Journal of Agricultural Science and Food Technology
Vol. 3 (5), pp. 78-87, October, 2017
ISSN: 2465-7522
Full Length Research Paper
http://pearlresearchjournals.org/journals/jasft/index.html

Soil moisture variability and uptake of selected nutrients by maize along the toposequence of terraced andosols in Narok, Kenya

[1]Ruto*, A.C, [1]Gachene, C. K., [2]Gicheru, P. T., [3]Mburu, D.M and [4]Zeinab, K.

Accepted 14 September, 2017

[1]University of Nairobi, Department of Land Resources Management and Agricultural Technology, Faculty of Agriculture, P. O. Box 29053-00625, Nairobi, Kenya.
[2]Kenya Agriculture and Livestock Research Organization, Embu P.O. Box 27-60100, Embu.
[3]Jomo Kenyatta University of Science and Technology, P.O. Box 62000-00100, Nairobi.
[4]United Nations Development Program P.O. Box 30218-00100 UN Complex Gigiri, Nairobi.

ABSTRACT

The primary purpose of terracing is to intercept runoff water and reduce soil erosion, as well as to improve land productivity in steep slopes. A field experiment was carried out in Suswa, Narok Country during the short and long rain seasons of 2013 to 2015 to assess the effect of slope position and cropping pattern on soil moisture distribution and nutrient uptake by maize along the toposequence of terraced andosols. A randomized complete block design was used with maize (*Zea mays* L) and beans (*Phaesolus vulgaris* L.) as the test crops. The study examined soil and maize grain samples in the upper (U), upper middle (UM), middle (M), lower middle (LM) and lower (L) positions of the terrace. Soil samples were collected at a depth of 50 and 75 cm at maize tasslelling stage. The results indicated that there were significant differences (p≤0.05) in soil moisture distribution and N, P and K uptake according to slope position with higher values in L>LM>UM>M>U. There was however no significant effect on N,P, and K uptake according to cropping pattern. The research shows that terracing have effect on soil moisture and nutrient variability and farmers can benefit from this spatial variability in the terraced fields as a low technology precision farming for increased yields.

Key words: Cropping pattern, Nutrient uptake, Slope position, Soil moisture and Terracing.

*Corresponding author. E-mail: arutoc@gmail.com.

INTRODUCTION

The principle objective of terracing is to reduce runoff and soil loss, according to Posthumus and De Graaff (2005), farmers practiced terracing for the purpose of preventing soil loss and to improve cropping conditions on their steep fields. Terraces can be designed so as to accumulate and retain water in the terrace channel so that it will eventually infiltrate and the sediment accumulates. The efficiency of terraces however can be increased by applying additional conservation practices such as appropriate land preparation (contour ploughing), appropriate cultivation of crops (strip cropping), permanent cover maintenance, application of manure and fertilizer to the soil (Dorren and Rey, 2004) and developing of an appropriate cropping pattern that will utilize the harvested water as well as the fertile soil at the deposition zone in the terraced field. Understanding the effects of agricultural terraces and toposequence on soil physical properties, is fundamental for improving resource use efficiency, such as water and nutrients, and thus becomes a valuable tool for precision agriculture and improved yields in terraced farms as well as better economic status at community and State levels.

The greater water content in the terrace ditch can lead to a better efficiency in the use of nutrients (Zoca et al.,

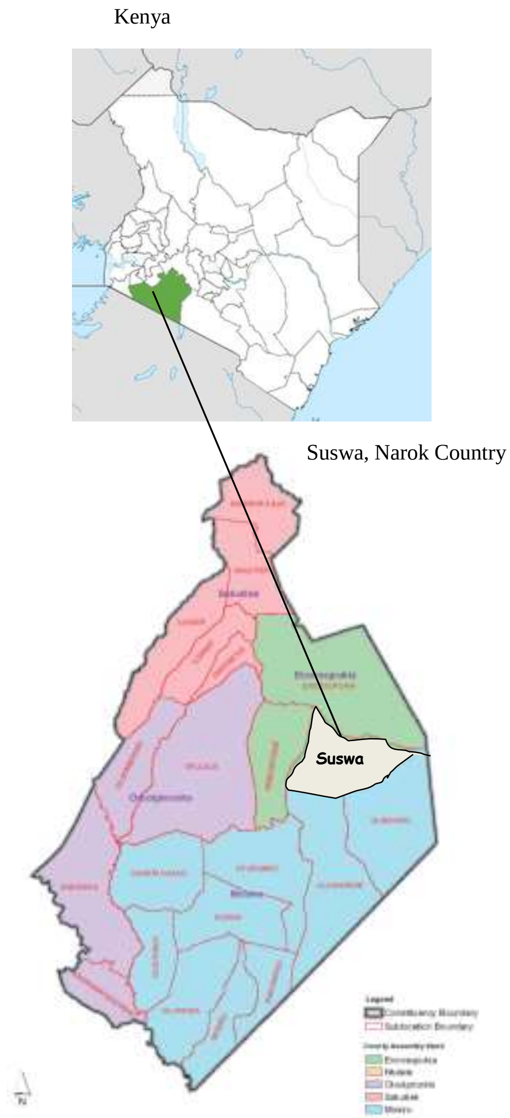

Figure 1. The study area in Narok Country. Source: Narok District Environment Action Plan 2009 to 2013.

2012). The major problems, among others of arid and semi-arid areas are insufficient soil moisture for plant growth and low amounts and imbalances of available plant nutrients. Soils in drylands are diverse in their origin, structure and physicochemical properties. Important features of dryland soils for agricultural production are their water holding capacity and their ability to supply nutrients to plants. Since there is little deposition, accumulation or decomposition of organic material in dryland environments, the organic content of the soils is often low and therefore, natural soil fertility is also low (Koohafkan and Stewart, 2008). According to Thomas (1997), increase in food production and household income in the dryland can be achieved through increase in biomass production per unit land and per unit water.

MATERIALS AND METHODS

Description of the Study Area

The study was carried out in Suswa, Narok County located in the Southwest of Kenya and lies between latitudes 34°45'E and 36°00'E and longitudes 0°45'S and 2°00'S (Serneels and Lambin, 2001; Jaetzold et al., 2010) (Figure 1). The study area is characterized by low, erratic, and poorly distributed bimodal rainfall with the long rains expected from mid March to June while short rains from mid September to November. The mean annual rainfall for Suswa area is 500 mm/yr (NEMA, 2009; Ojwang et al., 2010). During the study period Season 1(August to December 2013) recorded 450 mm of rainfall, Season II (February to June 2014) 416 mm,

Table 1. Characterization of the Suswa andosols.

Horizon	Depth (cm)	Average BD (g/cm^3)	Average % OM	Average Ksat (cm/h)	Sand	Clay	Silt	Texture class
A	0-10	1.36	1.29	0.85	62.4	17.6	20	SL
BU1	10-21	1.35		0.89	70.4	7.6	22	SL
BU2	21-31	1.19		0.96	58.4	19.6	22	SL
BC	31-49				70.4	7.6	22	SL

BD=Bulk density, OM= Organic Matter, Ksat= hydraulic conductivity, SL= Sandy loam. Source: Gachene, 2014.

Table 2. Soil nutrient chemical analysis at beginning and end of trials.

Slope	August, 2013					May, 2015				
	pH (H_2O)	C (%)	N (%)	P (ppm)	K (Cmol/kg)	pH (H_2O)	C (%)	N (%)	P (ppm)	K (Cmol/kg)
U	6.06	1.31	0.16	12.41	3.06	6.16	1.81	0.12	17.29	1.90
M	6.06	1.30	0.16	13.56	3.11	6.04	2.03	0.21	23.15	2.23
L	6.06	1.34	0.19	18.73	3.11	6.15	2.62	0.35	31.03	2.67
Means	6.06	1.32	0.17	14.9	3.09	6.12	2.15	0.23	23.82	2.26
LSD$_{(0.05}$	0.25	0.48	0.06	6.89	0.52					
CV (%)	2.5	16.8	19.8	21.8	11.9					
SE	0.13	0.24	0.03	3.44	0.26					

Table 3.Terrace treatment arrangements and layout.

B1	CP5 1	CP2 2	CP3 3	CP4 4	CP1 5
B2	CP3 10	CP4 9	CP2 8	CP5 7	CP1 6
B3	CP1 11	CP2 12	CP5 13	CP3 14	CP4 15

Season III (August to December 2014) 141 mm and Season IV (February to June 2015) 92.4 mm.

Suswa Soils

The soils at the trial site are humic andosols, well-drained, deep, dark brown, friable and smeary, sandy clay to clay, with acidic humic topsoil (Sombroek et al., 1982; Jaetzold et al., 2010). The horizons studied in this study had a sand to silt clay ratio of 2:1 on average (Gachene, 2014) and according to earlier studies by Maina (2013) the high silt /clay ratio**,** low organic matter, and high bulk density make the soils prone to erosion.

Soil Nutrient Distribution

Soil from the study site were analysed at the Soil Science laboratory, University of Nairobi (Table 1) at the beginning and at the end of the trial period. The analysis showed that soil nutrient status varied depeding on slope position, with the highest amount recorded at the lower slope position and the least values at the top slope position. The trasnsportation of nutrients both through natural and accelerated soil esrosion contribute to higher soil nutrient levels at the lower slope position (Table 2).

Experimental Layout and Design

The experiments were laid out in both the short and long rain seasons of 2013 to 2015, in a randominsed complete block design (RCBD). The treatments comprised of five cropping patterns each replicated three times as illustraed in Table 3.

Data Collection and Laboratory Analysis

The samples were collected in a line-by-line basis from

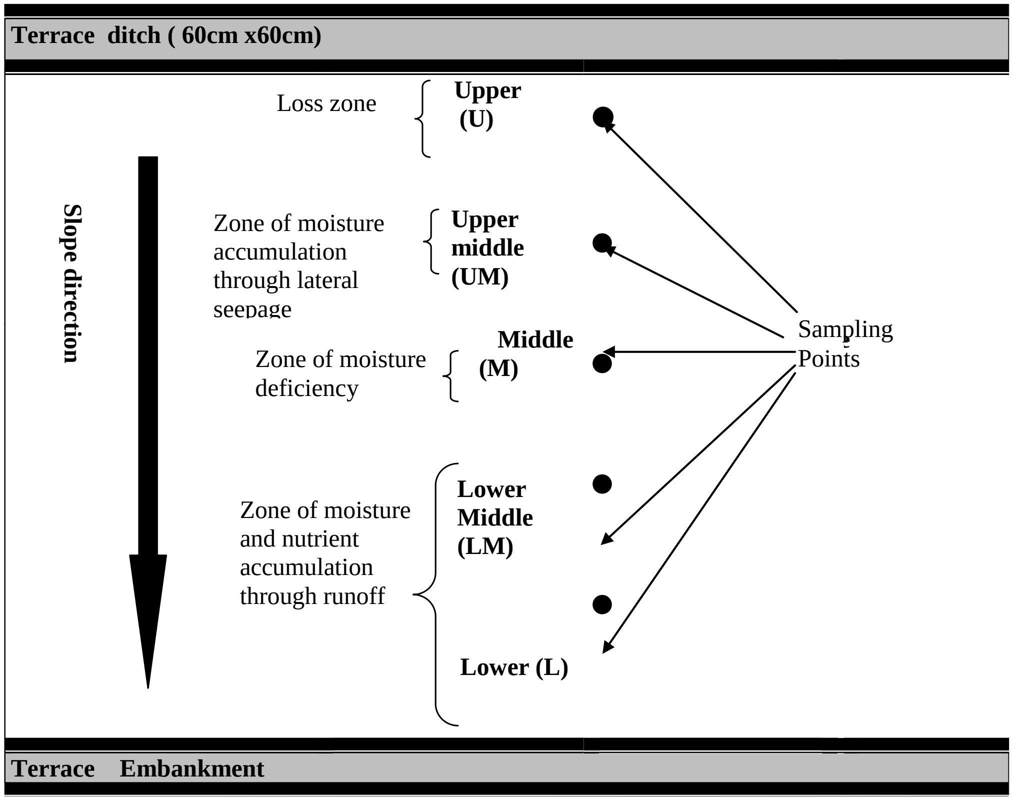

Figure 2. Soil and crop sampling points along the terrace.

the terrace ditch to the terrace and the experimental plots were divided into five equal portions for the purpose of data analysis as follows; U=upper slope position, UM = upper middle slope position, M = middle slope position, LM= lower middle slope position and L = lower slope position (Figure 2). Samples for the first three seasons were used because the fourth seasons' crop did not reach physiological maturity due to a dry spell experienced between the months of April to June 2015.

Soil Moisture Variability

To assess the effect of slope position and cropping pattern on soil moisture distribution along the toposequence of terraced andosols, soil moisture was monitored by collecting samples using an auger at the depth of 50 and 75 cm at tasselling stage and taken to the laboratory for moisture determination using gravimetric method (Okalebo et al., 2002). Soil samples were collected at this depth because though maize roots tend grow to over 100 cm, during flowering roots are more active at 50 to 70 cm depth and the rate of water absorption is very high within this soil depths. In addition shallow soil depths soil water is lost through evaporation due latent heat which is absorbed by soil water and hence subjecting the surface to more water loss (Mthandi et al., 2013).

Grain Nutrient Content

To assess nutrient uptake in maize grain, five crops were selected in each slope position from the terrace ditch to the embankment for the three seasons the crop reached maturity. Maize on cob was harvested and weighed using a spring balance (to the nearest 0.1kg) to determine the fresh weight (Burt, 2009). A representative sample was shelled and the grains dried at room temperature to a moisture content of 13%. The grains were then ground and passed through a 2 mm sieve for determination of total nitrogen (wet digestion /Kjeldahl method), available phosphorus (Mehlich method), and potassium (Flame photometry method) according to procedures and methods outlined by Okalebo et al. (2002). Treatment CP2 was not included in the analysis of NPK in grains because this treatment unlike the other treatments did have maize crop in all slope position.

Data Analysis and Management

The soil moisture and soil nutrient data were first entered and processed in Microsoft Excel 2007 software then exported to GenStat for *Windows* 14th edition for analysis of variance (GenStat, 2013). Significant difference between and within treatments was separated at $P \leq 0.05$ using Duncan's LSD

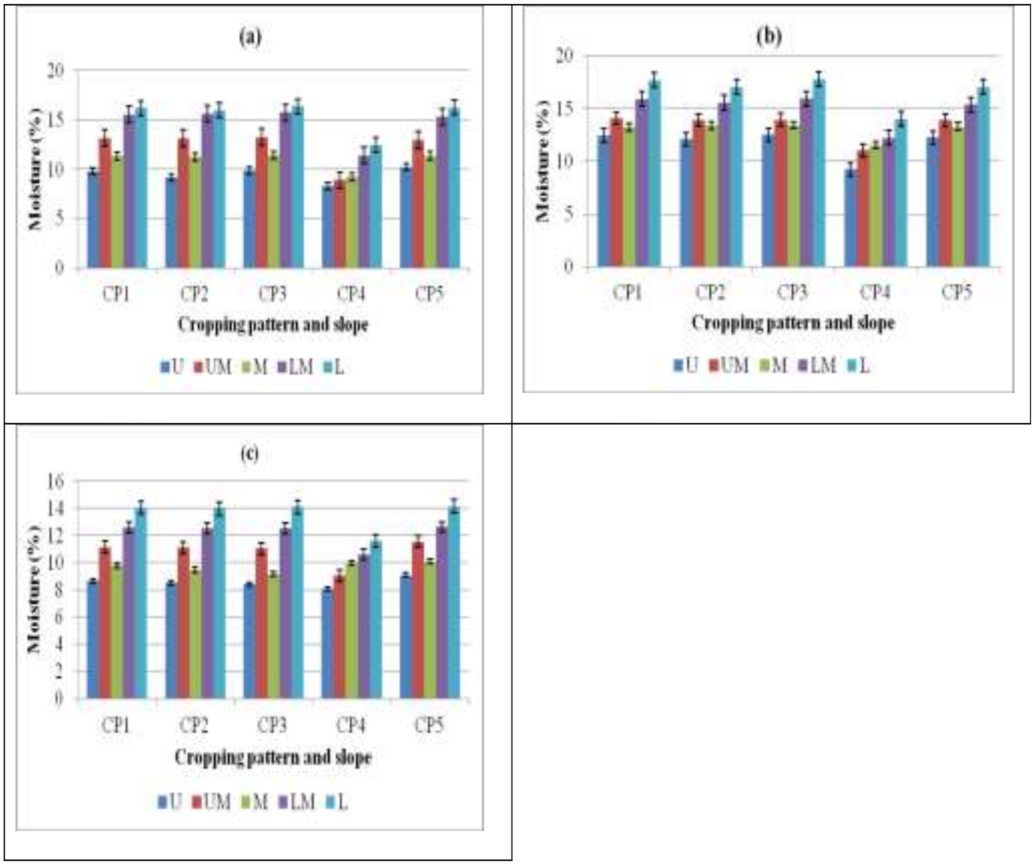

Figure 3. Soil moisture at 50cm in season I (a) season II (b) and season III(c). Key: U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower ($LSD_{0.05}$). Treatments: CP1: Maize and Bean intercrop in upper and lower zones and sole maize in the middle. CP2: Maize and Bean intercrop in the upper and lower zones and sole bean crop in the middle. CP3: Sole maize crop in all the three slope positions. CP4: Maize and beans intercrop in all the three slope positions (farmers' practice). CP5: Intercrop of maize and beans in upper, middle,

RESULTS AND DISCUSSION

The Effect Of Slope Position And Cropping Pattern On Soil Moisture Distribution And N,P,K Uptake By Maize Grain

Soil Moisture Distribution

Soil moisture content was found to exhibit a high degree of spatial and temporal variability. The lower slope position had significantly ($p \leq 0.05$) higher soil moisture % content than the other slope positions irrespective of cropping patterns and season. At the depth of 50 cm the moisture readings were 15.44 and 15.90% at 75 cm compared to the upper slope position which had on average 9.49 and 12.23% in season I (Figures 3 and 4), respectively. Similarly, cropping patterns and depth significantly ($p \leq 0.05$) influenced soil moisture content, with CP 4 (control) recording the lowest (11.59%) compared to the rest of the cropping patterns with 14% in the lower slope position in season III. The upper middle slope position had higher (13.99 and 12.97%) moisture readings than both the middle (12.69 and 11.36%) and upper (12.57 and 10.25%) positions respectively at the depth of 75cm and 50cm respectively in season I. The upper middle slope position had higher moisture readings than both the middle and upper positions, respectively; an observation was attributed to lateral seepage from the terrace ditch, because the soils (andosols) at the trial site were found to form surface crusting within the first 5 to 10 cm. The high silt /clay ratio, low organic matter and high bulk density probably could have made the soils more prone not only to erosion but also facilitated the lateral seepage hence the higher moisture at the upper middle position, the lower middle and lower slope positions. The same is echoed by Pimentel (2006), who found out that soil structure influences the ease at which it is eroded as soils with low organic matter and weak structural development like the andosols of Suswa have low infiltration and are subject to water erosion as soil particles are easily displaced. Reports by Qiu et al. (2001); Du-Plessis, (2003) also indicate that slope and season influence the spatial variability of soil moisture and during the growing period, crops in terraces can

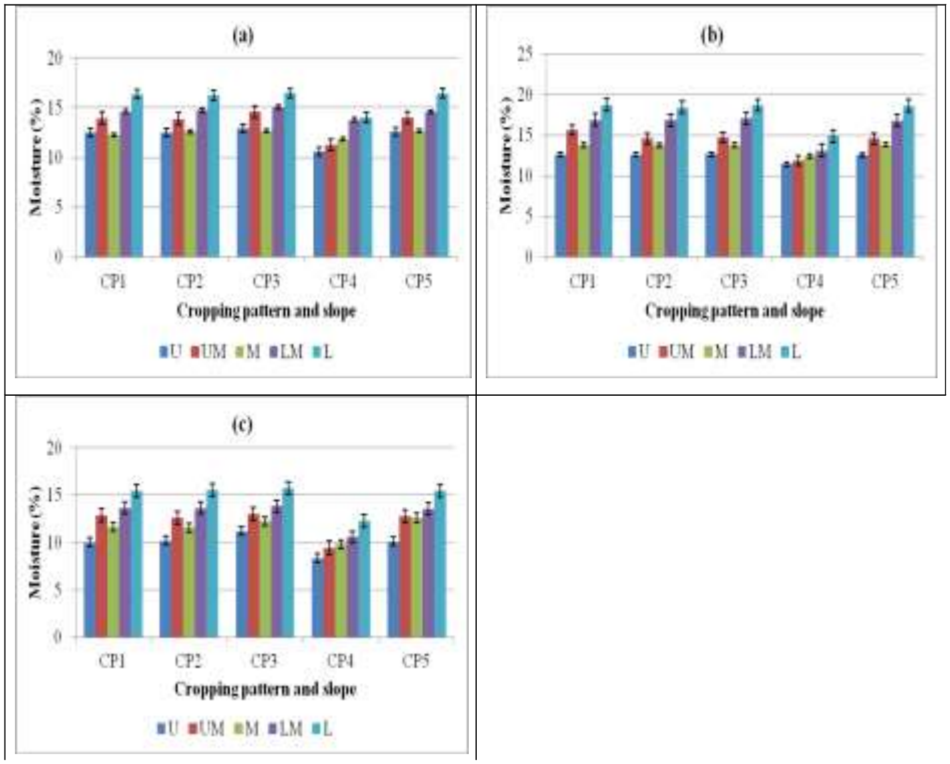

Figure 4. Soil moisture at 75 cm in season I (a), season II(b) and season III (c). Key: U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower ($LSD_{0.05}$). Treatments: CP1: Maize and Bean intercrop in upper and lower zones and sole maize in the middle. CP2: Maize and Bean intercrop in the upper and lower zones and sole bean crop in the middle. CP3: Sole maize crop in all the three slope positions. CP4: Maize and beans intercrop in all the three slope positions (farmers' practice). CP5: Intercrop of maize and beans in upper, middle and lower slope position.

absorb more water than in sloping land, thus increasing the uptake of deep moisture and reducing evaporation losses.

In this study the soil moisture content was seen to have been influenced by the amount of rainfall received, for example on average the soil moisture content in season I (13.7%) and II (14.1%) was higher compared to season III (11.7%) which received about 141mm of rainfall compared to season I (450 mm) and season II (416 mm). The moisture variations observed is explained by the fact that water would naturally move and carry sediments down slope due to forces of gravity, resulting in deeper soils at lower slope positions, which store more water while the upper and middle slope positions have shallower soils and therefore less water storage. The lower moisture readings for CP 4 was associated with the absence of terrace ditch and embankment hence loss of both soil and water through run-off. When plants take up water from these deep soil sections and from shallow soil sections results in a faster depletion of soil moisture in the shallower soil section. This in turn resulted in a relation between soil moisture and soil depth after leaf out. In addition, the Suswa andosols have very little clay content that would have absorbed and help hold water collected in the terrace ditch. Similarly Husain et al. (2013) reported that terraces increased the average soil moisture content in 90 cm soil depth by more than 50% than that of non-terraced land. Within the terraced field, compartmental bunding increased soil moisture by 18.2% higher than that of plain bed (control). This indicated that *in-situ* moisture conservation measures are effective to increase soil moisture compared to plain bed. It was also observed that the mean soil moisture fluctuation in the soil profile is moderately more at 60 cm depth compared to 30 cm irrespective of type of conservation techniques (Husain et al., 2013). In this study, the terrace embankment played a major role in trapping soil moisture down the slope with CP 3 reading 17% compared to 14% for CP 4 (control) at 75 cm depth and 16 and 13% at 50 cm depth in season II.

Nutrient Uptake

Nitrogen

The effect of slope positions on Nitrogen uptake in maize grain was observed in all the three seasons investigated (Figure 5), The lower slope position had 1.6% compared

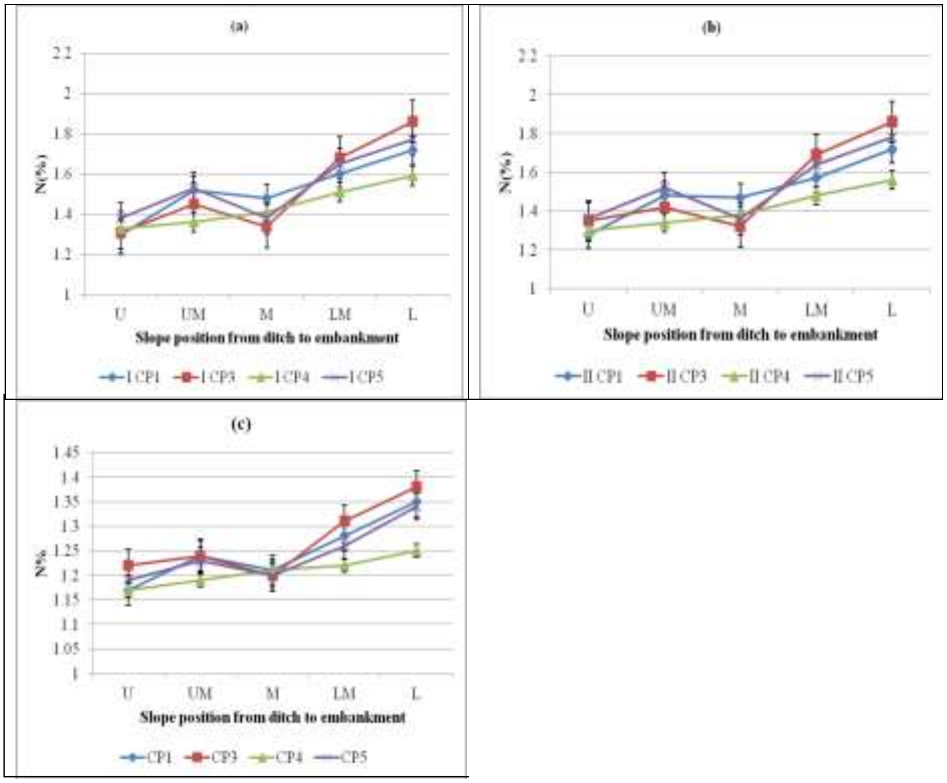

Figure 5. Maize grain N (%) uptake in season I (a), season II(b) and season III (c) Key: U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower Treatments: CP1: Maize and Bean intercrop in upper and lower zones and sole maize in the middle. CP3: Sole maize crop in all the three zones. CP4: Maize and beans in all the three slope positions (farmers' practice). CP5: Intercrop of maize and beans in upper, middle, and lower zone.

to upper position with 1.28%, on average. The UM slope position had 1.38% on average, which was attributed to presence of moisture due to lateral seepage and hence improved uptake of N at this slope position. There was no significant differences in N grain uptake as affected by cropping patterns, however CP3 on average recorded slightly higher N uptake compared to other cropping patterns in all the seasons, for example in season III CP3 had 1.27% compared to CP1-1.25%, CP5-1.24 % and CP4-1.21%. This observation was associated with the lack of competition for nutrients in this sole maize treatment. The results also showed that N uptake was generally higher in season I and II compared to season III across slope position and cropping patterns, an observation that was attributed to higher amount of rainfall in season I (450 mm) compared to season III (141mm). The lower N% uptake in season III for CP4 (control) was linked to the absence of terrace embankment, hence lack of zone of moisture and nutrient accumulation. The accumulation of Nitrogen at the terrace embankment, both through natural and accelerated soil erosion, contributed to higher soil N uptake at the lower slope position compared to other slope positions.

Phosphorus

There was a pronounced ($p \leq 0.05$) effect of slope position on P uptake in all three seasons (Figure 6). With the lower slope position on average reporting the highest (2679 ppm) values, followed by the lower middle (2307ppm), upper middle (2058 ppm), Middle (1876-ppm) and the least at the upper with 1727 ppm. This observation was occasioned by to improved nutrient uptake due to moisture and sediment accumulation in the L and LM slope position, lateral seepage in the UM and moisture and nutrient depletion due to erosion in the U and M slope positions. Cropping patterns had no significant effect on P grain uptake in all seasons; however, CP4 had the least P grain uptake, while CP3 had slightly higher readings. This observation was attributed to the absence of terrace embankment that would have caused the accumulation of moisture and sediments at the lower slope position for CP4 and lack of competition for nutrients in CP3 (sole maize crop). There were no observed differences in P grain uptake with seasonality, which was attributed to availability of adequate P early in the growing season. This availability ensured seed fill, because a large portion of P used for

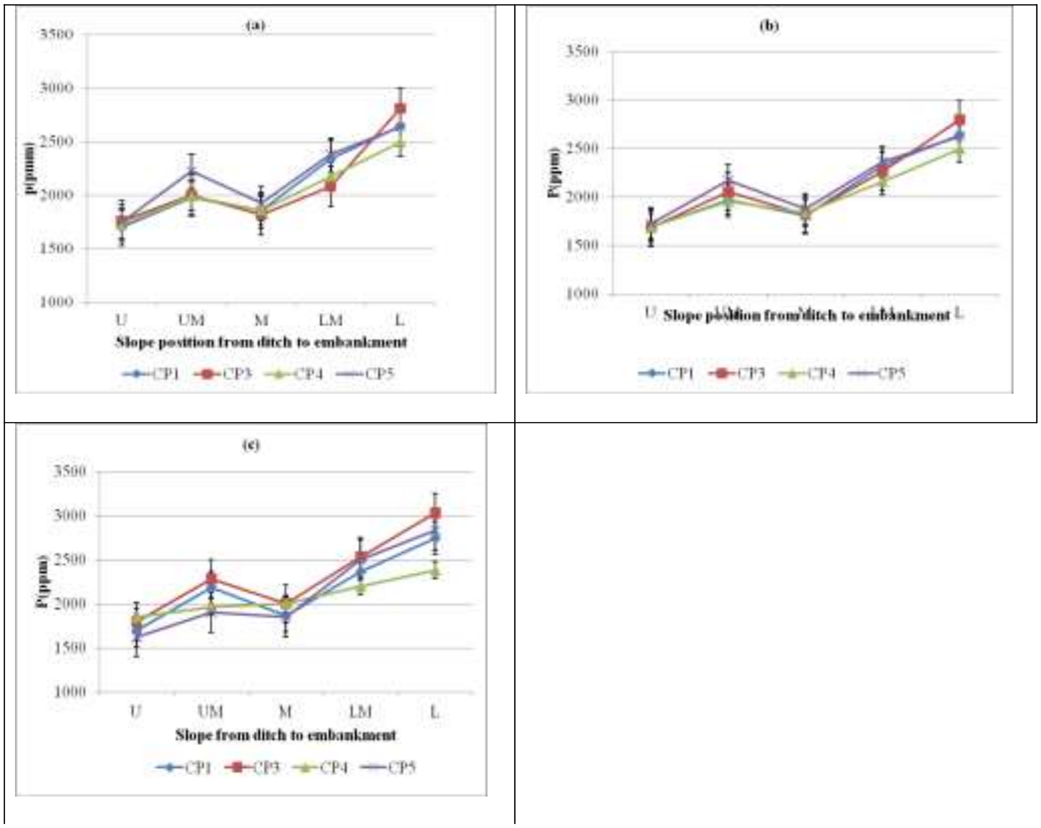

Figure 6. Maize grain P (ppm) uptake in season I (a), season II (b) and season III(c) Keys: U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower Treatments: CP1: Maize and Bean intercrop in upper and lower zones and sole maize in the middle. CP3: Sole maize crop in all the three zones. CP4: Maize and beans in all the three slope positions (farmers' practice). CP5: Intercrop of maize and beans in upper, middle and lower zone.

grain and seed fill comes from the stem, leaves, and head, rather than directly from the soil

Potassium

There were significant differences (p≤0.05) in maize grain K uptake as affected by slope positions in all seasons (Figure 7) with K distribution as follows; L>LM>UM>M>U. The lower slope position had on average (1301 ppm) more K uptake than the upper position. (This observation was associated to the presence of moisture in the L, LM and UM slope postion which facilitated K uptake. Spatial redistribution of surface runoff resulting in higher soil water availability on lower slope positions, contributed to the higher amounts of K available at the lower slope position. Also observed was the higher K uptake in all the slope position in season I and II compared to season III, which was occasioned by higher rainfall experienced in season I (450 mm) and season III (141 mm). Cropping patterns had no prounounced effect on K grain uptake in all seasons. However, CP3 had 653 ppm K uptake more than CP4 (control) in season III, which was due to abundant K availability for CP3 (sole crop) and absence of zones of moisture and nutrient accumulation in CP4 (control). These findings are in agreement with those of (Changere and Lal, 1997) who reported greater nutrient uptake in the lower slope position. Li et al. (2009) reported that the total N absorbed by the plant in a semiarid region depend greatly on the amount of moisture stored in the profile at planting, as well as on the amount of rainfall during the growing period.

A very closely linear relationship has been found between water content and mineralized N, due mainly to good aeration induced by deficit of water on drylands, ammonium-N both from soil and fertilizers can be quickly nitrified into nitrate-N. Thus, a large amount of nitrate-N often accumulates in soil profile that has been used as a good index for reflecting soil N-supplying capacity. Adequate soil water content significantly transfers a large portion of N to aboveground part, and increase N contents in seeds. The assimilation of nitrogen, phosphorus and potassium reaches a peak during flowering. At maturity, the total nutrient uptake of a single maize plant is 8.7 g of nitrogen, 5.1 g of phosphorus, and 4.0 g of potassium. Each ton of grain produced removes 15.0 to 18.0 kg of nitrogen, 2.5 to 3.0 kg of phosphorus

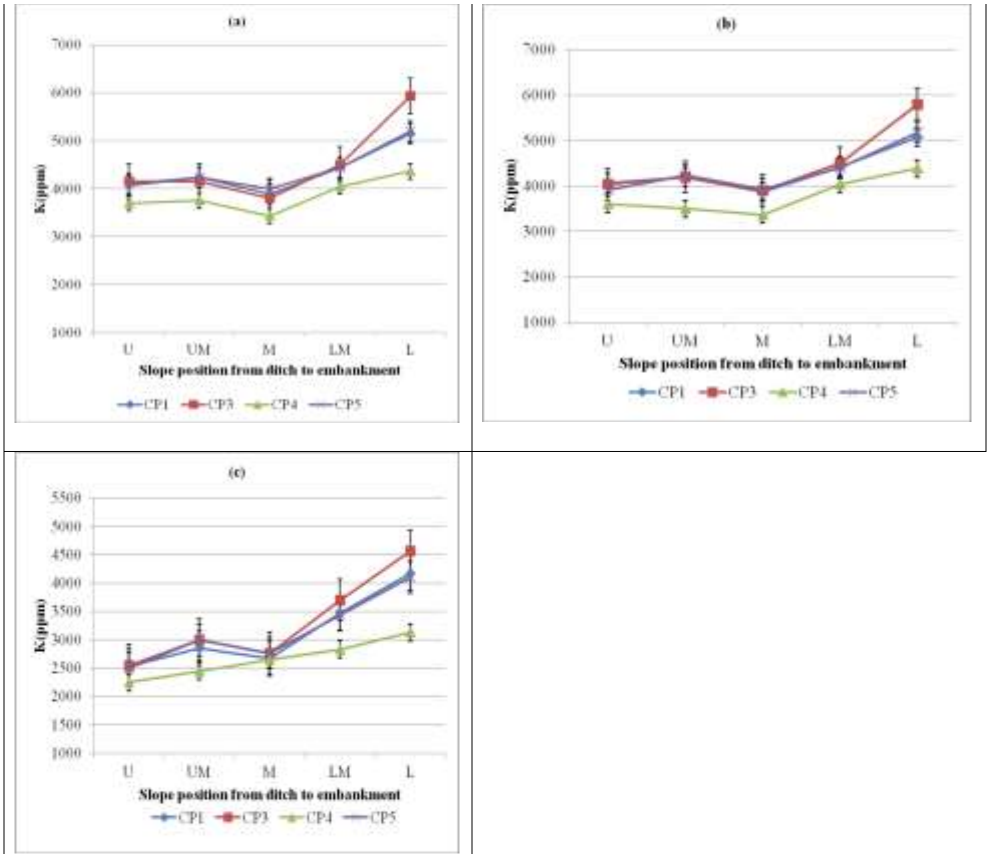

Figure 7. Maize grain K (ppm) uptake in season I (a), season II (b) and season III (c) Key: U-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower Treatments: CP1: Maize and Bean intercrop in upper and lower zones and sole maize in the middle CP3: Sole maize crop in all the three zones CP4: Maize and beans in all the three slope positions (farmers' practice) CP5: Intercrop of maize and beans in upper, middle and lower zone.

and 3.0 to 4.0 kg of potassium from the soil (Du-Plessis, 2003). This study also found higher levels of moisture at the lower slope position at all the investigated growth stages (germination 17%, 9th leaf stage 15.9% and at tasselling 15.5%) which gave rise to the higher N uptake by grain at this slope position. Small difference was most likely attributed to the fertility of the soils where the crop was planted and other environmental conditions.

CONCLUSIONS

Results from this study show that soil moisture and nutrient status differ depending on slope position and land management that is the presence or absence of soil and water conservation structures. Significant differences depending on slope position were found among the following nutrients; K, available P and N. Differences between slope base and other parts of the slopes was up to 80%, for N, 34% for P and 28% for K on average. Soil nutrients transported from the upper parts of the terrace were trapped by the conservation structures at the lower sides of the terraces (embankment) and maintained there, making significant difference in soil and nutrient accumulation and subsequent uptake between the lower and the upper slopes. Without soil conservation structures, the fate of accumulated moisture and nutrients would be washed away from the farm and transported to other ecosystems. The fertility status of the soil at different slope position of the study site showed significant differences. Lower fertility at the upper slope position was associated with erosion, while the higher fertility at the lower slope with moisture and sediment deposition. The research shows that different cropping patterns have variable impacts on soil moisture content, nutrient availabilty and eventual crop performance along the toposequence of terraced fields over time.

The research identified differences in mean seasonal soil moisture, and grain nutrient content among cropping patterns as a function of landscape position. This indicates differences in soil moisture and nutrient loss or availability among these slope positions. There was no significant relationship between cropping pattern and nutrient distribution in the three seasons during the study period, however CP 4(control) recorded the lowest value for both moisture and Nutrient content an indication that terracing plays a key role in improving land productivity and farmers can take advantage of the moisture and nutrient variability in terraced field to increase yields. The study has great policy implications for the drylands of Kenya on how the soil quality as well as crop yield could be improved and maintained sustainably with proper design and implementation of soil and water conservation structures. Terracing improves the basic agricultural cultivation conditions and agricultural development efficiency, establishing a base for sustainable agricultural development in the future in Suswa, Narok County, which can replicated in other arid and semi-arid regions of Kenya.

ACKNOWLEDGEMENTS

The authors wish to thank the United Nations Development Programme (UNEP) through the Sustainable Land Management (SLM) project for funding the research. We also acknowledge the State Department of Livestock, Narok County and Olesharo community for providing the trial sites.

REFERENCES

Burt R (Ed.) (2009). Soil survey field and laboratory methods manual. National Soil Survey Center, Natural Resources Conservation Service, US Department of Agriculture.

Changere A, Lal R (1997). Slope position and erosion effects on soil properties and corn production on a Miamian soil in Central Ohio. J. Sustain. Agric. 11 (1): 5-21

Dorren L, Rey F (2004). A Review of the Effect of Terracing on Erosion. In Asselen, S.V, Boix-Fayos C and Imerson A. (eds).Briefing Papers of the Second SCAPE Workshop CiqueTerre, Italy.

Du-Plessis J (2003). Maize production. agricultural information services. Department of Agriculture, Pretoria, South Africa. Retrieved from http. Fastonline. org/CD3WD, 40.(Access 12 August 2017)

Gachene CK (2014). Characterization and assessment of erodibility indexes of Suswa andosols. (Unpublished report).

GenStat (2013). Introduction to GenStat for Windows. 14th Ed. Lowes Agricultural Trust, Rothamsted Experimental station, Reading University, United Kingdom.

Husain J, Bahtiar NH (2013). Maize Performance in Terrace and Non-Terrace Sloping Land. International Maize Conference November 2012, At Gorontalo, Indonesia.

Jaeztold R, Schmidt H, Hornetz B, Shisanya C (2010). Farm Management Handbook of Kenya vol.

II Ministry of Agriculture, Kenya.

Koohafkan P, Stewart B (2008). Water and Cereals in Drylands. FAO and Earthscan. ISBN 78-1-84407-708-3 (Earthscan, paperback) 110 pages

Li SX, Wang H, Malhi SS, Li SQ, Gao YJ, Tian XH (2009). Nutrient and water management effects on crop production, and nutrient and water use efficiency in dryland areas of China. Adv.Agron. 102:223-265.

Mthandi J, Kahimba F, Tarimo A, Salim B, Lowole M (2013).Root zone soil moisture redistribution

in maize (*Zea mays* L.) under different water application regimes. Agric. Sci. 10:521-528

Nattional Environmental Management Authorithy (2009). Narok District Environmental Action Plan. 2009-2013.

Ojwang' GO, Agatsiva J, Situma C (2010). Analysis of Climate Change and Variability Risks in the Smallholder Sector Case studies of the Laikipia and Narok Districts Kenya. Electric Publishing Policy and Support Branch Community Division.

Okalebo JR, Gathna KW, Woomer PL (2002). Laboratory Methods of Soil and Plant Analysis: A Working Manual. 2nd Edn., Nairobi: Tropical Soil Fertility and Biology Prog.

Pimentel D (2006). Soil Erosion: A Food and Environmental Threat. Environ., Develop. and Sustain. 8;119-137.DOI 10.1007/sl0668-005-1262-8

Posthumus H, De Graaff J (2005). Cost-Benefit Analysis of Bench Terraces. A Case Study in Peru. Erosion and Soil & Water Conservation Group, Department of Environmental Sciences, Wageningen University, The Netherlands.

Qiu Y, Fu B, Wang J (2001). Spatial heterogeneity of soil moisture content on the Loess Plateau, China and its relation to influencing factors. Chinese J. Appl. Ecol. 12(5):715 720.

Sombroek WC, Braun HMH and van der Pour BJA (1982). Explanatory Soil Map and Agro climatic Zone Map of Kenya. Report E1. National Agricultural Laboratories, Soil Survey Unit, Nairobi, Kenya, p.56.

Serneels S, Lambin E (2001). Proximate causes of land-use change in Narok District, Kenya:

A Spatial statistical model. Agric., Ecosyst. Environ. 85:65-81.

Thomas (ed.) DB (1997). Soil and Water Conservation Manual for Kenya. Soil and Water Conservation Branch, Ministry of Agriculture, Livestock Development and Marketing. Press, Nairobi, Kenya.

Zoca S, Lollato R, Meeks K (2012). Influence of Agricultural Terraces on Soil Water and Physical Properties in Oklahoma.