ASSESSMENT OF SOIL MOISTURE AND NUTRIENTS ON TERRACE SLOPE OF HARD-SETTING SOILS IN SEMI-ARID EASTERN KENYA †

[EVALUACIÓN DE LA HUMEDAD DEL SUELO Y NUTRIENTES EN LA PENDIENTE DE LA TERRAZA DE SUELOS DUROS EN EL ESTE SEMIÁRIDO DE KENIA]

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SUMMARY

Background: Terraces are structures consisting of ditches and embankments used to control erosion and increase land productivity. There is, however, little emphasis on the effects of the ditch dimensions on soil moisture and nutrient dynamics. **Objective:** To determine the effect of varying ditch depths on soil moisture and nutrient quantities and their variability within the terrace slope on hard-setting soils. **Methodology:** Soil samples were collected seasonally in 2014 and 2015 from terraces with different ditch depths (60, 30, and 0 [control] cm) for the determination of soil moisture content (SMC). The samples were collected from the upper, middle and lower slope positions of each terrace. Soil from the three slope positions of each terrace was also sampled at the end of the study and analyzed for total nitrogen (%TN), available phosphorous (Av. P), exchangeable potassium (K^+) and % organic carbon (OC) contents. Data were subjected to a two-way analysis of variance and differences in means determined at a 95% level of confidence. **Results:** Significant interactions ($P<0.001$) in SMC were observed between seasons, ditch depths and slope positions. Higher SMC was found in treatments with 30 and 60 cm ditch depths in all the slope positions and seasons compared to the control. Soil moisture contents in the lower and upper slope positions were significantly different between the terraces with 30 and 60 cm ditch depths when rainfall was high and evenly distributed, but non-significant in poorly distributed rainfall seasons. Significant differences ($P \leq 0.05$) in contents of total nitrogen and available phosphorous were found between the upper and lower slope positions of the terraces with ditches. **Implications:** The effect of ditch depths on moisture, total nitrogen and available phosphorous contents and their variability within the slope depended on the amount and distribution of rainfall. **Conclusion:** Construction of terraces with shallow ditch depths (of 30 cm) is recommended to conserve soil moisture and nutrients nitrogen and phosphorous on hard-setting soils in the marginal areas of semi-arid Eastern Kenya.

Key words: Land productivity; ditch depth; variability; slope position; marginal areas

RESUMEN

Antecedentes: Las terrazas son estructuras que consisten en zanjas y terraplenes que se utilizan para controlar la erosión y aumentar la productividad de la tierra. Hay, sin embargo, poco énfasis en los efectos de las dimensiones de la zanja sobre la humedad del suelo y la dinámica de nutrientes. **Objetivo:** Determinar el efecto de variar la profundidad de las zanjas sobre la humedad del suelo y las cantidades de nutrientes y su variabilidad dentro de la pendiente de la terraza en suelos de fraguado duro. **Metodología:** Se recolectaron muestras de suelo en las estaciones de lluvias largas y lluvias cortas de 2014 y 2015 de terrazas con diferentes profundidades de zanja (60, 30 y 0 [control] cm) para la determinación del contenido de humedad del suelo (SMC). Las muestras se recolectaron de las posiciones de pendiente superior, media e inferior de cada terraza. También se tomaron muestras del suelo de las tres posiciones de pendiente de cada terraza al final del estudio y se analizaron los contenidos de nitrógeno total (%TN), fósforo disponible (Av. P), potasio intercambiable (K+) y % de carbono orgánico (OC). Los datos se

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sometieron a un análisis de varianza de dos vías y las diferencias en las medias se determinaron con un nivel de confianza del 95%. **Resultados:** Se observaron interacciones significativas ($P<0.001$) en SMC entre estaciones, profundidades de zanjas y posiciones de taludes. Se encontró mayor SMC en los tratamientos con profundidades de zanja de 30 y 60 cm en todas las posiciones de pendiente y estaciones en comparación con el control. El contenido de humedad del suelo fue significativamente diferente en las posiciones de pendiente inferior y superior entre las terrazas con zanjas de 30 y 60 cm de profundidad cuando la precipitación fue abundante y uniformemente distribuida, pero no significativa en las temporadas de precipitación escasamente distribuidas. Se encontraron diferencias significativas ($P \leqslant 0.05$) en los contenidos de nitrógeno total y fósforo disponible entre las posiciones de pendiente superior e inferior de las terrazas con zanjas. **Implicaciones:** El efecto de la profundidad de la zanja sobre la humedad, el contenido total de nitrógeno y fósforo disponible y su variabilidad dentro de la pendiente dependía de la cantidad y distribución de la lluvia. **Conclusiones:** Se recomienda la construcción de terrazas con zanjas de poca profundidad (de 30 cm) para conservar la humedad del suelo y los nutrientes nitrógeno y fósforo en suelos de fraguado duro en las áreas marginales del este semiárido de Kenia.

Palabras clave: Productividad de la tierra; profundidad de la zanja; variabilidad; posición de la pendiente; zonas marginales.

INTRODUCTION

Terraces are soil and water conservation structures adopted in many countries to reduce erosion and improve agricultural productivity (Dorren and Rey, 2004, Hussein *et al*., 2016). The structures consist of ditches and embankments constructed across the slope to minimize the speed and quantity of flowing water (Gichuki, 1991, Mutunga, 1991, Baptista *et al.*, 2015). The ditches and embankments increase infiltration by retaining runoff and are particularly important for the control of erosion in dry, hilly or mountainous regions (Baryła and Pierzgalski, 2008, Nyamadzawo *et al*., 2013, Wolka, 2014, Deng *et al*., 2021). This practice is promoted as the best suited for effective soil and water conservation and is the most widely used throughout the world (Widomski, 2011, Binyam and Asmamaw, 2015, Hussein *et al*, 2016).

Terrace ditches and embankments reduce the length and/or steepness of the slope (Gichuki, 1991). The embankments are constructed using excavated soil, stone lines, trash lines or grass strips. Several types of terraces are found and used in different regions depending on the needs of the farmers, the type and depth of soil, slope and precipitation (Widomski, 2011, Wei *et al*, 2016). The most common type in the semi-arid lands of Eastern Kenya is the *Fanya juu* bench terrace. This consists of a ditch/trench and embankment/wall of soil constructed across the slope to reduce its length and slow runoff by capturing water in the ditch. The *Fanya juu* type of terraces derive their name from the way they are constructed where a trench (ditch) is excavated and soil heaped uphill to form an embankment (Figure 1).

Fanya juu terraces were introduced in the semi-arid lands of Eastern Kenyan by the colonial government in the 1930s. The structures are used to-date by farmers to control erosion on sloppy fields (Gichuki, 1991, Biamah and Stroosnijder, 2005). During their construction, the ditch dimensions for *Fanya juu* terraces and the intervals from one ditch to the next are determined by several aspects including rainfall, soil type, slope and soil depth (Sheng, 2002, Widomski, 2011, Mati, 2012, Hussein *et al*., 2016). However, for simplicity and ease of adoption, general measurements of 0.6m deep and 0.6m wide were recommended in the semi-arid lands of Kenya (Mutunga, 1999, Mati 2005). These measurements are used to date regardless of differences in soil types and rainfall regimes.

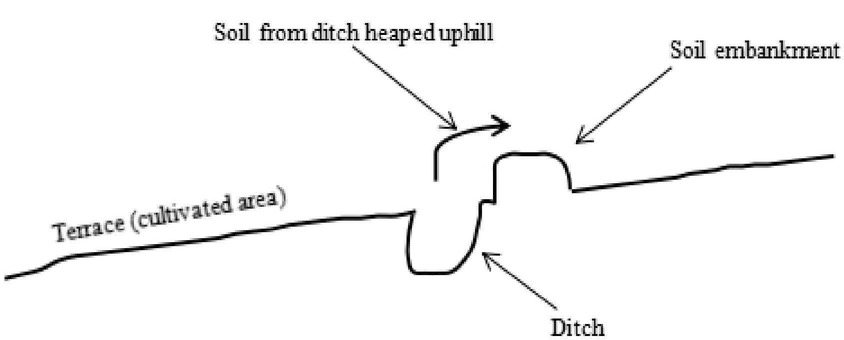

Figure 1. A sketch of the cross section of the *Fanya juu* terrace (Source: Authors' drawing).

Several reports indicate the importance of *Fanya juu* terraces in soil conservation (Gichuki, 1991, Dorren and Rey, 2004, Tenge *et al*. 2005 and 2011). However, until recently, few studies have emphasized their role in the spatial distribution of soil moisture and nutrients and the use of such knowledge to increase land productivity. Some studies in Kenya reported that there were differences in maize yields from different sections of the terrace slope (Gachene and Baaru, 2011, Wairimu, 2015, Ruto, 2015). These studies attributed these differences to variability in the distribution of soil moisture due to the effects of the ditches. The studies also indicated that the differences in yields from the various terrace positions depended on the type of soil. A study by Ruto, (2015) in Narok, Kenya concluded that the variability of yields in the terraced farms could influence change in the cropping patterns leading to an increase in land productivity. This study was therefore conducted to generate information on the role of terraces in nutrient and moisture contents and variability on crusting soils that are widespread in the semi-arid lands of Kenya. The objective was to determine the effect of varying ditch depths on soil moisture and nutrient contents and their variability within the terrace slopes on hard-setting soils.

MATERIALS AND METHODS

Description of Study Site

The study was conducted on-farm in two adjacent farms in Makyau village, Mua location, Machakos County in semi-arid Eastern Kenya. The trial was planted for four consecutive seasons during the long rain (LR) 2014, short rain (SR) 2014, LR 2015 and SR 2015. The farms are located on 37º15'29.124''E 1º29'40.776S and 37º15'29.1522''E 1º29'40.7112''S on the slopes of Mua hills at elevations of 1722.20 and 1722.26 m above sea level. Both farms are in the agro-ecological zone (AEZ) UM4. The area has an average annual rainfall of 673 mm with a bimodal pattern. Seasonal rains fall from March to May (referred to as the long rain [LR] season) with an average of 292 mm and October to December (short rain [SR]) season with an average of 382 mm. The rainfall is unreliable in amounts and distribution. The SR season has more rainfall and is more reliable than the LR (Jaetzold, 2006). Long dry spells and recurrent droughts occur during the rainfall season. These affect crop yields often leading to food insecurity (Mati, 2005, Jaetzold *et al*., 2006). There is an increase in the variability of rainfall onsets and cessations, incidents of extreme storms and concentration of the rains in few rainfall events (Ifejika, 2010). Annual temperatures range from 24.7^0 to 13.7ºC and rates of evapotranspiration are high (Jaetzold *et al*., 2006).

Soils in the study location are characterized as Luvisols (FAO/UNESCO, 1997), yellow-red sandy clay loam, and shallow with high percent base saturation. (Scott *et al*., 1963). Ponds of water easily form on their surface during rainfall events (Miriti *et al*., 2013). The ponding is followed by sealing and crusting as the water dries up. Results of analysis of a compound soil sample from the two farms showed that the soils are low in nitrogen (N), phosphorous (P) and organic carbon (OC) (Table 1). The farms had a slope range of 7.5 to 8.5%. The major type of farming practiced in the area is the mixed cropping/livestock system involving combining the cultivation of food crops and rearing of livestock. Maize is the most common cereal crop. This is grown as sole crop or intercropped in different patterns with legumes such as beans or pigeon peas.

Table 1. Physical and chemical properties of soil (0-30cm) of the experimental site at the beginning of the study.

Soil property	Values	Soil property	Values
pH-H_2o (1:2:5)	6.60	Sum me (%)	11.8
Organic carbon, (%)	0.63	Base Saturation (%)	71.2
Total Nitrogen (%)	0.07	ESP (%)	7.5
Phosphorous (ppm)	18.81	Bulk density (g/cm^3)	1.4
Calcium (Cmol/kg)	9.50	Sand (%)	69.00
Magnesium (Cmol/kg)	1.35	Silt (%)	8.00
Potassium (Cmol/kg)	0.51	Clay (%)	23.00
Sodium (Cmol/kg)	0.45	Texture Class	Sandy clay loam
CEC (Cmol/kg)	16.80		

Legend: *ppm - parts per million, Cmol/kg - Centimol/kilogram, CEC= Cation Exchange Capacity, Sum me% - Sum milliequivalent of base cations, ESP = Exchangeable Sodium Percentage*
**Values in the table are averages of the two farms.*

Experimental Design and Treatments

The study evaluated the effect of varying ditch depths on the spatial and temporal variability of nutrients and moisture in terraces on hard-setting soils. The trial was set out on two adjacent farms at 37º15'29.124''E 1º29'40.776"S and 37º15'29.152''E 1º29'40.711''S due to the scarcity of land to hold the trial on a single farm. A split-plot design with four replicates was used. Each farm carried two replicates. Treatments consisted of terraces of two ditch depths; 60 cm (D_{60}), 30 cm (D_{30}), and control, 0 cm (D_0), and three slope positions (upper, middle and lower). Ditch depth treatments were located on the main plots while the slope positions were the sub-plots. The main plots were 14 m long (the length of each ditch depth). A 2-m path separated adjacent ditches (plots) to stop water from one ditch from running over to the other. Each ditch marked the beginning of a terrace. Terraces with 30 and 60cm ditches had an embankment on the lower side of the slope. This embankment marked the end of the terrace. Ditches had a uniform width of 60 cm. In the control treatment, no ditch was dug and hence cultivation was carried out on a non-terraced slope. The cultivated area of each terrace was subdivided into three equal sections representing the upper (US), middle (MS), and lower (LS) slope positions. The US position was the section of the terrace next to the ditch. The LS was the immediate area adjacent to the embankment of the successive ditch. The terrace area between the upper and lower slope positions was the MS position (Figure 2).

Data collection

Soil sample collection and laboratory analysis for moisture determination

The soil samples were collected from the upper, middle and lower slope positions of each of the terraces defined by the three ditch depths for moisture determination. Samples were collected seasonally for comparison between seasons. Sampling was done at three different stages of maize growth (eighth leaf, tasseling and harvesting stages) during periods of a dry spell when the crop showed signs of moisture stress. The values of soil moisture content obtained from the three sampling stages per season were averaged to get the moisture content in each slope position across the crop growing period. Rainfall data was recorded from daily rain gauge readings and used to determine periods of dry spell. The dry spells were defined according to Stern *et al*. (2006) as periods of at least ten (10) consecutive days with 0.85 mm of rainfall or less after the last rainfall.

Three random cores were made in each slope position of every ditch depth using a soil auger at a 0-30 cm profile. A sample from a thorough mixture of the three cores was transferred into plastic bags, properly sealed and weighed before being taken to the laboratory. Each sample was placed in a tin of known weight and oven-dried to 105 ˚C for 24 hours. The dry weights of the soil minus the tins were recorded and used to calculate moisture contents at each slope position and ditch depth using the formula:

(i) $\text{Vol MC} = ((M_t - M_s)/M_s) \times D_b$

Where: Vol MC = Volumetric moisture content
M_t = Mass of soil before drying,
Ms=Mass of dry soil,
D_b = Soil bulk density

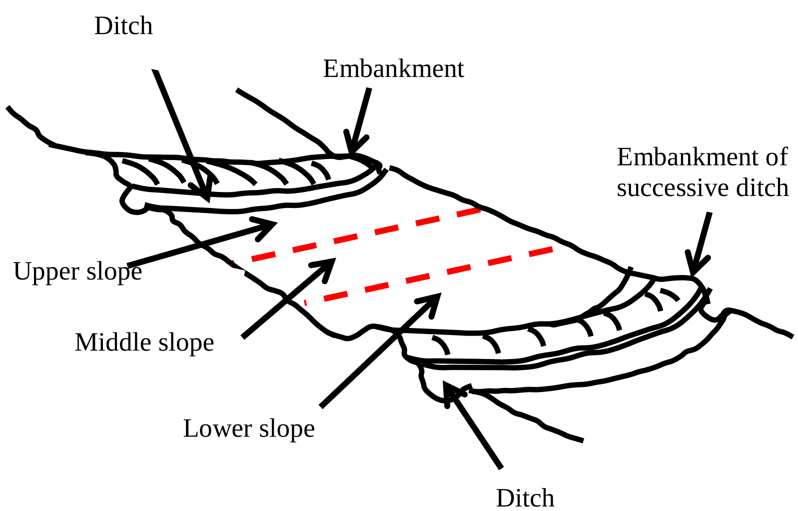

Figure 2. A sketch of the terrace showing the locations of the ditches, embankments and the three terrace slope positions (Source: Authors' drawing).

Soil bulk density was determined using metal core rings of known volume. The rings were gently pushed into the soil using a hammer. Intact samples collected in the rings were dried in the oven for two hours at 105^{o}C. The weight of dried soil was taken and soil bulk density was calculated from the formula:

(ii) $D_b = W_d/V_s$

Where D_b = Soil bulk density
W_d = Weight of oven-dry soil
V_s = Volume of soil (= volume of the core ring)

Calculated values for the three sampling stages in each season were averaged to denote soil moisture content across the season.

Sample collection and laboratory analysis for soil nutrient status

Soil samples were collected at the end of the study period for analysis of total nitrogen (TN), available phosphorous (Av. P), exchangeable potassium (K^+), and organic carbon (%OC) contents in the three slope positions of each terrace. Samples were collected from three random cores in each slope position using an auger at a depth of 0-30 cm. Soils from each position were carefully mixed in a clean disinfected bucket. A representative sample was packaged and later air-dried, ground using a pestle and mortar and sieved using a 2-mm sieve before chemical analysis. Soil total N was determined by the Kjeldahl technique as described by Bremner and Mulvaney (1982). Organic carbon was determined using the Walkley-Black oxidation method as described by Nelson and Sommers (1982). Available P was determined by Bray 2 method (Olsen and Sommers, 1982) while exchangeable K was determined using the flame photometer.

Statistical data analysis

Data was recorded and organized in the Excel spreadsheet. The data was subjected to a two-way analysis of variance (ANOVA) using the GenStat version 14.2 (2016) statistical package. Soil moisture data was analyzed for interactions between seasons, ditch depths and slope positions. In the soil nutrient data analysis interactions between ditch depths and slope positions were considered. Differences in means were determined at a 95% level of confidence. Fisher's protected least significant difference (LSD) test was used for post-hoc comparison of means.

RESULTS AND DISCUSSIONS

Effect of ditch depth and terrace slope position on soil moisture

Significant differences ($P \leq 0.05$) in soil moisture content were observed in interactions between seasons, ditch depths and slope position (Figure 3).

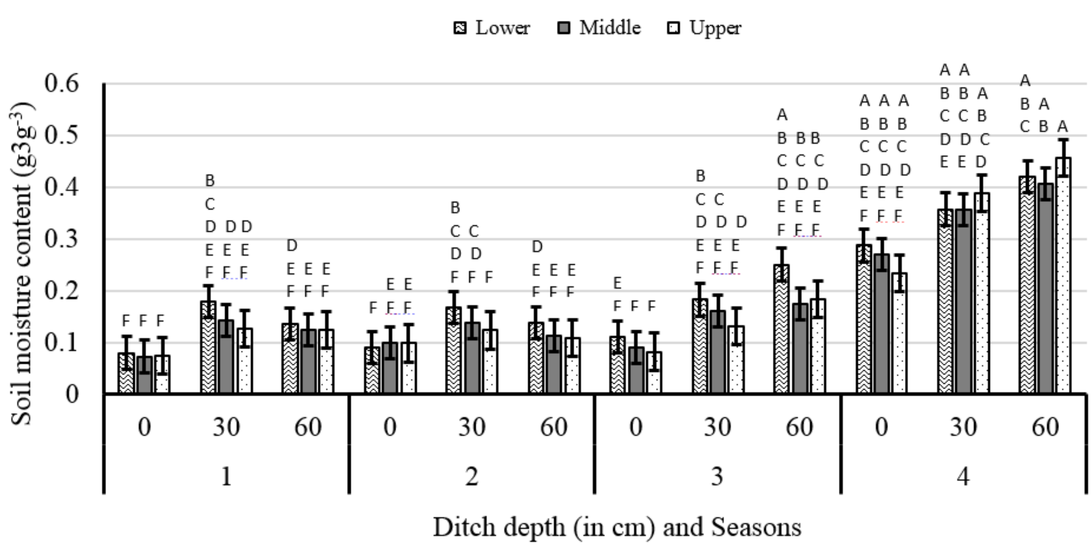

Figure 3. Soil moisture content in the upper, middle and lower slope positions in terraces with 0, 30 and 60 cm ditch depths during the four seasons of the trial. Legend: 1 - LR 2014, 2 - SR 2014, 3 - LR 2015, 4 - SR 2015. Error bars denote Standard error bars.

Treatments with ditches (D_{30} and D_{60}) had significantly higher ($P < 0.001$) soil moisture content than the control (D_0) in all seasons. This was attributed to a reduction in loss of runoff in terraced treatments through its collection in the ditches and interception by the ridges. Li *et al*. (2012) indicated that there was a possibility of 1.13 times more storage of rainfall in terraced than non-terraced systems from a study in Southern Ningxia. Runoff losses in this study were high where there were no terraces because of the crusting and sealing nature of the soil surface. This is supported by a statement by Bresson *et al*. (2006) in their review on soil crusting in Europe that the slumping of the surface layer of hardsetting soils decreases the porosity of the macropores leading to low infiltration and increased erosion. The results show that loss of rain water through runoff in these crusting soils was inevitable when conservation structures were not constructed. Similar reports emphasizing the role of terraces in moisture conservation have been given by other authors. Kannan *et al*. (2009) reported a 85.8% efficiency of water conservation by ridges and furrows in terraces compared to 13.9% in non-terraced fields from their work on Rubirizi farm in Rwanda. Similarly, Shimbahri *et a*l. (2019) found 110% average increase in soil moisture content in terraced than non-terraced fields in Ethiopia, while Bai *et al*. (2019) reported a 26.6% reduction in surface runoff in terraces in the Chinese Loess Plateau. Xu *et al*. (2021) also reported higher soil moisture in terraced than bare slope areas while working in Zhuanglang county in the Chinese Loess Plateau.

Significant differences were observed between treatments with ditches (D_{30} and D_{60}) and the control (D_0) in the three slope positions in the 3rd and 4th seasons (LR 2015 and SR 2015). Soil moisture content was significantly higher ($P < 0.001$) in D_{60} than D_{30} in the LS and US positions in season 4 (SR 2015) and the LS position in season 3 (LR 2015). It was observed that the contents of soil moisture in different ditches and positions of the terraces depended on the amounts and distribution of rainfall. The rainfall received in the fourth season was 31% higher than the long-term mean (382 mm) with an even distribution across the season. Rainfall in season three was well distributed in the last two months. From these results, it was noted that in high and evenly distributed rainfall soil moisture content was significantly higher in D_{60} than in D_{30}. A significant difference was also found between moisture contents in the US and LS positions. This implied that when rainfall was high and regular the ditches were effective in storing runoff thus increasing soil moisture in the adjacent slope position. At the same time, the ridges were also effective in intercepting the surface flow and storing it in the lower position of the terrace. The deeper ditch (D_{60}) however, collected more water and conserved it for longer periods than the shallow one (D_{30}). This resulted in higher soil moisture contents in D_{60} than in D_{30}.

Significantly higher ($P < 0.001$) soil moisture content in the US positions in the two ditches was attributed to the effect of water saturation resulting from the high volumes of runoff that collected in the ditches. A review by Dorren and Rey (2004) confirmed that soil saturation can occur in terraces as a result of the retention of too much water. Based on work by Daniells (2012) the unstable surface layer of hardsetting soils is pulverized with detached particles clogging and sealing the pores when soils are wet. The sealing impeded the flow of water through lateral seepage to the lower slope position thus partially explaining the lower contents in the deposition zone.

A non-significant ($P = 0.113$) interaction in soil moisture content observed between ditch depth and slope position in the first two seasons could have been due to the low and poorly distributed rainfall. The rainfall received in season one was unevenly distributed while the amount in season two was both low (147.2 mm) and unevenly distributed. The low rainfall and frequent dry spells restricted the amount of water that was collected and conserved in the ditches. The depths of the ditches did not, therefore, have any significant effect on soil moisture content during the poor rainfall seasons. It is however important to note that soil moisture content in D_{30} was higher than in D_{60} during these seasons. The higher but non significantly different moisture content in D_{30} than D_{60} was probably because of the differences in the depth of the lateral flow of runoff from the two ditches. Lateral seepage in D_{30} occurred at an upper soil profile compared to the flow in D_{60} where runoff was held at a deeper depth. Some of this water was lost through deep percolation at soil depths that were beyond the 0-30 cm soil layer from which sampling was done. A significant difference ($P \leq 0.05$) in moisture content was however, found between the lower slope and the middle and upper slope positions in D_{30} during these poor rainfall seasons. A combined effect of lateral seepage at an upper soil profile together with interception of surface runoff by the embankments in these poor rainfall seasons accounted for these differences. A report of non significant effect of ditch depths on soil moisture content was also given by Wairimu (2015) from an experiment conducted for two seasons on the heavy textured Vertisols in Eastern Kenya. He attributed this to the low water levels that collected in the ditches and the poor movement of water in wet Vertisols. Higher moisture in the lower slope position has also been reported in studies in Andosols in Narok, Kenya (Ruto *et al.*, 2017) and on newly constructed terraces in Tigray, Ethiopia by Shimbahri *et al*. (2019). In both cases the increase in moisture was attributed to the lateral flow of conserved water from the upper to lower slope positions.

Effect of ditch depths and slope position on soil nutrient contents

Interactions of ditch depth and slope positions were not significantly different for contents of total nitrogen (P = 0.063), exchangeable potassium (P = 0.548) and organic carbon (P = 0.804) in the soils at the end of the study. However, the interaction was significant (P = 0.004) for the contents of available phosphorous.

Total Nitrogen (%TN) contents

Contents of total nitrogen were significantly different between ditch depths (P = 0.002) (Figure 4 A) and slope positions (P < 0.001) (Figure 4 B).

Higher nitrogen quantities were observed in plots with ditches (D_{30} and D_{60}) compared to the control treatment (D_0). This was attributed to the reduction in losses through surface runoff. The terrace structures reduced runoff and loss of nitrogen through erosion as opposed to non-terraced treatments. These findings agree with results from work by Dercon *et al*. (2003), Hammad *et al*. (2004) and Dejene (2017). These authors reported higher concentrations of soil TN, Av. P, K^+, together with other soil components such as the cation exchange capacity in terraced than non-terraced fields mainly due to reductions in sediment loss through erosion. Dagnachew *et al*. (2020) observed that moisture and nutrients increased when soil water conservation measures were constructed in the Gojeb River catchment in Ethiopia. Significantly higher (P < 0.001) nitrogen content was also found in the LS than in the MS and US positions. This was probably caused by losses from the upper to the lower terrace areas through erosion. Most of the eroded nitrogen originated from the fertilizers applied to the crop during planting and topdressing. The embankments of terraces blocked runoff flow resulting in the deposition of sediments and accumulation of nitrogen at the lower slope position. The low content of nitrogen at the US position could also be attributed to leaching due to saturation of the area adjacent to the ditches in the high rainfall season. These results confirm the findings by Siriri *et al*. (2005) while working on Ferralsols in Western Uganda. The authors reported higher contents of nitrogen in the lower slope compared to the upper areas of the slope resulting from sediment erosion and deposition.

Available phosphorous (Av. P)

Significant differences (P = 0.004) were found in interactions of ditch depths and slope positions for contents of available phosphorous (Figure 5).

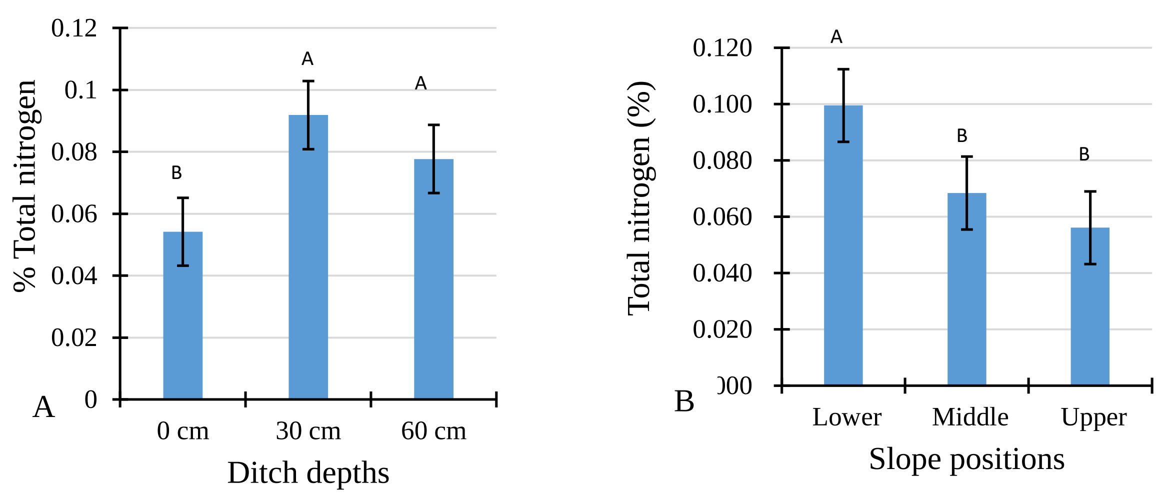

Figure 4 (A and B). Total nitrogen (%) contents in terraces with o, 30 and 60 cm ditch depths (A) and in the three slope positions of the terraces (B) at the end of the study. Legend: Error bars denote Standard error.

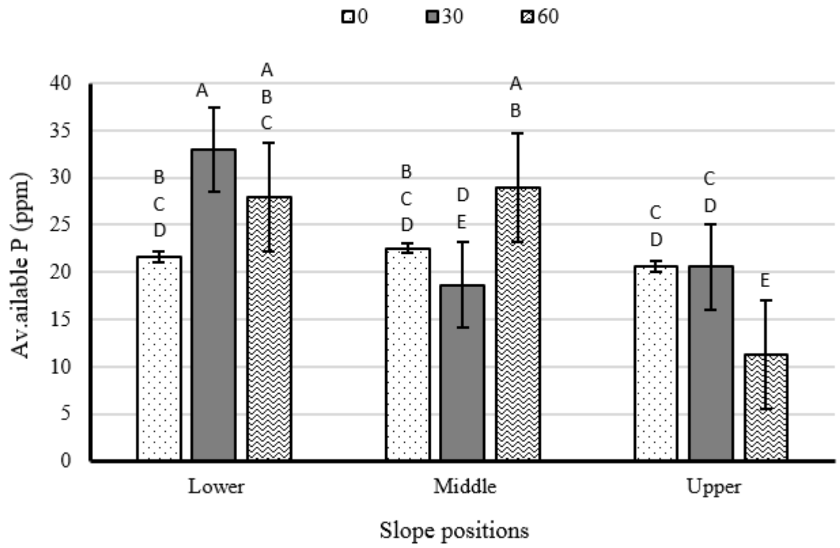

Figure 5. Contents of available phosphorous in the upper, middle and lower slope positions in terraces with 0, 30 and 60 cm ditch depths at the end of the study. Legend: Error bars denote Standard error.

The highest amount of available phosphorous (32.93 ppm) was found in the lower slope position in D_{30}. This was not significantly different from the amounts in the lower slope (27.95 ppm) in D_{30} and middle slope (28.98 ppm) in D_{60}. Lower quantities were found in the upper slopes in both D_{30} (20.55 ppm) and D_{60} (11.26 ppm) compared to the lower slope positions (32.93 ppm in D_{30} and in 27.95 ppm D_{60}) The differences in available phosphorous in the three positions was caused by the effects of surface erosion of the Diammonium phosphate (DAP) fertilizer which was applied to the maize crop in the terraces during planting. The fertilizer was eroded down the slope together with soil sediments resulting in higher quantities in the deposition site. Erosion was higher in D_{60} in the high rainfall season leading to higher losses of P. The results of this experiment confirm a report by Ruto (2015) who attributed the higher quantities of phosphorous in the lower slope position to erosion of the applied fertilizers from up slope and its deposition in the lower zone in the Andosols of semi-arid Kenya. On the contrary Shimeles (2012) reported nearly uniform amounts of soil nutrients in all the slope positions. This was under old terraces that had developed into benches with almost uniform gradient thereby allowing for an equal distribution of runoff and unloading of sediments within the terrace.

Exchangeable potassium (K^+)

No significant difference in the content of exchangeable potassium was found between terraces with different ditch depths (P = 0.606) or between slope positions (P = 0.096). This was partially because potassium was not added to the soil during the study and its movement through erosion was minimal. Shimeles *et a*l. (2012) also reported no significant differences in potassium levels between the slope positions from their study on terraces in Ethiopia. Similarly, Tadele *et al*. (2011) and Amare *et al.* (2013) reported a lack of significant differences in exchangeable potassium between different terrace slope positions in separate studies in Ethiopia. On the contrary, Dejene (2017) found significantly higher exchangeable potassium in the accumulation position than in the upper slope position on the shallow soils of Oromia in Ethiopia. This was attributed to the long term effects of erosion in the old terrace from the upper part of the terrace slope and deposition in the accumulation zones.

Soil Organic Carbon

No significant differences were found in soil organic carbon contents between terraces with different ditch depths (P = 0.414) or within slope positions (P = 0.670). This was because the short period covered by the experiment did not allow for sufficient production and accumulation of biomass and hence organic carbon. The rate of soil organic carbon accumulation under dryland conditions is generally low because of the high temperatures, low soil moisture and the low and slow production of plant biomass (Bernoux and Chevallier, 2014, Plaza-Bonilla *et al*., 2015). Similar results were reported by Posthumus and Stroosnijder (2010) who found no short-term effect of terraces on soil fertility and other properties in the Peruvian Andes. Contrary findings by Million (2003) in North Shoa, Ethiopia, Ofiri (2013) in Ahafo Ano South district, Ghana, and Amare *et al*. (2013) in Anjeni Watershed in Dembecha, Ethiopia, showed higher organic matter and organic carbon contents in the lower slope of the terrace. This was, however, in high rainfall areas where the construction of terraces reduced erosion and allowed biomass accumulation and its transportation from the upper to the lower slope positions through surface runoff and overload flow.

CONCLUSION

Based on the results of this study the role of terraces in conserving soil moisture, nitrogen and phosphorous in hard-setting soils was implied. The study also revealed that the effect of ditch depths on moisture contents and variability within the slope depend on the amount and distribution of rainfall. Terraces with 30 cm ditch depth conserved more moisture at the 0-30 cm soil profile than those with 60 cm in seasons of low and poorly distributed rainfall. In contrast, when rainfall was high and well distributed in SR 2015 soil moisture was higher in the terrace with 60 cm ditch than that of 30 cm. The effect of ditch depths on soil nutrients was seen in higher quantities of total nitrogen and available phosphorous in the lower slope positions of the two ditches. These findings imply that the construction of terraces with shallow ditch depths (of 30 cm) is recommended to conserve soil moisture and the nutrients nitrogen and phosphorous on hard-setting soils of semi-arid Eastern Kenya. The higher moisture and nutrients N and P levels can be utilized further through intensification of the lower slope position. This management practice will ensure that farmers sustainably exploit available moisture and nutrients in lower terrace positions consequently enhancing the efficient use of these resources for increased crop productivity.

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Conflict of interest. We declare that there is no conflict of interest associated with this publication.

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

Data availability . All data is presented in this paper.

Authors' contributions. E. Njiru - Investigation, methodology, data curation, formal analysis, writing - original draft, **M. Baaru** - Conceptualization, funding acquisition, supervision, writing - review and editing, **C. Gachene -** Conceptualization, methodology, supervision, writing - review and editing.

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