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SOIL MOISTURE VARIABILITY AND DISTRIBUTION OF SELECTED SOIL CHEMICAL PROPERTIES IN TERRACED ANDOSOLS IN NAROK COUNTY, KENYA.

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Abstract

A field experiment was carried out in Suswa, Narok County during the short and long rain seasons of 2013-2015 to assess the effect of terracing on soil moisture and nutrient distribution. A randomized complete block design was used with maize (Zea mays) and beans (Phaesolus vulgaris L.) as the test crops. The study examined soil moisture and distribution of pH, C, N, P and K along the top sequence of terraced and olols at 0-30 cm soil depth at the beginning (August, 2013) and at the end (May, 2015) of the experimental period in the upper (U), middle M) and lower (L) terrace slope positions. The results showed significant differences ($p \leq 0.05$) in moisture and nutrient distribution according to slope position with the lower position recording on average higher moisture content (15%) compared to 13% in upper position. The bottom slope position recorded 16 and 21% higher soil carbon and 33 and 48% higher N than the mid and upper slope positions, respectively. The bottom slope position had the highest soil P (24.88) followed by mid slope (18.36) and top slope (14.85) ppm. K however was not affected by slope position. The results shows that terracing has an effect on soil moisture and nutrient distribution within the terrace. The lower terrace position had the highest values followed by the middle and upper slope positions respectively.

Keywords: *Terracing, Slope Position, Soil Moisture, Soil Nutrients.*

INTRODUCTION

Terracing changes the slope gradient, shortens the slope length, and thus alters the pattern of water and soil conservation. Terraces have been used to regulate, discharge excess runoff and reduce soil loss, however their ability to influence moisture and nutrient distribution in the terraced field has not been fully investigated. Suswa area of South West Narok is ecologically frail, the soils are highly erodible resulting in poor water and nutrient conservation. The high silt /clay ratio, low organic matter and high bulk density have made the soils more prone to erosion leading to severe soil losses, Gachene, (2014) and Maina, (2013) indicate that the soils are stratified with hard pans underlain by soft clayish strata that are readily eroded.

According to Gicheru, *et al.,* (2012), Suswa area is characterized by loss of land cover, soil erosion, reduced water catchment areas and reduced soil nutrient availability. They further reported that from 1980 - 2007, soil erosion rate increased from 50% to 80%, and water availability reduced from 90% to 55% resulting in reduced crop and livestock productivity. The landuse change from pastoralism to agropatoralism on the sloping land meant cutting of trees to pave way for cutivation which immensely contributed to soil and water erosion especially during heavy rains resulting in widespread land degradation, including gully formation (Cheche, *et al* 2015; Maina, 2013 and Roba, 2013). Terraces were therefore established for the purposes of controlling soil erosion.

Thus understanding the effects of agricultural terraces on soil physical properties, in Suswa is fundamental for improving resource use, such as water and nutrients, and thus arises as a valuable tool for precision agriculture leading not only to improved crop yields but also farmland profitability through a more efficient use of fertilizer based on soil physical parameters. The objective of this research was therefore to establish the spatial and temporal effect of terracing on soil moisture and nutrients so as to support more efficient farming practices and maintenance of the sustainable development of future terraced fields.

MATERIALS AND METHODS

Description of the study area

The study was carried out in Suswa, Narok County located in the Southwest of Kenya. The study area is characterized by low, erratic and poorly distributed bimodal rainfall that makes crop production difficult under rain fed conditions. The long rains commence in mid March and June while short rains expected from September to November. The local variations in topography play a major role in the distribution patterns, with the highlands receiving as high as up to 2000mm/yr. while the drier areas receiving less than 500mm/yr (Ojwang' *et al.,* 2010). Two-thirds of the county is classified as arid and semi arid.

Soil moisture and nutrient variability

To evaluate the effect of terraces on soil moisture and pH, C, N, P, soil samples were collected using an auger at the beginning and at the end of the trials period at a depth of 0-30 cm at the upper (U) middle (M), and at the lower (L) terrace slope positions. Moisture was determined using gravimetric method (Okalebo *et al.,* 2002). For chemical analysis, the soil samples were first air-dried and sieved using a 2 mm sieve, total nitrogen and organic carbon % were determined using the wet digestion /Kjeldahl method, soil pH, available phosphorus using Mehlich method, and potassium by Flame photometry according to procedures and methods outlined by Okalebo *et al.* (2002).

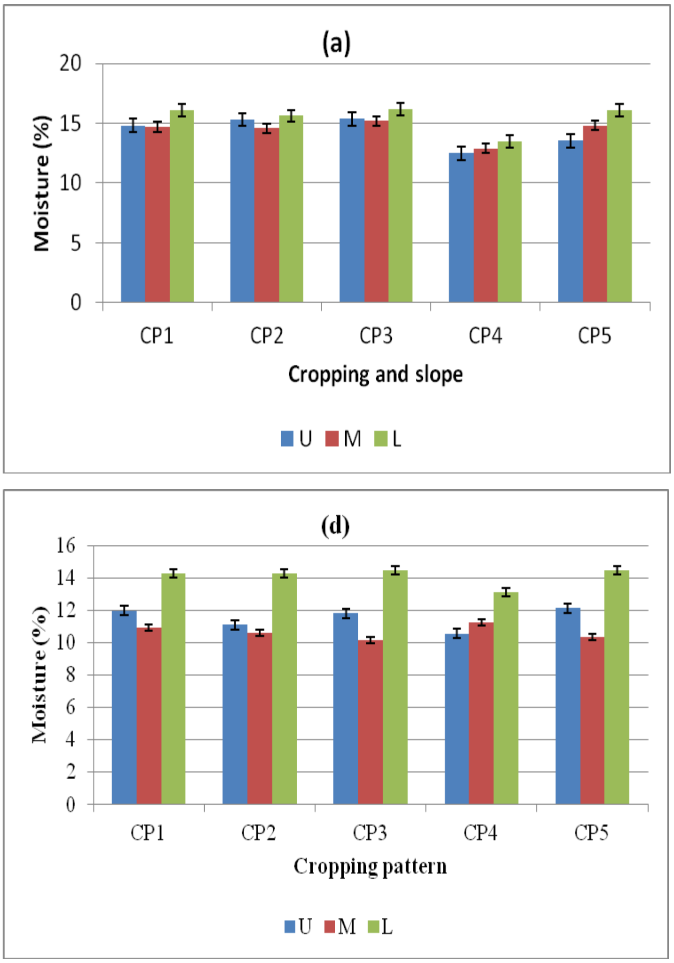
Data Analysis and management

Data was first entered and processed in Microsoft Excel 2007 software then exported to GenStat for *Windows* 15th edition for analysis of variance (GenStat, 2013). Significant difference between and within treatments was separated at $p \leq 0.05$ using Duncan's LSD.

RESULTS AND DISCUSSION

Soil moisture variability

Soil moisture content was found to exhibit a high degree of spatial and temporal variability (Fig.1). The lower slope position on average had significantly ($p \leq 0.05$) higher (15.47 and 14. 16%) soil moisture content both at the beginning and at the end of the trial period respectively compared to the upper (14.29 and 11.94%) and middle (14.42 and 10.74%) terrace slope position.



Fig(1) Soil moisture at beginning (a) of trials and at end of trial period (d).

Terrace position =U-Upper, M-Middle, L-Lower ($LSD_{0.05}$)
Treatments =
CP1: Maize and Bean intercrop in the 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

These moisture variations observed could be 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 position which store more water while the upper and middle slope positions have shallower soils and therefore less water storage. This is in agreement with Liu, *et al*., (2011) who observed that slope and land use (terracing or not) type can influence the soil moisture conservation. In this study the non terraced farmers' (CP 4) fields recorded lower (12%) soil moisture content compared to the terraced fields (14%), this observation may be due to absence of soil and water conservation structures hence loss of both soil and water through run-off.

It was also observed that soil moisture on average was higher (14.73%) at the beginning compared to the end (12.28%) an observation that may have been occasioned by the rainfall received (450 mm at the beginning and 92.4mm at the end of the rials period) this is agreement with observations made by Wang, *et al*., 2006 who indicated that soil moisture at vertical direction was influenced by soil factors such as texture, bulk density as well as environmental factors such as rainfall, evaporation and land use type. Reports by Qiu *et al*., (2001)

Du-Plessis, (2003) also indicated that slope and season influence the spatial variability of soil moisture and during the growing period, crops in terraces can absorb more water than in sloping land, thus increasing the uptake of deep moisture. According to Feng *et al*.,(2013), the spatial variability of both the time-averaged soil moisture and the layer-averaged soil moisture are influenced by the environmental attributes at site scale (slope angle), hillslope scale (hillslope position and relative elevation) and watershed scale (precipitation and land use). However, threlative roles of environmental attributes vary with soil depths and with seasonal evolution. Like wise in this study moisture distribution was presumed to be influenced by slope, terracing as well as rainfall received.

Soil PH

The value of pH in water for the upper and lower terrace slope positions showed no significant difference ($p \leq 0.05$) both at the beginning of the trials (August, 2013) and at the end (May, 2015). This result was in agreement with the finding of Asadi *et al.,* (2010) and Khan *et al.,* (2013), who found a non-significant difference in soil pH between soils on conserved dry farm land and those in semiarid degraded rangeland. According Merry, (2009) there are geographic, geological, biological and climatological reasons why soils are either acidic or alkaline.

The soil state can also be modified by human action. Merry (2009) indicated that in high rainfall areas weathering of soil minerals and leaching leave soils acidified, whereas in low rainfall areas soil leaching is usually not sufficient to completely remove salts from soil profiles therefore the pH remains neutral or alkaline overtime. The most probable explanation for the neutral pH at the trial site was due to low rainfall.

Soil Organic Carbon

Soil carbon was significantly ($p \leq 0.05$) affected by slope positions at the end of the period as shown in Table 1. Soil organic carbon is the organic matter constituent of soil, made of plant and animal residues synthesized by soil organisms at different stages of decay (Chan,2008; Esmaeilzadeh and Ahangar, 2014). Soil organic carbon (SOC) is of significant importance in soils because it has high water holding capacity as well as high cation exchange capacity (CEC) which influences plant nutrients availability, aggregate stability and microbial activity (Bationo *et al.,* 2006; Milne *et al*., 2006; Abera and Wolde Meskel, 2013; Liao *et al*., 2015). In this study, the lower slope position had the highest soil carbon content followed by mid and upper slope position. The lower slope position had 16 and 21% higher soil carbon than the mid and upper slope positions, respectively. This observation was probably occasioned by the settling of water and sediments at the terrace embankment resulting in increased microbial activity.

The lower rate of erosion at this slope position also resulted in deeper moist soils hence higher biomass production (7.5 t ha^{-1}) on average compared to the upper slope positions (3.5 tha^{-1}). Terracing therefore is an important factor of controlling soil organic carbon levels since it influences the amount and quality of litter input, the litter decomposition rates and the processes of organic matter stabilization in soils (Eaton *et al.,* 2007).

The results of this study were in agreement with those of Bot and Benites (2005); Alemayehu (2007) and Malgwi and Abu (2011), who reported that soils in lower topographic locations are not only characterized by lower slope angles but also held greater quantity of water than higher slope soil that slows down the rate of microbial degradation and mineralization of organic matter in toe and crest slope positions (Lopez *et al*., 2003 and Gao *et al*., 2009). Demelash and Stahr (2010) also found higher soil organic matter (3.69%) for conserved catchment as compared to a non- conserved one (2.24%).

Soil organic carbon contents between accumulation and loss zones were highly significantly different ($p \leq 0.01$), according to Million (2003) and Aweto and Enaruvbe (2010) the variations in mean value of organic carbon was attributed to the erosion reduction effects of soil and water conservation measures implemented and biomass accumulation. This observation was probably occasioned by the washing away of carbon from the upper part of terraces and settling down at the lower parts.

Soil nitrogen

The results show that soil N was significantly ($p \leq 0.05$) affected by different slope positions as shown in Table 1. The bottom slope position had the highest soil N content than both the mid and top slope position. The bottom slope position had 33 and 48% higher N than the mid and top-slope positions, respectively. This observation was presumed to be due to the transportation of nitrogen from the upper slope position, through run off erosion, hence contributing to higher soil nitrogen levels at the slope base compared to the middle and upper slope positions.

Moisture availability at this slope position resulted in improved N mineralization due to enhanced microbial activity hence the higher soil nitrogen while the lower moisture in the upper slope position may have reduced microbial biomass through restriction of bacterial movement.The slightly higher levels of total nitrogen at the end of the trial period may be attributed to the residual effect of fertilizer application during planting and top dressing.

Similar findings were echoed by Alemayehu (2007) and Ofori *et al.,* (2013), who reported higher total N levels on lower parts of the terrace compared to the upper parts. Siriri *et al*., (2005) also reported lower total N values on the upper parts of terraces and moderately increased on the lower parts. Mllion (2003) found out that the total nitrogen content of the terraced site with the slope of 15, 25 and 35% were higher by 26, 34 and 14%, respectively compared to their corresponding non-terraced sloping areas. Lower slope had the highest total nitrogen than all other positions followed by crest. Statistically, the difference between toe and crest was insignificant while toe slope significantly varied from back slope, shoulder slope and foot slope (Million, 2003). Mekuria, *et al* (2006) also showed that upper slope positions had lower total nitrogen than that of middle and foot slopes in the terraced fields.

Available phosphorus

Results showed that slope position and season had significant ($p \leq 0.05$) effects on phosphorus (P). The bottom terrace slope position had the highest soil P (31.03 ppm) followed by mid slope (23.15 ppm) and top slope (17.29 ppm) positions, respectively (Table:1). The increase in P at bottom slope was 25 and 44% higher than the mid and top slopes positions, respectively at the end of the trials. The variation in available P at the beginning and at the end of the trials as well as between deposition and loss zones could be attributed to washing out in the upper parts and accumulation at the lower parts leading to elevated amounts of moisture resulting in high (7.5 t^{-1}) biomass production and hence higher soil organic matter and microbial activity. The elevated moisture at the terrace embankment created suitable condtions for organic matter decomposition releasing P and hence the higher amounts of P at this slope position.

The higher levels of total available P at the end of the trial period were probably attributed to the residual effect of fertilizer application during the trials period. These findings were in agreement with those of Moges and Holden (2008) as well as Mekuria, *et al* (2006) who associated the higher P content in the lower terrace slope position with higher soil organic matter at the lower slope position. Similar results were reported by Tadele *et al.*, (2011) who found out that soil organic matter boosts soil microbial activity, which enhances the microbiologically-driven processes in soil phosphorus dynamics. The microbial phosphorus pool is increased when greater amounts of organic matter are made available.

Availble potassium

Potassium (K) was found not to be significantly different at the investigated slope positions, at the beginning as well as at the end of the trial period (Table 1). The bottom slope position however, had higher K readings comparatively. K content at the end of the trials period (May, 2015) was on average 16 and 29% higher in the bottom than in the mid and top slope positions, respectively. This observation could be attributed elevated moisture availability at the lower slope position giving rise to improved levels of soil available potassium (water soluble potassium) plus that held on the exchange sites on clay particles (exchangeable K).

The baseline (August, 2013) results for K showed no significant difference in all slope positions compared to the end of the experiment period. For example the upper, middle and lower slope positions had 3.06, 3.11 and 3.11Cmol/kg respectively at the beginning of the trials compared to 1.90, 2.23 and 2.67Cmols/Kg respectively at the end of the trials (Table 1). The lower values at the end of the trials was probably associated with lower rainfall (92.4mm) received compared to 450mm at the beginning of the trials.

This indicates that potassium may have been influenced by low moisture resulting in less recycling to the soil and less replenishment of the soluble or easily exchangeable soil K pools. It is therefore suspected that as the solution of the soil decreased with the low soil moisture, the potassium ions may have been bound into the soil layers resulting in lower potassium readings as soil analysis do not report on the bound potassium ions. The other probable explanation for the lower potassium levels at the end of the trials was due to harvest, since soils can become depleted in potassium when crops are harvested through removal of whole plant from the field since since most K is concentrated in the stalk and leaves.This is in agreement with Lei *et al., (*2000), who indicated that K concentration was 3.5 to 6.5 times greater in leaf and stem respectively than levels found in grain.The product of yield and K concentration in the harvested portion determines K removal and therefore recommends returning crop residue to the maize field in order to maintain soil K fertility. The results of this study are in agreement with Zougmore *et al*., (2002) and Tadele *et al*., (2011) who found a non significant difference in exchangeable bases among different soil and water conservation measures which could be as the result of lower erosion and higher deposition.

Findings by Ovuka (2000), indicate that there was a higher concentration of nutrients in the lower part of the slope an indication of erosion of top fertile soils up-slope. The report indicated that Nitrogen, Phosphorus and Carbon were the most affected nutrients regarding slope position. Nitrogen was found at high levels at the slope base and too low in upper slope position to support meaningful agricultural production. Compared with a 15% slope the soil organic content of the terraced land increased by 26%, total N by 8%, total P by 4%, fast acting N by 12%, and fast acting P by 20% (Liu, *et al*., 2011).

The tests showed that terracing created better conditions for water and nutrient conservation than the sloping land, especially in the 40–180 cm depths, was available to the crop for effective use during the dry season (Liu *et al*., 2011). Like wise the results of this study showed that differences in moisture and nutrient distribution according to slope position exist primarily because of changes in soils and their associated properties, meaning landscape position can be helpful in identifying zones of moisture and nutrient accumulation which can aid in fertilizer management decisions.

CONCLUSION

Terraces increase temporary surface moisture storage capacity and encourage infiltration and this study illustrates the large influence that land use, slope and precipitation can exert on soil moisture distribution with higher moisture registered at the lower slope position and lower in the upper. Terraces modify the spatio-temporal soil moisture distribution and must be taken into account in the understanding the hydrological soil properties.

Results regarding soil N, P, K and carbon revealed an increasing trend from top to bottom slope position which might be due to their downward movement with runoff water. Soil nutrients transported from the upper parts of the terrace were trapped by the conservation structures at the lower sides of the terraces and maintained there, making significant difference between the lower and the upper parts. Without these structures, the fate of accumulated and trapped nutrients would be washed away from the farm and transported to other ecosystems; mostly to water bodies.

The fertility status of the soil at different terrace slope positions showed significant differences, the lower being at the upper slope position which most likely is associated with erosion and the higher at the lower position. This study established that the variations of soil moisture and nutrient distribution in terraced fields as a function of slope position and rainfall resulting in either soil moisture and nutrient loss or availability among these positions.

The study has great policy implications for the drylands of Kenya on how soil quality 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 efficiency, hence establishing a base for sustainable agricultural development in the future. Soil and water productivity can therefore be improved by employing soil and water conservation structures. The technology should be promotedin other areas for the sustainability of the natural resources and improving livelihoods.

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Table(1) Soil chemical analysis at beginning and end of trials

Slope	Start-August, 2013					End-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					

Key: U-Upper, M-Middle, L-Lower