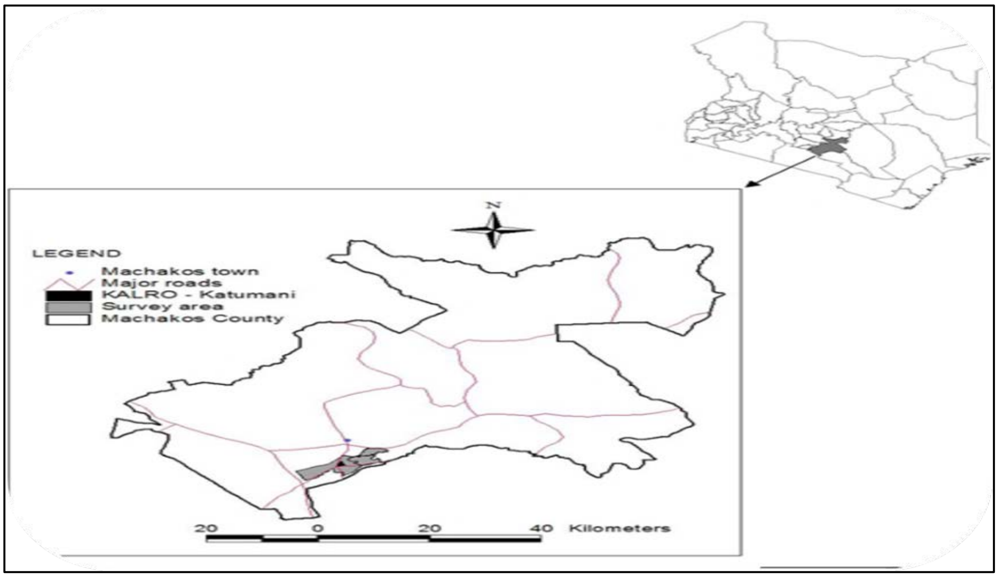

Figure 1: Represent map of the study area

2.3. Data Collection

This initial soil characteristics was done by sampling soil from a depth of 0 -30 cm from various points using an auger and a composite of the soil was used to carry out chemical analysis to determine the nutrient status of soil in the study area.

Rainfall and air temperature were collected from the nearby meteorological station held in the Katumani research station to determine the amount of rainfall for the season and temperature to determine rate of radiation to arrive at ETo for the season.

Total available water content (TAWC) ($m^{-3}.m^{-3}$) was taken at planting, vegetative, flowering and podding stages referred to as, at planting and Days after planting (DAP) using Neutron probe 503DR Hydro probe. This was calibrated using the gravimetric water content (g/100 g soil) by plotting a graph of neutron counts 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. Therefore, 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 content were converted into volumetric water content using the equation below:

$$\Theta = \boldsymbol{\omega}\boldsymbol{\rho_b} \div \boldsymbol{\rho_w} \qquad [1]$$

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

The soil moisture retention was determined from soil samples collected in the field from the Katumani Research station and analyzed at the University of Nairobi Soil Science Laboratory using various water retention points from 0 – 15 bar (pF 0 to 4.2) before planting to determine the saturation, field capacity, wilting point, limit of readily available water and permanent wilting point of the soil in the study area to serve as a guide to irrigation scheduling and early warning signs to farm managers and farmers.

Above biomass was collected after harvesting at the maturity stage of the crop from the inner rows after discarding the outer two rows from all four sizes of each experimental plot. Pods were extracted and the biomass were weighed per plot.

Grain yield was collected at the maturity stage of the crop after harvesting and sun dried at 13% commercial value and weighed. Harvested grain yield were converted to grain yield per hectare using the following formula;

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

2.4. Data Analysis

All data of 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 Randomized Completely Block Design (RCBD) (Model) where main plot factors were the tillage practices and sub-plots factors were the varieties.

3. Results and Discussions

3.1. The Initial Soil Characteristic of the Study Area (SR and LR)

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), which indicate the characteristic of luvisols in the study area [12]. 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 [21]. 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^3m^{-3} and 1.21 m^3m^{-3} which 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 [22]. 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 [23]. From the initials soil characteristic (Table 1), di-ammonium phosphate (DAP) 80 kg/ha and rhizobium inoculant (USDA 2667) at the rate of 150g/15 kg legume seeds, were used as soil amendments to improve the soil before planting during both seasons (SR and LR). 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 [26]; [24]& [34], that increased use of chemical fertilizer in dryland farming double grain yields and WUE

Table 2: Initial soil characteristics

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($g.cm^{-3}$)	1.40	1.40
Soil moisture content at planting ($m^3.m^{-3}$)	1.83	1.21

3.2. Rainfall and Air Temperature during Both SR and LR

Figure 1 represents the mean monthly rainfall amounts (mm) and temperature (^{O}C) and trends during the experimental period (October, 2016 to June, 2017). The cumulative rainfall for both the short and long rains were 184 mm and 380 mm which was below and above average respectively. During the SR, October and January had little or no rain and the peak of the rainfall during the short rain season was in November and this season experience erratic and spicily distributed rainfall with temperature rise up to 24^{O} C (Figure 1). However, during the LR, rainfall peak was in April and temperature rise was 25^{O} C and in March, the peak of the SR season experience little rainfall than the peak of the LR. The months of October and June were both the harvesting stages of the two seasons (SR and LR). Due to intense drought, actual planting took place in November due to insufficient rainfall to improve germination. On the contrary, Planting for the LR took place in March due to sufficient amount of rainfall received which was adequate for planting and seeds germination in these highland areas. Moreover, many agricultural systems in semi-arid tropics where soil evaporation, runoff and soil losses are important [27], [35] needs serious attention as it relates to crop production and food security for rural household dwellers. The rainfall of the study area during both cropping seasons (SR and LR) had a lot of variations due to seasonal effects cause by climate change and drought. [11], reported that increasing temperature and low rainfall couple with poor soil fertility impact negatively on productivity of various crops. The average temperature for the SR 22 ^{O}C and for the LR was 23^{O}C indicating that temperature was high and rainfall was insufficient for production during the SR while temperature for the LR was high with considerable amount of rain for production but not all this rainfall went to production due to higher evaporation and high rate of transpiration. Although evaporation and transpiration were not measured during this study but have been taken care of by other researchers, hence this study thought it prudent to use ETo to measure WUE as the best method [16]. Rainfall distribution greatly affected yield as is seen in (Figure 1) how precipitation was low and spicily distributed during the SR with November 2016 and rainfall during the LR was low during the onset of planting in March 2017 with peak in April. However, with these events of rainfall, (Figure 2) portray that during the SR crops experience moisture stress during the flowering stage hence causing abscission of more flowers before entering the podding stage which as a result contributed to low yield with drought exacerbating the problem (Figure 3 and 4). In addition, rainfall for the LR was favorable though similar trend experienced during the SR at flowering was also experienced during the LR but was short lived hence yield was not affected as is seen in (Figure 3 and 4) Rainfall and temperature of the study area falls in line with [28] where rainfall and temperatures were observed as normal, abnormal and warmest temperatures respectively. This could be the prevailing effect of low crop production in ASALs coupled with low soil moisture content and infertility during both SR and LR seasons. These changes in climate are expected to have differential impacts on agricultural productivity, food security across spatial and temporal scale. These erratic variability of rainfall experienced during the cropping season which is as a result of climatic effect caused by drought, is expected to have detrimental effects to agricultural livelihood in the tropic especially in Africa.

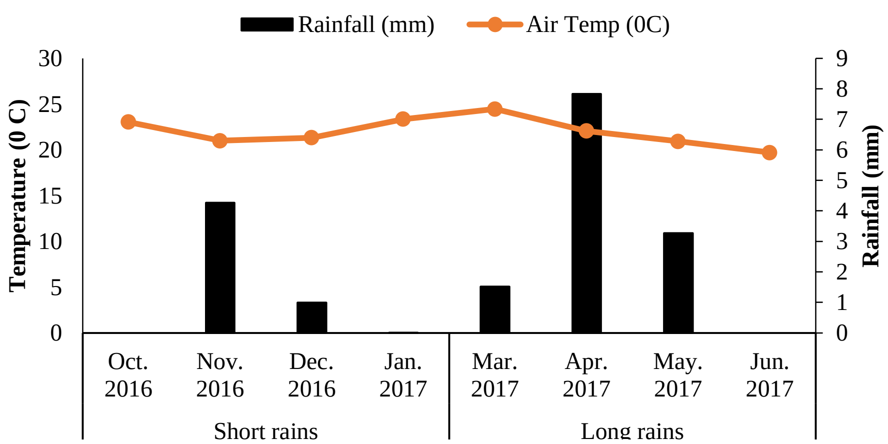

Figure 2: Rainfall and Air temperatures for the two cropping season (SR and LR)

3.3. Soil Moisture Variations under the Two Cropping Seasons (SR and LR)

Soil moisture content varied significantly between depth and season (P < 0.001, Table 2) but not between tillage systems (P = 0.052). However, during the SR seasons, soil moisture increased with depth in the upper 60 cm and decreased in the lower 80 cm depth while soil moisture decrease in the upper 60 cm depth and increase in the lower 80 cm depth during the LR season. The interaction between tillage practices × depth was not significant (P = 0.923), but significant interactions was observed among tillage systems × seasons × depth × season (P < 0.001, Table 1) respectively. However, interactions between tillage systems × depth × season was not significant (P = 0.818, Table 1). Soil moisture content was higher during the LR than the SR. This could probably be as a result of the negative impact of climate change effects like drought, temperature rise and decrease in rainfall that is so severe in hot and dry area. Moreover, during the SR cropping season 2016 the study area experienced induced drought with erratic rain falls with mean of 184 mm precipitation lower than the expected 283 mm and was sparsely distributed with temperature ranging from 26^o C to 14.23^{o}C and 380 mm rainfall, 26^{o}C to 14.3^{o}C in temperature for the LR as was reported by [9] that average rainfall for both long and short rains range between 283 mm and 301 mm respectively. But results from the study area agreed with [12] & [11] that rainfall occurs in events of unpredictable intensity, in areas of semi-arid eastern Kenya with coefficient of variation in seasonal rainfall often exceeding 50%. Similarly, soil moisture increased and decreased with depth during the SR cropping season in the upper 60 cm to the lower 80 cm depth while during the long rains cropping season, soil moisture decreased in the upper 60 cm and increased in the lower 80 cm depth. This could be as a result of the soil structure and texture that is well drained, deep to very deep and sandy to sandy clay loam [8,29] or could probably be due to effect of tillage or rate of soil evaporation. However, soil moisture variation in the soil of the study area is attributed to the tillage systems and the seasons whilst soil moisture variation in the various depth of the soil is depicted by the seasons and the amount of rainfall received as well as the rate of evaporation due to temperature penetrating the soil surface and back to the atmosphere [30], argue that moisture at 30 cm top soil are lost via neutron escape into the air and are not detected by neutron probe. This could be the reason probe reading during the SR which was marked by events of dryness cause by drought was difficult due to like of moisture in the upper soil layers.

Table 3: Soil moisture variation under the two cropping seasons

		Cropping seasons	
Type of tillage	Soil depth (cm)	Short rains	Long rains
Conventional tillage	20	10.0 ± 0.57	14.7 ± 0.84
	40	14.4 ± 0.47	15.4 ± 0.58
	60	15.0 ± 0.44	15.2 ± 0.46
	80	13.9 ± 0.53	15.6 ± 0.46
Minimum tillage	20	11.5 ± 0.67	14.1 ± 0.75
	40	15.9 ± 0.53	15.0 ± 0.44
	60	16.4 ± 0.53	14.8 ± 0.40
	80	16.3 ± 0.82	15.0 ± 0.43
Zero tillage	20	11.0 ± 0.49	14.4 ± 0.78
	40	15.2 ± 0.43	15.1 ± 0.47
	60	15.1 ± 0.48	15.2 ± 0.44
	80	13.7 ± 0.46	15.4 ± 0.46

P-value, tillage (P = 0.052), depth and season (P < 0.001), tillage and depth (P = 0.923), tillage and season and depth and season (P < 0.001) and tillage and depth and season (P = 0.818). Moisture values are mean ± S. E (standard errors)

3.4. Tillage Effect on Soil Moisture Trend from Planting to Seventy Days of Plant Growth in the Short and Long Rains

Soil moisture trend was high during the onset of the SR as compared to LR (Fig. 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. Results of the study showed variations in soil moisture trends during various phenological stages. This could be as a result of erratic rainfall variability experienced during both seasons. However, varieties did not influence soil 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 and intensity of tillage on soil micro and macro pores. In the study area, rainfall drop from 283 mm to 184 mm for the SR below the average rainfall of 283 mm while the LR was above average from 301 mm to 380 mm. However, yield losses associated with drought at different crop growth stages of plant development have been looked at by many studies [31, 32,27], propended that evaporation can be quite high > 40% of total rainfall. Runoff from rainfall can reach 10% of total rainfall [33,34] . Moreover, deep percolation in ASALS are negligible [33]. Soil moisture measurement was taken bi-weekly for the entire season (SR and LR) from planting up to crop maturity stage. There was a decreased over time in soil moisture at different weeks after planting during the long and short rains (2016-2017). In both season, the order range from MT (14.9%), ZT (14.4%) and CT (14.3%) and soil moisture content was higher in the 40-60 cm depth (15.2% and 15.3%) than in the 20-80 cm depth (12.6% and 15.0%) during the both season. The trend in soil moisture content in the soil profile could be as a result of rainfall and soil pores, crop water uptake, transpiration, evaporation and deep percolation [15]. These variation occurred under the tillage systems after precipitation. Minimum tillage (MT) had high soil moisture content due to reduce disturbance and surface roughness which support moisture infiltration and minimized erosion hence increase soil moisture storage followed by No-till (NT) and Conventional tillage (CT). This could be due to the topography and undisturbed porosity but on the contrary, the impact of rain droplets on the soil surface, and crusting [29] could be the cause of increased erosion and low moisture infiltration NT system. [36], showed that crown root initiation and anthesis as the two stages in which losses from drought stress can be more critical in wheat.

Moreover, [37] reported increase in moisture supply leading 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 (Figure 3 and 4) [38], reported that between two moisture stress treatments, 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.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 variation in climate.

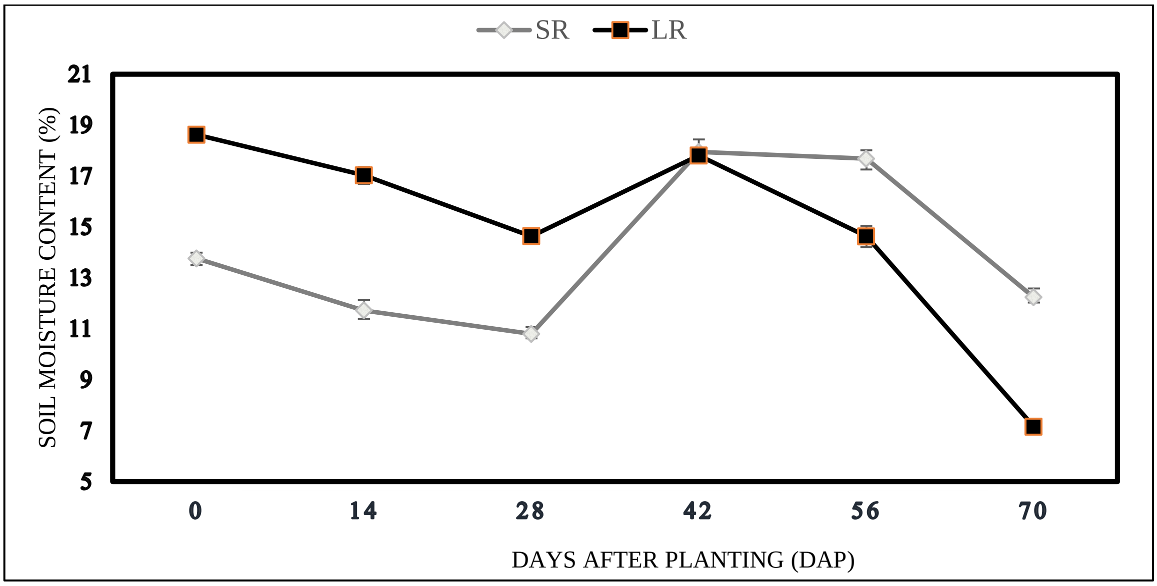

Figure3: Soil moisture trend from planting to seventy days of plant growth in short and long rains (SR and LR)

3.5. Effect of Tillage Practices on Grain Yield

Generally, tillage had no significant effect on grain yields (P = 0.651, Figure 3), but there was significant effects found between the interactions of tillage × season (P = 0.037, Figure 3) and could be as a result of climatic factors and the type of tillage system that conserve moisture for crop and avail to plant for proper growth and productivity. Seasons also had significant effect on grain yields (P < 0.001, Figure 3). However, tillage and varieties had no significant effects on grain yields (P = 0.382) but there was some variations observed among treatments increasing with GLPX92, KATB1, KATX56 and KATRAM though not significant. Moreover, similar trend was observed among the tillage systems increasing with NT, CT and decreasing with MT but was not significant. This concurs with [29], that inadequate moisture coupled with transpiration decrease plant growth rate and the final grain yield and this can also be in the reversed. Interestingly, season and the interaction between tillage and season had significant effect on grain yield. This could be attributed to the effect of soil properties such as low carbon to nitrogen ratio, low to medium P levels acidity of the soil couple with climatic factors like drought, erratic rainfall and increase temperature. The study area like other semi-arid areas, was severely hit by the event of drought during the SR season 2016, which led to crop failures and low grain yield. The average rainfall of the study area was 184 mm for the SR below the minimum average of 283 mm whereas the LR season was reliable exceeding the minimum average of 301mm to 380 mm of rainfall. However, tillage and varieties had no effect on grain yield but the treatments had some variation which was not significant decreasing with GLPX92, KATB1, KATX56 and KATRAM. But GLPX92 was performing better in terms of higher grain yield in both season in all tillage systems followed by KATB1, KATX56 and KATRAM but the yields weren’t significant. Similarly, the same order was observed in tillage practices (NT, CT and MT). Moreover, during the LR season in 2017, soil moisture content was high as a result of favorable rainfall giving higher grain yield.

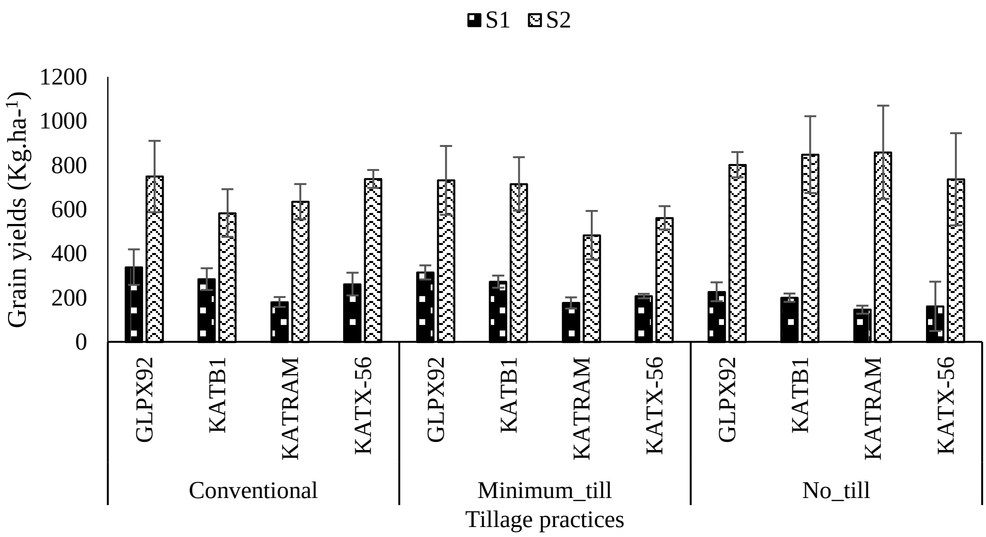

Figure 4: Effect of tillage practices on grain yield

S1- season one (SR), **S2-** season two (LR)

3.6. Effect of Tillage Systems on WUE Grain Yield

Tillage and varieties had no effect on WUE grain yield (P = 0.582, 0.181), while the interaction between tillage and varieties had no significant effects on the WUE of grain yields (P = 0.439, Figure 4) but seasons had significant effects on WUE of grain yield ($P < 0.001$). The interactions between tillage and season was not significant on grain yields WUE (P = 0.055, Figure 4). The interactions between varieties and season was not significant on grain yield WUE (P = 0.994) while the interaction among tillage, varieties and season had no significant effects on grain yields WUE (P = 0.867). This could be attributed to the two broad variation experienced during the two cropping season (SR and LR) base on the semi-arid nature of the study area [23]. Though tillage and varieties had no effect on WUE of grain yield, but during the SR season marked by extreme drought, it was observed that crops grown in the CT and MT performed better than NT though not significant. From the results obtained, the LR in 2017, performed better on WUE grain yield under conservation tillage system with favorable climatic condition and good soil moisture availability.

Moreover, according to [1], tillage impact on yield is related to its effects on root growth, water and nutrient use efficiencies and most importantly agronomic yield. Moreover, climate adaptation benefits of NT can be significant. However, from this studies it was observed that this depends on the region, soil properties and soil structure. More besides, the report also stated that wheat grown during Kazakhstan's 2012 drought and high temperature, under NT practices were more resilient, leading to higher yield over conventional. The results emanating from this studies shows that during the SR season yields were low and NT performed least while CT and MT performed better during the drought period though statistically insignificant. This could be associated to lack of soil moisture, hard bulk density, drought and increased temperatures. This study concurs with [40] that tillage had no influence on the total WUE of crop during the both season. This could be attributed to the difficulties to determine crop transpiration accurately under field conditions [5]. However, most researchers are using evapotranspiration (ET) to describe WUE though transpiration, erosion and evaporation has being taken care of [16]. This study did not measure these variables due to lack of equipment and financial constraints and so the best option was to use ETo where WUE was measure by expressing biomass or grain yields over ET common crop.

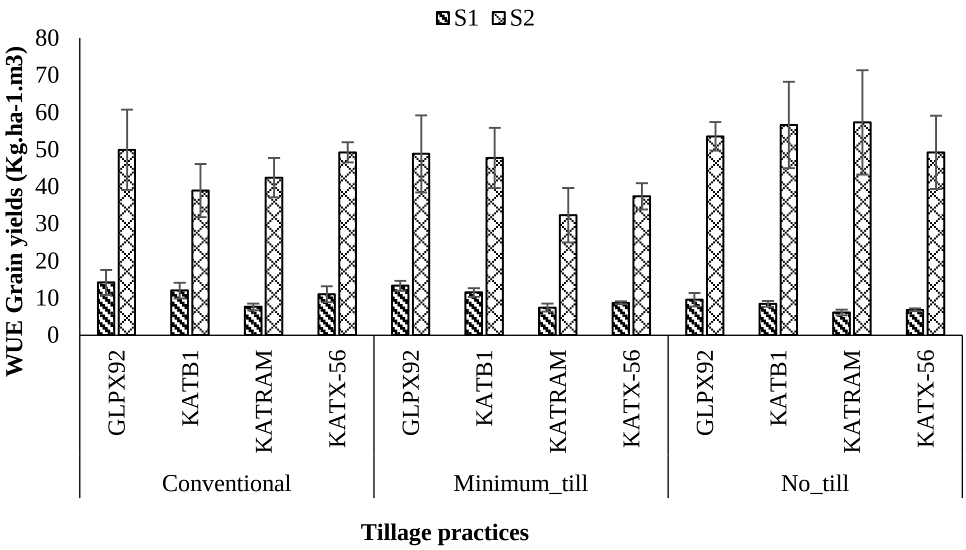

Figure 5: Effect of tillage practices on WUE of grain yield

S1- season one (SR), **S2-** season two (LR)

3.7. Effect of Tillage Systems and Varieties on Biomass WUE

Tillage and varieties effects on WUE of biomass yields were not significant (P = 0.320, 0.604 respectively, Table 3). The interactions between tillage × varieties had no significant effects on biomass WUE (P = 0.260) however, observed was significant effect of season on biomass WUE (P < 0.001) and interactions between tillage and season had significant effect on biomass WUE (P = 0.010) but interaction between varieties × season had no significant effect on biomass WUE (P = 0.985, Table 3) while the interaction between tillage × varieties × season had no significant effect on biomass WUE (P = 0.756, Table 3). Similar trend was observed with tillage having no significant effect on biomass yields (P = 0.336, Table 3) while varieties and the interactions between tillage × varieties had no effects on biomass yields respectively (P = 0.463, 0.247) but observed was season and the interaction between tillage × season having significant effects on biomass yields (P < 0.001, 0.009, Table 3) respectively. Moreover, the interactions between varieties × season had no significant effects on biomass yields at (P = 0.988, Table 3) and no significant effects of interactions between tillage × varieties × season was observed on biomass yields (P = 0.819, Table 3). This could probably be as a result of climatic conditions, due to moisture stress or soil moisture availability. However, there was an effect of season observed on biomass WUE during the two cropping season (SR and LR) which is either as a result of increased temperature, higher evaporation rate from the soil (Figure 1). Moreover, observed was varietal variation on WUE existing within the common bean varieties grown in the experimental plots under the two season (SR and LR) using three tillage systems CT, MT and NT) respectively. This variation could be utilized in selecting varieties for breeding suited to field sites of varying water availability [24]. The results of this study disagrees with [41] that varieties which may have higher WUE under water stress may not be the most superior one in terms of WUE under well-watered conditions. However, GLPX92 during the two cropping seasons had the highest yield under moisture stress during the SR drought and also under favorable season of the LR with in the various tillage practices. Moreover, there was no interaction found between varieties and season on biomass WUE. This is because total dry weight of biomass can be attributed to the balance between photosynthesis and respiration [41] which indicate that a lower respiration would increase the total biomass accumulated per unit of water transpired. However, varieties and tillage and season had no significant interaction on biomass WUE. Results from this study agrees with [41] that WUE be a promising selection criterion when breeding for drought tolerant, in combination with conservation tillage system which promote soil health and viable soil moisture storage to enhance growth of crops in the semi-arid areas.

Table 4: Effect of tillage practices on biomass yield and water use efficiency among different common bean varieties

		Short rains		Long rains	
Type of Tillage	Varieties	Biomass	WUE	Biomass	WUE
Conventional	GLPX92	654 ± 280.2	27.5 ±11.7	1392 ± 380.7	92.8 ± 25.4
	KATB1	569 ± 237.7	23.9 ±10.0	1160 ± 371.7	77.3 ± 24.8
	KATRAM	535 ± 141.8	22.5 ± 6.0	1342 ± 323.0	89.5 ± 21.5
	KATX-56	604 ± 184.8	25.4 ± 7.8	1419 ± 240.1	94.6 ± 16.0
Minimum till	GLPX92	569 ± 100.5	23.9 ± 4.2	1283 ± 446.9	85.5 ± 29.8
	KATB1	577 ± 91.0	24.2 ± 3.8	1275 ± 374.3	85 ± 25.0
	KATRAM	450 ± 105.4	18.9 ± 4.4	944 ± 425.2	62.9 ± 28.3
	KATX-56	485 ± 62.2	20.4 ± 2.6	1123 ± 233.9	74.9 ± 15.6
No till	GLPX92	492 ±151.8	20.7± 6.4	1479 ± 248.2	98.6 ± 16.6
	KATB1	435 ± 127.7	18.3 ± 5.4	1744 ± 540.4	116.3 ± 36.0
	KATRAM	423 ±73.8	17.8 ± 3.1	1623 ± 481.2	108.2 ± 32.1
	KATX-56	462 ±33.2	19.4 ± 1.4	95.9 ± 28.1	95.9 ± 28.1

P-values, tillage (P = 0.320), varieties (P = 0.604), tillage and varieties (P = 0.260), season ((P < 0.001), tillage and season (P = 0.010), varieties and season (P = 0.985), tillage and varieties and season (P = 0.756), Biomass Yield – Tillage (P = 0.336), varieties (P = 0.463), tillage and varieties, (P = 0.247*)*, season (P < 0.001*), tillage* *and season (*P < 0.009) and varieties and season (P = 0.988)

3.8. Relationship among Tillage Systems, Common Bean Varieties, Biomass and Grain Yield, Water Use Efficiency Biomass and Water Use Efficiency Grain Yield and Seasonal Moisture Content

There was a strong correlation between biomass and grain yield (R = 0.98) and also observed was a strong correlation between WUE of biomass and grain yield (R = 0.97). Similar relationship was observed between WUE of grain yield and grain yield (R = 0.99) while a strong correlation was observed between biomass yield and WUE grain yield (R = 0.98), WUE of biomass and WUE grain yield (0.98). This implies that the effect of season on soil moisture will determine dry matter weight and grain yield under drought and favorable season as was express in yields during both seasons (SR and LR) (Figure 3). However WUE cannot be measured in the absence of the two components (biomass and grain). Moreover, WUE from this study, was derived from both the biomass and grain yield express over the ET common crop. [42], reported that the decrease in WUE under alternative practices can be attributed to the corresponding decrease in the grain yield, in agreement with the strong positive relationships between the WUE and grain yield of the study result (Table 4). Moreover, there was no relationship among seasonal moisture content, tillage systems, common bean varieties and biomass and grain yield to biomass yield WUE and grain yield WUE. However, the positive correlation between WUE and biomass and grain yields and harvest index at 70 DAP adds weights to the significance of WUE as a useful selection criterion in breeding and selection of cultivar for high performance under drought in semi-arid areas and the world at large.

Table 5: Correlation among Tillage, Common Bean Varieties, Biomass and Grain Yield, WUE Biomass and WUE Grain Yield and Seasonal Moisture Content

	Tillage	Varieties	Grain yield	Biomass	WUE-B	WUE-G	SM
Tillage	-						
Varieties	-0.01	-					
Grain yield	0.04	0.01	-				
Biomass	0.04	0.01	0.98*	-			
WUE-B	0.05	0.01	0.97*	0.99*	-		
WUE-G	0.05	0.01	0.99*	0.98*	0.98*	-	
SM	-0.11	0.16	0.04	0.07	0.08	0.05	-

WUB-B- water use efficiency biomass, WUE-G – water use efficiency grain yield, SM – soil moisture

4. Conclusion

The results evolving from this study indicate that soil conservation tillage systems is significant for yield of different drought tolerant common bean varieties and WUE in Machakos County, Eastern Kenya. This is from the backdrop that conservation tillage systems conserved higher moisture content and kept the soil micro and macro pores intact as well as soil structure while influencing soil moisture trend during the phenological stages. This is evident based on the results from both season with NT having higher variation in grain yield than CT followed by MT though insignificant. However, for the four varieties GLPX92, KATB1, KATX56 and KATRAM used in the two season (SR & LR), it was observed that GLPX92 had the highest yield followed by KATB1, KATX56 and KATRAM though insignificant. Higher yield in CT is as a result of the loosening of the soil allowing for ease of roots penetration and easy infiltration of rain water. From other studies, many researchers argues that this practice is not sustainable in semi-arid areas in that it will further degrade the soil due to higher impact of raindrop on soil surface and increasing erodibility due to increased fragility of soil. However in the near future, soil compaction will occur and rain water infiltration will be hampered. Unlike conservation tillage systems will promote soil moisture storage and increased soil stability and reduce the level of radiation entering the soil and increasing grain yield and higher WUE. There is a need for further research to determine why GLPX92 exhibited such dominant characteristic in yields and WUE above KAT/B1, KATX56 and KATRAM during the both seasons (SR & LR).

5. Recommendations

Results emanating from this studies, recommend conservation tillage systems to be the best option for the cultivation of different drought tolerant common bean varieties in semi-arid areas like Machakos County due to the soil moisture conservation ability of said practices as compares to conventional tillage systems which is not a sustainable practice in such marginal areas.

That these varieties, GLPX92, KAT/B1, KATX56 and KATRAM are short duration crops which are tolerant to both drought and favorable cropping seasons and can be used to reduce poverty and increase for security in semi-arid areas like Machakos County.

Finally, I would recommend the arguments of other researchers who argues that conventional tillage systems is unsustainable in that it further degrade the soil and reduce soil moisture content, increased soil erodibility, increased soil radiation and reduce grain yield and WUE.

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