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Differences of Soil Properties between Planned and Unplanned Grazing Sites in Semi-Arid Pastoral Rangelands of Northern Kenya

Lutta Alphayo
Student, Department of Land Resource Management and Agricultural Technology,
Faculty of Agriculture, University of Nairobi, Kenya
Dr. Oliver V. Wasonga
Senior Lecturer, Department of Land Resource Management and Agricultural Technology,
Faculty of Agriculture, University of Nairobi, Kenya
Dr. Wilfred O. Odadi
Senior Lecturer, Department of Natural Resource Management, Egerton University, Egerton, Kenya
Robinson K. Ngugi
Professor, Department of Land Resource Management and Agricultural Technology,
Faculty of Agriculture, University of Nairobi, Kenya

Abstract:
Livestock grazing can affect soil structure, function and productivity, with the strength of its effects hinging heavily on the type of grazing management system adopted. Planned grazing management, involving short-duration, high-intensity, rotational grazing has been proposed as a tool for improving rangeland soils, but its efficacy in this regard has never been evaluated in communal pastoral lands. This study compared soil physical and chemical properties between sites subjected to planned grazing management and those managed under non-planned open access continuous grazing in a semi-arid pastoral rangeland in northern Kenya. Soil organic carbon, total nitrogen, CEC, K^+ and P, moisture content, aggregate stability, hydraulic conductivity was significantly higher in planned than in non-planned grazing areas. Conversely, soil bulk density and penetration resistance were significantly lower in planned grazing sites. These findings show that planned grazing as practiced under the conditions of this study could potentially be used to enhance soil productivity in pastoral rangelands.

Keywords: *Livestock grazing, soil physical properties, semi-arid, Laikipia, short-duration, rotational grazing*

1. Introduction

Arid and semi-arid rangelands across the world, and especially in Africa, are currently experiencing high levels of degradation, thus reducing their contribution to livestock production, wildlife conservation and human livelihoods (Galvin, 2009). One manifestation of rangeland degradation is loss of soil fertility resulting from reduced vegetation cover, a vital contributor of soil organic matter. Soil organic matter is the main reservoir of soil organic carbon and plays a major role in the chemical, biological and physical functions of the soil (Bardgett, 2005, Weber, 2011). Impaired soil fertility results in negative feedbacks on the vegetation and the overall health of the ecosystem.

The process of soil degradation can be triggered and accelerated by poor grazing management practices. For instance, a study by Savadogo *et al.,* (2007) showed that grazing animals can increase soil compaction, resulting in high bulk density and reduced water infiltration into the soil. Such effects can depress vegetation biomass production and reduce soil organic carbon storage. In addition, frequent defoliation by grazing animals reduces the leaf area of plants resulting in reduced primary production, and subsequently reduced soil carbon. Below ground biomass, which contributes greatly to soil organic matter can also be affected by grazing animals (Reeder *et al.,* 2004) resulting in the reduced soil organic matter content. Reeder *et al*., (2004) found that soil organic matter decreased with increasing defoliation due to reduced root growth occasioned by preferential allocation of food reserves and carbon to meristematic tissues for the replacement of above ground tissues. Studies have shown that when degraded rangelands are restored, they can greatly enhance soil properties (Soussana *et al.,* 2010; Teague *et al*., 2010, Derner *et al.,* 2006, Allard *et al.,* 2007).

Planned grazing management, involving high intensity short duration rotational grazing has been suggested to improve rangeland soil health through maximization of animal impact (dunging, urination and hoof action) by concentrating (bunched) livestock herds. However, its efficacy in improving soil health in pastoral systems remains largely unknown. Understanding the effects of this system on soil properties is critical in assessing the value of its implementation in pastoral lands. The aim of this study was to test if there were any detectable differences in soil characteristics between sites under planned grazing and those under non-planned, unrestricted access grazing in a pastoral setting. Soil physical and chemical properties were compared between sites where planned grazing had been practiced for approximately three years, and adjacent control sites where non-planned grazing was continuing.

2. Materials and Methods

2.1. Study Area

The study was conducted in IlMotiok and Koija pastoral group ranches located in Laikipia Plateau, Kenya. The study area is in Agro-climatic zone VI (Muthiani *et al.,* 2011), and falls within temperature Zone 4, with a temperature range of 18-20^{o}C. Rainfall is generally low in the area, averaging 371mm annually, and is highly variable both spatially and temporally. Vegetation is largely wooded grassland. The soils are predominantly sandy loam with relatively uniform texture. Livestock production through pastoralism and wildlife conservation are the dominant land uses in the area.

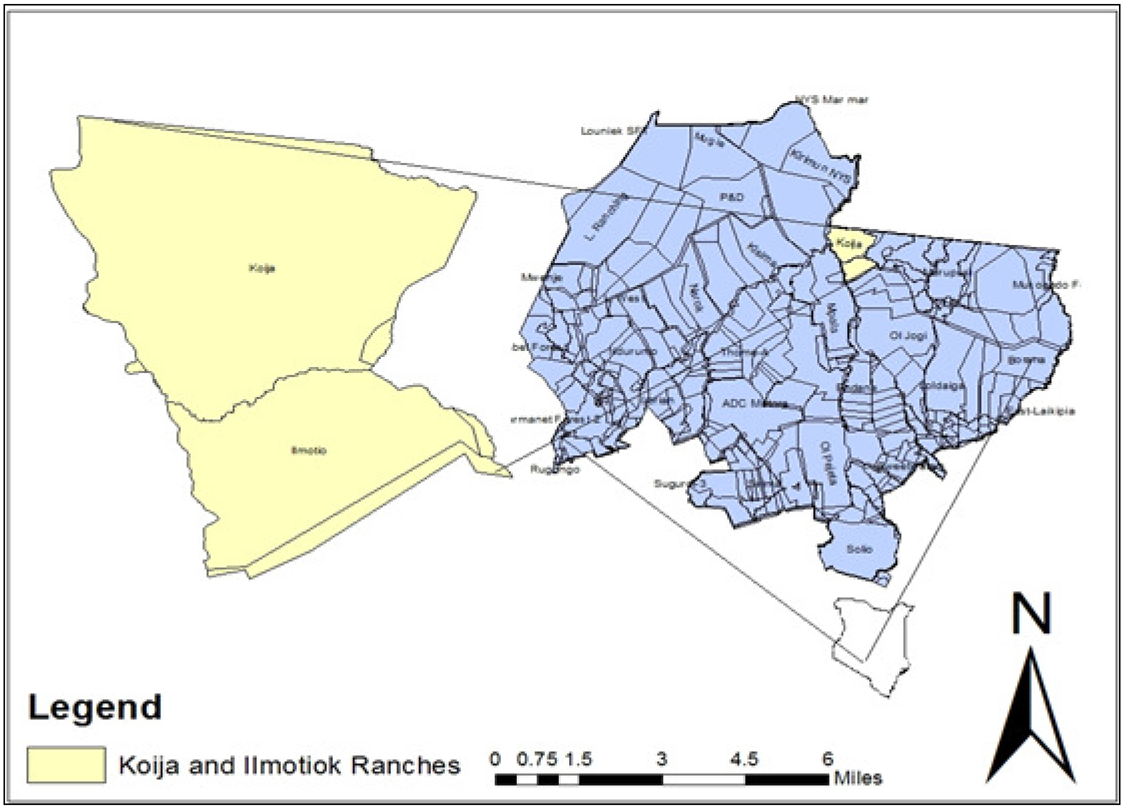

Figure 1: The Study area (Koija and Il Motiok group ranches).

2.2. Experimental Design

The two study sites, Koija and II Motiok group ranches represented two different grazing management regimes. By the time of the study, planned grazing had been practiced on approximately 2,000 ha of Il Motiok for 3 years. The choice of the portion of the land to be put under holistic grazing practices was made by community members. Anecdotal accounts indicate that the area was selected based on the view that it appeared relatively degraded and thus needed to be improved. The planned grazing area consisted of four grazing blocks, each measuring approximately 500 ha. Cattle accessed the planned grazing areas twice a year: April-July and October-January. At the start of each of these grazing periods, community members aggregated all cattle into one large herd of approximately 600 head of cattle. The aggregated herd was then herded in the grazing blocks sequentially, with grazing being completed in one block before the herd moves to the next block, cattle bomas were moved with the animals. The residence time in each grazing block during each grazing period was 20 days. Three grazing sites were used, namely, planned grazing in Il Motiok (PG), areas adjacent to the planned grazing areas (Control II Motiok) and continuous grazing in Koija (Control Koija, CK), were used. The two controls were selected to show whether there is any significant difference between the areas under complete planned grazing (PG), partial planned grazing (CI) and those under continuous grazing (CK). Sampling was conducted in five plots measuring 20m by 20m established in each of the grazing treatments.

2.3. Soil Sampling and Laboratory Analyses

Soil samples were obtained at 10meter intervals along two diagonal transects in four 20x20m plots. Soil samples were collected at 0-10cm and 10-20cm depths using a standard soil auger and immediately placed in air tight plastic bags to prevent the loss of moisture. The soil samples from each plot were then composited by depth into a single sample. Each composite soil sample was then sieved to remove foreign materials like plant roots, stones and organic residues using a 2 mm mesh. The sieved composite soil sample was then divided into two sub-samples. One sub-sample was used for soil carbon/organic matter analysis, while the other was dried to a constant weight and used to estimate moisture content, pH, CEC, nitrogen, phosphorus and potassium content. Collected soil samples were analyzed for chemical and physical characteristics at the University of Nairobi's Soil Science Laboratory.

Total organic carbon, total nitrogen, phosphorus and potassium were estimated using the Walkley-Black method (Walkley & Black,1934), Kjeldahl (Bradstreet, 1965), spectrophotometer (Anderson & Ingram, 1993) and flame photometry (Anderson & Ingram, 1993) techniques, respectively. The cation exchange capacity (CEC) was quantified using ammonium acetate buffered to pH 8.2 (Anderson & Ingram, 1993). Soil moisture content was estimated using the gravimetric method (Okalebo *et al*., 2002) Soil aggregate stability was determined using the wet sieving method (USDA, 1996). Measurements of the hydraulic conductivity of saturated soils were based on the constant head method (Wessolek *et al* 1994). Bulk density was determined using the core method as described by Okalebo *et al*., (2002). To estimate penetration resistance, W-shaped lines were drawn within each plot and at each peak corner of the line a penetrometer was pushed through the soil profile to two depths (0 to 10 and 10 to 20) to assess surface and subsurface compaction. The average resistance of five points within each plot was done at every depth.

2.4. Data Analysis

Data were analysed using a 3-way ANOVA to test for differences across grazing treatments (PG, CI and CK), seasons (wet vs. dry) and soil depth (0-10 vs. 10-20), with interactions (grazing x season, grazing x soil depth, season x soil depth, grazing x season x soil depth) included in the model. Tukey's HSD post hoc test was used to separate means for significant treatment and interaction effects. Significant differences were accepted at $P < 0.05$.

3. Results

3.1. Soil Chemical Properties

Soil organic carbon (SOC) and nitrogen were both higher in planned (PG) than unplanned (CI and CK) grazing areas (Fig2a). Both nitrogen and soil carbon were significantly higher at the top soil than at the subsoil (P = *0.018*) with more percent carbon content and nitrogen within 0-10 cm compared to 10-20 cm across all the treatments. Both parameters did not differ significantly between seasons (carbon $P = 0.291$; nitrogen $P = 0.056$).

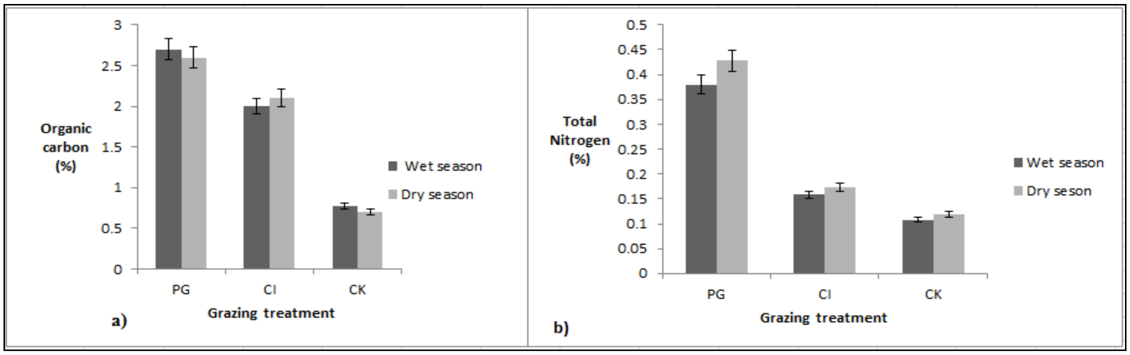

Figure 2: Average soil organic carbon (%) and total nitrogen (%) across grazing treatments

Soil potassium, and phosphorous were significantly higher in PG than CI and CK. However, these parameters did not differ significantly across seasons ($P = 0.064$ and 0.0813 for K and P, respectively) and soil depths ($P = 0.053$ and 0.062 for K and P, respectively).

	Wet season				**Dry season**			
	PH		CEC		PH		CEC	
Depth	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20
PG	6.8^{b}	6.9^{b}	20.1^{c}	18.2^{c}	6.9^{b}	6.9^{b}	20.4^{c}	10.2^{b}
CI	6.4^{a}	6.3^{a}	15.8^{b}	14.4^{b}	6.4^{a}	6.4^{a}	15.9^{b}	14.7^{a}
CK	5.9^{a}	6.0^{a}	12.7^{a}	11.6^{a}	6.0^{a}	6.03^{a}	13.1^{a}	13.2^{a}
LSD	0.4	0.4	1.3	1.6	0.3	0.4	1.4	1.9
CV%	4.0	4.0	5.1	6.8	3.6	4.0	5.1	7.8

Table 1: Average soil pH, and CEC (Cmol/kg) under the grazing treatments
Means with the same letters within the row are not significantly different (P <0.05).

Cation exchange capacity (CEC) was significantly higher in PG than CK and CI (Table 1). This parameter was higher in the top soil (0-10 cm) than the subsoil (10-20 cm), but did not differ significantly (*P* = 0.631) between seasons (Table 1). Soil pH ranged between 5.9 and 6.9, and was significantly higher in PG than CK and CI (Table 1). There were no significant differences in soil pH between CK and CI.

	Wet Season				**Dry Season**			
	K		**P**		**K**		**P**	
Depth	**0-10**	**10-20**	**0-10**	**10-20**	**0-10**	**10-20**	**0-10**	**10-20**
PG	1.27^{b}	1.25^{b}	80.25^{b}	78.12^{b}	1.27^{b}	1.28^{b}	85.80^{b}	77.82^{b}
CI	0.52^{a}	0.46^{a}	58.18^{a}	57.40^{a}	0.55^{a}	0.50^{b}	61.63^{a}	58.42^{a}
CK	0.44^{a}	0.42^{a}	36.63^{a}	36.30^{a}	0.48^{a}	0.41^{ba}	36.78^{a}	34.97^{a}
LSD	0.25	0.25	44.57	40.77	0.25	0.48	44.57	45.65
CV	18.4	19.90	32.00	30.50	18.4	38.00	32.0	33.70

Table 2: Average Soil potassium (Cmol/kg) and phosphorous (mg/kg) under the grazing treatments
Means with the same letters within the row are not significantly different (P <0.05).

3.2. Soil Physical Properties

Soil aggregate stability and hydraulic conductivity were higher in PG than in CI and CK (Fig 3). However, there were no significant differences between CI and CK for both grazing treatments.

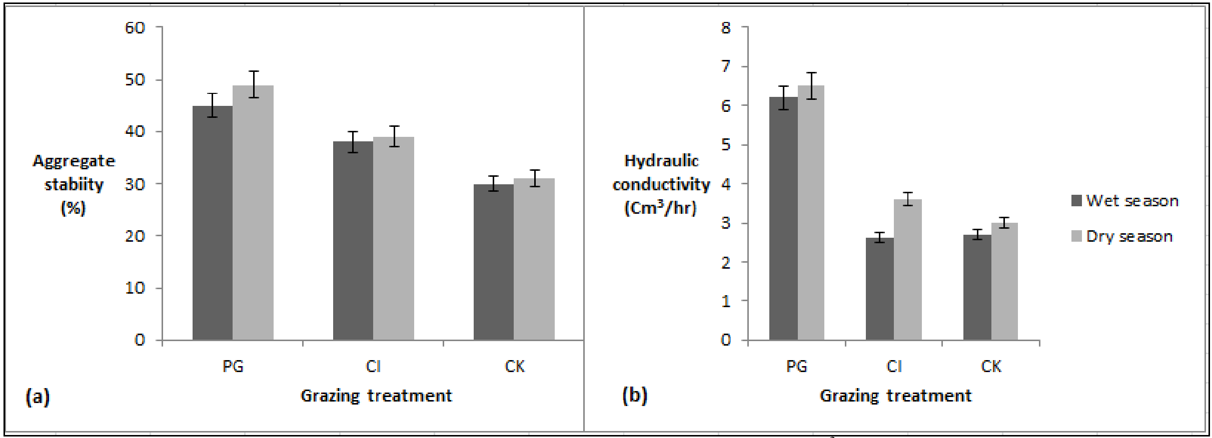

Figure 3: Average aggregate stability (%) and hydraulic conductivity (Cm^{3}/hr.) during wet and dry seasons

The average soil moisture was significantly higher in PG than in CI (*P* = 0.03) and CK (*P* = 0.01), but did not differ (*P* = 0.121) between the latter two treatments (Fig 4a). Available water content was higher (*P*< 0.05) in PG than CI and CK (Fig 4b). In addition, available water content was higher (*P* = 0.014) in CI than in CK (Fig 4b). There was no significant difference in the amount of available water content (*P* = 0.158,) across soil depths,

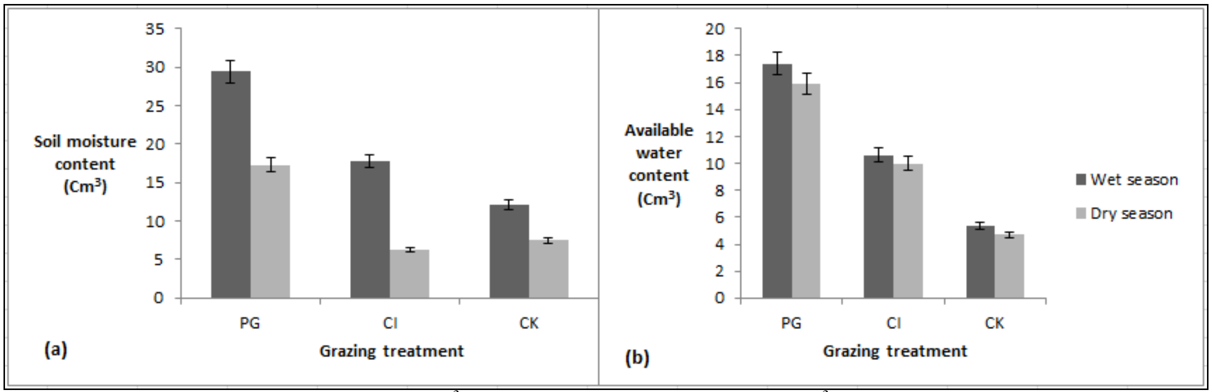

Figure 4: Mean soil moisture (cm^{3}) and available water content (cm^{3}) across grazing treatments

Bulk density was higher (*P*< 0.05) in CK than CI and PG, and higher (*P*< 0.001) in CI than PG (Fig 5a). However, this measure did not differ significantly between the season (*P* = 0.864). Penetration resistance was significantly lower in PG than CI and CK, and lower in CI than CK (Fig 5b).

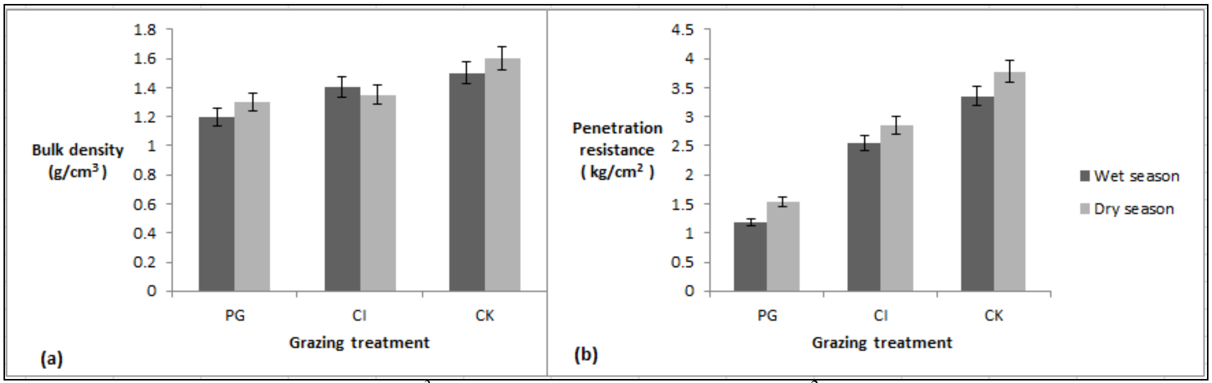

Figure: 5: Average Bulk density (g/cm^3) and penetration resistance (kg/cm^2) under different grazing treatments

There was no significant difference between soil texture properties of the planned and unplanned grazing areas (Table 3). Likewise, soil texture did not differ significantly across the treatments, depths and seasons.

Soil properties	SAND	SILT	CLAY
PG	76.85^a	3.01^a	25.17^a
CK	78.41^a	4.27^a	17.32^a
CI	79.30^a	4.26^a	20.41^a
LSD	3.33	2.98	5.18
CV%	2.70	43.80	16.40

Table 3: Soil texture results of planned and unplanned grazing
Means with the same letters within the row are not significantly different ($P < 0.05$).

4. Discussion

4.1. Soil Chemical Properties

Soil chemical properties were enhanced in areas subjected to planned grazing management. Enhanced soil organic carbon (SOC) and nitrogen (N) content in the planned grazing sites can be attributed to higher aboveground biomass. In a concurrent assessment (L.A. unpublished data), above ground standing biomass was found to be higher in planned than unplanned grazing sites. Higher biomass in planned grazing reduced loss of organic matter and nutrients from the soil-plant system through soil erosion as more vegetation remained after grazing. Consequently, more stubble biomass is expected under planned grazing sites than non-planned 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. Therefore, the observed increases in soil C and N under planned grazing could also be attributed to increased belowground biomass. Plant root residues are the primary source of soil organic matter (Reeder *et al.,* 2004) and therefore increase of below ground biomass may enhance soil organic matter in the soil.

Increased carbon concentration can also be attributed to better microclimates in planned grazing sites that resulted from increased herbaceous cover which reduced the soil temperatures and subsequent rate of evapotranspiration. Low plant covers as a result of low aboveground standing biomass results in exposed soils, which suffer from increased soil temperatures and evapotranspiration rates. This increases decomposition of organic matter resulting in higher losses of carbon from the soil (Southorn, 2002). High grazing intensities in the unplanned grazing sites may have stimulated soil mineralization, ammonification and nitrification, resulting in higher respiration rates and nitrogen oxide emissions. This may have reduced the concentration of carbon (C) and nitrogen (N) in the soil (Polley *et al*., 2008).

In a study on the dynamics of soil carbon in rangelands, Ritchie *et al.,* 2012, reported that prolonged, heavy continuous grazing in northern Kenyan pastoral lands depleted most of the soil organic pools, resulting in bare ground and increased soil erosion that reduces productivity of the range. As observed by Derner *et al.,* 2006, continuous heavy grazing decrease both the aboveground litter deposition and belowground carbon allocation which may be attributed to the low carbon and nitrogen observed in the unplanned grazing sites. In a six-year study in semi-arid rangelands of South Africa, a relative increase in soil organic matter under time controlled grazing as opposed to under continuous grazing was reported (Sanjari *et al.,* 2008). This was attributed to higher rates of grass growth and rest periods that increased the accumulation of litter. This suggests that adequate rest periods are vital in the recovery of the grazed plants and enhanced above ground organic matter and its incorporation to enhance the soil pool.

Different studies have reported divergent results on the effect of clay content on carbon storage in the soil. Conant *et al.,* 2001 found that the rates of carbon sequestration were not strongly related to soil texture. Similarly, Silver *et al.,* 2010 found clay content to be only weakly positively correlated with carbon content, while Burke *et al.,*1989 found that silt and clay content increased carbon content in rangeland soils. There was no relative difference in sand, silt and clay content between areas under planned grazing and those under unplanned grazing in this study. Therefore, the difference in the amount of soil organic carbon could not be attributed to texture.

Studies have shown that grazing increases soil nitrogen content (Frank *et al.,* 2004, Han *et al.,* 2008) input through faecal matter droppings and changes in plant species composition of grazed communities of plants. In the current study, areas under planned grazing sites had higher soil nitrogen content than the unplanned grazing sites. As reported by Frank *et al*., 2004 and Han *et al.*, 2008 nitrogen losses from the soil occur through processes such as NH_3 volatilization, denitrification and leaching. However, in this study leaching may not have been a problem since water was limiting in all the study sites, and the soil aggregates in planned grazing sites were found to be stable to permit the loss of N through leaching. NH_3 volatilization which is the loss of nitrogen as free ammonia (NH_3) could have contributed more to loss of N from the study sites.

High temperatures enhance NH_4^+ - NH_3 dissociation and reduce the solubility of NH_3 in soil water (McGarry *et al.,* 1987). This promotes the conversion of N to NH_3 which is easily lost through volatilization (Frank *et al.,* 2004). Reduced soil covers and aboveground biomass observed under unplanned grazing may have resulted in increased soil temperature due to direct exposure to solar radiation thereby leading to N losses through volatilization.

Whereas grazing is known to increase N loss through NH_3 volatilization, grazing animals can also increase deposition of more urine and dung in grazed fields resulting in increased soil N abundance. The latter is, however, contrary to the findings in unplanned grazing areas, partly because the rate at which nitrogen was lost from the soil through volatilization could have been higher than the rate of deposition through dung and urine.

The lower K^+ in unplanned grazing sites could be due to soil degradation and losses through leaching as these areas were stripped of vegetation cover due to high grazing pressure. There was also low organic matter in these areas, which could also reduce the amount of soil potassium concentrations in the soil. Organic matter is known to be rich in negatively charged ions that are known to adsorb more potassium cations in the soil (Evans *et al.,* 2012). Higher herbaceous biomass in planned grazing sites could also be responsible for the pumping of more K^+ from the subsoil to the topsoil hence accounting for the decreasing K^+ with increasing depth.

The low Phosphorous (P) levels in the unplanned grazing sites can be attributed to high erosive processes that occur in these areas due to lack of vegetation cover. As indicated by Quinton *et al*., 2001, phosphorous is normally lost through erosion as is the case when soil lacks cover. As grass cover decreases due to animal grazing and trampling, erosion of P forms increases.

The concentration of CEC was found to be low in unplanned grazing treatments, indicating low levels of soil fertility in these areas. Grazing animals usually deposit more organic manure through dung and urine, which are normally a large source of $Ca^{2+,}$ K^+, P, and Mg^{2+} that increase cation exchange capacity of the soil. However, bare soil promotes erosion and exposure of micro-aggregate organic carbon and organic matter to microbial decomposition by changing the moisture and temperature regimes. This reduces the organic matter concentrations in the soil therefore reducing the CEC of the soil (Johnson, 2002). According to Mureithi *et al.,*2014, soils with high organic matter content have high cation exchange capacity. Organic matter increases the available negative charges in the soil, hence increasing the CEC.

4.2. Soil Physical Properties

High aggregate stability in planned grazing sites could be attributed to high standing crop in these areas which kept the soil protected against erosion agents. Enhanced soil aggregation could also be as a result of buildup organic matter due to high biomass production associated with grazing management (Curran, 2010). Grasses have dense fibrous root systems that increase the organic matter content in the soil and also encourage more microbial activity which binds the soil particles together increasing aggregation (Wasonga, 2009). The increased organic matter in the soil enhances biological activity that, in turn, accelerates the accumulation of cations such as calcium and magnesium (USDA, 2001). These processes are known to enhance the aggregate stability of the soil, thereby reducing disintegration into individual particles that may close down the soil pores to cause crusts that impede water infiltration and aeration (USDA, 1996). The expansion and contraction of clay particles may break the soil aggregates (USDA, 2001). However, soil texture in the sites of the current study was not significantly different and therefore this could not have contributed to the differences in soil aggregate stability between the treatments.

The low bulk density in planned grazing sites can be attributed to the minimum livestock impact (Tufour, 2014) and loafing (Wang, 2014) due to short duration grazing that gives maximum rest to the grazed plants. The high soil bulk density in unplanned grazing sites, on the other hand, is probably a result of soil compaction due to continuous grazing (Wolf, 2011; Curran, 2010). According to the USDA, 2008, long-term solutions to bulk density and soil compaction problems revolve around the reduction of soil disturbances and increasing organic matter content. High BD minimizes runoff, improves water quality, and reduces storm-water flow, which reduces water infiltration capacity of the soil and subsequent available water for plant use (Igwe, 2005).

The higher soil penetration resistance values of the unplanned grazing sites could be as a result of soil compaction associated with continuous grazing. Crush, 2011, found that pressures of 490 kPa can be exerted by a front foot of a 500-kg cow and that this is enough to compact wet soil to a point where the growth of grass root is restricted. This could partly explain why penetration resistance under unplanned grazing was relatively high. According to Lemus, 2011, increased soil compaction reduces soil pore spaces as a result of disintegrated soil particles that cause soil crusts. Such alteration of soil physical properties leads to poor forage establishment, uneven plant stands, shallow root system and consequently lower biomass production (Orwin *et al*., 2010).

Important properties that affect hydraulic conductivity include pore size distribution, pore shape, specific surface, and porosity. When the pore spaces reduce, the amount of water in the soil reduces too, and this means that the little water available in the soil becomes more bound on the soil particle with a high suction force. This makes water unavailable for plant use because of the high suction force required to access the water bound on the compacted soil particles (Amiri, 2008). In the current study, areas under planned grazing had high aggregate stability through increased organic matter which could have enhanced hydraulic conductivity.

Previous studies by Igwe, 2005 and Zhang *et al*., 2001 have attributed the relatively higher soil moisture to soil organic matter and a little contribution from the clay content. Azarnivand, 2010, found that areas under continuous grazing had very low soil moisture content which was attributed to decreased soil porosity as a result of compaction caused by livestock trampling. Livestock grazing intensity decreases vegetation cover of the soil, which consequently lowers water infiltration, hydraulic conductivity as well as water holding capacity of the soil.

5. Conclusions

Despite both sites having similar ecological conditions, areas under planned grazing showed better physical and chemical soil properties than those under non-planned grazing management. These results show that the success of all grazing systems is constrained by similar ecological variables, and therefore the difference in their performance is as a result of the effectiveness and the efficiency with which the grazing management practices is used rather than ecological variables. This study suggests that soil properties and range productivity can be enhanced when grazing animals are bunched to assert maximum impact on soil and pasture for a short duration followed by adequate rest period to allow post-grazing pasture recovery. Improved soil physical and chemical properties in the planned grazing sites are expected to translate to enhanced productivity and therefore improved rangeland health. Continuous monitoring of the study sites would be helpful in determining the long-term effects of planned grazing management in communal pastoral rangelands. Whereas soil microorganisms play a vital role in determining the organic matter dynamics in the soil, this study did not investigate the effect of soil microorganism on soil properties. Therefore, further research on the effects of planned grazing on soil microorganisms would help to further reveal the mechanisms underlying the observed enhancement of the measured soil properties under planned grazing management.

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