

Soil moisture variability effects on maize crop performance along a toposequence of a terraced vertisol in Machakos, Kenya

Mbugua H.^{1*}, Baaru M. W.² and Gachene C. K.¹

¹Department of Land Resource Management and Agricultural Technology, Faculty of Agriculture, University of Nairobi, P. O. Box 29053-00625, Nairobi, Kenya.

²Department of Environmental Studies and Community Development, Kenyatta University, P. O. Box 43844, Nairobi, Kenya.

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Recurrent droughts are often associated with crop failure and therefore food insecurity especially in semi-arid areas of Kenya. A study was conducted in Machakos County in the long rain and short rain seasons of 2014 to determine the effect of soil moisture variability on crop performances and yields along the toposequence of a terraced vertisol. The crops were grown as either sole maize, sole beans or maize-bean intercrop. An experiment was laid in a randomized complete block design (RCBD) and each treatment replicated three times. Data collected included maize height and leaf area index at 9th leaf and tassel stage, maize and bean yield and soil moisture content. The results showed significant variations ($p < 0.05$) in soil moisture content, maize height, above ground maize biomass yield and maize and bean grain yield at different slope positions. The lower slope position recorded significantly ($p < 0.05$) higher mean soil moisture content (20.6%) compared to the middle (16.1%) and upper (16.3%) slope positions. The lower slope position recorded significantly ($p < 0.05$) higher mean biomass yield of 4.94 ton/ha compared to the middle and upper (4.30 and 4.12 ton/ha, respectively). Results of this study indicate that terracing has an effect on soil moisture content variability and that farmers can benefit from low-cost technology using soil and water conservation structures to increase yields.

Key words: Soil moisture variability, terrace embankment, slope position, toposequence, vertisols, crop yields.

INTRODUCTION

Water resources continue to decline steadily because of population growth and expected climate change as a result of global warming (Handia et al., 2003). Various studies (Qiu et al., 2001; Dercon et al., 2003; Zougmore et al., 2004) have reported that soil moisture content is mainly dependent on soil water recharge by rains and other alternate sources like irrigation. Increasing the

efficiency of soil water use is an important target to achieve future food security in Kenya particularly in semi-arid areas exposed to drought. On sloppy non-terraced lands, less water infiltrates into the soil and is mostly lost as runoff due to fast velocity. This is primarily due to the fact that surface water, as well as sub-surface water, runs from high to low levels of elevation on sloping land. The

*Corresponding author. Email: wairimuharun@gmail.com. Tel: 254-714-005-295.

Table 1. Chemical and physical properties of Machakos study area.

Soil property	Value	Soil property	Value
pH (water)	7.20	Sand %	28.20
pH (CaCl ₂)	6.30	Silt %	20.50
Total N %	0.05	Clay %	51.30
Exch. Ca %	29.90	Textural class	Clay
CEC	39.90	Cracks	2-3 cm
Bulk density g/cm ³	1.50	-	-

CEC: Cation exchange capacity.

principle of terracing is to reduce runoff and soil loss and contribute to increased soil moisture content through improved infiltration. Soil water management practice through terracing conserves soil moisture for sustainable crop production in the semi-arid areas. Various studies to compare the effectiveness of terraced and non-terraced farms have shown that terraced farms as more efficient in terms of rainfall catchment and recorded high yields compared to non-terraced farms (Damene et al., 2012; Goto et al., 2012). Ramos and Cassanova (2006) compared to soil moisture content on terraced and non-terraced fields and reported more soil moisture content on terraced fields compared to non-terraced fields. The availability of soil moisture differs from position to position in the toposequence of the semi-arid environment (Homma et al., 2001). Various studies (Homma et al., 2004; Samson et al., 2004; Sunday et al., 2011; Ruto et al., 2017) have reported that in the toposequence of terraced lands high positions along the toposequence recorded lower available soil moisture content compared to the middle and lower slope positions. This study aimed at evaluating the role of vertisol to spatial soil moisture distribution along a toposequence of a terraced field. Vertisols are composed of 2:1 montmorillonitic mineral that expands when water is absorbed and shrink when soil moisture content decreases. Vertisol offer opportunities for better crop production in the semi-arid areas with erratic and variable rainfall compared with other soil types due to their high moisture holding capacity which allow crops to survive for longer drought periods. There is little information on toposequential soil moisture variation on a terraced vertisol in relation to rainfed crop production for semi-arid areas. The objective of this study was to investigate the effects of toposequence positions on water losses and productivity in maize cropping systems in semi-arid Machakos County.

MATERIALS AND METHODS

Study site description

The experiment was carried out in Kathekakai location in Central division in Machakos County (Figure 1). It is on latitude 0° 45' and 1°

31' south, longitude 36° 45' and 37°45' east and 1500 m above mean sea level. The average annual rainfall is 400 mm and average annual maximum and minimum are, respectively 36.9 and 22.7°C; the long-term average rainfall 540 mm which is bimodally distributed in two seasons, which are divided by distinct dry season. Long rains are low in amount and poorly distributed are expected in mid-March to June while the short rains fall from October to December. The study area has clay soils that are generally deep with less than 2% organic matter, high in clay content, high in the water holding capacity (Table 1). The clay soils of study site are situated in a gently sloping area (2.3-1.8% slope along the toposequence) unlike in many other parts of the world where most vertisols are either found in valley bottoms or low lying flat areas.

Experimental design and layout

The experiment was laid out during long rain season (March-May 2014) and short rain season (October 2014-January 2015) in a randomized complete block design (RCBD). The treatments comprised 3 cropping patterns (sole maize, sole beans, and maize-bean intercrop) each replicated three times (Table 2). The land was cultivated with an ox plough. Maize (Duma hybrid variety) and beans (Rose coco: GLP 2) were planted as sole crops and intercrops as shown in the experimental layout. Maize was planted at a spacing of 75 × 30 cm in pure stands while beans were planted at a spacing of 45 × 15 cm. In all experimental plots, nitrogen was applied at 50 kg N ha⁻¹ (Di-ammonium Phosphate 18:46:0) at planting to maize and additional 50 kg N ha⁻¹ when maize was four weeks after planting. All plots were hand weeded as practiced by the farmers during the cropping periods.

Data collection on soil moisture variability

Soil samples were collected using a soil auger for gravimetric moisture analysis at depth of 0-30 and 30-60 cm at both 9th leaf stage and tassel formation stages from the U=upper, M=middle and L=lower slope positions when crops started to show signs of moisture stress. Soil moisture content was determined by the gravimetric method (Hess, 1971). Soil samples were first weighed to record the weight of wet soil samples. The soil samples were then oven dried at 105°C in an electric oven for 24 h and then re-weighed to determine soil moisture content on a dry basis as follows:

$$\text{Moisture content \%} = \frac{\text{wt of wet sample} - \text{wt of oven dry sample}}{\text{Wt of oven dry sample}} \times 100 \quad (1)$$

where wt = soil sample weight in grams.

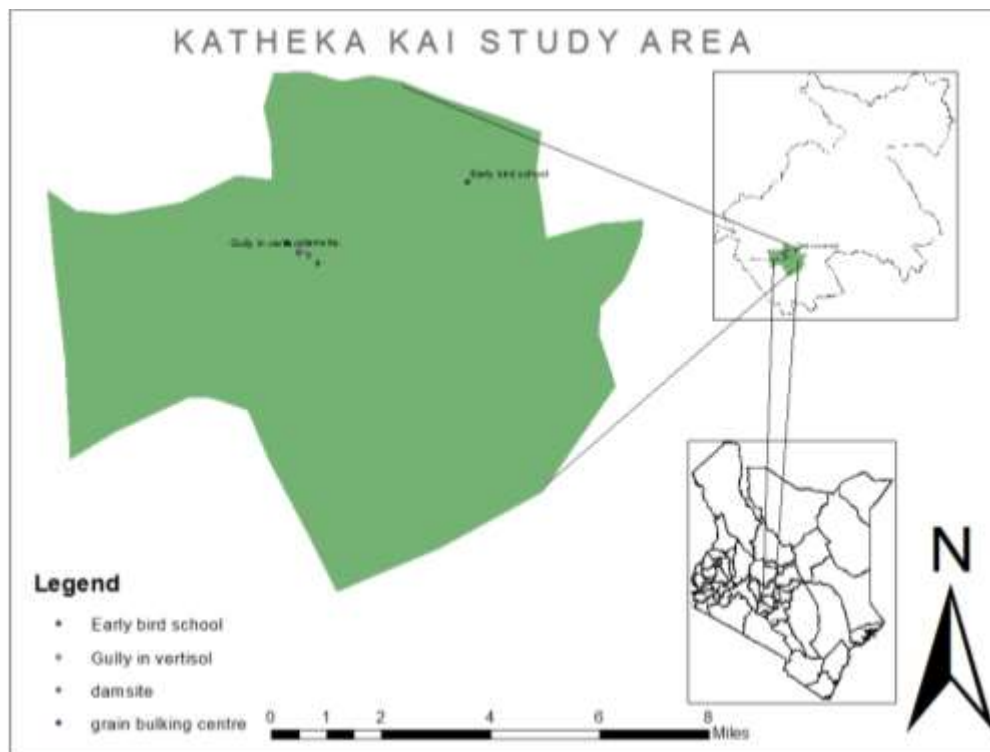


Figure 1. Study area in Machakos County.

Table 2. Terrace treatment arrangement.

		Maintained terrace ditch				
Terrace position	-	Description	CP 2	CP 1	CP 3	
Upper	Slope direction	Zone of moisture accumulation	Sole maize	Sole beans	Maize bean intercrop	
Middle		Zone of moisture deficiency	Sole maize	Sole beans	Maize bean intercrop	
Lower		Zone of moisture and sediments accumulation	Sole maize	Sole beans	Maize bean intercrop	
Maintained terrace embankment						

CP 1 is cropping pattern with sole beans; CP 2 is cropping pattern with sole maize and CP 3 is maize-bean intercrop.

Data on crop performance indicators

Crop performance was evaluated by monitoring crop height, leaf area index and yield in the upper, middle and lower slope positions of the terraced vertisol. Maize height was measured from the base of the maize plant at soil level to the highest point and to the tip of the tassel at 9th leaf and tassel stage, respectively. The length and breadth of all fully opened leaf lamina per plant of five plants were measured and recorded at 9th leaf and tassel stage. The product of leaf length and breadth were multiplied by the correction factor (0.73309) to obtain the leaf area in dm^2 per plant. Leaf area index was determined at 9th and tassel stage. Leaf area index was calculated by dividing the leaf area per plant by the land area occupied by a single plant. Aboveground biomass was determined by selecting five plants at random in the upper, lower and middle slope positions. The samples were cut at ground level and weighed using a spring balance. A representative sample of fresh biomass weight was oven dried at about 70°C to obtain oven dried weight of above ground biomass. The number of pods from five randomly

selected plants in the upper, middle and lower slope positions were recorded and used to estimate bean performance. Harvesting of both crops was done at physiological maturity from an area of 6.1 m^2 in the upper, middle and lower slope positions. Each treatment plot at the three slope positions was 10 m^2 . Maize and bean grain harvested, shelled and weighed to give yield in kg per square meter which was later extrapolated to ton per hectare. Grain yield data used was for only long rain season (LRS) 2014 because short rain season (SRS) did not reach physiological maturity due to a dry spell experienced between the months of December 2014 and January 2015.

Data analysis

The soil moisture, crop performance and yield data collected were subjected to analysis of variance (ANOVA) to evaluate the treatment effects using GenStat for Windows 14th Edition statistical software. One way analysis of variance was used to assess

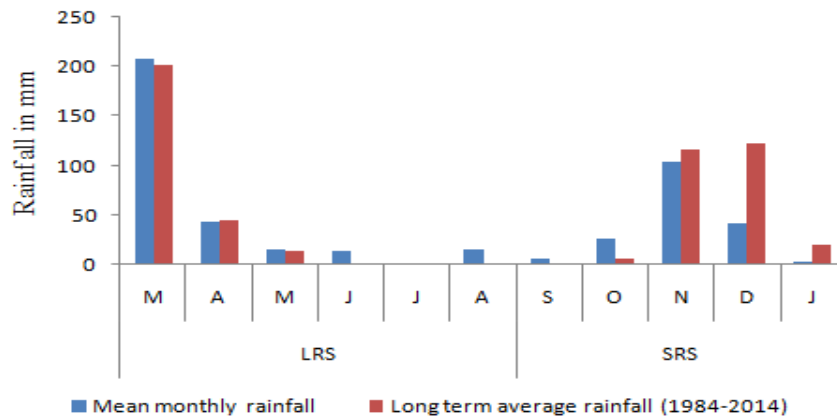


Figure 2. Seasonal rainfall received in study area 2014 against the long-term average rainfall of the area. LRS: Long rain season; SRS: short rain season.

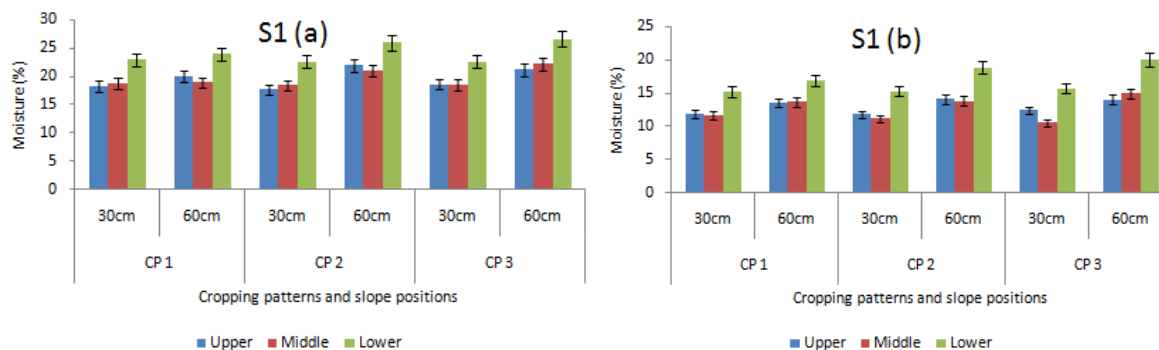


Figure 3. Soil moisture content in season 1 at 9th leaf stages (a) and tassel formation stage (b). Treatments: CP 1: Sole bean crop in all the upper, middle and lower slope positions; CP 2: Sole maize crop in all the upper, middle and lower slope positions; CP 3: Intercrop of maize and beans in all the upper, middle and lower slope positions.

significant differences among treatments. Levene's test was used to check for equality of variances and the study found insufficient evidence to claim that variances are not equal. Significant differences between and within treatments means were separated at $P < 0.05$ using Duncan's LSD.

RESULTS AND DISCUSSION

Seasonal distribution of rainfall

The pattern of rainfall distribution showed marked variations in both frequency and amount of rainfall during the two rainy seasons (Figure 2). The long rainy season (March-April-May) in 2014 was not well distributed whereby most of the rainfall was received in the month of March while in the second season (Oct-Nov-Dec) rainfall showed a fairly normal distribution. In seasons 1 and 2, the total rainfall was 266.2 and 172.9 mm which was 46.8 and 65.4%, respectively lower than the long-term average rainfall for the area (500 mm). Rainfall totals in

2014 were 27.9% lower than what had been received in 2013 and 28.6% lower than the long-term average and this deficit was greatly felt in the second season of 2014 where no maize grain was realized and the maize crop dried before flowering towards the end of December 2014. The non-availability of water at any growth stage will affect the productivity of the crops. A number of authors (Rockström and De Rouw, 1997; Gomez et al., 2000; Huang et al., 2003; Muroke et al., 2005) have reported that the maximum plant water availability favors the growth and development of plants. They concluded that under normal soil moisture content, the growth of the plant is not affected but under drought stress, the plants wilt due to low plant water availability.

Effects of slope position on soil moisture content

Soil moisture content at 9th leaf and tassel stages varied with slope positions in both seasons 1 and 2 (Figure 3). Soil moisture content was significantly ($p < 0.05$) higher in

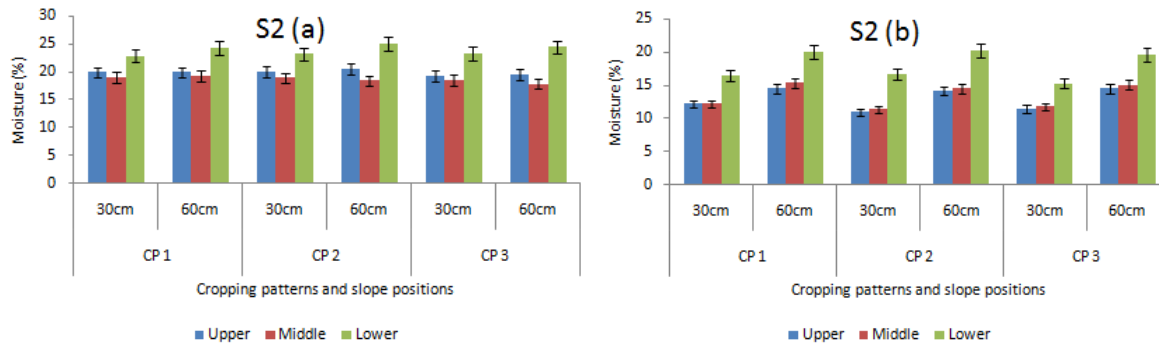


Figure 4. Soil moisture content in season 2 at 9th leaf stages (a) and tassel formation stage (b). Treatments: CP 1: Sole bean crop in all the upper, middle and lower slope positions; CP 2: Sole maize crop in all the upper, middle and lower slope positions; CP 3: Intercrop of maize and beans in all the upper, middle and lower slope positions.

the lower slope position compared to middle and upper slope positions irrespective of the cropping patterns and seasons (Figures 3 and 4). These findings are credited to water movement down the slope and deposition of sediments at the lower slope providing a bigger soil moisture storage capacity at this position. The terrace embankment apparently played a key role in trapping and retaining soil moisture at the lower slope position. Earlier studies have also shown that along the slope toposequence, soil moisture content increases significantly downslope and is entirely dependent on rainfall distribution (Fu et al., 2000; Wang et al., 2001; Dijk et al., 2003; Fu et al., 2003). Liu and Zhang (2007) reported that soil water content along a slope in a regosol decreased more rapidly on the upper slope compared to the middle and lower slope positions.

Soil moisture content at 30-60 cm soil depth was significantly ($p < 0.05$) higher compared to 0-30 cm depth regardless of the slope position and cropping pattern in both seasons 1 and 2 (Figures 3 and 4). Qiu et al. (2003) and Fu et al. (2003) observed that the mean soil moisture content increased significantly with increasing soil depth. Surface soil (0-15 cm) of hill slope recorded lower soil moisture content compared to the subsurface soil (10-75 cm) and they concluded that maximum soil moisture is accumulated on the subsurface of terraced lands. The results of the current study correlate with the findings of Brocca et al. (2007) who evaluated the soil moisture variability in Central Italy. Their comparison of the terraced and sloppy field's soil moisture content showed that the subsurface terraced field had more moisture as compared to sloppy fields.

Effects of slope positions on the height of maize and leaf area index

Leaf area index and maize height are presented in Table 3 for both seasons 1 and 2 as influenced by soil moisture content at various slope positions along the

toposequence.

There was no significant ($p < 0.05$) variation in maize leaf area index at 9 leaf and tassel stages in both seasons 1 and 2. Maize height showed significant variations at tassel stages but none in the 9 leaf stage in both seasons 1 and 2. The study revealed that the lower slope position recorded the tallest maize (150.1 cm) followed by the upper and middle slope positions (134.0 and 132.2 cm, respectively) in descending order in season 1 at tassel stage. In season 2, the lower slope position recorded the enhanced maize height (145.0 cm) followed by the middle and upper slope positions (128.2 and 125.0 cm) in descending order. The upper and middle slope positions recorded shorter maize plants and this could be attributed to the fact that these positions are soil moisture loss zones. Plant vegetative growth is generally affected by soil moisture stress. High maize plant height recorded in the lower slope positions was probably due to the presence of the terrace embankment which promoted infiltration of soil moisture at this slope position. Increased soil moisture content in the lower slope position could have resulted in improved translocation of nutrients resulting in increased maize height and plant growth and development at this slope position. Generally, sole maize in all the slope positions recorded taller maize crop compared to intercropped maize. A number of studies have reported high plant height in terraced farms than in non-terraced farms (Homma et al., 2003; Husain et al., 2013). The findings of the current study are consistent with those of Ruto et al. (2017) who observed high plant height in terraced andosols which was attributed to the interaction of increased nutrient and soil moisture content leading to better uptake and efficient use of water.

Effects of slope position on aboveground biomass and grain yield

Table 4 shows data on bean grain, maize grain and

Table 3. Leaf area index and maize height at 9th leaf and tassel growth stages along the toposequence.

Growth stage	Parameter	Season	Upper slope position	Middle slope position	Lower slope position	SE	P<0.05
9th leaf stage	Leaf area index	S1	1.21 ^a	1.23 ^a	1.26 ^a	±0.06	Ns
		S2	1.11 ^a	1.13 ^a	1.14 ^a	±0.07	Ns
	Maize height	S1	81.60 ^a	82.60 ^a	84.00 ^a	±2.47	Ns
		S2	73.50 ^a	72.50 ^a	73.90 ^a	±1.93	Ns
Tassel stage	Leaf area index	S1	3.72 ^a	3.79 ^a	4.05 ^a	±0.25	Ns
		S2	3.12 ^a	3.14 ^a	3.58 ^a	±0.20	Ns
	Maize height	S1	134.00 ^a	132.20 ^a	150.10 ^b	±3.69	*
		S2	125.00 ^a	128.20 ^a	145.00 ^b	±4.11	*

Means not sharing a common letter in a row differ significantly with each other at *=0.05 level of probability. Ns: Non significant effect of soil moisture content on different parameters at different slope positions. Maize height is given in cm. SE is the standard error of means.

Table 4. Maize and bean grain yield and maize biomass yield along the toposequence.

Yield (t/ha)	Season	Upper slope position	Middle slope position	Lower slope position	SE	P<0.05
Maize biomass	S1	4.39 ^a	4.49 ^a	5.26 ^b	±0.22	*
	S2	3.96 ^a	4.10 ^{ab}	4.61 ^b	±0.19	*
Bean grain	S1	0.64 ^a	0.63 ^a	0.77 ^b	±0.03	*
Maize grain	S1	2.57 ^a	2.58 ^a	3.07 ^b	±0.05	*

Means not sharing a common letter in a row differ significantly with each other at *=0.05 level of probability. Ns: Non significant effect of soil moisture content on yield at different slope positions. SE is the standard error of means.

maize biomass yield at different slope positions as influenced by soil moisture content at various slope positions along the toposequence.

There were significant differences ($p<0.05$) in maize biomass yield with different slope positions. The lower slope position had on average maize biomass yield of 5.26 ton/ha followed by the middle and upper slope positions (4.49 and 4.39 ton/ha, respectively) in season 1. During the second season, season 2 the lower slope position recorded 4.61 ton/ha maize biomass more than the middle (4.10 ton/ha) and upper (3.96 ton/ha). The higher aboveground biomass yield could be attributed to the accumulation of soil moisture in the lower slope position due to the presence of the terrace embankment. Maize aboveground biomass was hence found to increase with increased soil moisture availability. Ruto et al. (2017) attributed increased biomass yield at the lower slope position to the synergetic interaction between increased soil moisture content and availability of major nutrients (N, P and K) at this slope position.

There was a severe drought in the tassel and silk formation stage in season 2 and no grain yield was recorded. The lower slope position recorded significantly

($p<0.05$) higher bean grain yield (0.77 ton/ha) compared to the upper and middle slope positions (0.64 and 0.63 ton/ha, respectively) in season 1. The higher yields recorded in the lower slope position is credited to sufficient soil moisture leading to improved nutrient uptake and utilization by the bean plants. Lack of bean grain yield in season 2 was attributed to lower rainfall received compared to season 1 (172.9 and 266.2 mm, respectively). Homma et al. (2003, 2004) noted that the effect of drought on yields is most severe when crops are stressed by water deficit in pre-flowering phase. In season 1, the lower slope position recorded significantly ($p<0.05$) high maize grain yield (3.07 ton/ha) compared to upper and middle slope positions (2.57 and 2.58 ton/ha, respectively). The higher yields recorded in the lower slope position were attributed to increased soil moisture availability at the terrace embankment that led to enhanced nutrient uptake and use by the maize plant. The upper and middle slope positions may have suffered from the loss of soil moisture and nutrients through erosion hence the low yields recorded (Rockström and De Rouw 1997). Additionally, higher leaf area index noted at the lower slope position meant production of

more photosynthates consequently leading to increased maize and bean grain yields. Aung et al. (2013) while assessing the spatial variability in soil characteristics and crop yield in Vietnam reported that grain yields were lowest on upper slopes and increased progressively downslope. They attributed the increase in yields to higher nutrient levels at the lower slope position. In addition to the soil moisture availability, Homma et al. (2003) in their study in Northeast Thailand reported that the available soil nutrients depend greatly upon water flow along the toposequence. Accordingly, soils in the lower position of the toposequence have higher organic carbon and clay content, as a result of the runoff of surface water and the selective erosion of finer particles from upper to lower slope positions. Similarly, Ruto et al. (2017) reported that maize grain yield was 50% more than the upper and middle slope position and bean grain yield in the lower slope position were four times the yields in the upper slope position.

Conclusions

Soil moisture distribution in the vertisols varies with slope position and this variation is more pronounced with the presence of soil and water conservation structures (embankment). Thus, in a toposequence of a terraced field, upper slope positions will record lower amounts of available soil moisture. The upper slope position becomes the input in the lower slope position resulting in higher yields and better crop performance. There was no significant interaction between cropping patterns and slope positions in both seasons 1 and 2. This implies that either sole maize or maize-bean intercrop can be embraced and expected to perform well at the lower slope position in presence of an embankment. The current study indicates that the presence of terrace embankment at the lower slope position facilitated the accumulation of soil water and nutrients as a result of selective erosion of finer particles from the upper to lower slope positions. Farmers can, therefore, take advantage of increased soil moisture content in the lower slope positions and use of embankments in terraced fields to increase yields. The study has great policy implications for the drylands of Kenya on how soil quality, as well as crop yields, could be improved and maintained sustainably with proper design and implementation of soil and water conservation structures.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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