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Fanya juu Terraces Improve Maize *(Zea mays L.)* and Bean *(Phaseolus vulgaris L)* Grain Yields on Hardsetting Soils of Semi-arid Eastern Kenya

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Authors' contributions

This work was carried out in collaboration among all authors. Author ENN carried out the investigation, managed the analyses of the study, managed the literature searches and wrote the first draft of the manuscript. Author MWB wrote the protocol, designed the study, acquired funding, did the review and editing. Author CKG wrote the protocol, designed the study, supervised, did the review and editing. All authors read and approved the final manuscript

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ABSTRACT

Aims: *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. The aim of this study 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.
Study Design: Split-split plot design with four replications.
Place and Duration of Study: The trial was established on Luvisols in Mua location, Machakos County in Eastern Kenya at 37o15'E 1o29'S and 37o15'E 1o29'S during both long rain (LR) and short rain (SR) seasons of 2014 and 2015 (February 2014 to March 2015).
Methodology: Treatments consisted of three ditch depths (60 cm, 30 cm and 0 cm (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

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positions of the terraces using analysis of variance and means separated using least significant difference at $P \leq 0.05$.

Results: There were significant differences in maize grain yields in the 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 with 30 cm ditch by 49.8% and in the 60 cm by 41.6%. Average yields from treatments with 30 cm ditch were significantly higher than from the control but non-significant from those in the 60 cm ditch. Significant differences (P=0.037) in bean grain yields were observed in interactions of ditch depth and slope position. Higher yields were obtained from the lower position of the 30 cm ditch than the middle and upper positions. Significant differences (P=0.033) were also found in interactions of ditch depths, cropping systems and seasons.

Conclusion: The results indicate that *Fanya juu* terraces had a significant effect on crop yields on hardsetting soils. The study recommends construction of *Fanya juu* terraces with a ditch depth of 30 cm and intensive management of the lower slope position for improved maize and bean production on hardsetting soils in marginal areas.

Keywords: Embankment; 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 [1]. 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. This is followed by sealing and crusting as the water dries up [2]. On drying, the soils acquire high soil strength and crusting properties and the upper layer gets compacted [3]. Repeated cycles of sealing, crusting and compaction results in the hard-setting nature [1,3,4]. The crusting, compaction, ponding and hardness limit crop emergence, development of plant roots and infiltration and increases surface erosion [1,5].

Hardsetting soils are common in the arid and semi-arid lands (ASALs) of sub-Saharan Africa (SSA). They are found in large parts of Eastern and Southern Africa and the Sudan-Sahelian region of West Africa [6]. Most of the soils in the ASALs of SSA are low in moisture and nutrient contents as a result of marginal rainfall, high evaporation rates and inadequate application of fertilizer inputs [7,8,9]. Rainfall is erratic and at times comes in intensive storms with escalated runoff causing further loss of nutrients and rainwater through erosion [10]. 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 [11,12,13]. 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 [13,14,15,16]. At the same time the structures increase infiltration and can sustain productivity in sloppy areas with marginal rainfall [17,18,19,20].

Several studies have reported differences in crop yields between terraced and non-terraced fields as well as within the terraces [21,22]. Studies have also indicated that crop yields vary along the terraces slope and that this variability is dependent on the type of soil [23,24,25,26]. 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 [23]. 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 [24]. 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 [25] 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 [24] 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.

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°15'E 1°29'S and 37°15'E 1°29'S (Fig. 1).

Rainfall is bimodal from March to May (long rains [LR] season) and October to December (short rains [SR] season) [27]. 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°C [27]. The rainfall seasons 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 [27]. 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 [27]. 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 [28,27,29]. Fig. 2a and b show rainfall distribution during the four seasons of the study.

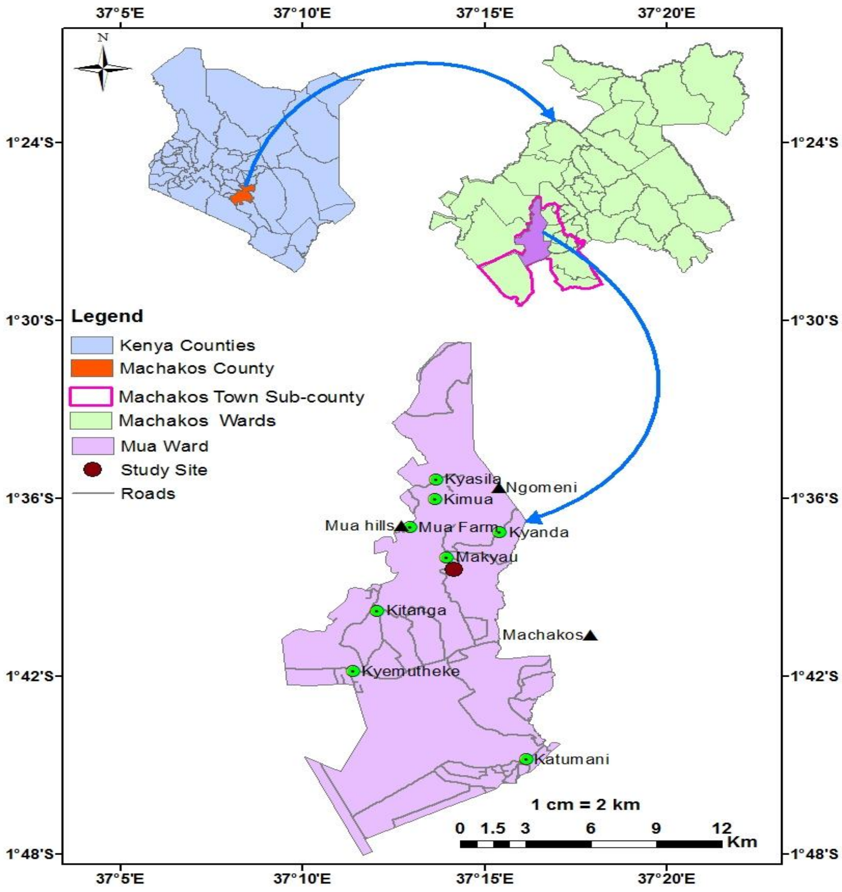
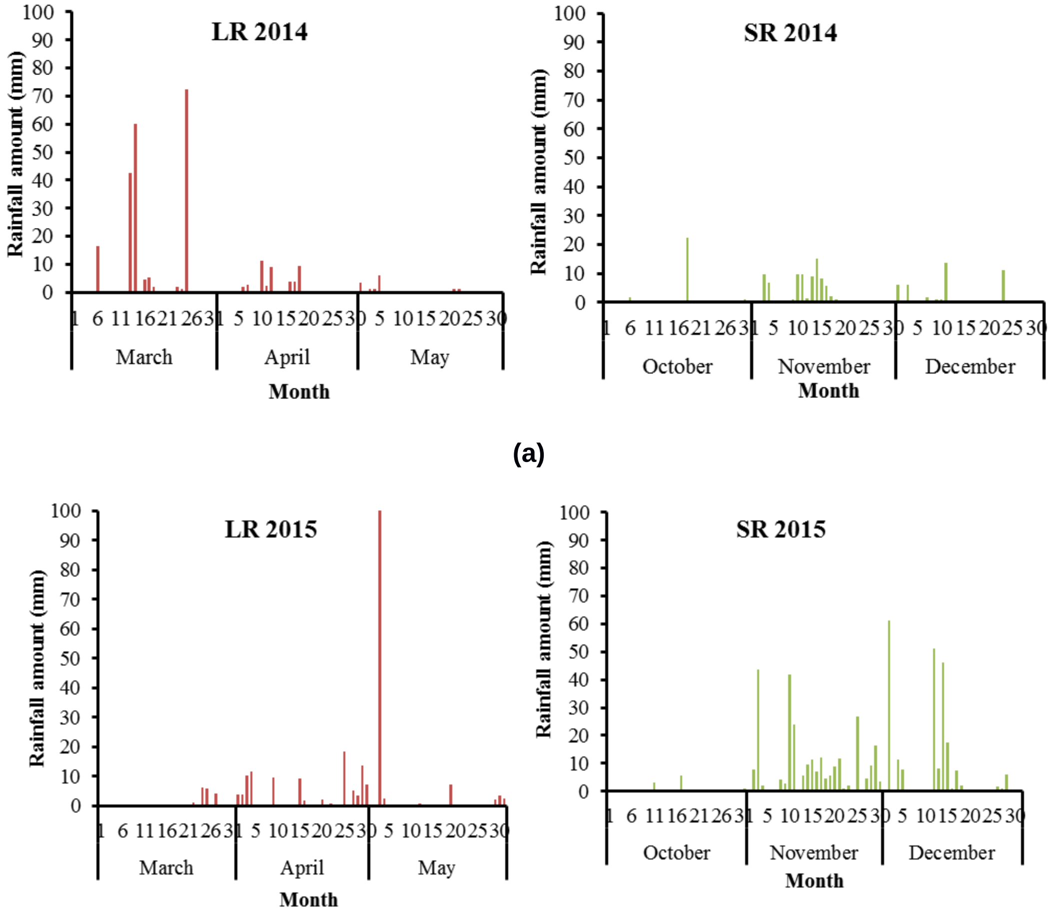


Fig. 1. A map showing the study site



(a)

(b)

Fig. 2. Seasonal rainfall distribution during LR and SR 2014 (a) and 2015 (b)

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

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 [30]. 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 [2,31,32]. 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 the Common bean *(Phaseolus vulgaris* L.*)* and pigeon peas *(Cajanus cajan)* legumes. The maize is usually grown in 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.

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 depth dimensions; 60, 30 and 0 cm (Control) located 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 (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) meter path separating adjacent plots. Each main plot had three sub plots of 4 m and a one (1) meter 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 (Fig. 3). These sections formed the sub sub-plots from which data for analysis was collected.

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 positions. The 30 and 60 cm trenches were measured and soil dug out by hand at the beginning of the first season.

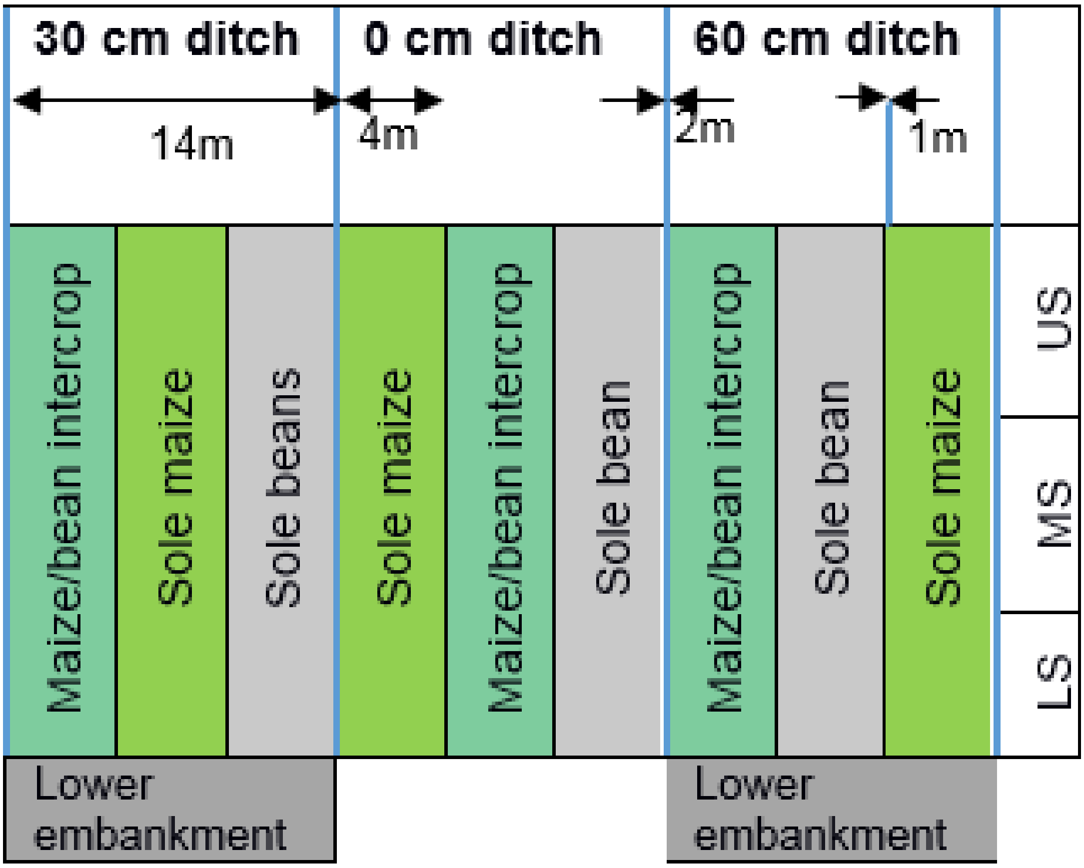


Fig. 3. Sketch of a single replicate of the trial showing measurements and allocations of ditches (main plots), cropping systems (sub-plots) and slope positions (sub-sub plots)
Legend: US Upper - slope position, MS - middle slope position, LS – lower slope position

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}. Napier 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, 3m long) in both sole and intercropped systems and 10.8 m^2 for beans 3 meters by (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.

2.4 Data Analysis

The crop data was subjected to GenStat [33] 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 DISCUSSION

3.1 Effect of Ditches, Ditch Depths and Slope Positions on Maize Grain Yields

Significant differences in maize grain yields were observed in interactions of ditch depths and seasons (P<0.001) and ditch depths and slope positions (P=0.004) as shown in Fig. 4.

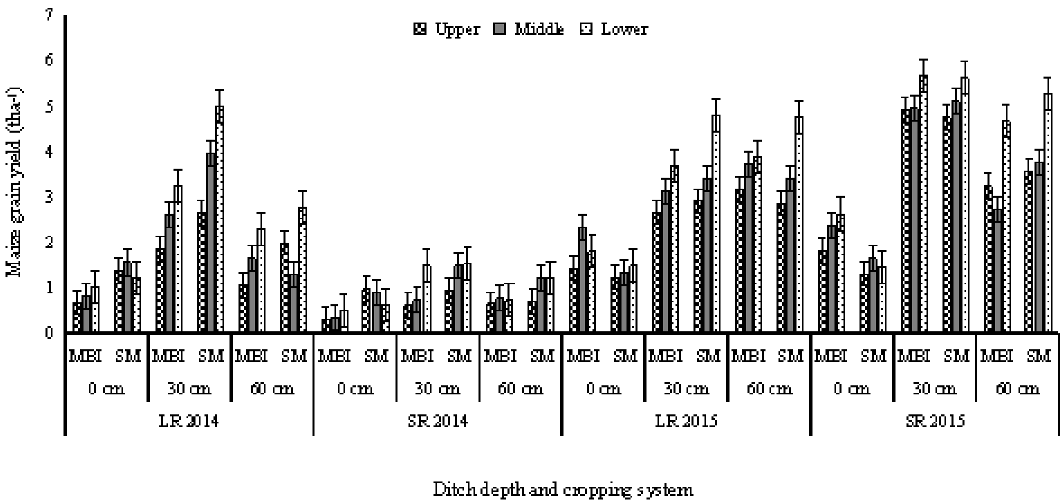


Fig. 4. Maize grain yields under sole maize (SM) and maize/bean intercrop (MBI) systems in the lower, middle and upper slope positions in terraces with 0., 30 and 60 cm ditch depths
Legend: M/BI -Maize and bean intercrop system, SM - Sole maize system

Maize grain yields averaged over the four seasons 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 [3]. This may 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 some authors [15,18,34] *Fanya juu* terraces are effective in reducing water and soil losses. They increase infiltration when water is held in the trenches for longer 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. These results confirm a report by [35] indicating an increase in yields in terraced fields in Ethiopia. Similarly [11] also reported an increase in wheat grain resulting from 16% increase in soil moisture content when terraces were constructed in the sloppy rain-fed areas of Pakistan.

Maize grain yields from terraces with 30 cm ditch depth (irrespective of the cropping system) were higher (average 3.24 t ha^{-1}) but not significantly different from those obtained from treatments with 60 cm ditch (2.55 t ha^{-1}). This implies that varying the depth of the ditch did non-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 30 cm 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. This was more evident in seasons with low or poorly distributed rainfall (LR and SR 2014). As stated by [36] 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. In SR 2015 the amount of rainfall received was high and evenly distributed with runoff filling the deeper ditches for several days during the season. This may have caused leaching of nutrients in terraces with 60 cm ditch depth and lower yields than those from terraces with 30 cm ditch. 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 [25] 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 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 positions by 49.8% in the 30 cm and 41.6% in the 60 cm ditch treatments. 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%. Maize grain yield from the lower slope position was higher than from the upper position in terraces with the 60 cm ditch. Significant difference between yields from upper and lower slope positions in the 60 cm ditch treatment were observed in the last two seasons of the study (LR 2015 and SR 2015) when rainfall was high and/or evenly distributed. 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. A study by [37] showed that the crust strength increases as soil water content decreases. Other studies by [38,39] indicated that 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. The higher moisture at the lower slope position could have reduced the strength of the crust and provided a conducive environment for the maize to grow. The availability of soil moisture at the lower slope position in treatments with ditches could have contributed to reducing moisture stress in maize. 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 [40,41]. 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 [42] 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. Similarly, [26] 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 maize grain yields between 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*≤0.05) 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 [43,44,45] moisture stress reduces bean yields and the severity depends on the stage at which the stress occurs. According to [46] 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 subsequently 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) (Fig. 5).

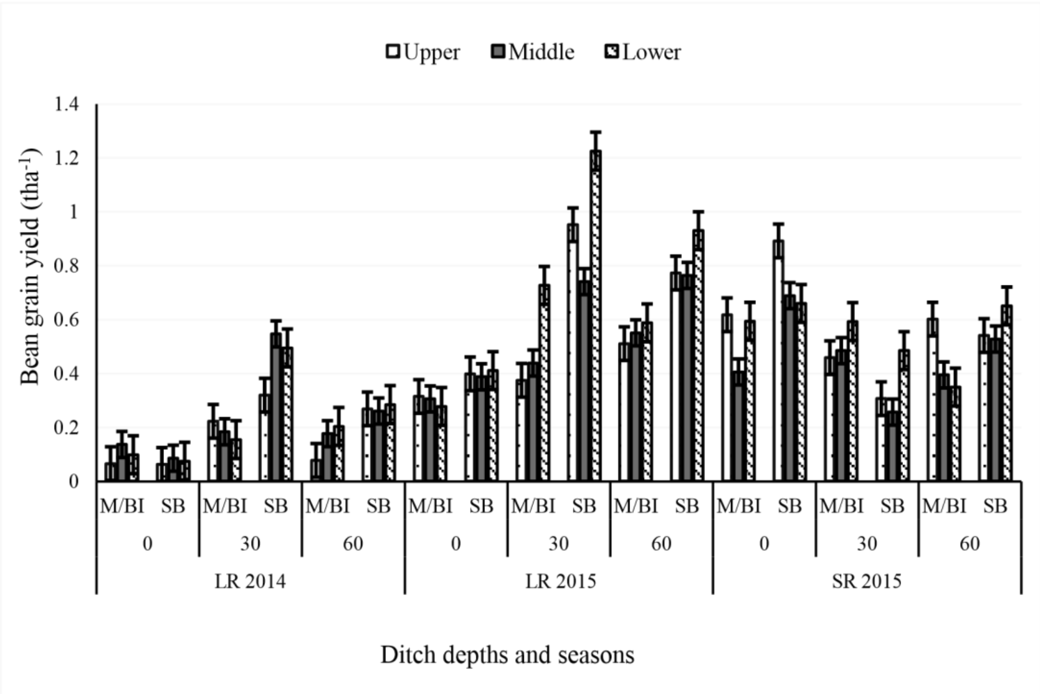


Fig. 5. Bean grain yields under sole and intercropped cropping systems in the lower, middle and upper slope positions of terraces with 0, 30 and 60 cm ditch depths
Legend: M/BI -Maize and bean intercrop system, SB - Sole bean cropping system

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 30 cm 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 [26] who reported higher bean yields in the lower slope position as a result of deposition of nutrients from the terrace through surface runoff milar results were reported by [47] who found that sorghum yields increased from 0.4 t ha^{-1} in the upper area of the slope to 2.4 t ha^{-1} in the lower position. Average bean 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 grain yields from the lower slope position were significantly higher (*P*=0.015) in treatments with ditches than from 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 unfavorable 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 [46].

4. CONCLUSION 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 grain yields than the control and higher bean yields 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. Yields were higher in treatments with 30 cm than the 60 cm ditches. Farmers can therefore save on labor 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 hardsetting 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 marginal areas of Kenya.

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COMPETING INTERESTS

Authors declare that there are no competing interests associated with this publication

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