Original Research Article

Fanya juu terraces improve maize _(Zea mays L.)_ and bean _(Phaseolus vulgaris L)_ grain _y_ields on hardsetting soils of semi-arid Eastern Kenya

ABSTRACT

Fanya juu terraces are constructed by digging a ditch and throwing the soil up-slope with the sole purpose of maintaining an embankment to slow down runoff flow. The effect of the terraces on crop yields along the slope varies with the soil type. A trial was established on luvisols in Mua location, Machakos County in Eastern Kenya at 37^{o}15'E 1^{o}29'S and 37^{o}15'E 1^{o}29'S during both long rain (LR) and short rain (SR) seasons of 2014 and SR 2015. The objective was to determine the effect of *Fanya juu* terraces on maize (*Zea Mays* L.) and bean (*Phaseolus vulgaris* L.) yields and how these yields differ with slope positions and depth of the ditches. A split-split plot design with four replications was used. Treatments consisted of three ditch depths (60cm, 30cm and 0cm (control)) in the main plots and three cropping systems (maize/bean intercrop, sole maize and sole bean) in the sub-plots. Grain yields were compared across the seasons at the upper, middle and lower slope positions of the terraces using analysis of variance and means separated using least significant difference at $P \leq 0.05$. Significant differences were observed between maize grain yields in interactions of ditch depth and slope position (P=0.004) and ditch depth and season (P<0.001). Higher maize yields were realized when ditches were constructed than in the control. Yields increased from the lower to the upper slope position of the terraces by 49.8% in the 30cm and 41.6% in the 60cm ditch depths. Yields were significantly higher in the 30cm ditch than the control, but non-significant from those in the 60cm ditch. Bean grain yields were significantly different between interactions of ditch depth and slope position (P=0.037) with higher yields in the lower position of the 30 cm ditch than the middle and upper positions. Significant differences (P=0.033) were also found between interactions of ditch depths, cropping systems and seasons. This study recommends a ditch depth of 30 cm and intensive management of the lower slope position in *Fanya juu* terraces for improved maize and bean production on hard setting soils.

Key words: *Fanya juu terraces; soil type; slope position; crop yields*

1. **INTRODUCTION**

Hardsetting soils have an unstable structure which collapses when the soil is wet and shrinks and hardens as the soil moisture dries up (Daniells, 2012). These soils are pulverized as a result of the instability of the surface layer and the detached particles clog and seal pores when soils are wet. The surface of the soils easily pond during rainfall events followed by sealing and crusting as the water dries up (Miriti et al, 2012). On drying, the soils acquire high soil strength and crusting properties and the upper layer gets compacted (Giarola et al., 2011). Repeated cycles of sealing, crusting and compaction results in the hard-setting nature (Bresson et al, 2006, Giarola *et al.*, 2011, Daniells, 2012). The crusting, compaction, ponding and hardness limit crop emergence, development of plant roots and infiltration and increases surface erosion (Rao et al., 1994, Daniells, 2012).

Hardsetting soils are common in the arid and semi-arid lands (ASALs) of sub-Saharan Africa (SSA). Most of these soils in the ASALs of SSA are low in moisture and nutrient contents as a result of marginal rainfall, high evaporation and inadequate application of fertilizer inputs (Fries et al., 2020, Masso et al., 2017, Recha et al., 2016). Rainfall is erratic and at times comes in intensive storms with escalated runoff causing further loss of nutrients and rainwater through erosion (UNDP, 2013). Soil and water conservation measures are therefore of paramount importance for effective crop production.

Terraces are widely adopted to reduce erosion from the impacts of torrential rainfall and conserve soil and water in low rainfall areas (Rashid et al., 2016, Widomski et al. 2011). The *Fanya juu* type of terraces are constructed by digging a ditch and throwing the soil up-slope with the sole purpose of maintaining an embankment to slow down runoff flow and hold soil sediments. The ditches and embankments shorten the length of the slope and minimize soil and water loss by reducing the speed and quantity of runoff flow (SUSTAINET EA, 2010, Mesfin, 2016, Gachene et al., 2019). At the same time the structures increase infiltration and can sustain productivity in sloppy areas with marginal rainfall (Sheng, 2002, Doreen and Rey, 2004, Youssef et al., 2008, Hussein et al, 2016).

Several studies have reported differences in crop yields between terraced and non-terraced fields as well as within the terraces (Barungi et al., 2013; Binyam et al., 2015). Studies have also indicated that crop yields vary along the terraces slope and that this variability is dependent on the type of soil (Gachene and Baaru, 2011, Ruto, 2015, Wairimu, 2015). For instance, in well-drained Luvisols maize rows bordering the terrace ditch were more vigorous in growth and gave higher yields compared to those in the section away from the ditch (Gachene and Baaru, 2011). This was attributed to an increase in soil moisture next to the ditch resulting from lateral seepage of water. In the light-textured Andosols maize rows next to the ditch had retarded growth and low yields due to excessive drainage and leaching of nutrients caused by moisture that was captured in the ditch (Ruto, 2015). These were immediately followed by rows of taller maize that benefited from moisture and nutrients that flowed laterally from the ditch before another set of rows of retarded maize at the depletion zone. A similar study in the heavy-draining Vertisols (Wairimu, 2015) indicated increased yields from rows in the lower position at the furthest end of the slope compared to those next to the ditch. All these studies attributed the differences in maize yields to variations in soil moisture content along the terrace slope in the different soil types. According to Ruto (2015) the information on variability in crop performance in terraces is crucial in designing appropriate cropping systems for different slope positions in order to improve productivity in the ASALs. There is, however, limitation of this knowledge on different types of soils. This brought about the need to study effect of terraces on crop yield variability on hardsetting soils that are common in the ASALs of Eastern Kenya for enhanced exploitation of available resources.

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2. MATERIALS AND METHODS

2.1. **Description of study location**

The study was conducted for four seasons in Mua location of Machakos county in Eastern Kenya. The county is situated between longitudes 36° 45' E and 37° 45' E and latitudes 0º 45' S and 01º 31' S. It lies at altitudes of 1000 to 1600 meters above sea level (asl). The trial was set up in two adjacent farms at 37^{o}15'E 1^{o}29'S and 37^{o}15'E 1^{o}29'S (Figure 1).

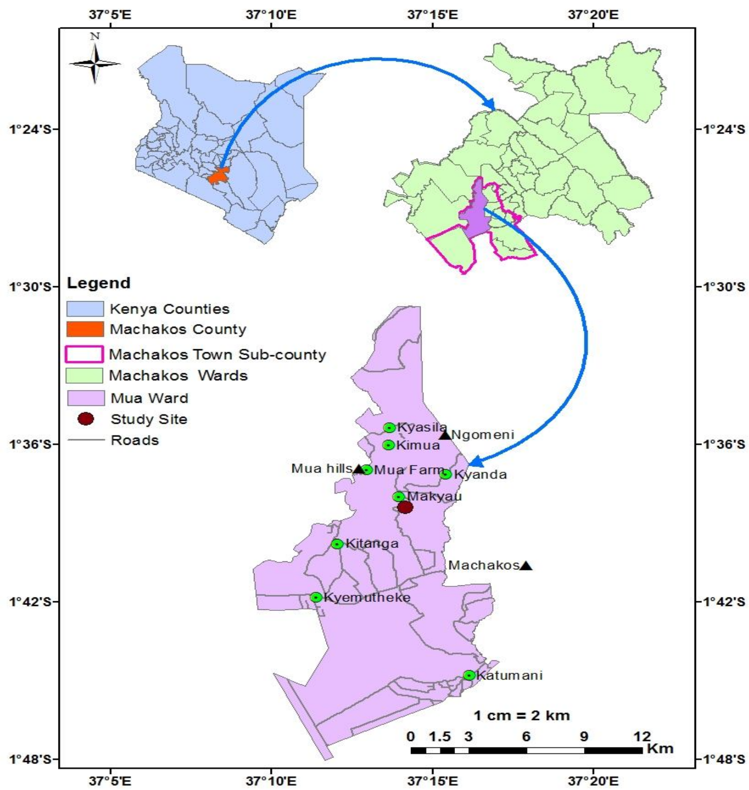
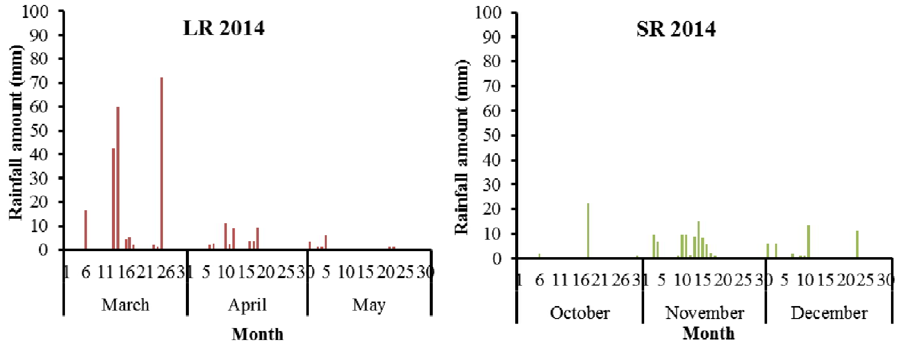
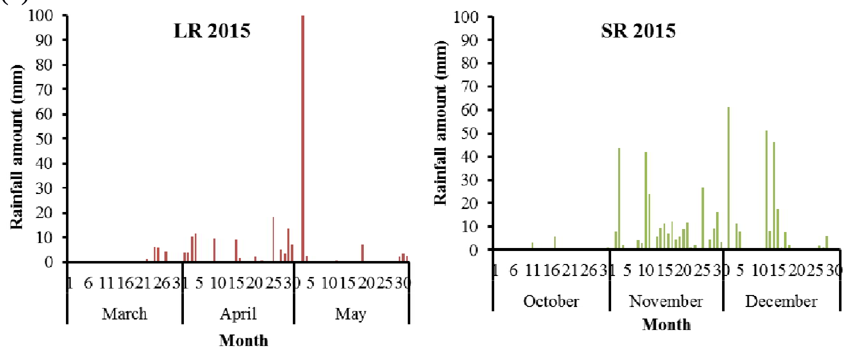


Figure 1: A map showing the study site

Rainfall is bimodal from March to May (long rains [LR] season) and October to December (short rains [SR] season) (Jaetzold et al., 2010). The experiment was conducted during long rains (LR) 2014, short rain (SR) 2014, LR 2015 and SR 2015 seasons. The mean annual rainfall is 650 mm with seasonal mean of 270 mm in LR and 380 mm in SR. Annual temperatures range from 13 to 24^{o}C (Jaetzold et al., 2010). The rainfall season are also the crop growing seasons in the area. The SR season is more reliable in amount and distribution with a higher probability of occurrence than the LR (Jaetzold et al., 2010). A dry period extending from August until mid-October separates the two rainfall seasons. Evapotranspiration rates are high and exceed precipitation for most part of the year (Jaetzold et al., 2010). Poor distribution of rainfall and recurrent droughts during the crop growing season are common. The onsets, cessations, distribution and amounts vary from season to season with considerable effects on crop yields and food security particularly under rain-fed conditions (Mati, 2005, Jaetzold et al., 2010, Omoyo, et al., (2015). Figures 2a and b show rainfall distribution during the four seasons of the study.



(a)



(b)

Figure 2: Seasonal rainfall distribution during LR and SR 2014 (a) and 2015 (b)

Soils are sandy clay loam in texture with pH (H_2O 1:2:5) of 6.60. They are classified as luvisols under FAO/UNESCO soil classification (FAO/UNESCO1997). The soils are shallow and low in water holding capacity. They are pulverized and prone to surface sealing and crusting. They easily pond during rains especially when ridges are used at planting and crust at the surface when water dries up (Scott et al., 1963, Miriti et al., 2012, Karuma et al, 2014). The soils are low in nutrients contents especially nitrogen and organic carbon (Table 1). The major cereal crop grown in the area is maize *(Zea Mays L.)* while the major pulses are Common bean *(Phaseolus vulgaris L.)* and pigeon peas *(Cajanus cajan)*are the major legumes. The maize is grown as a sole crop system or intercropped with the pulses. During the two seasons previous to the study the experimental land was under maize/bean intercrop followed by sole maize system.

Table 1: The pH, %Total Nitrogen, Available Phosphorous, Exchangeable Potassium and Organic Carbon contents of the soil in the trial site at commencement of study

Soil property	Status	Soil property	Status
pH-H_2o (1:2:5)	6.60	Potassium (Cmol/kg)	0.51
Total Nitrogen (%)	0.07	Organic carbon (%)	0.63
Phosphorous (ppm)	18.81	CEC) (Cmol/kg)	16.80

Legend: *CEC-Cation exchange capacity, ppm-parts per million, Cmol/kg-Centimols per kilogram*

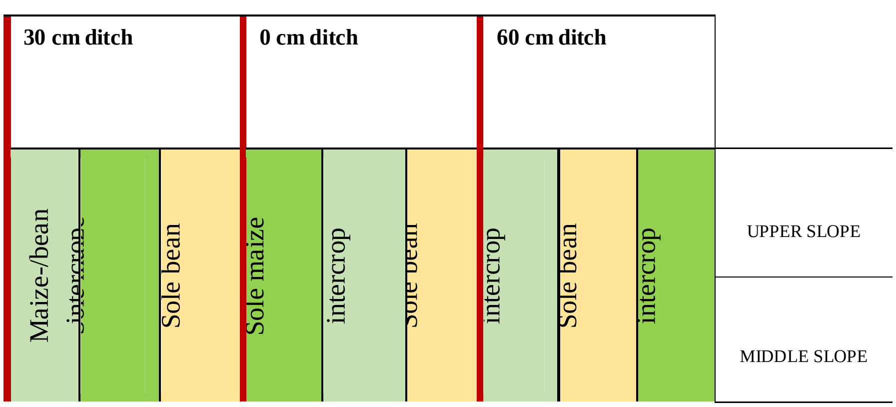
2.2. **Experimental design and treatments**

The trial was planted in a split-split plot design with four replications. Treatments consisted of terraces with three ditch dimensions; 60, 30 and 0 cm (Control) deep in the main plots and three cropping systems in the sub-plots. The cropping systems were maize/bean intercrop (M/BI), sole maize (SM) and sole bean (SB). Treatments were combined as summarized in Table 2.

Table 2: Summary of treatments studied in a split-split plot design, where ditch depths were allocated to the main plots, cropping system to the sub-plots and slope position to the sub-sub-plots

Treatment	Combination
T1	60 cm ditch + maize/bean intercrop
T2	60 cm ditch + sole maize
T3	60 cm ditch + sole bean
T4	30 cm ditch + maize/bean intercrop
T5	30 cm ditch + sole maize
T6	30 cm ditch + sole bean
T7	0 cm ditch + maize/bean intercrop,
T8	0 cm ditch + sole maize
T9	0 cm ditch + sole bean

The main plot were 14 m wide with a two (2) metre path separating adjacent plots. Each main plot had three sub plots of 4 m and a one (1) metre path between subsequent sub-plots. The length of the terraces depended on the slope and ranged from 14 to 17 m. The terrace area below each ditch was subdivided into three equal sections which were designated as the upper (next to the ditch), middle (at the centre of the terrace) and lower (adjacent to the embankment of the subsequent ditch) positions of the slope (Figure 3). During data collection each sub-plot was divided into three slope positions of equal length. These were designated as the upper, middle and lower slope positions. Crop data for analysis was collected from each of these slope positions.



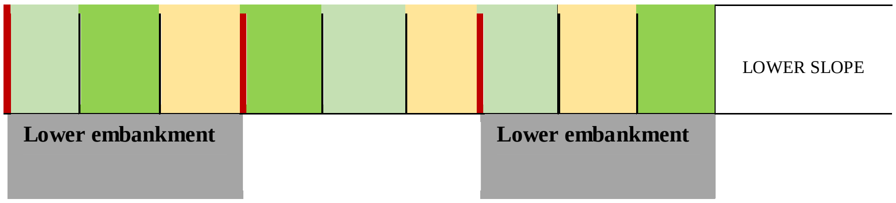


Figure 3: Sketch of a single replicate of the trial showing measurements and allocations of ditches (main plots), cropping systems (sub-plots) and slope positions (sub-sub plots)

2.3. **Land preparation and planting**

The land was prepared by clearing, ploughing and digging out the ditches before the onset of rains. The locations of the ditches were identified using the rod and string method and the three ditch treatments randomly allocated to the main plots along the identified positionn.s The 30 and 60 cm trenches were measured and soil dug out by hand at the beginning of the first season. The first and subsequent land preparation was done using the oxen plough (common farmer practice) and the field leveled out by hand hoes before planting. Planting was done every season at the on-set of rains to maximize on available rainfall. During the planting treatments on cropping system (maize/bean intercrop, sole maize or sole beans) were randomly allocated to the sub-plots. Maize *(Zea mays* L.*)* variety Duma 43 and common bean (*Phaseolus vulgaris* L.) variety Kat B1 were used as the test crops. Maize was planted at a spacing of 90 x 30 cm. Beans were planted at 45 x 20 cm in the sole crop system and at 90 x 20 cm (one row between two maize rows) in the mixed system,. Two seeds were planted per hill and the seedling thinned to on plant per hill two weeks after emergence. Maize was planted with Di-ammonium phosphate (DAP) and later top-dressed with calcium ammonium phosphate (CAN) at the recommended rate of 40 kg P_2O_5 and 40 kg N ha^{-1}. Nappier grass was planted on the terrace embankments for stabilization and ditches maintained in consequent seasons by scooping out any soil filing up the trench and heaping it back on the embankment. Prevailing agronomic practices were adopted for weeding, pest and disease control and the general management of the crop until harvest time.

2.4. **Data collection**

All the crop data was collected from each of the sub-sub-sub plots (slope position). The data included dates of planting, percent germination and stand after thinning for both maize and beans. At physiological maturity yield data was collected from a net plot area within each slope position. Yield data included number of plants harvested (both maize and beans), number of maize cobs harvested, field weights of cobs, grain weights of maize and bean per plot, and moisture contents of maize and bean grains at harvest. Dimensions of net plot areas were 13.5m^2 for maize (5 rows) in both sole and intercropped systems and 10.8 m^2 for beans (8 rows in pure stand and 4 rows under intercropped system). Data was entered in Excel spreadsheets for ease of management. The yield and field grain moisture content data were used to compute the final grain yields in t ha^{-1} corrected to 12% moisture content.

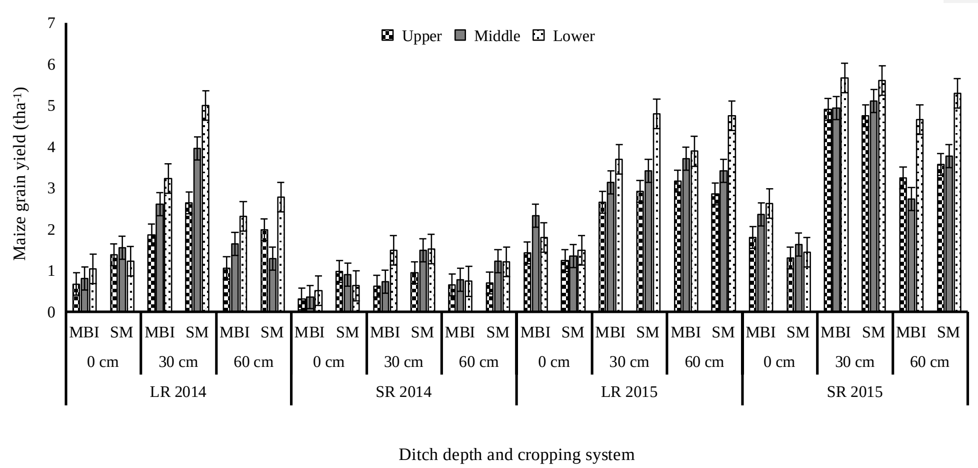
2.5. Data analysis

Te crop data was subjected to GenStat (2016) statistical package for two-way analysis of variance (ANOVA). Means were separated at 95% level of confidence. The Fishers' protected least significant difference of means (LSD) and Duncan Multiple Range Test (DMRT) were used for comparison of significant means.

3. .RESULTS AND DISCUSSIONS

3.1. Effect of ditches, ditch depths and slope positions on maize grain yields

Significant difference (P=0.004) in yield were observed between ditch depths and in interactions of ditch depth and slope position (Figure 4).



Legend: *M/BI -Maize and bean intercrop system, SM - Sole maize system*

Figure 4: Maize grain yields under sole maize (SM) and maize/bean intercrop (MBI) systems in the lower, middle and upper slope positions in terraces with 0., 30 and 60 cm ditch depths

Maize grain yields were significantly higher in the 30 (3.24 t ha^{-1}) and 60 cm (2.55 t ha^{-1}) ditch treatments than in the 0 cm (1.28 t ha^{-1}) ditch. This could be attributed to the surface crusting and compacting nature of hardsetting soils (Giarola *et al*., 2011). This could have increased the loss of water and nutrients through runoff resulting in reduction in maize yields especially in the control treatment where the ditch was not constructed. According to Dorren and Rey (2004) and Tenge et al. (2011) *Fanya juu* terraces are effective in reducing water and soil losses and increasing infiltration when water is held in the trenches for loner periods. The maize in treatments with ditches therefore, benefited from an increased availability of soil moisture from the lateral flow of water held in ditches and the nutrients that were retained in the terraces. The low yields in the non-terraced treatment inform on what the farmers who have not constructed terraces get in this area.The results imply that farmers can benefit from the little rainfall by constructing terraces to capture runoff and using it in their farms to increase production. The results confirm a report by Kosmowski (2018) indicating an increase in yields in terraced fields in Ethiopia. Rashid et al. (2016) also reported an increase in wheat grain resulting from 16% increase in soil moisture content when terraces were constructed in the sloppy rainfed areas of Pakistan.

Maize grain yields were higher in treatments with 30 cm ditch depth (average 3.21 t ha^{-1}) but not significantly different from those in the 60 cm ditch (2.55 t ha^{-1}). This implies that varying the depth of the ditch did not significantly affect grain yields although the conditions provided by the shallow ditch were more conducive for the maize performance than in the deeper one. It could be argued that the 30cm ditch held the runoff at an upper soil depth compared to the 60 cm ditch. The lateral flow of water in the shallow depth was closer to the upper soil horizon making it more available to the crop at the zone with high root concentration. As stated by Rossato et al. (2017) the response of plants to rainfall in the top layers of the soil is better compared to that in deeper profiles. Water in the deeper ditch was held at lower depths and could have been lost through deep percolation and lateral flow below the root zone. Construction of terraces with 30 cm ditch depth could therefore be beneficial to the farmers through increased chances of soil moisture availability at the crop root zone and reduction in labour. Wairimu (2015) reported no differences in maize yields from terraces with different ditch depths in a trial conducted in Vertisols. This was attributed to an impediment of the movement of water in wet Vertisols.

The lower slope position were generally recorded higher maize yields than the upper and middle slope positions of treatments with ditches in all seasons. Yields increased from the upper to the lower slope position by 49.8% in the 30cm and 41.6% in 60cm ditch depths. Significant difference (P=0.004) in yields was observed between slope positions in terraces with 30 cm ditch. These increased from the upper to the middle position by 20.7% and to the lower position by 49.8%. In the 60 cm ditch maize grain yields from the lower slope position were higher than from the upper position and significantly different in the last two seasons of the study. Higher yields in the lower slope position may have resulted from the effect of soil moisture and nutrients trapped by the embankment as well as from the lateral seepage of the water in the ditches. Gicheru et al. (2004) reported an increase crust strength when soil water content decreased. The increased moisture could have reduced the strength of the crust at the lower slope position providing a conducive environment for the maize to grow. Maize performance is affected by lack of water at all stages of growth and especially at flowering period when the crop is most sensitive to drought (Spitkó et al., 2014, Aslam et al. 2015). The availability of soil moisture at the lower slope position in treatments with ditches could have contributed to reducing this stress. Earlier studies have proved that higher water content in the ditch can lead to efficient use of nitrogen and that increases in soil moisture can improve nitrogen absorption, transportation and accumulation resulting in enhanced crop yields (Dijkstra and Cheng, 2008, Huang et al., 2022). In view of this the maize crop therefore benefited from nitrogen uptake in the roots through mass flux facilitated by the presence of water. The conducive environment created by the presence of the moisture can be exploited through intensification of the lower slope position in order to increase production and the benefits of constructing terraces in hardsetting soils. The results of this experiment concur with reports from studies conducted by Amare et al. (2013) in the Central highlands of Ethiopia. The authors found higher maize and wheat yields in the lower slope position than the upper slope and attributed it to increased fertility in the deposition zone. Ruto et al. (2017) similarly reported increase in yields in the lower slope of the terrace compared to the upper slope as a result of accumulation of nutrients and moisture at this site. No significant difference ($P<0.05$) was found between maize grain yields in the three slope positions in the control treatment. This was because runoff was not trapped in a particular area giving no variations in accumulation of moisture or nutrients. This is the normal situation in farms where terraces have not been constructed in the area.

There were no significant differences ($P\leq0.05$) in maize grain yield between the sole maize and maize/bean intercrop systems or in interactions of cropping systems, ditch depth and slope positions. Maize grain yields were not significantly affected by the type of cropping system (sole maize or maize/bean intercrop). This was probably because of lack of effective competition from the bean crop. Rainfall during the study seasons was either too low and sparsely distributed for the beans to survive and compete with maize for resources, or well distributed and high enough to provide sufficient soil water for both crops.

3.2. Effect of ditches, ditch depths and slope positions on bean grain yields

No bean grains were obtained in SR 2014. This was partially caused by the low (149.2 mm) and unevenly distributed rainfall. As reported in several studies (Boutraa and Sanders, 2001, Molina et al., 2001, Robel et al., 2019) moisture stress reduces bean yields with severity depending on the stage at which the stress occurs. According to Ntukamazina (2017) even brief periods of dry spell affect both the quality and quantity of bean yield. Such dry spells were common during the season. The ditches captured too little or no runoff to create any changes in soil moisture and subsequetly on the yields of beans.

Significant differences in bean green yields were found between interaction of ditch depth and slope positions ($P=0.015$) and cropping systems and slope position ($P=0.037$) (Figure 5).

Legend: *M/BI -Maize and bean intercrop system, SB* **-** *Sole bean cropping system*

Figure 5: Bean grain yields under sole and intercropped cropping systems in the lower, middle and upper slope positions of terraces with 0, 30 and 60 cm ditch depths

Significantly higher (P=0.019) bean grain yields were obtained from treatments with 30 cm (0.497 t ha^{-1}) and 60 cm (0.469 t ha^{-1}) ditch depths compared to the control (0.359 t ha^{-1}). Higher and significantly different mean bean yield (0.61t ha^{-1}) was recorded in the lower slope position in treatments with 30cm ditch depth than in the upper slope position of the control (0.33 t ha^{-1}). Yields from the lower part of the slope in treatments with ditches were higher than those from the middle and upper slope positions of the same ditches depths. Higher yields in treatments with ditches and in the lower slope than the middle and upper positions was probably a result of the availability of water and nutrient trapped by the terrace embankments. The results concur with findings by Ruto et al. (2017) who reported higher bean yields in the lower slope position as a result of deposition of nutrients from the terrace through surface runoff. Siriri et al. (2005) similarly found an increase from in sorghum yields from 0.4 t ha^{-1} in the upper area of the slope to 2.4 t ha^{-1} in the lower position. Yields obtained from treatments with ditches were lower than from the control during SR 2015 season. A comparison between similar positions of the terraces also indicated that average bean grain yields in the lower slope position were significantly higher (P=0.015) in treatments with ditches than in the control treatment except in SR 2015. Lower yields in treatment with ditches during SR 2015 season could be attributed to the effect of excessive rainfall. Conditions of high soil moisture contents can be unfavourable for proper bean performance because of the imbalances in oxygen levels in the root area and increase in infestation by pathogens which both cause losses in yields Ntukamazina (2017).

4. CONCLUSIONS AND RECOMMENDATIONS

From the results of the trial, terraces had a significant effect on crop yields on hardsetting soils depending on the amount and distribution of rainfall. Treatments with ditches had significantly higher maize and bean grain yields than the control in seasons with low and unevenly distributed rainfall. This indicates that farmers in low rainfall areas can increase crop production by constructing terraces to capture runoff. Increasing the depth of the ditch did not significantly affect the yields of maize in marginal rainfall seasons. Yields were however,higher in treatments with 30 cm than the 60 cm ditches. Farmers can therefore save on labour and still achieve better yields by constructing terraces with the shallow ditch depth (30 cm). The lower slope position provided a more conducive environment for maize and bean production resulting in higher yields than the upper slope position. The conducive environment can be exploited through increased intensification in order to enhance production and increase the benefits of constructing terraces in hardsetting soils. The type of cropping system (sole or intercropped) did not affect maize yields. However, sole bean cropping system is recommended for production in low rainfall, terraced hardseting soils. This study recommends construction of *Fanya juu* terraces with a ditch depth of 30 cm and intensive management of the lower slope position for enhanced crop production on hardsetting soils in Kenya

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