CROP YIELDS ALONG THE TOPOSEQUENCE OF TERRACED ANDOSOLS IN NAROK, KENYA[1]

[RENDIMIENTO DE CULTIVOS A LO LARGO DE LA TOPOSEQUENCIA DE TERRAZAS DE ANDOSOLES EN NAROK, KENYA]

Alice Ruto[1]*, Charles Gachene[1], Patrick Gicheru[2], David Mburu[3] and Zeinabu Khalif[4]

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

SUMMARY

The principle objective of terracing is to reduce runoff and soil loss but it also contributes to increasing the soil moisture content through improved infiltration. A field experiment was conducted in Suswa, Narok County during the short and long rain seasons of 2013-2015 to assess the effect of terracing on crop yields. A randomized complete block design was used with maize and beans as the test crops. The study examined maize plant height, leaf area index (LAI), above ground biomass yields, number of bean pods and grain yields in the upper (U), upper middle (UM), middle (M), lower middle (LM) and lower (L) terrace, slope positions with farmers' fields where terraces were not maintained were used as the control. The results showed that yields were significantly (P<0.05) higher in L>LM>UM>M>U, with values ranging from 7.2 t ha^{-1} to 3.0 t ha^{-1} for maize and 1374 kg ha^{-1} to 306 kg ha^{-1} for beans. Significant differences (P<0.05) were also observed according to cropping patterns with CP2 on average recording the highest (803 kg ha^{-1}) bean yields and CP4 (control) the lowest (576 kg ha^{-1}) in season I. CP3 had the highest (4.97 t ha^{-1}) maize yields compared to CP4 (3.25 t ha^{-1}) in season II. From the results of the study, it was possible to conclude that soil conservation measures and cropping patterns implemented at Suswa increased crop yields and the technology should be promoted for improved livelihoods.

Key words: Terracing; Slope position; Cropping pattern; Crop yields.

RESUMEN

El objetivo principal de las terrazas es reducir la escorrentía y la pérdida de suelo, pero también contribuye a aumentar el contenido de humedad del suelo a través de una mejor infiltración. El experimento de campo se llevó a cabo en Suswa, Narok County durante las temporadas de lluvias cortas y largas de 2013-2015 para evaluar el efecto de terrazas en los rendimientos de los cultivos. Se utilizó un diseño de bloques completos al azar con maíz y frijoles como cultivos de ensayo. El estudio examinó la altura de la planta de maíz, el índice de área foliar (IAF), los rendimientos de la biomasa sobre el suelo, el número de vainas de frijol y los rendimientos de grano en la parte superior (U), media superior (UM), media (M), media inferior (LM) e inferior, las posiciones de la pendiente en los campos de los granjeros donde las terrazas no fueron mantenidas fue empleadas como el control. Los resultados mostraron que los rendimientos fueron significativamente mayores (P<0.05) en L> LM> UM> M> U, con valores entre 7.2 t ha^{-1} y 3.0 t ha^{-1} para maíz y 1374 kg ha^{-1} a 306 kg Ha^{-1} para los frijoles. También se observaron diferencias significativas (P<0,05) según los patrones de cultivo con CP2 en promedio registrando los rendimientos de frijol más altos (803 kg Ha^{-1}) y CP4 (control) el más bajo (576 kg Ha^{-1}) en la temporada I. El mayor rendimiento de maíz (4.97 t Ha^{-1}) comparado con el CP4 (3.25 t Ha^{-1}) en la temporada II. A partir de los resultados del estudio, se pudo concluir que las medidas de conservación del suelo y los patrones de cultivo implementados en Suswa aumentaron los rendimientos de los cultivos y que la tecnología debería ser promovida para mejorar los medios de vida.

Palabras clave: Terrazas; Posición de la cuesta; Patrón de cultivo; Rendimientos de los cultivos.

---

[1] *Submitted August 27, 2016 – Accepted February 05, 2017.*

INTRODUCTION

The principle objective of terracing is to reduce runoff and soil loss but it also contributes to increasing the soil moisture content through improved infiltration. The efficiency of terraces can, however 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. Proper husbandry of rainwater is a key aspect of integrated water resources management as it enhances groundwater recharge, balances water resources demands, and favours ecological sustainability (Botha *et al.,* 2007).

The rising demands for food and uncertainties associated with climate change call for a paradigm shift in water management with a stronger focus on rainfed agriculture with emphasis on securing water to bridge the dry spells and to increase agriculture and water productivity (Ngigi *et al.,* 2005). According to Rockström *et al*. (2010), the actual cause of crop failure is poor distribution of rainfall other than absolute water scarcity and that farming systems regularly suffer from agricultural droughts and dry spells caused by management induced water scarcity. On-farm water balance analysis indicated that, in savannah farming systems in sub-Saharan Africa less than 30 % of rainfal reicieved is used for productive transpiration by crops and on severely degraded land, this proportion can be as low as 5 % (Rockström, 2003). Thus, crop failures commonly blamed on drought, might be prevented in many cases through better farm-level water management (Rockströmm *et al.,* 2010). In rainfed farming the constraint is not only the erratic rainfall distribution but the amount of rainfall that can be stored in the root zone and its effective utilization, hence there is need for field specific management practices in order to improve crop production and maximize on the limited soil nutrients and moisture in the drylands. The objective of this study was therefore to assess crop yields within terraced fields in andosols under different cropping patterns and how the farmers can exploit the spatial yield variability for increased farm productivity.

MATERIALS AND METHODS

Description of the study area

The study was carried out in Suswa, Narok County located in the Southwest of Kenya.The county experiences bi-modal pattern of rainfall with long rains expected from mid March to June and short rains 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 2000 mm per year while the drier areas receiving less than 500 mm per year (Ojwang *et al.,* 2010). Two-thirds of the county is classified as arid and semi arid.

Experimental layout and design

The experiments were laid out in both the short and long rain seasons of 2013-2015, in a randominsed complete block design (RCBD) with five treatments each replicated three times as follows, CP1: Maize and bean intercrop planted in the upper and lower position of the terrace and sole maize in the middle position, CP2: Maize and bean intercrop in the upper and lower zone and sole bean crop in the middle zone, CP3: Sole maize crop in all slope positions, CP4: the control plot where terrace was not maintained had maize and bean intercrop in all the three slope positions and CP5: maize and bean intercrop in all the three slope positions.

Crop performance

The crop performance was evaluated by monitoring maize plants height, maize leaf area index, number of bean pods per plant, estimating maize above ground biomass yields and weighing grains yields for both maize and beans on a line by line basis from the terrace ditch to the terrace embankment.

Maize plant height

A representative sample of five maize plants were selected randomly on a line by line basis from the terrace ditch to the terrace embankment and average height recorded. According to Yin *et al.* (2011), corn yield could be predicted with plant height measurements collected during the plant critical growth stages (V10 to V12**).**

Leaf area index

LAI is a direct measure of the photosynthetically-active surface area which converts light energy into plant biomass (Ömer *et al.,* 2011). Five plants were selected randomly per row were used. The average total leaf area per plant was estimated according to the method of Duncan and Hesketh (1968) for the maize crop. Where LA = L x W x 0.75, where LA is the average total leaf area per plant, L is the average leaf length, W the average greatest width. Leaf area index (LAI) = LAI is the leaf area per unit area of soil below (FAO, 1998), therefore LAI= 0.75 x L x W x nPx nL/land area covered. Where nP and nL are the number of plants and the number of leaves respectively.

Crop yield

Five plants were selected in each line from the terrace ditch to the embankment. The samples were cut and weighed using a spring balance (to the nearest 0.1kg) to determine the fresh weight (Burt, 2009). Representative samples were shelled and the grains dried at room temperature to a moisture content of between 13-15%, then weighted to give the yield in kilograms per square meter which was later adjusted to metric tons per hectare.

Data analysis

Data was first entered and processed in Microsoft Excel 2007 software then exported to GenStat Windows 14th edition for analysis of variance (GenStat, 2013). Significant difference between and within treatments was separated at $P<0.05$ using Duncan's LSD.

RESULTS AND DISCUSSION

Maize plant height at 9th leaf stage

There were significant differences ($p<0.05$) in maize height as affected by slope positions and cropping patterns in all the seasons (Fig. 1).

Maize plant height at tasseling

There were significant differences ($p<0.05$) in maize height as affected by slope positions and cropping patterns in all the seasons (Table 1). At the 9th maize leaf stage height on average at the lower slope position was highest (122 cm) followed by the lower middle position (97 cm) and the upper middle position (83 cm) respectively.

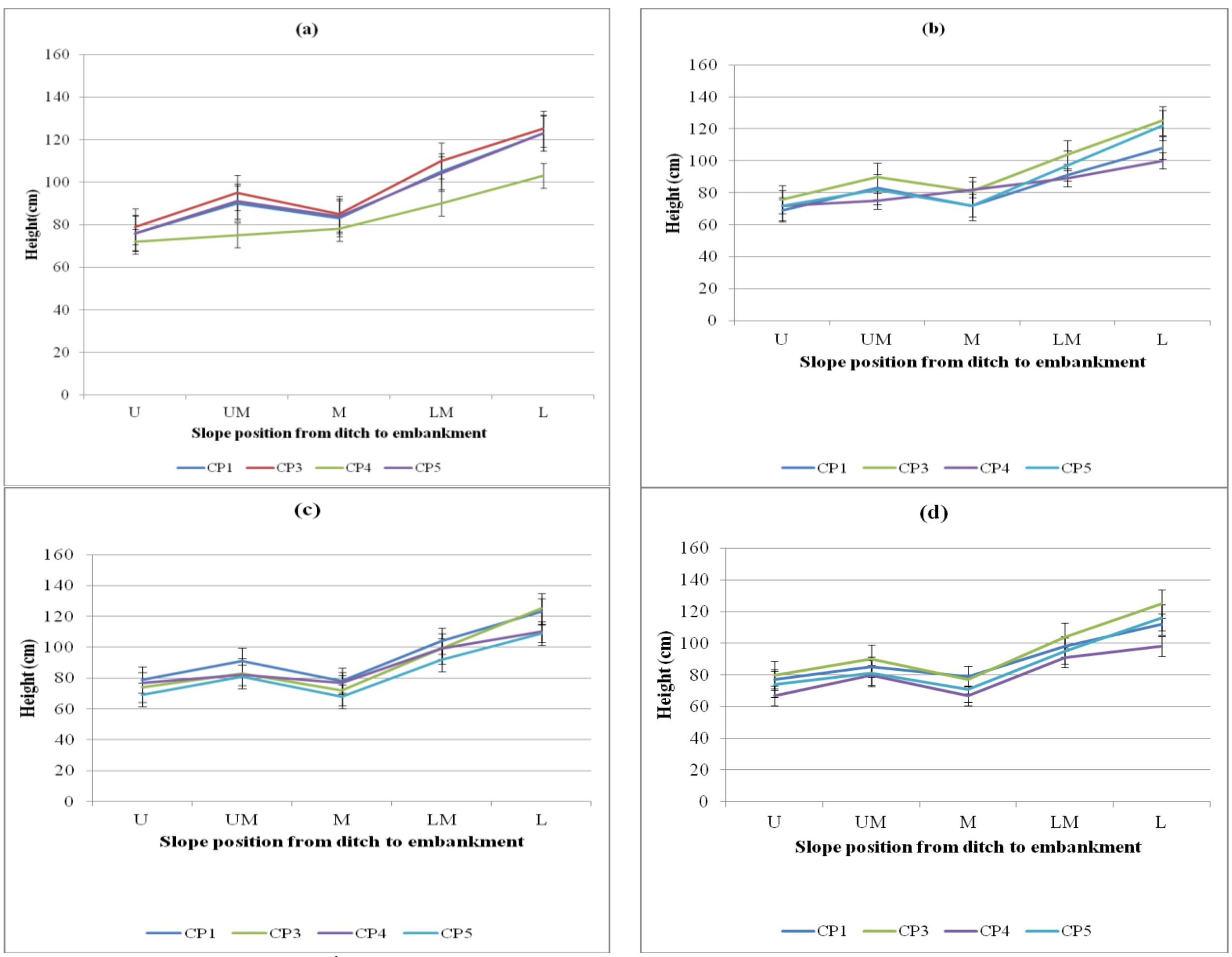

Figure 1: Maize height (cm) at 9th leaf stage in seasonI (a), season II (b), season III(c), season IV(d).
Key: U-Upper, UM-Upper middle, M-Middle, LM-Lower Middle, L-Lower
Treatments: CP1: Maize and Bean intercrop in the upper and lower zones and maize in the middle. CP3: Sole maize crop in all the three 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.

Table 1: Maize plant height (cm) at tasseling

Slope	Season I						Season II					
	CP1	CP2	CP3	CP4	CP5	Mean	CP1	CP2	CP3	CP4	CP5	Mean
U	133	131	136	125	134	132	126	129	133	106	131	125
UM	157	150	155	135	157	151	155	153	160	128	159	151
M	148	*	144	143	148	146	136	*	148	137	139	140
LM	180	169	176	152	170	169	168	174	173	150	175	168
L	199	195	196	164	196	190	180	187	187	162	182	180
Means	163	161	161	144	161		153	181	160	137	158	
Slope	Season III						Season IV					
	CP1	CP2	CP3	CP4	CP5	Mean	CP1	CP2	CP3	CP4	CP5	Mean
U	120	117	122	124	120	121	104	102	104	102	110	104
UM	138	133	138	131	132	135	120	120	124	118	124	121
M	128	*	130	136	125	130	118	*	115	114	118	116
LM	148	148	150	144	147	148	134	133	134	130	134	133
L	163	166	166	151	165	162	143	143	144	140	144	143
Means	139	139	141	137	138		124	125	124	121	126	

*=Bean plot

CV(%) = 3.7, $LSD_{(0.05)}$= 4.937 , SE(TREATMENTS)=0.56, SE(SEASONS*CROPPING PATTERNS*SLOPE POSITION)=2.52

U-Upper, UM-Upper middle, M-Middle, LM-Lower Middle, L-Lower

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 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

The study revealed significant enhancement in plant height at the lower middle and lower slope position occasioned by moisture and nutrient availability next to the terrace embankment resulting in improved availability of nitrogen which may have caused rapid cell division and elongation. CP 4 (control) had the lowest height across all seasons. This observation was probably due to the absence of the terrace ditch which encouraged lateral seepage at the upper middle slope position and terrace embankment which promoted the settling and infiltration of moisture at the lower middle and lower slope position, hence the lower heights recorded. The results are in agreement with those of Husain *et al.* (2013) who reported that, plant height at the terrace plot was higher than that of control. The highest plant at terrace plot was 156.6 cm while for control was 73.92 cm. The general observation was that vegetative and generative performances of maize planted in terrace were higher than that of control (non-terrace).

Leaf area index

There were significant differences (P<0.05) in LAI of maize as affected by slope position and cropping pattern at 9th leaf stage and at tasselling stage (Fig. 2 and 3). The lower slope position had on average the highest LAI (1.96 at 9th leaf stage and 3.69 at tasseling stage) whereas the upper position had the least (0.79 at 9th leaf stage and 1.34 at tasseling stage). The upper middle slope position recorded higher (1.03 and 2.01) LAI compared to both the middle (0.84 and 1.73) and upper (0.79 and 1.34) slope position in all the four seasons. CP 4 had the least LAI (1.68) in season IV while CP 1 had the highest (3.29) in season one. The lower slope position had on average the highest LAI (4.95) in season I whereas the upper position had the least (1.49) in season two. In all the four seasons the LAI in the upper middle slope position was on average higher than in the middle and upper position in both crop stages (9th leaf and tassling stage). This may have been attributed to higher moisture and nutrient supply due lateral seepage in the upper middle slope position and due to sediment deposition, moisture and nutrient availability at the terrace embankment, which resulted in improved translocation of nutrients, water and root growth. This could have been attributed to higher moisture and nutrient supply due lateral seepage in the upper middle slope position and due to sediment deposition, moisture and nutrient availability at the terrace embankment, which resulted in improved translocation of nutrients, water and root growth which enhanced leaf area and duration hence the high

LAI. Thus, with the optimum supply of moisture and nutrients, the basic infrastructural frame and the photosynthesis production efficiency of leaves were improved.

The generally lower LAI indices in season III and IV was probably due to low rainfall received compared to season I and II (450 mm in season I, 416 mm in season II, 141 mm in season III and 92.4 mm in sseason IV). The results agree with those of Gul *et al.* (2015) and Amin *et al*. (2006), who found that ridge sowing of maize resulted in higher leaf area index at different stages, which was attributed to improved water and nutrient availability due to loose fertile soil at the on ridges, resulting in better uptake of nutrients. The availability of sufficient nitrogen is linked to rapid cell division and cell elongation thereby resulting in increased leaf area. Shivay and Singh (2000) also found improvement in leaf area index with incread levels of nitrogen.

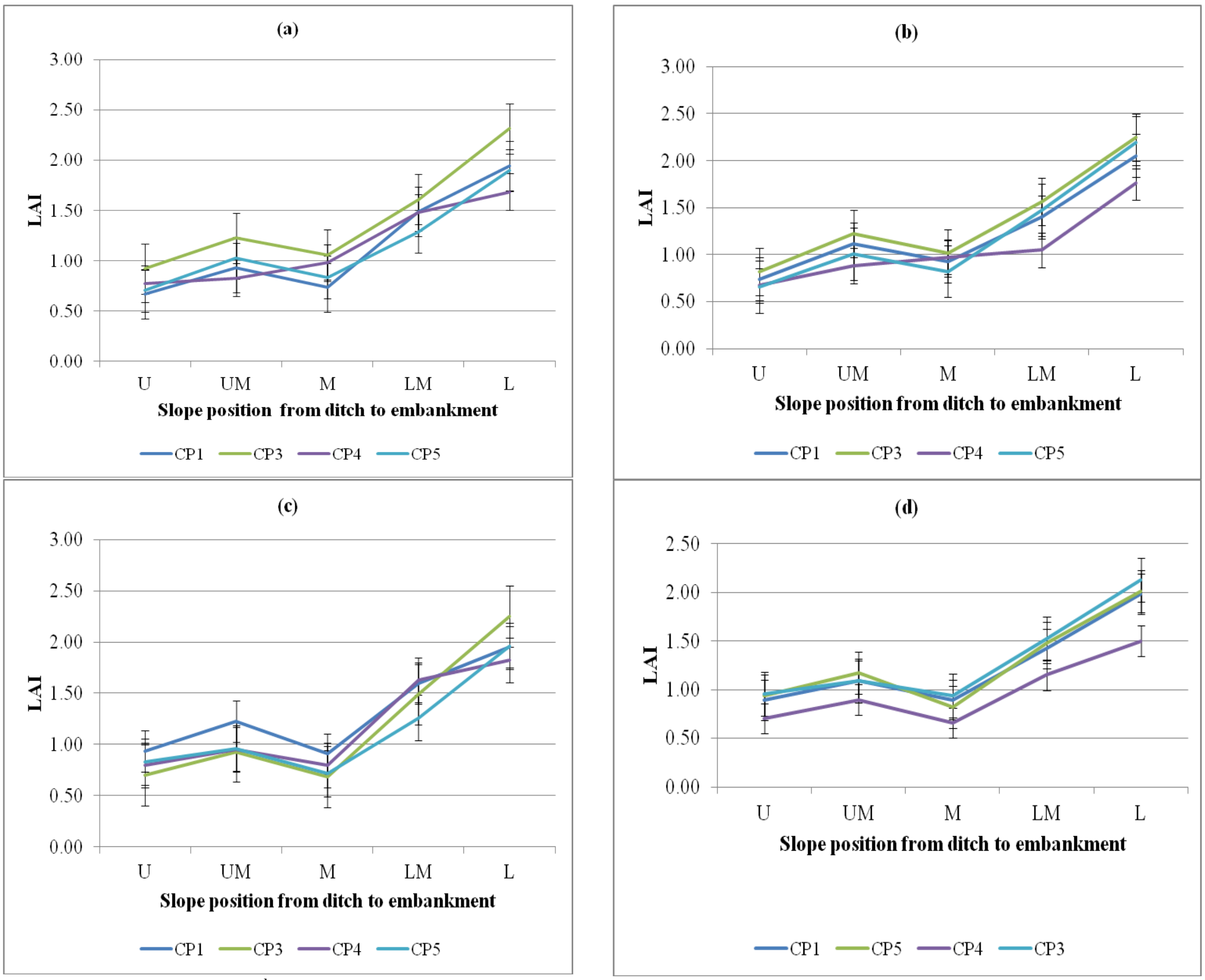

Figure 2: Maize LAI at 9th leaf stage in season I (a), season II (b), season III(c) and season IV(d).
Key: U-Upper, UM-Upper middle, M-Middle, LM-Lower Middle, L-Lower ($LSD_{0.05}$)
Treatments: CP1: Maize and Bean intercrop in upper and lower zones and sole maize in the middle. CP3: Sole maize crop 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

.

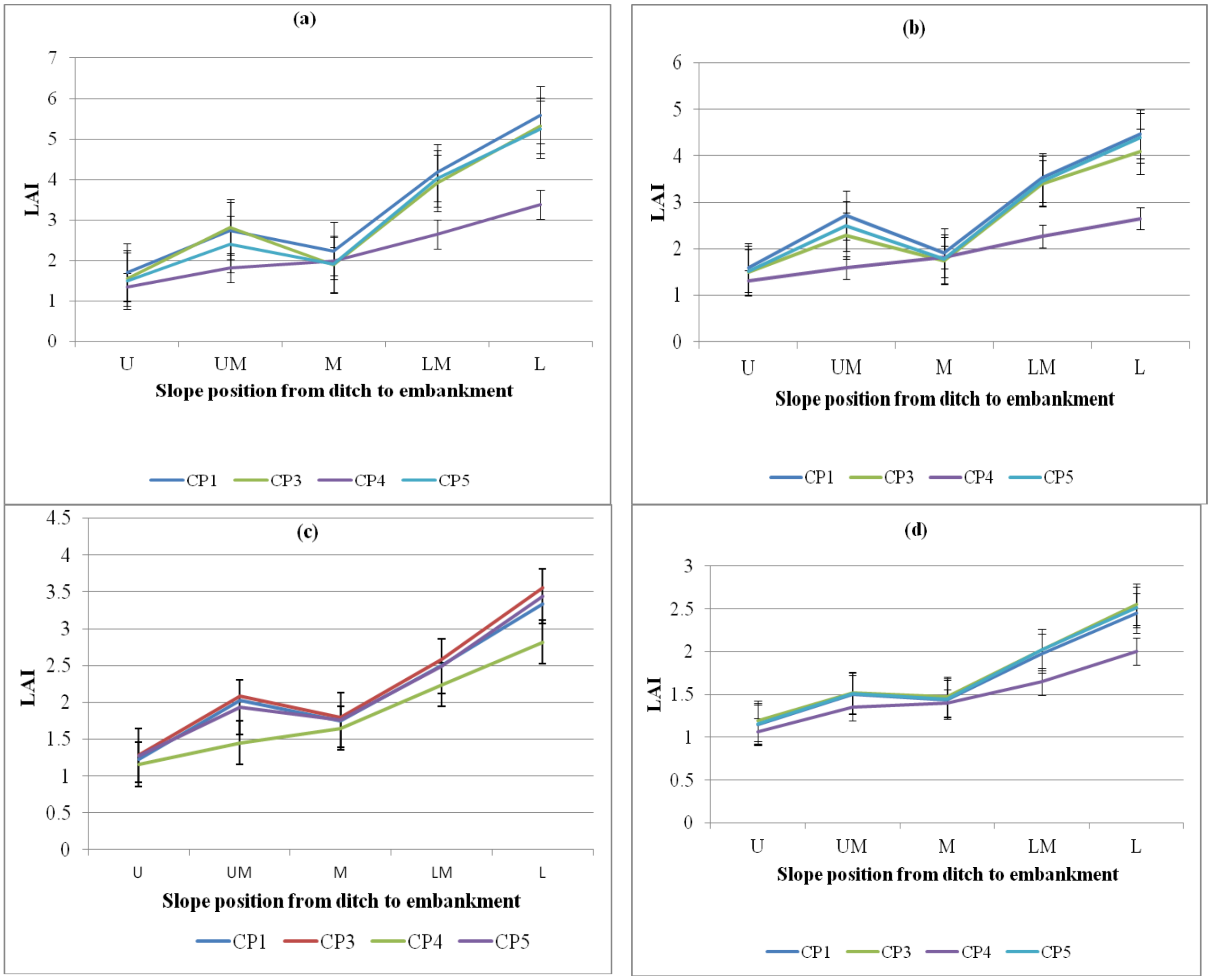

Figure 3: Maize LAI at tasseling season I (a), season II (b), third season III(c) and season IV (d).
Key: U-Upper, UM-Upper middle, M-Middle, LM-Lower Middle, L-Lower
Treatments: CP1: Maize and Bean intercrop in upper and lower zones and sole maize in the middle. CP3: Sole maize crop in all the three 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.

.

Maize above ground biomass yields

There were significant differences (P<0.05) in maize above ground biomass as affected by slope position and cropping patterns in the two seasons (Fig. 4). CP 3 had the highest (7.5 t ha^{-1}) yield whereas CP 4 yielded the lowest (4.8 t ha^{-1}) in season I. The lower slope position had the highest (> 6 t ha^{-1}) yield of maize above ground biomass compared to the upper slope position (< 4 t ha^{-1}) in both seasons (Fig. 4). The upper middle slope position had higher (5 t ha^{-1}) above ground biomass yield than the middle (4.2 t ha^{-1}) and upper (3.8 t ha^{-1}) positions. The higher yields in the lower position may have been attributed to the accumulation of sediment and moisture resulting in not only the availability of nutrients but also their synergetic interaction. This also could explain the low above ground biomass yields in the loss zones and in the control plot. Season IV had the lowest yields across all treatments which was probably attributed to lower rainfall received (416 mm in season II and 92.4 mm in season IV). The results are in agreement with those of Nwachukwu and Ikeadigh (2012) and Di Paolo and Rinaldi (2008) who reported a linear relationship between water use, nutrient uptake and above ground biomass yield in maize crops. The increase in the growth of maize was also reported by Adesoji *et al.*, (2013) to be as result nitrogen effects that lead to increased cell division, cell expansion and increase in size of all morphological parts. CP 3 (sole maize) had the highest (7.5 tha^{-1}) aboveground biomass yield whereas CP 4 (control) yielded the lowest (4.8 tha^{-1}) biomass in season II. This observation may have been attributed to lack of competition for nutrients and moisture in the sole crop compared with intercrops, which agree with observations by Egbe *et al*. (2010) and Maluleke *et al.* (2005) who reported that intercropping maize with cowpea significantly decreased ear length, cob length, dry cob weight, dry grain yield and dry total plant biomass.

Number of bean pods

There were significant differences ($p<0.05$) in number of in bean pods according to slope position and cropping patterns (Fig. 5). CP 1, 2, 3 and 5 had the highest (19) number of pods whereas CP 4 had the lowest (12) pods in all seasons. The lower slope position had the highest (above 19) number of pods as compared to the upper slope position (below 7) in both seasons (Fig. 5). Like other yield parameters the number of pods per plants was probably due to the moisture and nutrient availability in the upper middle position occasioned by lateral seepage and at the lower middle and lower slope position by moisture and sediment accumulation. This deposition zones created a suitable environment for nutrient uptake, resulting in increased pod formation.

It was also observed that there was a general decline in the number of pods in season III and IV with the highest recording 15 pods on average in the lower slope position and 5 in the upper slope position compared to season I with 19 pods in the lower slope position and 8 in the upper slope position. This low number of pods was likely associated with lower rainfall (141 mm in season III and 92 mm in season IV) compared to 450 mm in season I and 416 mm in season II. The control plot recorded on average the lowest number of pods (12) in all seasons, an observation that was linked to the absence of zones of moisture and nutrient accumulation present in the other treatments.

Similar results were reported by Nuñez *et al*. (2005) who indicated soil water deficits that occur during the reproductive development of dry beans decrease the number of flowers, pods and number of seeds per pod. The same is echoed by Emam *et al.* (2010), who reported that plant height, number of leaves, leaf area, number of pods, pod dry weight and total dry weight of two common bean cultivars were significantly reduced due to to moisture stress conditions.

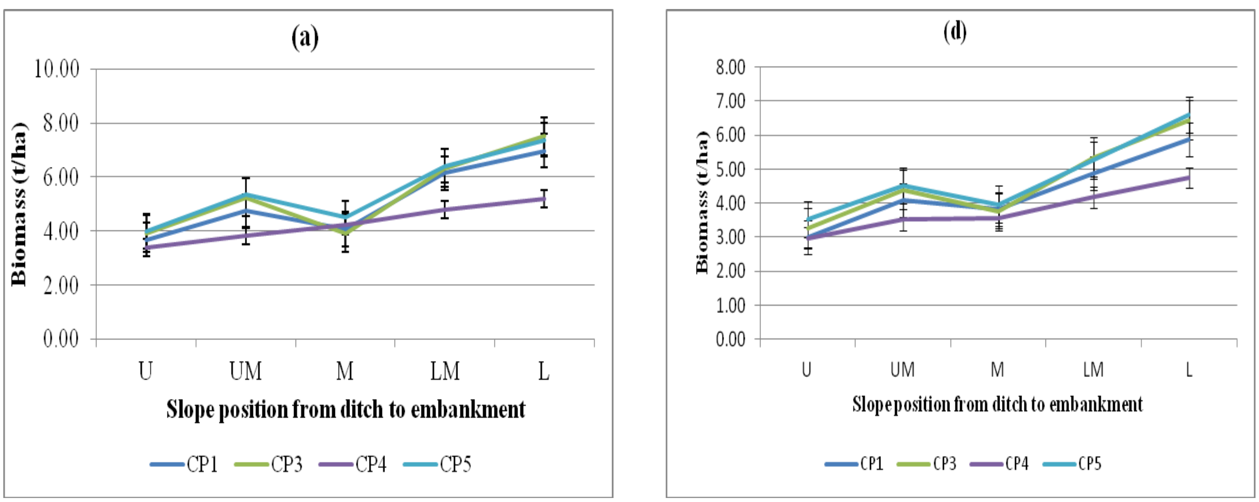

Figure 4 Maize above ground biomass yields in season II (a) and and season IV (d).
Key-Upper, UM=Upper middle, M-Middle, LM-Lower Middle, L-Lower (LSD $_{0.05}$)
Treatments: CP1: Maize and Bean intercrop in the upper and lower zones and sole maize in the middle. CP3: Sole maize crop in all the three slope positions. CP4: Maize and beans in all the three slope positions (farmers' practice). CP5: Intercrop of maize and beans in upper, middle and lower slope position.

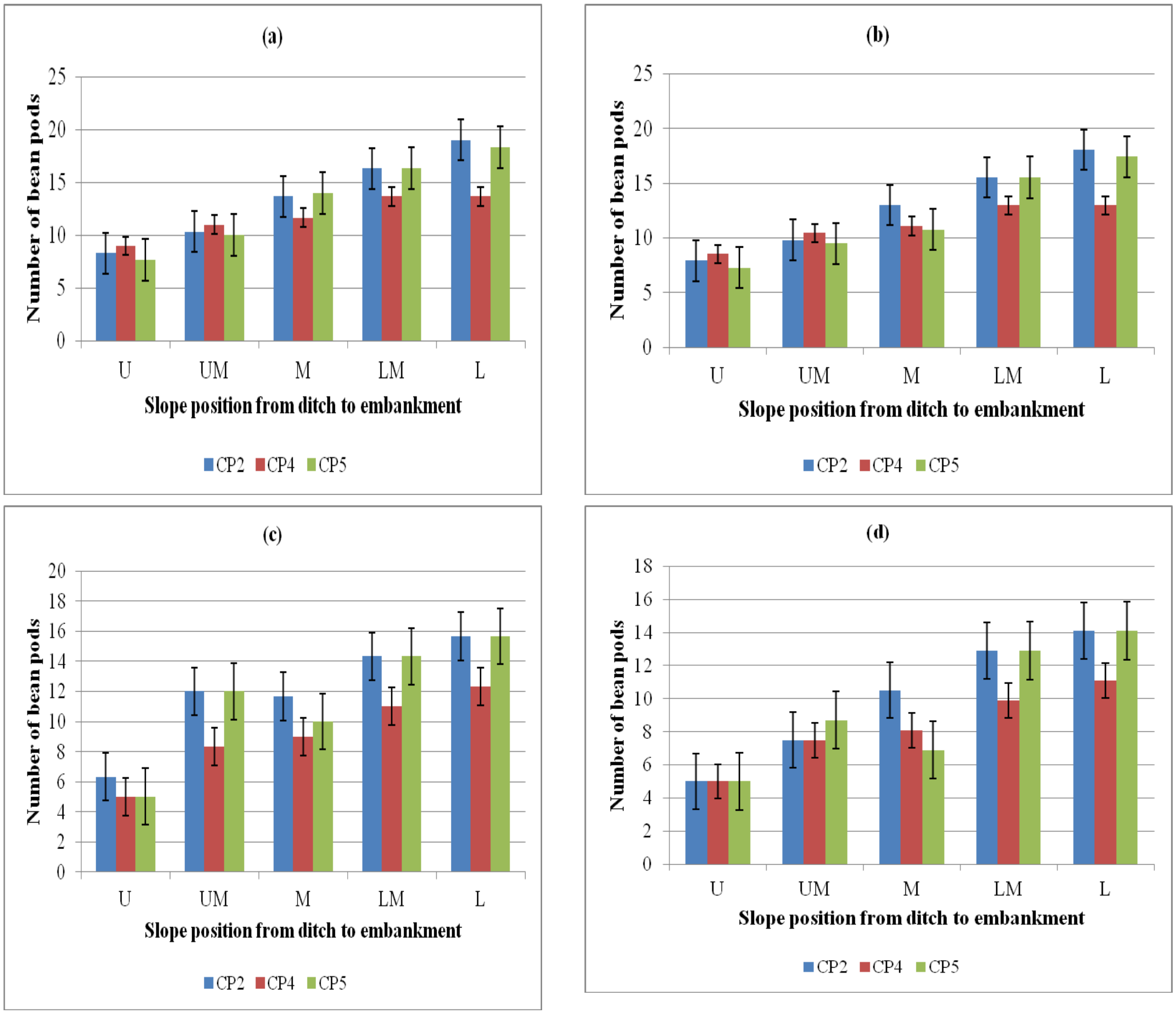

Figure 6. Number of bean pods in season I (a), season II (b), season III (c) and season IV (d).
Key: U-Upper, UM-Upper middle, M-Middle, LM-Lower Middle, L-Lower,
Treatments: CP2: Maize and Bean intercrop in the upper and lower zones and sole bean crop in the middle. CP4: Maize and beans in all the three slope positions (farmers' practice). CP5: Intercrop of maize and beans in upper, middle and lower zone.

Bean grain yield

There were significant differences ($p<0.05$) in bean grain yields as affected by slope positions and cropping patterns in all seasons (Fig. 7). The lower slope position had the highest (above 1380 $kgha^{-1}$) bean grain yields, followed by the lower middle slope position with 1200 $kgha^{-1}$ while the upper middle slope position recorded about 500 $kgha^{-1}$ compared to the upper slope position (below 250 kg ha^{-1}) and middle slope below 400 $kgha^{-1}$ in all seasons (Fig. 4.12). CP 2 and CP5 had the highest (1350 and 1250 kg ha^{-1}) bean grain yields in season I and II whereas CP 4 (control) had the lowest (900 kg ha^{-1}), in the lower slope position. In the low rainfall season III (141 mm) and IV (92.4 mm) the highest yields realised were 680 and 570 kg ha^{-1} in the lower slope position compared to 250 and 220 kg ha^{-1} in the upper slope position. The higher yields recorded in the upper middle position, lower middle and lower slope position was likely occasioned by the availability of moisture leading to improved nutrient uptake and use by the plant. The same results are echoed by Araújo and Teixeira (2008) who reported that continuous N and P uptake due to favourable rainfall distribution during early pod filling was responsible for higher grain yields of common bean.

The lower yields in season III and IV were associated with lower rainfall received compared to season I and II (450 and 416 mm respectively).

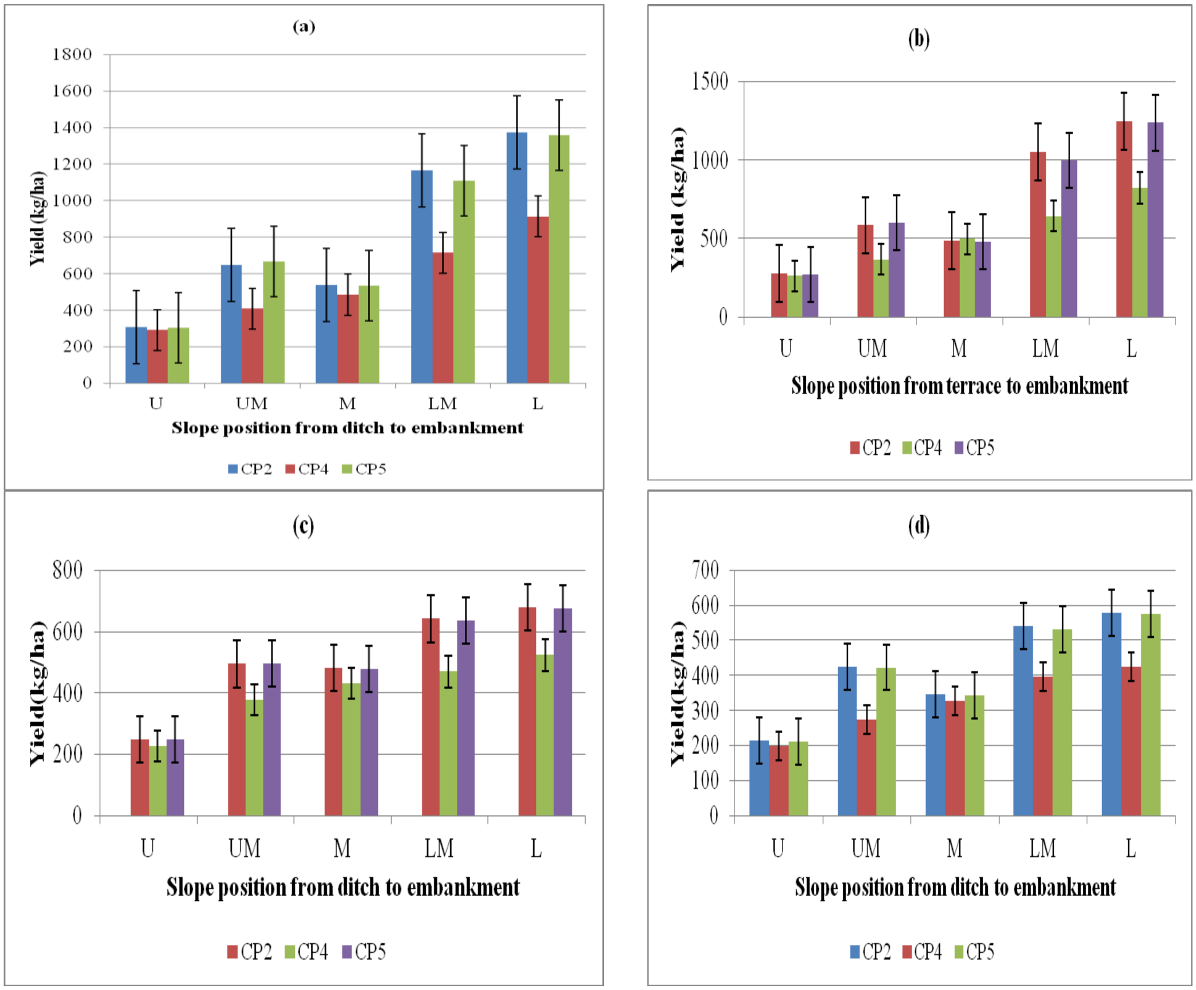

Figure 7. Bean yields in season I (a), season II (b), season III and season IV (d).
Key: U-Upper, UM-Upper middle, M-Middle, LM-Lower Middle, L-Lower
Treatments: CP2: Maize and Bean intercrop in the upper and lower zones and sole bean crop in the middle. CP4: Maize and beans intercrop in all the three slope positions (farmers' practice). CP5: Maize and beans intercrop in all the three slope positions

Maize grain yield

There were significant differences ($P<0.05$) in maize grain yields as affected by slope position and cropping patterns in all seasons (Fig. 8). CP 3, 1 and 5 had the highest (5 and 4.8 t ha^{-1}) maize grain yields whereas CP 4 had the lowest (3.6 tha^{-1}) on average in season one. CP 3 had the highest (7.2 t ha^{-1} and 4.62 t ha^{-1} maize grain yields as compared to the upper slope position (3 t ha^{-1} and 1 t ha^{-1}) in season II and III (Fig. 8) respectively. The upper middle slope position had on average higher (4.2 t ha^{-1}) yields than the middle (3.8 t ha^{-1}) and upper (3.1 t ha^{-1}) slope positions in season I and II. Season III recorded the lowest yields at all slope position on average, with the upper slope position having (0.85 t ha^{-1}) and the lower slope (4.13 t ha^{-1}).

The yield gradient observed was probably attributed to spatial redistribution of surface runoff resulting in higher soil water availability and hence improved utilization of nutrients (nitrogen and phosphorus) at the lower slope positions.The presence of water and nutrients at this slope position resulted in higher plant height and leaf area index providing more availability of assimilates which improved grain rows and number of grain rows per cob and hence overall seed weight. In this study it was observed that the maize at the embankment had well filled double cobs compared to one small cob near the terrace ditch. The lower yields in season III was attributed to low rainfall (141 mm) received compared to the amount received in season I (450 mm), which restricted nutrient uptake. In addition the moisture and nutrient availability occasioned by deposition at the terrace embankment and lateral seepage in the upper middle slope position created a suitable environment for N x P x K interaction resulting in improved uptake of N which significantly improved number of branches, leaves and bean pods and the higher maize yields. Moreover, higher leaf area index values noticed at these slope positions meant the production of more photosynthates leading to increase in grain number and weight. Similar results were reported by Shehu *et al*. (2009), who indicated that significant interaction of N x P x K improved seed yield and dry matter due to nutritional balance that favours the functioning of each nutrient in the growth and development of crops. The lower yields recorded across season and slope position for CP 4 (control), may have been associated with the absence of both terrace ditch and terrace embankment which would have created the zones of moisture and nutrient accumulation found in the other treatments. The same could explain observations in the upper and middle slope position which suffered loss of both moisture and nutrient due to erosion hence the low yields recorded. Ovuka (2000) also reported that there were lowest grain yields on upper slopes, increasing steadily down slope to often double grain yields on the lower slopes indicating massive transfer and deposition of nutrients. Similar results were obtained in this study, where maize crops in the lower slope position next to the terrace embankment had up to two big cobs compared to one small cob in the upper slope position.

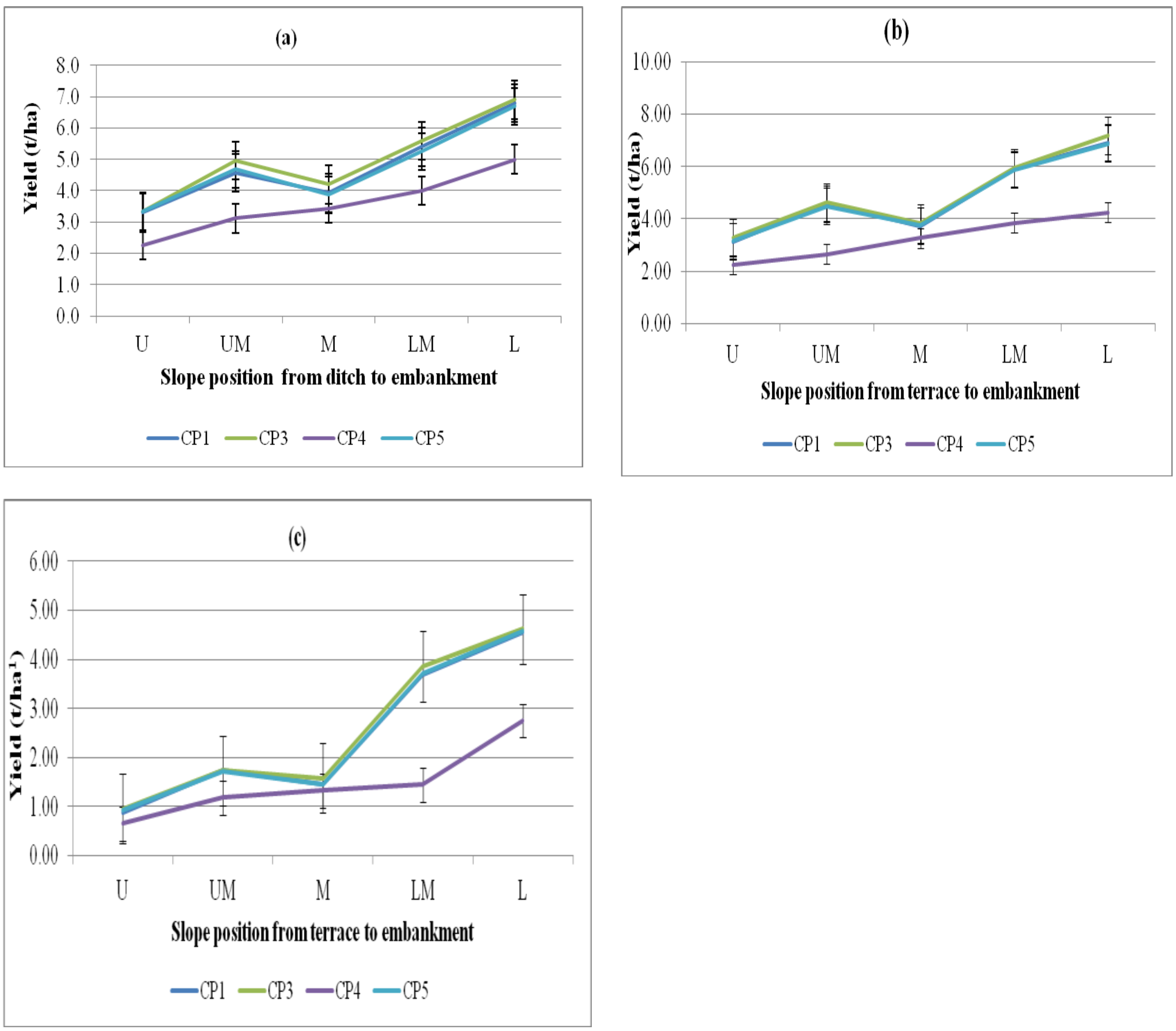

Figure 8: Maize grain yields in season I(a), season II (b) and season III(c)
Key: U-Upper, UM-Upper middle, M-Middle, LM-Lower Middle, L-Lower
Treatments: CP1: Maize and Bean intercrop in upper and lower zones and sole maize in the middle. CP3: Sole maize crop in all the three zones. CP4: Maize and beans in all the three slope positions (farmers' practice). CP5: Intercrop of maize and beans in upper, middle and lower zone.

According to Shiene (2012) and Vancampenhout *et al.* (2006), higher maize grain yield differences were observed between lower and upper terrace positions. The lower terrace position had 2.51 t h^{-1}, compared to 1.64 t h^{-1} and 1.24 t h^{-1} for middle and upper positions respectively and the grain yield on the lower position was found to be 51 % higher than that on the upper terrace position. Similarly in this study maize grain yield in the lower slope position was 50 % more than in the upper slope position and bean grain yields in the lower slope were four times the yields in the upper slope position.

The results are consistent with previous studies where yield and soil moisture increased as one proceeded downslope resulting in highest biomass production, greater nutrient uptake, and highest maize grain yield in the lower slope position (Earnshaw and Orr, 2013; Jiang and Thelen, 2004; Gebremedhin *et al.,* 1999). Jiang and Thelen (2004) reported that the combined effect of soil moisture and topography explained 28 to 85 % of the observed yield variability. Report by Husain, *et al.* (2013) also showed that the grain number of terrace plot was higher (486) than that of control (218) and in addition the weight of 100 dry grains was higher for terrace plot (29 g) compared to that of control (24 g). Kravchenko and Bullock (2000) indicate a correlation between rainfall distribution and the performance of yield components, and a timing of leaf growth to soil water availability and spatial variability can be exploited in favour for increased crop production, as shown for soil properties when using site specific precision farming (Bouma *et al*., 2012). A significant increase in the crop yield for maize and beans by implementing bench terraces, *fanya juu* or grass strips was reported by Tenge and Hella (2005) however, the results clearly showed that cross-slope barriers alone may not significantly increase crop yields unless these are followed by other practices such as manure/fertilizer application as well as appropriate cropping pattern.

CONCLUSIONS

This study demonstrates the benefit of using terrace in sustaining crop yields and land productivity as well as reducing soil erosion of cultivated sloping land. It was revealed that maize height, maize leaf area index and grain yields of both maize and beans at terrace plots were higher than that of control. The research identified differences in maize and beans performance among cropping patterns as a function of slope position. The overall results showed that there is a substantial increase in yields in the lower slope position compared to other slope position. The research also showed that the upper middle slope recorded higher yields compared to the upper and middle slope position indicating the effect of lateral seepage from the terrace ditch, meaning that there is need to monitor and understand different soil types so as to come up with suitable cropping patterns. From the results of this study, it is possible to conclude that terracing reduced soils erosion, improved soil moisture and nutrients resulting in increased crop yield, implying that there is an untapped potential for yield improvement and farmers can benefit from the spatial nutrient and moisture variability as a low technology precision farming for increased crop 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. This can also be replicated in other arid and semi-arid regions of Kenya.

Acknowledgements

The authors wish to thank the United Nations Development Programme 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

Adesoji, G., Abubakar, U., Tanimu, B. and Labe, A. 2013. Influence of incorporated short duration legume fallow and nitrogen on maize (*Zea mays L*.) growth and development in northern Guinea savannah of Nigeria. Agriculture and Environmental Sciences, 13(1):58-67.

Amin, M., Razzaq, A., Ullah, R. and Ramzan, M. 2006. Effect of planting methods, seed density and nitrogen phosphorus (NP) fertilizer levels on sweet corn (*Zea mays L*.). Journal of Research (Science). 17(2):1-2

Araújo, A.P. and Teixeira, M.G. 2008. Relationships between grain yield and accumulation of biomas nitrogen and phosphorus in common bean cultivars. Revista Brasileira de Ciência do Solo, 32(5):1977-1986.

Botha, J., Anderson, J., Groenewald, C., Nhlabatsi, N., Zere, B., Mdibe, N. and Baiphethi, N. 2007. On-farm application of in-field rainwater harvesting techniques on small plots in the Central Region of South Africa, Volume 1 of 2.. Water Research Commision. Report No. TT 313/07. South Africa.

Bouma, J, Brouwer, J. and Verhagen, A. 2012. Site specific management on a field level: high and low tech approaches. Kluwer Academic Publishers, Dordrecht.

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

Di Paolo, E. and Rinaldi, M. 2008. Yield response of corn to irrigation and nitrogen fertilization in a Mediterranean environment. Field Crops Research, 105(3): 202-210.

Dorren, L. and Rey, F. 2004. A review of the effect of terracing on erosion. In Briefing papers of the 2nd SCAPE workshop, Cinque Terre, Italy. 97-108.

Duncan, W.G. and Hesketh, J.D. 1968. Net photosynthetic rates, relative leaf growth rates, and leaf numbers of 22 races of maize grown at eight temperatures, Crop Science, 8:671-674.

Egbe, O. 2010. Effects of plant density of intercropped soybean with sorghum on competitive ability of soybean and economic yield in, Benue, Nigeria. Journal of Cereals and Oilseeds, 1(1):1-10.

Earnshaw, K. M. and Orr, B. 2013. Soil moisture, field-scale toposequential position, and slope effect on yields in irrigated rice (*Oryza sativa* L.) fields in Honduras. Agricultural Sciences, 4(8A):1-8.

Emam, Y., Shekoofa, A., Salehi, F. and Jalali, A.H., 2010. Water stress effects on two common bean cultivars with contrasting growth habits. American-Eurasian Journal of Agricultural and Environmental Sciences, 9(5):495-499.

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

Gebremedhin, B., Swinton, S. and Tilahun, Y. 1999. Effects of stone terraces on crop yields and farm profitability: Northern Ethiopia. Journal of Soil and Water Conservation, 54(3):568-573.

Gul, S., Khan, M., Khanday, B. and Nabi, S. 2015.Effect of sowing methods and NPK levels on growth and yield of rainfed maize (*Zea mays L*.). Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology Kashmir, Budgam-India.

Husain, J., Bahtiar and Nurdin, H. 2013. Maize Performance in Terrace and Non-Terrace sloping land, International Maize Conference: 22-24 November 2012 Gorontalo, Indonesia. https://www.researchgate.net/.../257069026.

Jiang, P. and Thelen, K. D. 2004. Effect of soil and topographic properties on crop yield in a North-Central corn–soybean cropping system. Agronomy Journal, 96 (1): 252-258.

Kravchenko, A. N, and Bullock, D. G. 2000. Correlation of corn and soybean grain yield with topography and soil properties. Agronomy Journal, 92(1), 75-83.

Maluleke, T., Thomas, V., Cousins, T., Smits, S. and Moriarty, P. 2005. Securing Water to Enhance Local Livelihoods (SWELL): Bushbuckridge, South Africa: AWARD, CARE, IRC and MUS project.

Ngigi, S., Rockstrom, J and Savenije, H. 2006. Assessment of Rainwater Retention in Agricultural Land and Crop Yield increase due to Conservation tillage in Ewaso Ng'iro river basin, Kenya. Physics and Chemistry of the Earth 31: 910-918.

Nuñez Barrios, A., Hoogenboom, G. and Nesmith, D.S., 2005. Drought sress and the distribution of vegetative and reproductive traits of a bean cultivar. Scientia Agricola, 62(1):18-22.

Nwachukwu, O. I. and Ikeadigh, M. C. 2012. Water use efficiency and nutrient uptake of maize as affected by organic and inorganic fertilizer. Production Agriculture and Technology Journal, 8(1): 199-208.

Ojwang, G., Agatsiva, J. and Situma, C. 2010. Analysis of climate change and variability risks in the smallholder sector. Department of Resource Surveys and Remote Sensing (DRSRS) in collaboration with the Food and Agriculture Organization of the United Nations, Rome.

Ömer, K., Mahmut, Ş., İlyas, B. and Kamil, Ç. 2011. Relationships between Soil Properties and Leaf Area Index in Beech, Fir and Fir-Beech Stands. Journal of the Faculty of Forestry, Istanbul University 2011, 61 (1): 47-54.

Ovuka, M. 2000. Effects of Soil Erosion on Nutrient Status and Soil Productivity in the Central Highlands of Kenya. Physical Geography, Department of Earth Science, Goteborg University, Sweden

Rockström, J., Karlberg, L., Wani, S., Barron, J., Hatibu, N., Oweis, T., Bruggeman, A., Farahani, J. and Qiang, Z., 2010. Managing water in rainfed agriculture-The need for a paradigm shift. Agricultural Water Management, 97(4):543-550.

Shehu, H., Kwari, J., and Sandabe, M. 2009. Nitrogen, Phosphorus and Potassium Nutrition of Sesame (*Sesamum indicum*) in Mubi, Nigeria. Research Journal of Agronomy, 3, 32-36.

Shiene, S.D., 2012. Effectiveness of soil and water conservation measures for land restoration in the Wello area, northern Ethiopian highlands (Doctoral dissertation, Universitäts-und Landesbibliothek Bonn).

Shivay, Y. and Singh, R. 2000. Growth, yield attributes, yields and nitrogen uptake of maize (*Zea mays L.)* as influenced by cropping systems and nitrogen levels. Annals of Agricultural research, 21(4). 494-498.

Tenge, A.J. and Hella, J.P., 2005. Financial efficiency of major soil and water conservation measures in West Usambara highlands, Tanzania. Applied Geography, 25(4): 348-366.

Vancampenhout, K., Nyssen, J., Gebremichael, D., Deckers, J., Poesen, J., Haile, M. and Moeyersons, J., 2006. Stone bunds for soil conservation in the northern Ethiopian highlands: Impacts on soil fertility and crop yield. Soil and Tillage Research, 90(1):1-15.

Yin, X., McClure, A., Jaja, N., Tyler, D. and Hayes, R. 2011. In-season prediction of corn yield using plant height under major production systems. Agronomy Journal, 103(3): 923-929.