

1
2 ***Fanya juu* terraces improve maize (*Zea mays* L.)**
3 **and bean (*Phaseolus vulgaris* L) grain yields on**
4 **hardsetting soils of semi-arid Eastern Kenya**

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8
9 **ABSTRACT**
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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 37°15'E 1°29'S and 37°15'E 1°29'S during both long rain (LR) and short rain (SR) seasons of 2014 and SR 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 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 by 49.8% in the 30 cm and 41.6% in the 60 cm 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.

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.

11
12 *Keywords: Embankment; soil type; slope position; crop yields*
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14 **1. INTRODUCTION**
15

16 Hardsetting soils have an unstable structure which collapses when the soil is wet and
17 shrinks and hardens as the soil moisture dries up [1]. These soils are pulverized as a result
18 of the instability of the surface layer and the detached particles clog and seal pores when
19 soils are wet. The surface of the soils easily pond during rainfall events followed by sealing
20 and crusting as the water dries up [2]. On drying, the soils acquire high soil strength and

21 crusting properties and the upper layer gets compacted [3]. Repeated cycles of sealing,
22 crusting and compaction results in the hard-setting nature [1,3,4]. The crusting, compaction,
23 ponding and hardness limit crop emergence, development of plant roots and infiltration and
24 increases surface erosion [1,5].

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26 Hardsetting soils are common in the arid and semi-arid lands (ASALs) of sub-Saharan Africa
27 (SSA). They are found in large parts of Eastern and Southern Africa and the Sudan-Sahelian
28 region of West Africa [6]. Most of the soils in the ASALs of SSA are low in moisture and
29 nutrient contents as a result of marginal rainfall, high evaporation and inadequate application
30 of fertilizer inputs [7,8,9]. Rainfall is erratic and at times comes in intensive storms with
31 escalated runoff causing further loss of nutrients and rainwater through erosion [10]. Soil and
32 water conservation measures are therefore of paramount importance for effective crop
33 production.

34 Terraces are widely adopted to reduce erosion from the impacts of torrential rainfall and
35 conserve soil and water in low rainfall areas [11,12,13]. The *Fanya juu* type of terraces are
36 constructed by digging a ditch and throwing the soil up-slope with the sole purpose of
37 maintaining an embankment to slow down runoff flow and hold soil sediments. The ditches
38 and embankments shorten the length of the slope and minimize soil and water loss by
39 reducing the speed and quantity of runoff flow [13,14,15,16]. At the same time the structures
40 increase infiltration and can sustain productivity in sloppy areas with marginal rainfall
41 [17,18,19,20].

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43 Several studies have reported differences in crop yields between terraced and non-terraced
44 fields as well as within the terraces [21,22]. Studies have also indicated that crop yields vary
45 along the terraces slope and that this variability is dependent on the type of soil
46 [23,24,25,26]. For instance, in well-drained Luvisols maize rows bordering the terrace ditch
47 were more vigorous in growth and gave higher yields compared to those in the section away
48 from the ditch [23]. This was attributed to an increase in soil moisture next to the ditch
49 resulting from lateral seepage of water. In the light-textured Andosols maize rows next to the
50 ditch had retarded growth and low yields due to excessive drainage and leaching of nutrients
51 caused by moisture that was captured in the ditch [24]. These were immediately followed by
52 rows of taller maize that benefited from moisture and nutrients that flowed laterally from the
53 ditch before another set of rows of retarded maize at the depletion zone. A similar study in
54 the heavy-draining Vertisols [25] indicated increased yields from rows in the lower position at
55 the furthest end of the slope compared to those next to the ditch. All these studies attributed
56 the differences in maize yields to variations in soil moisture content along the terrace slope
57 in the different soil types. According to [24] the information on variability in crop performance
58 in terraces is crucial in designing appropriate cropping systems for different slope positions
59 in order to improve productivity in the ASALs. There is, however, limitation of this knowledge
60 on different types of soils. This brought about the need to study effect of terraces on crop
61 yield variability on hardsetting soils that are common in the ASALs of Eastern Kenya for
62 enhanced exploitation of available resources.

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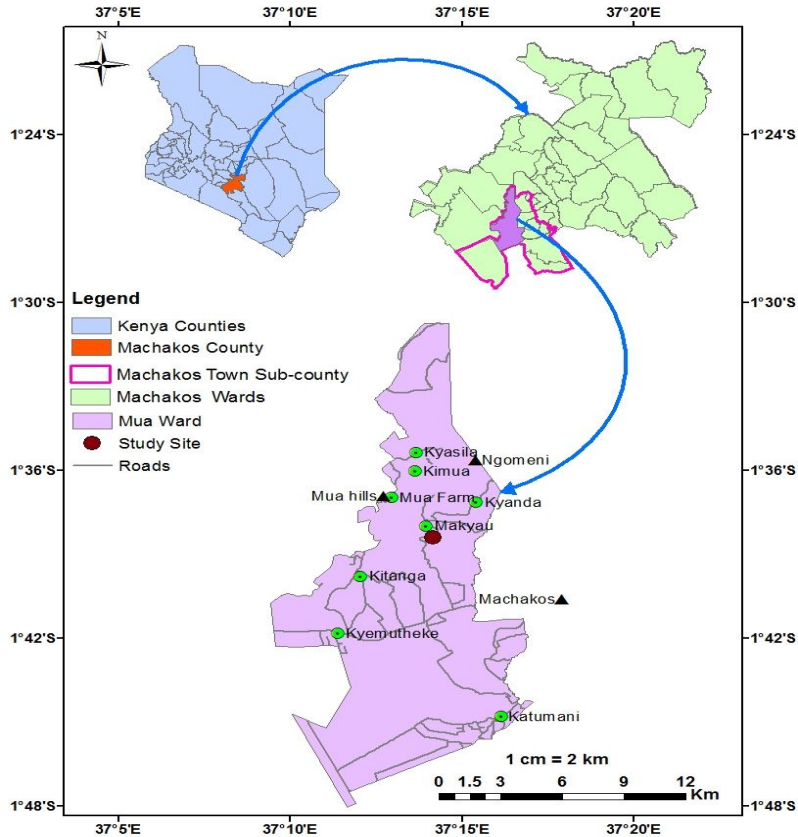
64 **2. MATERIAL AND METHODS**

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66 **2.1 Description of study location**

67 The study was conducted for four seasons in Mua location of Machakos County in Eastern
68 Kenya. The county is situated between longitudes 36° 45' E and 37° 45' E and latitudes 0°
69 45' S and 01° 31' S. It lies at altitudes of 1000 to 1600 meters above sea level (asl). The trial
70 was set up in two adjacent farms at 37°15'E 1°29'S and 37°15'E 1°29'S (Figure 1).

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Figure 1: A map showing the study site

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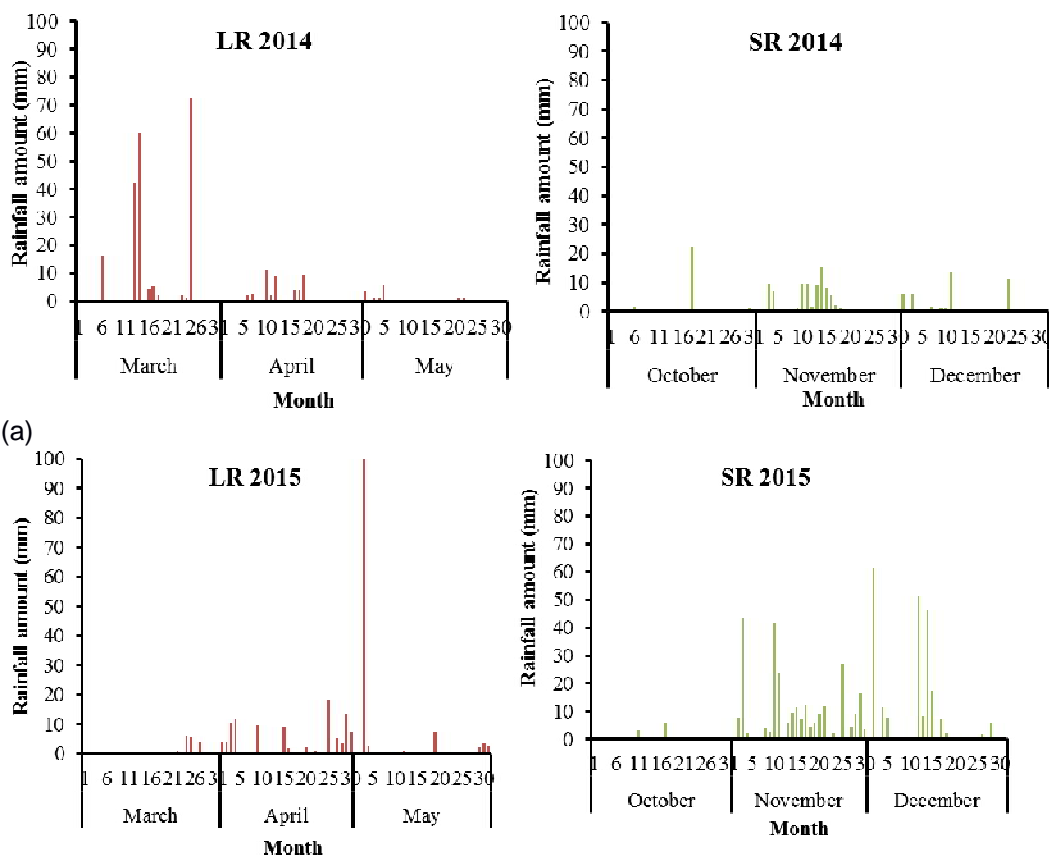
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Rainfall is bimodal from March to May (long rains [LR] season) and October to December (short rains [SR] season) [27]. The experiment was conducted during long rains (LR) 2014, short rain (SR) 2014, LR 2015 and SR 2015 seasons. The mean annual rainfall 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]. Figures 2a and b show rainfall distribution during the four seasons of the study.



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

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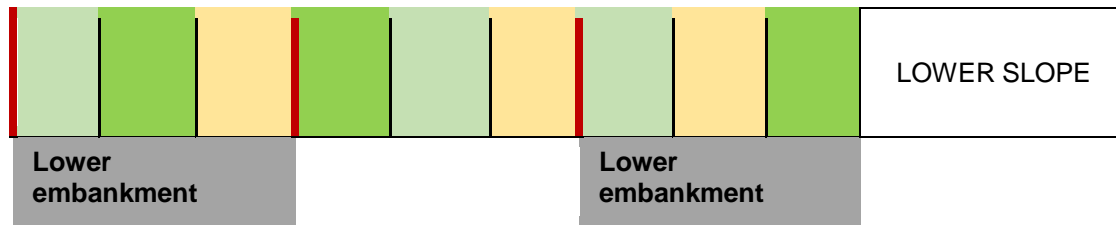
Soils are sandy clay loam in texture with pH (H₂O 1:2:5) of 6.60. They are classified as luvisols under FAO/UNESCO soil classification [30]. The soils are shallow and low in water holding capacity. They are pulverized and prone to surface sealing and crusting. They easily pond during rains especially 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 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 ₂ o (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

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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 positions. 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 one 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 P₂O₅ 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 filling 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 13.5m² for maize (5 rows) in both sole and intercropped systems and 10.8 m² 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.

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174 2.4 Data analysis

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176 The crop data was subjected to GenStat [34] statistical package for two-way analysis of
177 variance (ANOVA). Means were separated at 95% level of confidence. The Fishers'
178 protected least significant difference of means (LSD) and Duncan Multiple Range Test
179 (DMRT) were used for comparison of significant means.

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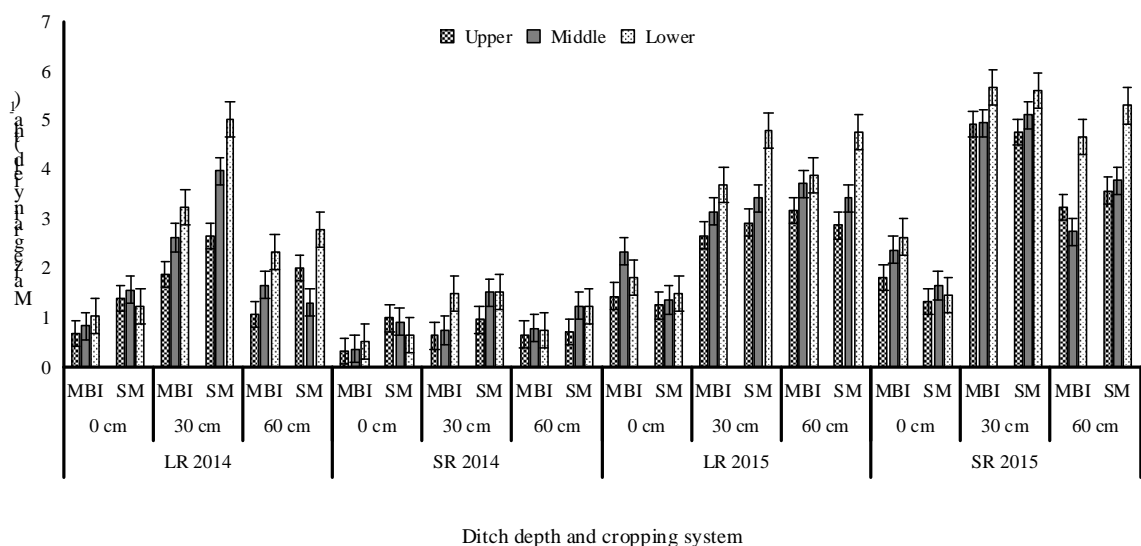
181 3. RESULTS AND DISCUSSION

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183 3.1 Effect of ditches, ditch depths and slope positions on maize grain yields

184 Significant differences in maize grain yields were observed between interactions of ditch
185 depths and seasons ($P<0.001$) and ditch depths and slope positions ($P=0.004$) as shown in
186 Figure 4 .

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

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

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195 Maize grain yields were significantly higher in the 30 (3.24 t ha^{-1}) and 60 cm (2.55 t ha^{-1})
196 ditch treatments than in the 0 cm (1.28 t ha^{-1}) ditch. This could be attributed to the surface
197 crusting and compacting nature of hardsetting soils [3]. This may have increased the loss of
198 water and nutrients through runoff resulting in reduction in maize yields especially in the
199 control treatment where the ditch was not constructed. According to some authors [15,18,33]
200 *Fanya juu* terraces are effective in reducing water and soil losses. They increase infiltration
201 when water is held in the trenches for longer periods. The maize in treatments with ditches
202 therefore, benefited from an increased availability of soil moisture from the lateral flow of
203 water held in ditches and the nutrients that were retained in the terraces. The low yields in
204 the non-terraced treatment inform on what the farmers who have not constructed terraces
205 get in this area. The results imply that farmers can benefit from the little rainfall by
206 constructing terraces to capture runoff and using it in their farms to increase production. The
207 results confirm a report by [35] indicating an increase in yields in terraced fields in Ethiopia.

208 [11] also reported an increase in wheat grain resulting from 16% increase in soil moisture
209 content when terraces were constructed in the sloppy rain-fed areas of Pakistan.

210

211 Maize grain yields were higher in treatments with 30 cm ditch depth (average 3.24 t ha⁻¹) but
212 not significantly different from those in the 60 cm ditch (2.55 t ha⁻¹). This implies that varying
213 the depth of the ditch did not significantly affect grain yields although the conditions provided
214 by the shallow ditch were more conducive for the maize performance than in the deeper one.
215 It could be argued that the 30 cm ditch held the runoff at an upper soil depth compared to
216 the 60 cm ditch. The lateral flow of water in the shallow depth was closer to the upper soil
217 horizon making it more available to the crop at the zone with high root concentration. This
218 was more evident in seasons with low or poorly distributed rainfall (LR and SR 2014). As
219 stated by [36] the response of plants to rainfall in the top layers of the soil is better compared
220 to that in deeper profiles. Water in the deeper ditch was held at lower depths and could have
221 been lost through deep percolation and lateral flow below the root zone. In SR 2015 the
222 amount of rainfall received was high and evenly distributed. This may have caused leaching
223 of nutrients in terraces with 60 cm ditch depth and lower yields than those from terraces with
224 30 cm ditch. Construction of terraces with 30 cm ditch depth could therefore be beneficial to
225 the farmers through increased chances of soil moisture availability at the crop root zone and
226 reduction in labour. [25] reported no differences in maize yields from terraces with different
227 ditch depths in a trial conducted in Vertisols. This was attributed to an impediment of the
228 movement of water in wet Vertisols.

229

230 The lower slope position were generally recorded higher maize yields than the upper and
231 middle slope positions of treatments with ditches in all seasons. Yields increased from the
232 upper to the lower slope position by 49.8% in the 30cm and 41.6% in 60cm ditch depths.
233 Significant difference ($P=0.004$) in yields was observed between slope positions in terraces
234 with 30 cm ditch. These increased from the upper to the middle position by 20.7% and to the
235 lower position by 49.8%. Maize grain yield from the lower slope position was higher than
236 from the upper position in terraces with the 60 cm ditch. Significant difference between yields
237 from upper and lower slope positions were observed in the last two seasons of the study (LR
238 2015 and SR 2015) when rainfall was high or evenly distributed. Higher yields in the lower
239 slope position may have resulted from the effect of soil moisture and nutrients trapped by the
240 embankment as well as from the lateral seepage of the water in the ditches. [37] reported an
241 increase crust strength when soil water content decreased. The increased moisture could
242 have reduced the strength of the crust at the lower slope position providing a conducive
243 environment for the maize to grow. Maize performance is affected by lack of water at all
244 stages of growth and especially at flowering period when the crop is most sensitive to
245 drought [38,39]. The availability of soil moisture at the lower slope position in treatments with
246 ditches could have contributed to reducing this stress. Earlier studies have proved that
247 higher water content in the ditch can lead to efficient use of nitrogen and that increases in
248 soil moisture can improve nitrogen absorption, transportation and accumulation resulting in
249 enhanced crop yields [40,41]. In view of this the maize crop therefore benefited from
250 nitrogen uptake in the roots through mass flux facilitated by the presence of water. The
251 conducive environment created by the presence of the moisture can be exploited through
252 intensification of the lower slope position in order to increase production and the benefits of
253 constructing terraces in hardsetting soils. The results of this experiment concur with reports
254 from studies conducted by [42] in the Central highlands of Ethiopia. The authors found
255 higher maize and wheat yields in the lower slope position than the upper slope and attributed
256 it to increased fertility in the deposition zone. [26] similarly reported increase in yields in the
257 lower slope of the terrace compared to the upper slope as a result of accumulation of
258 nutrients and moisture at this site. No significant difference ($P<0.05$) was found between
259 maize grain yields from the three slope positions in the control treatment. This was because
260 runoff was not trapped in a particular area giving no variations in accumulation of moisture or

261 nutrients. This is the normal situation in farms where terraces have not been constructed in
 262 the area.

263

264 There were no significant differences ($P \leq 0.05$) in maize grain yield between the sole maize
 265 and maize/bean intercrop systems or in interactions of cropping systems, ditch depth and
 266 slope positions. Maize grain yields were not significantly affected by the type of cropping
 267 system (sole maize or maize/bean intercrop). This was probably because of lack of effective
 268 competition from the bean crop. Rainfall during the study seasons was either too low and
 269 sparsely distributed for the beans to survive and compete with maize for resources or well
 270 distributed and high enough to provide sufficient soil water for both crops.

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272 3.2 Effect of ditches, ditch depths and slope positions on bean grain yields

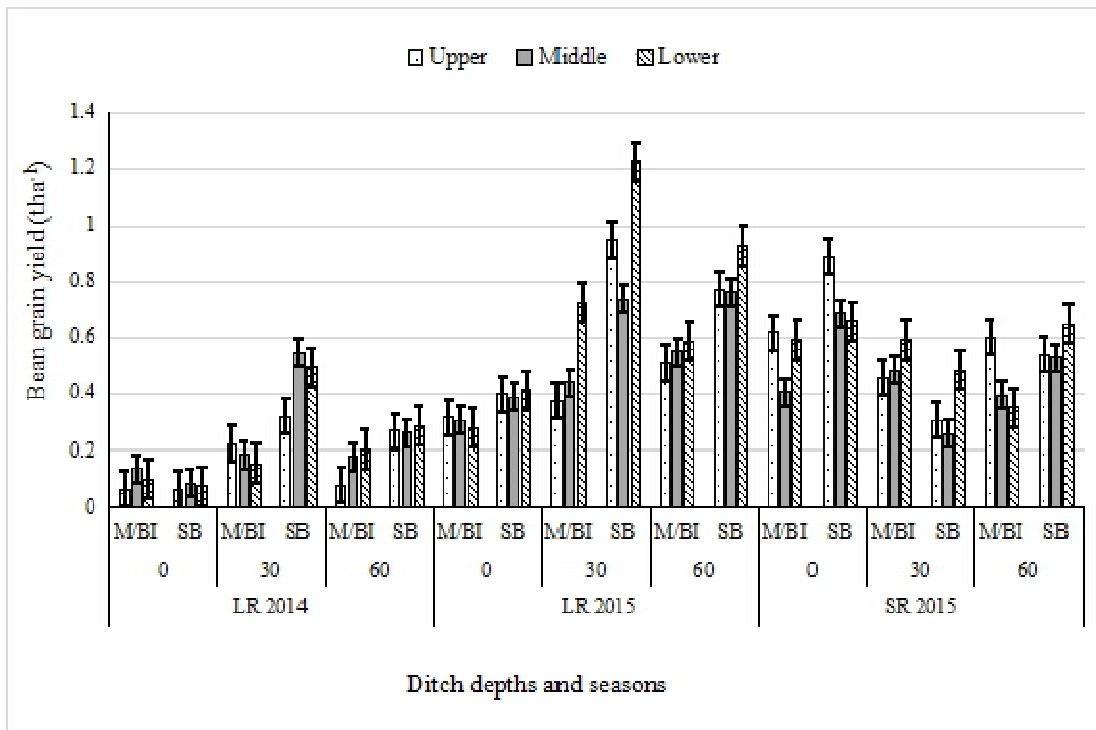
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274 No bean grains were obtained in SR 2014. This was partially caused by the low (149.2 mm)
 275 and unevenly distributed rainfall. As reported in several studies [43,44,45] moisture stress
 276 reduces bean yields with severity depending on the stage at which the stress occurs.
 277 According to [46] even brief periods of dry spell affect both the quality and quantity of bean
 278 yield. Such dry spells were common during the season. The ditches captured too little or no
 279 runoff to create any changes in soil moisture and subsequently on the yields of beans.

280

281 Significant differences in bean green yields were found between interaction of ditch depth
 282 and slope positions ($P=0.015$) and cropping systems and slope position ($P=0.037$) (Figure
 283 5).

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

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

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290 Significantly higher ($P=0.019$) bean grain yields were obtained from treatments with 30 cm
 291 (0.497 t ha^{-1}) and 60 cm (0.469 t ha^{-1}) ditch depths compared to the control (0.359 t ha^{-1}).

292 Higher and significantly different mean bean yield (0.61 t ha^{-1}) was recorded in the lower
293 slope position in treatments with 30 cm ditch depth than in the upper slope position of the
294 control (0.33 t ha^{-1}). Yields from the lower part of the slope in treatments with ditches were
295 higher than those from the middle and upper slope positions of the same ditches depths.
296 Higher yields in treatments with ditches and in the lower slope than the middle and upper
297 positions was probably a result of the availability of water and nutrient trapped by the terrace
298 embankments. The results concur with findings by [26] who reported higher bean yields in
299 the lower slope position as a result of deposition of nutrients from the terrace through
300 surface runoff. [47] similarly found an increase from in sorghum yields from 0.4 t ha^{-1} in the
301 upper area of the slope to 2.4 t ha^{-1} in the lower position. Yields obtained from treatments
302 with ditches were lower than from the control during SR 2015 season. A comparison
303 between similar positions of the terraces also indicated that average bean grain yields in the
304 lower slope position were significantly higher ($P=0.015$) in treatments with ditches than in the
305 control treatment except in SR 2015. Lower yields in treatment with ditches during SR 2015
306 season could be attributed to the effect of excessive rainfall. Conditions of high soil moisture
307 contents can be unfavorable for proper bean performance because of the imbalances in
308 oxygen levels in the root area and increase in infestation by pathogens which both cause
309 losses in yields [46].

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311 **4. CONCLUSION AND RECOMMENDATIONS**

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

329

330 **ACKNOWLEDGEMENTS**

331

332 The authors sincerely thank the European Union through NACOSTI for their support in
333 funding the study and the farmers for providing land for the experiments.

334

335 **COMPETING INTERESTS**

336

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

338

339 **AUTHORS' CONTRIBUTIONS**

340

341 **E. Njiru** - carried out the investigation, managed the analyses of the study, managed the
342 literature searches and wrote the first draft of the manuscript. **M. Baaru** - wrote the protocol,
343 designed the study, acquired funding, did the review and editing. **C. Gachene** - wrote the

344 protocol, designed the study, supervised, did the review and editing. All authors read and
345 approved the final manuscript

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347 **CONSENT (WHERE EVER APPLICABLE)**

348

349 The study did not require consent

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351 **ETHICAL APPROVAL (WHERE EVER APPLICABLE)**

352

353 The nature of this study does not require approval by a (bio)ethical committee since no
354 human participants or animals were used in the experiment by the authors.

355

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