Contents available at ISC and SID

Journal homepage: www.rangeland.ir

Research and Full Length Article:

Soil Organic Carbon Content and Stocks in Relation to Grazing Management in Semi-Arid Grasslands of Kenya

Hillary Kipngetich Rotich[A]*, Richard Onwonga[B], Judith Syombua Mbau[B] , Oscar Kipchirchir Koech[B]
[A]Department of Land Resource and Agricultural Technology, University of Nairobi. P.O Box 29053-00625, Nairobi, Kenya, *(Corresponding Author), Email: hillaryrotich2010@gmail.com
[B]Department of Land Resource and Agricultural Technology, University of Nairobi. P.O Box 29053-00625, Nairobi, Kenya

Received on: 09/05/2017
Accepted on: 18/07/2017

Abstract. Rangelands cover approximately 85% of Kenya's land mass and is a major resource for livestock farming with a considerable potential to mitigate climate change, yet these lands are stressed differently by various management. Our study aimed at determining the influence of grazing management systems (rotational, continuous and ungrazed) on soil organic carbon stocks in Yoani ranch located in the southern rangelands of Kenya (2016). This research was conducted on a commercial grazing ranch, a section of it was converted from continuous grazing into rotational grazing and has been under rotational grazing for 11 years during the time the research was conducted. Within the same ranch, there was a section with similar geomorphology and soils as the rotationally grazed which was not converted and has been continuously grazed for over 30 years to represent the continuous grazing system. The ungrazed area consists of an abandon section of the ranch for more than 30 years due to a deep gully which was formed by gully erosion creating an isolated area inaccessible by livestock. Soil samples were taken up to a depth of 1.2m, at an interval of 0-10, 10-20 cm, 20-30 cm, 30-60 cm, 60-90 cm and 90-120 cm. The difference between soil sampling depths is because the upper layer between 0-30 cm is more dynamic with respect to soil microbial activities which can be influenced by grazing as compared to the deeper depths along the soil profile. The ungrazed site recorded significantly ($P<0.5$) higher soil organic carbon concentrations than rotational and continuously grazed sites for all soil layers up to 1.2m depth. The rotationally grazed site had higher soil organic carbon concentrations across depths compared to continuously grazing system which was attributed to grazing management effects.

Key words: Soil organic carbon stocks, Grazing systems, Rangelands

Introduction

Rangelands are important ecosystems that occupy approximately than half of the earth's terrestrial surface and are characterised by low-stature vegetation, owing to temperature and moisture restrictions (Brown & Thorpe, 2008). On global scale, rangelands provide up to 70% of the forage for livestock and contribute to the livelihoods of more than 800 million people (Brown & Thorpe, 2008; J. Derner & Schuman, 2007). Rangelands also provide essential ecosystem services. Among the most important of these services are climate regulation, the ability to sequester carbon as well as the mitigation of greenhouse gases such as carbon dioxide (Briske *et al.*, 2008; Brown & Thorpe, 2008). Africa's rangelands cover about 43% of its landmass and are characterized as woodlands, Shrublands and/or grasslands (Hoffman & Vogel, 2008). In Kenya, rangelands occupy more than three quarters of land and the primary users of these are pastoral communities whom practice extensive grazing. Besides, a smaller number of agro-pastoralists and commercial farms exist. Livestock production in these areas has gained importance due to the increasing human population and hence causing increased food demand. Consequently, this has led to and increased grazing pressure in most of the rangeland areas. Forage quality and quantity are determinants of rangeland's sustainability and profitability (Briske *et al.*, 2008). However, rangelands have experienced soils and vegetation degradation due to overgrazing, climate change and plant invasions (Asner *et al.*, 2004; DeLonge *et al.*, 2014; Manjarrez-Dominguez *et al.*, 2015). Thus, management practices that will favour plant production and hence livestock productivity also have considerable potential to restore or even increase grassland soil carbon (C) storage and provide a potential positive feedback on the global C cycle (J. Derner & Schuman, 2007; Follett & Reed, 2010; Pete Smith *et al.*, 2010). Currently, there is widespread interest in harnessing the large soil carbon sequestration potential of rangelands to offset global greenhouse gas (GHG) emissions, due to their vastness, history of degradation, and potential for improved management. Their aptitude for soil C storage is estimated to be in a similar order of magnitude as that of croplands and forests (Pete Smith *et al.*, 2008).

Grazing directly affects the structure and function of plant communities through selective plant removal (HilleRisLambers *et al.*, 2010; Huntsinger *et al.*, 2007), defoliation, and changing the amount and composition of residual biomass (Bartolome & McClaran, 1992; Dudney *et al.*, 2016; Ford, 2015; Tastad, 2013). The amount of defoliation also affects subsequent forage production by changing light competition and residual biomass. With the change in vegetation cover caused by grazing, soil moisture decreases and temperature increases (Asner *et al.*, 2004; Bremer *et al.*, 2001), which can result in more decomposition at the soil surface and less transfer of plant litter into the soil organic matter pool.

The impact of grazing management on the soil biogeochemical approaches that regulate rangeland carbon dynamics isn't always nicely understood due to heterogeneity in grassland sorts. (Bakker *et al.*, 2006) evaluated 34 information units to examine soil carbon of grazed and ungrazed areas and found that about 40% of these results indicate an increase in soil carbon because of grazing and about 60% showed a decrease or no response to grazing. The impact of grazing on ecosystem processes is stimulated by way of the volume of the removal of photosynthetic biomass (defoliation), which is determined in element through grazing intensity; treading and trampling and fecal and urine depositions (Heitschmidt *et al.*, 2004).

The quantity of defoliation relies upon on plant morphology, production levels, and the provision of water and nutrients. Repeated grazing reduces plant increase and productiveness, whereas mild-to-moderate tiers motive suppression of growth with occasional production enhancement (Green & Detling, 2000). Selective defoliation modifies species composition, which often affects in low productivity and undesirable plant compositions. Trampling and treading compact the soil surface hence increases the soil bulk density while hoof motion deteriorates soil aggregate stability. Adverse changes in soil physical residences may also purpose a decline in water infiltration and root increase. The addition of nutrients within the form of fecal and urine affects the soil biogeochemical methods. Altogether, grazing has the capability to steer rangeland carbon dynamics through changing plant litter chemistry (Neff *et al.*, 2009), plant biomass allocation patterns clutter production, and the spatial distribution of nutrients (Grayston *et al.*, 1997). Relying on the intensity, grazing strain can also lead to gradual decomposition by way of reducing plant muddle carbon to nitrogen (C: N) ratio, or due to reduced standing biomass, can also boost up the decomposition via increasing soil temperature (Ingram *et al.*, 2008)

Regardless of the above noted grazing effect on rangeland carbon dynamics, most research results showed a wide variation ranging from positive to negative to no response. (Gill, 2007)evaluated the impact of ninety years of protection from grazing on carbon dynamics in subalpine rangeland and mentioned that farm animals grazing had no significant impacts on general soil carbon or particulate organic matter, however active soil carbon content increased. The loss of carbon from the active carbon pool become higher in grazed plots (4.6% of general carbon) than in ungrazed plots (3.3% of general carbon). Those effects suggest that grazing can also convert the recalcitrant carbon pool into easily mineralizable carbon fraction. The exclusion of grazing prompted an increase in annual forbs and grasses missing in dense fibrous rooting structure conducive to soil organic matter formation and accumulation (Reeder & Schuman, 2002). Similarly, other scientists have reported the various impacts of grazing management on rangeland soil organic matter, for instance, a study by (Conant *et al.*, 2003)in pastures of Virginia, USA, found that soil organic carbon averaged 8.4 mg c ha^{-1} more under intensive management or light rotation grazing than considerably grazed or hayed sites. (Naeth *et al.*, 1991) reported a negative impact on soil organic carbon in heavy intensity or early season grazing, compared to mild depth or overdue season grazing in the grasslands of Alberta, Canada. Heavy grazing resulted in vast discounts in height of status and fallen clutter, and a decrease in stay vegetative cover and natural matter mass.

Furthermore, the vertical distribution Soil carbon storage is rarely estimated at the natural landscapes (Y. Wang *et al.*, 2010). How much carbon is underestimated in global budgets below the first meter is surely a bigger question mark.(Batjes, 1996) stimates a 60% increase in the global Soil Organic Carbon (SOC) storage with depth extended to 2.0 m. A recent estimate of SOC storages has reported with a 56% increase at global level when the third meter of soil was also included (Jobbágy & Jackson, 2000). An increasing understanding of the importance of deep soil carbon is reflected in the mounting global estimates of soil carbon storages (Veldkamp *et al.*, 2003). The biomes with the most SOC at 1–3 m depth were tropical evergreen forests and tropical grasslands/savannas (Jobbágy & Jackson, 2000). Soil C pool that remains poorly understood is its vertical distribution, especially the differences of this vertical distribution across management types. Most previous studies on soil carbon storage have been focused on upper layer, although deeper profile was known to be important in soil carbon storage (Mi *et al.,* 2008). Although the effects of grazing impact on soil C storage and greenhouse gas emissions have been extensively studied in a wide range of ecosystems worldwide (Pelster *et al.*, 2015), there is no existing literature on studies done to examine the linkage between SOC storage and grazing systems in the southern rangelands of Kenya. Understanding the effects of livestock grazing management systems on SOC stocks is of essence for rational utilization of grassland. Therefore, we investigate the influence of three different grazing management systems (continual and rotational grazing system and an ungrazed area) on SOC.

Materials and Methods

Study area

The study was conducted in Yaoni ranch located in Makueni County, approximately 125 km southeast of Nairobi, Kenya (Fig. 1). The county borders several counties which include Kajiado to the West, Taita Taveta to the South, Kitui to the East and Machakos to the North. It lies between Latitude 1º35´ and 30º00´ South and Longitude 37º10´ and 38º30´ east.

The area lies at an altitude of between 1200-1400 m above sea level and receives bimodal rainfall with long rains falling between the months of March to May and short rains in October to December. Total annual rainfall is ranged 400 to 600mm. In between the rainy seasons, the area experiences intervening dry spells in January/February as well as July to September.

The county is largely semi-arid and usually prone to frequent droughts with respect to annual rainfall. The study site falls under agro-ecological zone IV and V (Jaetzold *et al.*, 2006) In terms of agro-ecological potential,(Jaetzold *et al.*, 2006) classifies the area as a ranching zone naturally suited for extensive livestock production and wildlife.

The terrain is characterized by plains to the North, undulating hills to the South. The geology of the study area is characterized by relatively deep over-burden, with very few exposures of the underlying basement rock. The basement system are crystalline rocks of pre-cambrian age often occurring as fine–grained schists and course gneisses, that have been invaded by pink quartzo feldspathic pegmatites. The soils are highly varied, dominated by sandy soils punctuated with vertisols, acrisols and cambisols. The natural vegetation of the study area consists of *Themeda triandra*, a tufted perennial grass species that is preferred by grazers, and *Themeda – Balanites* or Themeda – Acacia wooded grassland (Kinyua *et al.*, 2000).

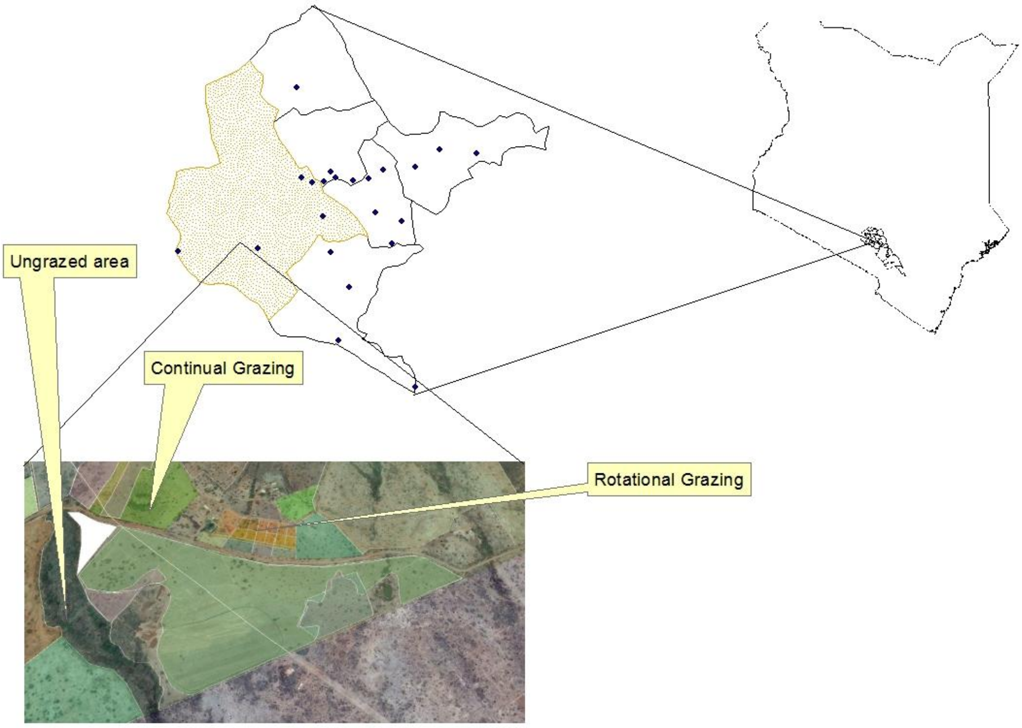

Fig. 1. Study area (Robin and Stanley ranch)

Experimental design

The experimental design was Completely Randomized Design (CRD) involving two grazing systems and ungrazed area: continuous grazing, rotational grazing and ungrazed area (control). This research site was on a commercial grazing ranch, which a section of it was converted from continuous grazing into rotational grazing and has been under rotational grazing for 11 years during the time the research was conducted. Within the same ranch, there was a section with similar geomorphology and soils as the rotationally grazed which was not converted and has been continuously grazed for over 30 years to represent the continuous grazing system. Under rotational grazing, a large herd of livestock is moved between paddocks for short periods of time. These periods of grazing are considerably shorter than the rest durations for cattle. A general recommendation suggests 30–90 days for the rest durations, which shortens during rapid plant growth and lengthens as plant growth slows (Gillen *et al.*, 1991). Such flexibility in rest duration is also the case for grazing periods and stocking rates, therefore livestock could be moved between nine paddocks at any time depending on grass growth rate and feed on offer, which was actually the case in our study area. The ungrazed area consist of an abandon section of the ranch for more than 30 years due to a deep gully which was formed by gully erosion creating an isolated area inaccessible by livestock as shown in (Fig. 1).

Sampling method and soil analysis

Nine representative spots per grazing system were randomly selected. For each spot, a soil profile was dug using pick axe and a shovel. Thereafter, soil was sampled at intervals of 0–10, 10-20, 20-30, 30-60, 60-90 and 90-120 cm depth using a soil auger. The difference between soil sampling depths is because the upper layer between 0-30 cm is more dynamic with respect to soil microbial activities which can be influenced by grazing as compared to the deeper depths along the soil profile. In each plot, two soil samples were mixed to a composite soil sample per respective depths. A total of 108 (two samples per depth) samples were collected in each grazing system, which were composited into 54 Samples per grazing system. The composited samples were packed in a well level polythene bags for transportation. In addition, undisturbed soil samples for each depth were collected using core rings with a defined volume (100 cm^3) from each sampling plot for bulk density determination.

Samples were brought to ILRI Mazingira Centre in an airtight bag for analysis. The soil samples were air-dried and passed through a 2 mm sieve. In order to determine soil total C and N content, 20 g of sieved soils were dried at 40°C for 48hrs and thereafter ground with a hammer mill (RetschMM400Mixer Mill, Retsch GmbH, Germany). A 20g subsample was then analysed for C and N concentrations using a high-temperature oxidative combustion system (Elementar Vario Max Cube). The bulk density for each depth was estimated by core method (Blake, 1965).

Soil carbon stocks were calculated following (Equation 1):

$SOCStock = C \times BD \times D$ (Eq.1)

Where:

C= carbon concentration (%)

BD= bulk density (gcm^{-3})

D= the respective soil depth (m)

SOC is the soil organic carbon stock (Mg C ha^{-1})

SOC is the soil organic carbon concentration (%), which is then converted, to g C g^{-1} soil.

Statistical analysis

Analysis of variance (ANOVA) was performed to determine if the measured soil organic stocks were significantly different among the grazing regimes. Significant differences for the analysis of variance were accepted at $P<0.05$. Tukey's HSD post hoc was used to separate means of the measured soil attributes under the various grazing treatments.

Results

The results for bulk densities along the soil profile and across the different grazing management system is shown in Table 1. Along the soil profile, we observed a significant difference ($p\leq0.05$) in soil bulk density up to 30 cm depth with continuously grazed site showing the highest values followed by rotationally grazed area and ungrazed, respectively. But, there was no significant difference in bulk density at the lower across the management regimes (Table 1).

Table 1. Soil bulk density (gcm^{-3}) across grazing management systems

Soli Depth (cm)	Ungrazed	Rotational	Continuous	CV%
0 -10	1.22±0.02 a	1.45±0.01 b	1.57±0.02 c	3.2
10-20	1.17±0.02 a	1.38±0.04 b	1.46±0.04 c	3.9
20-30	1.13±0.02 a	1.24±0.01 b	1.28±0.03 c	1.9
30-60	1.06±0.03 a	1.14±0.08 a	1.22±0.03 a	7.6
60-90	1.08±0.02 a	1.10±0.02 a	1.14±0.24 a	19.8
90-120	1.07±0.02 a	1.08±0.02 a	1.18±0.06 b	1.8

Means with different letters within the row are significantly different ($P \leq 0.05$)

The SOC concentrations results are presented in Fig. 2. The ungrazed site showed higher SOC concentrations than both rotational and continued grazed sites along all of soil profile. Similarly, the rotationally grazed site showed higher SOC concentrations for the 10-20 and 20-30 cm soil depths compared to continual grazing system (control). For other soil depths the difference in SOC concentration was not statistically different ($p<0.05$) (Fig. 2).

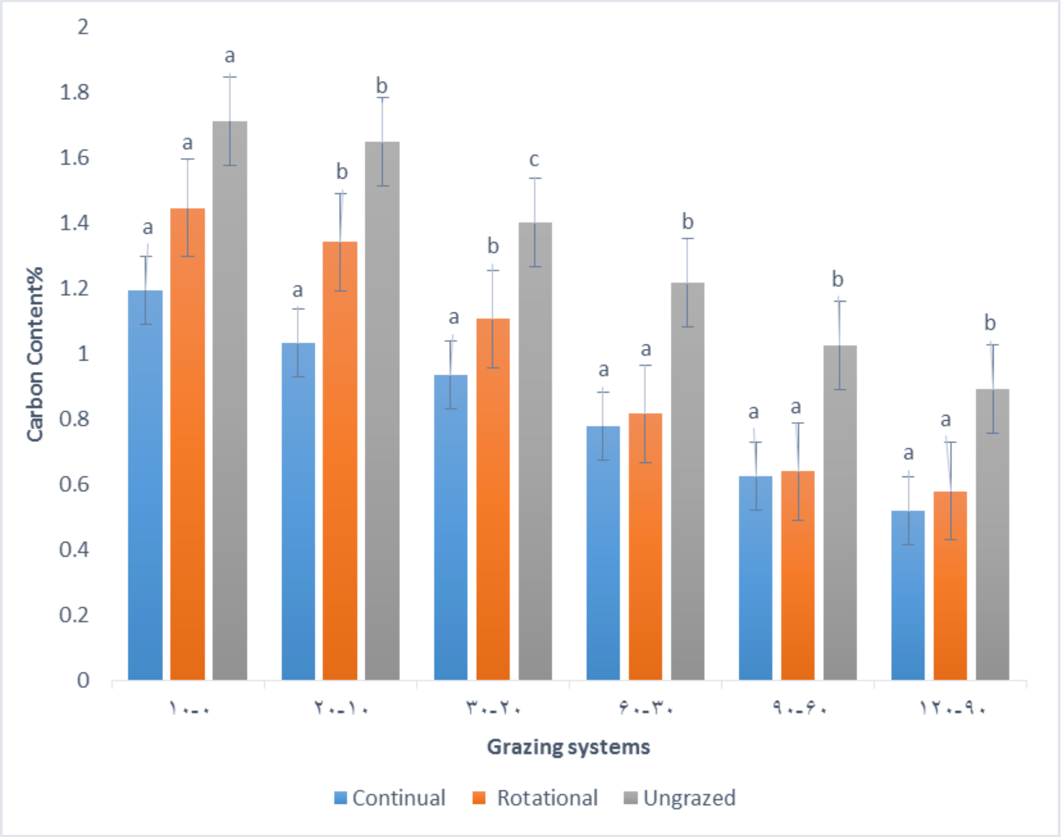

Fig. 2. Soil organic carbon concentrations (%) across different grazing management system Different letters indicate significant differences (p <0.05)

The SOC stocks results are presented in Table 2. The ungrazed site showed higher SOC stocks than both rotational and continued grazed sites from 20 to 120 cm. Similarly, the rotationally grazed site showed higher SOC stocks for 90-120cm sampled soil depths compared to continual grazing system (Table 2).

Table 2. Means +SE of Soil organic carbon stocks (MgC/ha^{-1}) across different grazing management systems along the soil profile

Depth (cm)	Continual grazing	Rotational grazing	Ungrazed
0 -10	18.66±2.82 a	20.90±1.83 a	20.95±1.43 a
10-20	14.95±2.00 a	18.85±0.51 a	19.42±1.65 a
20-30	11.97±2.41 a	13.67±2.11ab	15.93±4.73 b
30-60	26.79±2.37 a	28.63±2.52 a	38.76±3.57 b
60-90	21.10±2.37 a	23.14±2.87 a	33.47±2.82 b
90-120	17.05±0.57 a	22.03±1.65 b	28.60±2.04 c

Means with different letters within the row are significantly different (P≤ 0.05)

Discussion

Animal trampling may have a severe effect on soil compaction and bulk densities (Medina-Roldán *et al.*, 2012; Sanjari *et al.*, 2008; Su & lin Zhao, 2003). The continuous grazed rangelands were mostly compacted. Similar effects have been observed for other grassland ecosystems (Daniel *et al.*, 2002; Savadogo *et al.*, 2007; Stavi *et al.*, 2008; Wei *et al.*, 2011), and also (Steffens *et al.*, 2008) monitored significant higher bulk densities in a semi-arid steppe in heavily grazed plots compared with ungrazed or only winter-grazed plots. In our study, the low bulk density in the ungrazed area can be attributed to the lack of grazing disturbance from livestock, while the lower bulk densities in rotational grazing compared to continual grazing sites can be attributed to the minimum livestock impact

(Tuffour *et al.*, 2014) and loafing (Q. Wang & Batkhishig, 2014) due to short duration grazing that gives maximum rest to the grazed area. The higher soil bulk density in continuous grazing sites, on the other hand, is probably a result of soil compaction due to continuous grazing (Curran Cournane, 2010; Wolf, 2011). According to the (Li *et al.*, 2008) long-term solutions to bulk density and soil compaction problems revolve around the reduction of soil disturbances and increasing organic matter content. (Igwe, 2005) found that areas grazed continuously exhibited higher bulk density than the areas under moderate grazing in south eastern Nigeria. This finding was attributed to consistent animal trampling that increases soil compaction.

The above results (Fig. 2) showed that continual grazing depresses SOC content and storage which is in accordance with some previous studies (Snyman & Du Preez, 2005; Wu *et al.*, 2010). The observed low carbon content under the continual grazing system can be due to the high compaction of the Soil which reduces water infiltration and will increase runoff, thus decreasing available water for plant growth (Abel & Blaikie, 1989; Savadogo *et al.*, 2007). Furthermore, less pore space limits gas exchange and cut back root growth. The two mechanisms counsel that soil compaction reduces plant production and thus SOC storage.

The difference in SOC content and stocks across the grazing systems can also be attributed to the difference in the herbaceous vegetation cover. The higher aboveground standing biomass under rotational grazing and ungrazed sites significantly reduced loss of organic matter and nutrients from the soil-plant system through soil erosion. Also, more stubble biomass is expected under rotational grazing sites than continual grazing sites, which means a conversion of the atmospheric carbon through the process of photosynthesis into carbon and nitrogen compounds that are returned to the soil through litter fall and dead plant materials. The higher SOC content stocks in the rotational grazing management system can therefore be attributed to increased belowground biomass.

The observed high carbon concentration and stocks can also be due to better microclimates in rotational grazing and ungrazed sites that results from adequate herbaceous cover and woody vegetation respectively which reduces the soil temperatures and evapotranspiration rates. The low herbaceous plant cover under the continual grazing system as a result of high grazing pressure exposes soils to sun rays leading to increased soil temperatures and evapotranspiration rates hence increases the decomposition of organic matter resulting in higher losses of carbon from the soil (Tom *et al.*, 2006). (Ritchie *et al.*, 2012) in her study on soil carbon dynamics, in the northern rangelands of Kenya reported that prolonged, heavy continuous grazing depleted most of the soil organic pools, resulting in bare ground and increased soil erosion that reduces productivity of the range. Also (J. D. Derner *et al.*, 2006) observed that continuous heavy grazing decreases both the aboveground litter deposition and belowground carbon allocation which may be attributed to the low C and N observed in the continually grazed sites. (Sanjari *et al.*, 2008) in his study carried out in semi-arid rangelands of South Africa, pointed out that, a relative increase in soil organic matter under time controlled grazing as opposed to under continuous grazing was and attributed to higher rates of grass growth and rest periods that lead to an increase in litter accumulation and subsequent increase of extra 1.37 ton/ha carbon in the top 10 cm of the soil under time rotational grazing compared with the continuous grazing. This observed results confirms that adequate rest periods in the rotational grazing system sites are important in giving the grazed plants an amble recovery time/period which increases the above ground organic matter and its incorporation to increase the soil organic matter pool. (Reeder & Schuman, 2002) in their study found similar results with areas that were under low/slightly grazed having more soil organic carbon than areas that the heavily grazed areas. They argued that the observed increase in SOC was because of the increase in the rates of nutrient cycling, annual shoot turnover and altered plant species composition. In a study by (Han *et al.*, 2008) on the effects of grazing intensity on soil carbon in Mongolia, they reported less organic carbon in areas with high grazing intensity than the areas under low grazing intensities and attributed the results to high net primary production under the light grazing intensities.

Furthermore, the presence of deep-rooted plants (trees) that gradually decompose when plant dies in combination with leaf litter decomposition may have contributed to high SOC in ungrazed and rotationally grazed area than in continually grazed area. A few shrubs, grasses and herbs with shallow roots contribute to annual litter deposition that is also suppressed by herbivores and this resulted into low SOC accumulation in the area under continual grazing.

In contrast to the findings of this study,(Ingram *et al.*, 2008) reported that areas under continuous heavy grazing had more organic carbon stocks than areas that were lightly grazed, because of the higher root mass they observed in areas under high grazing pressure. (Piñeiro *et al.*, 2010) in his review of different on the effect of grazing on soil organic carbon revealed divergent results where grazing increased SOC while in some instances, it reduced or had no influence on SOC. The results of this study show that grazing animals may affect soil organic carbon by altering soil organic matter that affects the nitrogen cycling, net primary production and decomposition which in turn affects the amount of nitrogen and carbon available in the soil. Derner and Schuman (2007) in their study on the potential of rangelands in sequestrating carbon, noted that grazing usually increases carbon storage on C4 dominated grasslands. A high rate of soil organic matter decomposition is partly the reason why areas that are under intense grazing involving excessive trampling have a low SOC. However, these results contradict that of (Liebig *et al.*, 2006) who found that SOC in the surface soil of heavily grazed pasture was greater than that of moderately grazed pasture in the great plains of Northern America a scenario which was attributed to the redistribution of dung and urine.

Conclusions

Areas under rotational grazing showed higher soil organic carbon concentration and stocks and low soil bulk density along the soil profile up to depth 1.2m than those under continual grazing management. These shows, that the success of all grazing systems when constrained by similar ecological variables, the difference in their performance with respect to their impact on soil organic carbon is as a result of the effectiveness and the efficiency with which the grazing management practices are used rather than ecological variables.

Acknowledgement

The authors gratefully acknowledge Australian government for funding the study through the System for Land based Emission Estimation in Kenya (SLEEK). We are indebted to the Robin & Stanley limited for providing the experimental fields. The International Livestock and Research Institute Kenya Agricultural Research Institute and Department of Land Resource Management and Agricultural Technology– University of

Nairobi are also acknowledged for providing the laboratory facilities.

References

Abel, N., & Blaikie, P., 1989. Land degradation, stocking rates and conservation policies in the communal rangelands of Botswana and Zimbabwe. *Land Degradation & Development*, *1*(2), 101-123.

Asner, G. P., Elmore, A. J., Olander, L. P., Martin, R. E., & Harris, A. T., 2004. Grazing systems, ecosystem responses, and global change. *Annu. Rev. Environ. Resour.*, *29*, 261-299.

Bakker, E. S., Ritchie, M. E., Olff, H., Milchunas, D. G., & Knops, J. M., 2006. Herbivore impact on grassland plant diversity depends on habitat productivity and herbivore size. *Ecology Letters*, *9*(7), 780-788.

Bartolome, J. W., & McClaran, M. P., 1992. Composition and production of California oak savanna seasonally grazed by sheep. *Journal of Range Management*, 103-107.

Batjes, N. H., 1996. Total carbon and nitrogen in the soils of the world. *European Journal of Soil Science*, *47*(2), 151-163.

Blake, G., 1965. Bulk density. Methods of Soil Analysis. Part 1. Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling(methodsofsoilana), 374-390.

Bremer, D. J., Auen, L. M., Ham, J. M., & Owensby, C. E., 2001. Evapotranspiration in a Prairie Ecosystem. *Agronomy Journal*, *93*(2), 338-348.

Briske, D. D., Derner, J., Brown, J., Fuhlendorf, S., Teague, W., Havstad, K., Willms, W. (2008). Rotational grazing on rangelands: reconciliation of perception and experimental evidence. *Rangeland Ecology & Management*, *61*(1), 3-17.

Brown, J. R., & Thorpe, J., 2008. Climate change and rangelands: responding rationally to uncertainty. *Rangelands*, *30*(3), 3-6.

Conant, R. T., Six, J., & Paustian, K., 2003. Land use effects on soil carbon fractions in the southeastern United States. I. Management-intensive versus extensive grazing. *Biology and fertility of soils*, *38*(6), 386-392.

Curran Cournane, F., 2010. Impacts of livestock grazing on soil physical quality and phosphorus and suspended sediment losses in surface runoff. Lincoln University.

Daniel, J., Potter, K., Altom, W., Aljoe, H., & Stevens, R., 2002. Long-term grazing density impacts on soil compaction. *Transactions of the American Society of Agricultural Engineers*, *45*(6), 1911-1915.

DeLonge, M. S., Owen, J. J., & Silver, W. L., 2014. Greenhouse Gas Mitigation Opportunities in California Agriculture.

Derner, J., & Schuman, G., 2007. Carbon sequestration and rangelands: a synthesis of land management and precipitation effects. *Journal of Soil and Water Conservation*, *62*(2), 77-85.

Derner, J. D., Boutton, T. W., & Briske, D. D., 2006. Grazing and ecosystem carbon storage in the North American Great Plains. *Plant and Soil*, *280*(1), 77-90.

Dudney, J., Hallett, L. M., Larios, L., Farrer, E. C., Spotswood, E. N., Stein, C., & Suding, K. N., 2016. Lagging behind: have we overlooked previous- year rainfall effects in annual grasslands? *Journal of Ecology*.

Follett, R. F., & Reed, D. A., 2010. Soil Carbon Sequestration in Grazing Lands: Societal Benefits and Policy Implications. *Rangeland Ecology & Management*, *63*(1), 4-15. doi: http://dx.doi.org/10.2111/08-225.1

Ford, R. M., 2015. The effects of fire and grazing management on unpalatable climax grasslands dominated by *Hyparrhenia hirta* and *Cymbopogin validus*. University of Pretoria.

Gill, R. A., 2007. Influence of 90 years of protection from grazing on plant and soil processes in the subalpine of the Wasatch Plateau, USA. *Rangeland Ecology & Management*, *60*(1), 88-98.

Gillen, R. L., McCollum, F. T., Hodges, M. E., Brummer, J. E., & Tate, K. W., 1991. Plant community responses to short duration grazing in tallgrass prairie. *Journal of Range Management*, 124-128.

Grayston, S., Vaughan, D., & Jones, D., 1997. Rhizosphere carbon flow in trees, in comparison with annual plants: the importance of root exudation and its impact on microbial activity and nutrient availability. *Applied soil ecology*, *5*(1), 29-56.

Green, R. A., & Detling, J. K., 2000. Defoliation- induced enhancement of total aboveground nitrogen yield of grasses. *Oikos*, *91*(2), 280-284.

Han, G., Hao, X., Zhao, M., Wang, M., Ellert, B. H., Willms, W., & Wang, M., 2008. Effect of grazing intensity on carbon and nitrogen in soil and vegetation in a meadow steppe in Inner Mongolia. *Agriculture, Ecosystems & Environment*, *125*(1), 21-32.

Heitschmidt, R., Vermeire, L., & Grings, E., 2004. Is rangeland agriculture sustainable? *Journal of Animal Science*, *82*(13_suppl), E138-E146.

HilleRisLambers, J., Yelenik, S. G., Colman, B. P., & Levine, J. M., 2010. California annual grass invaders: the drivers or passengers of change? *Journal of Ecology, 98*(5), 1147-1156.

Hoffman, T., & Vogel, C., 2008. Climate change impacts on African rangelands. *Rangelands, 30*(3), 12-17.

Huntsinger, L., Bartolome, J. W., & D'Antonio, C. M., 2007. Grazing management on California's Mediterranean grasslands. *California grasslands*, 233-253.

Igwe, C., 2005. Soil physical properties under different management systems and organic matter effects on soil moisture along soil catena in southeastern Nigeria. *Tropical and subtropical agroecosystems*, *5*(2).

Ingram, L., Stahl, P., Schuman, G., Buyer, J., Vance, G., Ganjegunte, G., Derner, J., 2008. Grazing impacts on soil carbon and microbial communities in a mixed-grass ecosystem. *Soil Science Society of America Journal, 72*(4), 939-948.

Jaetzold, R., Schmidt, H., Hornetz, B., & Shisanya, C., 2006. Ministry of Agriculture Farm Management Handbook of Kenya VOL. II-Part C Subpart C1. *Nairobi, Kenya: Ministry of Agriculture*.

Jobbágy, E. G., & Jackson, R. B., 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications, 10*(2), 423-436.

Kinyua, P. I., van Kooten, G. C., & Bulte, E. H., 2000. African wildlife policy: protecting wildlife herbivores on private game ranches. *European Review of Agricultural Economics, 27*(2), 227-244.

Li, C., Hao, X., Zhao, M., Han, G., & Willms, W. D., 2008. Influence of historic sheep grazing on vegetation and soil properties of a Desert Steppe in Inner Mongolia. *Agriculture, Ecosystems & Environment, 128*(1), 109-116.

Liebig, M., Gross, J., Kronberg, S., Hanson, J., Frank, A., & Phillips, R., 2006. Soil response to long-term grazing in the northern Great Plains of North America. *Agriculture, Ecosystems & Environment, 115*(1), 270-276.

Manjarrez-Dominguez, C., Pinedo-Alvarez, A., Pinedo-Alvarez, C., Villarreal-Guerrero, F., & Cortes-Palacios, L., 2015. Vegetation landscape analysis due to land use changes on arid lands. *Polish Journal of Ecology, 63*, 167-174.

Medina-Roldán, E., Paz-Ferreiro, J., & Bardgett, R. D., 2012. Grazing exclusion affects soil and plant communities, but has no impact on soil carbon storage in an upland grassland. *Agriculture, Ecosystems & Environment, 149*, 118-123.

Mi, N., Wang, S., Liu, J., Yu, G., Zhang, W., & Jobbagy, E., 2008. Soil inorganic carbon storage pattern in China. *Global change biology, 14*(10), 2380-2387.

Naeth, M., Bailey, A., Pluth, D., Chanasyk, D., & Hardin, R., 1991. Grazing impacts on litter and soil organic matter in mixed prairie and fescue grassland ecosystems of Alberta. *Journal of Range Management*, 7-12.

Neff, J., Barger, N., Baisden, W., Fernandez, D., & Asner, G., 2009. Soil carbon storage responses to expanding pinyon–juniper populations in southern Utah. *Ecological Applications, 19*(6), 1405-1416.

Pelster, D., Rufino, M. C., Rosenstock, T., Mango, J., Saiz, G., Diaz-Pines, E., Butterbach-Bahl, K., 2015. Smallholder African farms in western Kenya have limited greenhouse gas fluxes. *Biogeosciences Discuss, 12*, 15,301-315,336.

Piñeiro, G., Paruelo, J. M., Oesterheld, M., & Jobbágy, E. G., 2010. Pathways of grazing effects on soil organic carbon and nitrogen. *Rangeland Ecology & Management, 63*(1), 109-119.

Reeder, J., & Schuman, G., 2002. Influence of livestock grazing on C sequestration in semi-arid mixed-grass and short-grass rangelands. *Environmental pollution, 116*(3), 457-463.

Ritchie, M., Mayemba, E., McSherry, M., & Tear, T., 2012. Soil carbon dynamics in the Northern Rangelands Trust Member Conservancies, Kenya.

Sanjari, G., Ghadiri, H., Ciesiolka, C. A., & Yu, B., 2008. Comparing the effects of continuous and time-controlled grazing systems on soil characteristics in Southeast Queensland. *Soil Research, 46*(4), 348-358.

Savadogo, P., Sawadogo, L., & Tiveau, D., 2007. Effects of grazing intensity and prescribed fire on soil physical and hydrological properties and pasture yield in the savanna woodlands of Burkina Faso. *Agriculture, Ecosystems & Environment, 118*(1), 80-92.

Smith, P., Bhogal, A., Edgington, P., Black, H., Lilly, A., Barraclough, D., Merrington, G., 2010. Consequences of feasible future agricultural land- use change on soil organic carbon stocks and greenhouse gas emissions in Great Britain. *Soil use and management, 26*(4), 381-398.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., Rice, C., 2008. Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences, 363*(1492), 789-813.

Snyman, H., & Du Preez, C., 2005. Rangeland degradation in a semi-arid South Africa—II: influence on soil quality. *Journal of Arid Environments, 60*(3), 483-507.

Stavi, I., Ungar, E. D., Lavee, H., & Sarah, P., 2008. Grazing-induced spatial variability of soil bulk density and content of moisture, organic carbon and calcium carbonate in a semi-arid rangeland. *Catena, 75*(3), 288-296.

Steffens, M., Kölbl, A., Totsche, K. U., & Kögel-Knabner, I., 2008. Grazing effects on soil chemical and physical properties in a semiarid steppe of Inner Mongolia (PR China). *Geoderma, 143*(1), 63-72.

Su, Y. Z., & lin Zhao, H., 2003. Soil properties and plant species in an age sequence of Caragana microphylla plantations in the Horqin Sandy Land, north China. *Ecological Engineering, 20*(3), 223-235.

Tastad, A. C., 2013. The relative effects of grazing by bison and cattle on plant community heterogeneity in northern mixed prairie. University of Manitoba.

Tom, N., Raman, A., Hodgkins, D. S., & Nicol, H., 2006. Populations of soil organisms under continuous set stocked and high intensity‐ short duration rotational grazing practices in the central tablelands of New South Wales (Australia). *New Zealand Journal of Agricultural Research, 49*(3), 261-272.

Tuffour, H. O., Bonsu, M., & Khalid, A. A., 2014. Assessment of soil degradation due to compaction resulting from cattle grazing using infiltration parameters. *IJSRES, 2*, 139-149.

Veldkamp, E., Becker, A., Schwendenmann, L., Clark, D. A., & Schulte‐ Bisping, H., 2003. Substantial labile carbon stocks and microbial activity in deeply weathered soils below a tropical wet forest. *Global change biology, 9*(8), 1171-1184.

Wang, Q., & Batkhishig, O., 2014. Impact of overgrazing on semiarid ecosystem soil properties: A Case study of the Eastern Hovsgol Lake Area, Mongolia. *Journal of Ecosystem & Ecography, 4*(1), 1.

Wang, Y., Li, Y., Ye, X., Chu, Y., & Wang, X., 2010. Profile storage of organic/inorganic carbon in soil: From forest to desert. *Science of the Total Environment, 408*(8), 1925-1931.

Wei, L., Hai-Zhou, H., Zhi-Nan, Z., & Gao-Lin, W., 2011. Effects of grazing on the soil properties and C and N storage in relation to biomass allocation in an alpine meadow. *Journal of soil science and plant nutrition, 11*(4), 27-39.

Wolf, K., 2011. Effects of High-Density, Short-Duration Planned Livestock Grazing on Soil Carbon Sequestration Potentials in a Coastal California Mixed Grassland. California Polytechnic State University, San Luis Obispo.

Wu, G.-L., Liu, Z.-H., Zhang, L., Chen, J.-M., & Hu, T.-M., 2010. Long-term fencing improved soil properties and soil organic carbon storage in an alpine swamp meadow of western China. *Plant and Soil, 332*(1-2), 331-337.

مقدار کربن آلی خاک و رابطه بین میزان آن و مدیریت چرا در مراتع نیمه خشک کنیا

هیلاری کپنگتیچ روتیچ[الف*]، ریچارد اونوونگا[ب]، جودیت سیموبا ماباو[ب] و اسکار کیپچیرچیر کوئچ[ب]
[الف] گروه منابع زمین و فن آوری کشاورزی، دانشگاه نایروبی، نایروبی، کنیا *(نگارنده مسئول)، پست الکترونیک: hillaryrotich2010@gmail.com
[ب]گروه منابع زمین و فن آوری کشاورزی، دانشگاه نایروبی، نایروبی، کنیا

تاریخ دریافت: ۱۳۹۶/۰۲/۱۹
تاریخ پذیرش: ۱۳۹۶/۰۴/۲۷

چکیده. مراتع کنیا حدود ۸۵ درصد از اراضی کشور را پوشش می‌دهد و منبع اصلی برای دامداری است که پتانسیل قابل توجهی برای مقابله با تغییرات آب و هوایی دارد، با این حال، این مناطق تحت تاثیر مدیریت و فشارهای مختلف قرار گرفته است. مطالعه حاضر با هدف تعیین تأثیر سیستم‌های مدیریت چرای (چرخشی، مداوم و بدون چرا) بر ذخائر کربن آلی خاک در مراتع تجاری یوانی، واقع در مراتع جنوب کنیا در سال ۱۳۹۵ انجام شد. بخشی از این مراتع تحت مدیریت چرای مستمر و بخشی به چرای چرخشی به مدت ۱۱ سال برای انجام تحقیقات مورد استفاده قرار گرفت. در هر دو تیمار چرای مستمر و چرای چرخشی شرایط خاکی و زمین‌شناسی یکسان بود و در بخش چرای مستمر به مدت بیش از ۳۰ سال برای نشان دادن اثر آن بر میزان کربن آلی خاک مورد استفاده قرار گرفت. در بخشی از مراتع این منطقه گالی یا خندق عمیقی قرار دارد که بیش از ۳۰ سال است غیر قابل چرا شده است. نمونه‌های خاک تا عمق ۱/۲ متری برداشت شدند. از عمق‌های ۱۰-۰، ۲۰-۱۰، ۳۰-۲۰، ۶۰-۳۰، ۹۰-۶۰ و ۱۲۰-۹۰ سانتی‌متری نمونه‌های خاک جمع‌آوری شدند. تفاوت بین عمق نمونه‌برداری از خاک به این دلیل است که در لایه بالایی یعنی بین ۰ تا ۳۰ سانتی متر فعالیت‌های میکروبی خاک بیشتر است که می‌تواند تحت تأثیر چرای بیشتر در مقایسه با قسمت‌های عمیق خاک قرار گیرد. نتایج نشان داد که در تیمار فرسایش یافته به طور معنی‌داری ($P<0.5$) بیشترین میزان غلظت کربن آلی خاک در تمام لایه‌های خاک تا عمق ۱/۲ متری نسبت به تیمارهای چرای مداوم و چرای چرخشی نشان می‌دهد. همچنین در تیمار با چرای چرخشی، غلظت کربن آلی خاک در قسمت‌های عمیق در مقایسه با سیستم چرای مداوم بیشتر بود که این موضوع شاید به دلیل اثرات مدیریت چراگاه باشد.

کلمات کلیدی: ذخایر کربن آلی خاک، سیستم‌های چرا، مراتع