Journal of Soil Science and Environmental Management Vol. 2(11), pp. 370-374, 29 November, 2011
Available online at http://www.academicjournals.org/JSSEM
ISSN 2141-2391 ©2011 Academic Journals

*Full Length Research Paper*

# Different land use types in the semi-arid rangelands of Kenya influence soil properties

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Accepted 27 October, 2011

**Rangelands in semi-arid Kenya have recently witnessed extensive land use changes. These changes can mainly be attributed to increased livestock populations and the response of the increased human population to both local and exogenous opportunities and constraints. This study was carried out in Kibwezi district of Kenya mainly inhabited by agro-pastoralists. The main objective of this study was to establish how different land use types influence soil properties in tropical semi-arid rangelands. Disturbed and undisturbed soil samples from three land use types namely cultivated land (CL), grazing land (GL) and fallow land (FL) at a depth of 15-30cm were collected and analyzed using standard laboratories for soil nutrients and soil physical properties. Results show open grazing lands (CEC 19.59 meq/100g) to be more fertile than cultivated (13.88 meq/100g) and fallow (6.40 meq/100g) lands. This was attributed to the continuous dropping of faecal material by grazing livestock. Higher bulk density in grazing land (1.36 g/cm$^3$) compared to cultivated and fallow lands with 1.29 g/cm$^3$ and 1.33 g/cm$^3$ was attributed to the hoof action of livestock. These results suggest that different land use types in the semi-arid rangelands contribute immensely to soil properties.**

**Key words**: Bulk density, cation exchange capacity (CEC), drylands, grazing lands, Kibwezi district, livestock.

## INTRODUCTION

Kenyan rangelands are home for millions of pastoralists and agro-pastoralists. The semi-arid lands form part of the vast rangelands of Kenya, which occupy over 80% of the country's total land area (Mwang'ombe et al., 2011). The semi-arid rangelands in Kenya are characterized by a number of habitat structures ranging from open grasslands to closed woody or busy vegetation with varying amounts and composition of grass cover and grass species respectively. The composition of the grass species and abundance of vegetation cover are dependent on a number of ecological conditions including; thermal regimes, rainfall amounts and duration of wet versus dry seasons, soil moisture content and the phenology of the shrub and tree canopies in the areas they grow. Livestock is the major user of primary production in these semi-arid rangelands (Nyangito et al., 2009). Livestock production is partly dependant on the cultural/economic interest of the main ethnic group occupying the area. The herd size (livestock numbers) and structure (composition of goats, sheep and cows) varies from place to place and ethnic group to ethnic group, but they are not dependent on ecological productivity potential.

The semi-arid African rangelands are often characterized by threshold dynamics and alternate stable states that are highly resilient (Kinyua et al., 2010). However, the interaction of heavy grazing and climatic variability can cause dramatic ecological degradation (Wessels et al., 2007). Nevertheless, communities

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inhabiting semi-arid rangelands in Kenya have been in a dynamic equilibrium with their environment and ecological degradation has been, for the most part, non-existent. Over the last few decades, much has changed. The changes are a response to a mix of factors including land privatisation and other government policies, population growth and migration, and changing national and international markets for crops and livestock products (LUCID, 2006).

Human and livestock populations within and outside the semi-arid rangelands in Kenya have greatly increased (Ngugi and Nyariki, 2003). Increased livestock numbers has resulted to heavy grazing which has altered vegetation composition and decreased primary productivity. This has led to the reduction of species diversity and increased exposure to bare ground, leading to increased runoff and increased erosion, which in turn has led to reduced water availability, nutrient retention and plant establishment. In Eastern and Southern Africa, many rangelands are now pockmarked by large bare areas with minimal organic matter and a smooth, sealed surface crust (Kinyua et al., 2010). Additionally, the rapid human population growth has put intense pressure on the semi-arid lands leading to the increased conversion of pastureland to cropland for subsistence crop production.

The destruction of pasture ecosystems and conversion to cropland can reduce soil productivity, because of increased erosion, decline in fertility, changes in aeration and moisture content, salinization or change in soil flora and fauna (Emadi et al., 2008). Land use induced changes in nutrient availability may influence secondary succession and biomass production (Foster et al., 2003) and reduce soil organic carbon (SOC) which plays a crucial role in sustaining soil quality, crop production and environmental quality. Such changes directly affect soil physical, chemical and biological properties such as soil water retention and availability, nutrient cycling, gas influx, plant root growth and soil conservation (Emadi et al., 2008).

Identifying and monitoring changes in soil quality is important in counteracting ecological degradation in the fragile semi-arid rangelands. The objective of this study was to establish the contribution of different land use types in a semi-arid rangeland in Kenya to chemical and physical soil properties.

## MATERIALS AND METHODS

This research was conducted in the year 2008 in semi-arid Kibwezi district, Kenya. Kibwezi lies between latitudes 2º 6′S and 3ºS and longitude 37º 36′E and 38º 30′E respectively and has a total area of 3400 km$^2$ (Mwang'ombe et al., 2011). The climate is typical semi-arid characterised by low and unreliable supply of enough moisture for plant growth (Mganga et al., 2010). The average annual rainfall is 600 mm (Musimba et al., 2004). Kenya receives a bi-modal rainfall pattern with the long rains expected between April-May and short rains between November-December. Soils in the semi-arid environment in Kenya are considered problematic because of their physic-chemical properties that limit their use for cultivation of crops (Biamah, 2005). They generally have low organic matter contents and unstable structure. Problems associated with the soils are high levels of salinity and sodicity, poor drainage, soil erosion, soil compaction, soil crusting and low soil fertility. Such soils are generally very vulnerable to physical erosion, chemical and biological degradation (El Beltagy, 2002).

The largest community in the area are the Kamba who practice agro-pastoralism as their mainstream economic activity. Crops grown include a variety of drought tolerant grains like maize, sorghum, millet, beans and pigeon peas. Livestock kept consist of local breeds mainly the Small East African Shorthorn Zebu cattle, Red Maasai sheep and the Small East African Goat (Nyangito et al., 2009).

Soil samples were collected from the three land use types: cultivated land (CL), open grazing land (GL) and fallow land (FL). The three land use types were located in close proximity within the same physiographic unit and with similar slope and topography. Soil samples: disturbed and undisturbed, were taken from 15-30 cm at each of the three locations in each land use type. Eighteen sampling points were randomly selected and composite soil samples made for analysis.

Disturbed soil samples were taken to determine soil moisture, soil texture and soil nutrients. Soil chemical analysis for nitrogen, phosphorus, potassium, carbon and cation exchange capacity (CEC) were done using standard soil laboratory analysis procedures. Organic carbon (OC) was determined by the Walkley and Black method (1934). Total Nitrogen (TN) was determined with the Kjeldahl method (McGill and Figueiredo, 1993) available Phosphorus (P) was measured by the Olsen method (Olsen et al., 1954). These tests were done to establish and compare the nutrient contents of the sampled soils under the different land use systems.

Soil moisture content of the samples was determined by the gravimetric method (Rowell, 1994). Soil texture was determined following the hydrometer method as described by Gee and Baunder (1986). The fine fraction of soil passing through a 2 mm sieve was taken for texture analysis using the Buoyoucos hydrometer. The textural class was determined using the standard USDA Triangle (USDA, 1975). Undisturbed soil core samples were used to determine soil bulk density and saturated hydraulic conductivity. Bulk density was determined by the core method (Blake and Hartge, 1986). Constant head permeameter as described by Klute and Dirksen (1986) was used to determine saturated hydraulic conductivity (Ksat).

Soil physical and chemical properties in the three land use systems were compared using One-Way Analysis of Variance (ANOVA) and means separated using Tukey's-B. Mean comparison were performed at $p < 0.05$ level. The Statistical Package for Social Sciences (SPSS) (Einstein and Abernethy, 2000) computer programme was used to analyze data.

## RESULTS

Results from this study showed that there was significant difference ($p<0.05$) in the cation exchange capacity (CEC) in the different land use types (Table 1).

Soils in the open grazing lands (GL) showed the highest cation exchange capacity (CEC) of 19.59 me/100g. Cultivated land and fallow land were ranked second and third with 13.88 me/100 g and 6.40 me/100 g respectively. Results also showed that the soils in all the land use types were deficient of nutrients mostly potassium and nitrogen. The most abundant nutrient in all the three sites occurrence was phosphorus. Grazing land (GL) recorded the highest amounts of phosphorus 15.38

**Table 1.** Soil chemical properties in the study sites.

| Land Use | C (%) | N (%) | P (ppm) | CEC (me/100g) | K (me/100g) |
|---|---|---|---|---|---|
| Cultivated | 1.56 ± 2.02 | $0.37^{ab}$ ± 0.06 | 13.90 ± 8.42 | $13.88^{a}$ ± 7.45 | 2.03 ± 0.31 |
| Grazing Land | 0.75 ± 0.12 | $0.32^{a}$ ± 0.04 | 15.38 ± 4.63 | $19.59^{a}$ ± 3.63 | 2.21 ± 0.78 |
| Fallow | 0.92 ± 2.20 | $0.43^{b}$ ± 0.04 | 13.72 ± 5.47 | $6.40^{b}$ ± 6.91 | 1.92 ± 0.45 |

Column means with different superscripts are significantly different at p< 0.05

ppm. Cultivated land (CL) and fallow land (FL) were ranked third and fourth with 13.90 and 13.72 ppm respectively. However, there was no significant difference in the amounts of phosphorus in all the three land use types. Results from this study also showed that there was no significant difference in amounts of potassium in the soils sampled from the three land use types.

Percentage of carbon and nitrogen were very low in all the three land use types. Fallow land (FL) had the highest percent of nitrogen (0.43%), followed by cultivated land (CL) and open grazing land (GL) with 0.37 and 0.32% respectively. Percentage of nitrogen in the open grazing land was significantly different (p<0.05) from percentage of nitrogen in the cultivated land and fallow land. However, percentage of nitrogen was not significantly different between the site under cultivation and fallow land. Soils under cultivation had the highest percent carbon (1.56%). Fallow land and grazing land were ranked second and third with 0.92 and 0.75% respectively. There was no significant difference in percent carbon in all the three land use types.

Saturated hydraulic conductivities in the three land use systems were significantly different (p< 0.05) (Table 2). Soils under fallow land, which had a sandy clay loam soil texture showed the highest rates of hydraulic conductivity. Cultivated land and grazing land which had the same soil texture of sandy clay were ranked second and third respectively. The percentage of soil moisture in all the three sites was generally low. There was significant difference (p< 0.05) in percentage of moisture content between soils sampled from fallow land and those sampled from grazing and cultivated land. Grazing land had the highest percent moisture followed by cultivated and fallow lands which were ranked second and third respectively. Bulk densities in the three land uses showed a no significant difference (p> 0.05). However, grazing land recorded the highest bulk density. Fallow land and cultivated land were ranked second and third respectively.

## DISCUSSION

Cation exchange capacity (CEC) is a measure of the ability of a soil to retain cations, some of which are plant nutrients. Higher CEC values in cultivated and grazing lands than fallow land can be attributed to the soil texture. Sandy clay soils have a higher clay content compared to sandy clay loams. Soils with higher clay content tend to have higher CEC. These results compare with those of Githae et al. (2011) who found sandy clay loams to have a higher CEC of 18.78 meq/100 g compared to sandy loams and loamy sands with 18.73 and 12.75 meq/100g respectively. Soils that have a low CEC hold few cations and may require more frequent applications of fertilizers and amendments than soils that have a high CEC. These results suggest that cultivated and grazing land have greater water holding capacity thus a higher capacity to hold cations compared to fallow land.

Moreover, CEC in the soil is a function of organic matter. The continuous faecal droppings in the open grazing lands could have also contributed to a higher CEC values in the open grazing land as compared to cultivated land and fallow land. Addition of organic manure in the soil has residual effects on the field (Kihanda et al., 2007). According to Gachene and Kimaru (2003), the CEC measurements indicate overall assessment of the potential fertility of a soil and possible response to fertilizer application. Soils with a CEC of <16 meq/100 g are considered not to be fertile and such soils are highly weathered while fertile soils have a CEC of >24 meq/100 g. Results from this study suggest that soils in the fallow land (CEC 6.40 meq/100 g) and cultivated land (13.88 meq/100 g) are not fertile, whereas the fertility of the soils in the grazing land (CEC 19.59 me/100g) is average. The poor fertility in the fallow and cultivated lands can be attributed to the continuous mining and depletion of soil nutrients as a result of continuous cultivation of crops and soil erosion.

The difference in the saturated hydraulic conductivities (Ksat) in the different land use types can be explained by the difference in soil types and the texture of the soils. Higher saturated hydraulic conductivity in the fallow land can be attributed to its sandy clay loam texture. Saturated hydraulic conductivity is influenced by grain size, which is reflected in the texture of the soil. Soils from the fallow land had a higher percentage of sand, which has larger soil grains, thus higher hydraulic conductivity. The cultivated and open grazing lands had sandy clay textured soils. This explains the lower hydraulic conductivities due to a higher percentage of clay, which has smaller grains. This trend of results is comparable to those found by Clapp and Hornberger (1978) who found higher saturated hydraulic conductivities in sandy clay

**Table 2.** Soil physical properties in the study sites.

| Land Use | K sat (cm/hr) | Texture | Moisture (%) | Bulk density ($g/cm^3$) |
|---|---|---|---|---|
| Cultivated | $2.8^{a} \pm 1.31$ | Sandy Clay | $6.9^{a} \pm 0.88$ | 1.29 ± 0.09 |
| Grazing land | $1.9^{ab} \pm 1.39$ | Sandy Clay | $7.4^{a} \pm 1.69$ | 1.36 ± 0.11 |
| Fallow land | $4.9^{b} \pm 3.64$ | Sandy Clay Loam | $2.5^{b} \pm 0.82$ | 1.33 ± 0.07 |

Column means with different superscripts are significantly different at $p< 0.05$.

loam textured soils (Ksat $1.99 \times 10^{2}$ m/yr) compared to sandy clay textured soils (Ksat $6.84 \times 10^{1}$ m/yr).

Low levels of percentage of carbon in all the three land use types suggest low levels of organic matter content in the soils. The soil organic carbon content observed in the present study ranged from 0.75 to 1.56%. Results from a study conducted in a semi-arid environment in Kenya (Githae et al. 2011), the percent soil organic carbon ranged from 0.9 to 3.2%. The higher lower and upper limits in this study can be attributed to a higher litter fall from the *Acacia senegal* species, thus increase in levels of organic matter on the upper soil horizons. Organic matter is the reservoir that holds the nutrients which can be released to the soil. The low amounts of soil nutrients in all the soils can therefore be attributed to the low amounts of organic matter. Moreover, soils with low organic matter have low water holding capacity and poor structure making them prone to erosion and vulnerable to degradation. This premise is supported by the findings of El Beltagy (2002) who concluded that soils in the semi-arid environment are generally very vulnerable to degradation through physical erosion and to chemical and biological degradation. Frequent soil erosion through wind and water in form of run-off has also contributed to the low nutrient levels. Overgrazing by livestock which depletes vegetation cover is a major contributor to soil degradation in the semi-arid ecosystems. Reduced vegetation cover leads to increased runoff and increased erosion, which in turn leads to reduced water availability, nutrient retention and plant establishment (Jones and Elser, 2004).

Higher amounts of phosphorus in the open grazing land compared to cultivated and fallow lands can be attributed to the continuous addition of organic manure in form of faecal droppings by the free grazing livestock. A study by Kihanda et al. (2007) on the effects of manure application on crop yield and soil chemical properties in a long-term field trial in semi-arid Kenya showed an increase in phosphorus after continued application of goat manure. The sites under cultivation and fallow lands are often excluded from livestock interference, thus no addition of animal manure. Animal manure contains significant amounts of phosphorus in organic forms. Organic manure has residual effects on the field (Kihanda et al., 2007). The higher amounts of potassium in the cultivated and grazing land can also be attributed to higher clay mineral content in the soil. As the clays weather, the potassium ions sand-witched between the layers are released. Furthermore, the amount of this exchangeable potassium in a soil depends on the cation exchange capacity (CEC) of the soil. Low levels of nitrogen in all the land use types can be attributed to nitrogen losses due to number of factors notably; low levels of organic matter, runoff and soil erosion. Soil erosion is the most visible form of land degradation in the area.

Higher bulk density in the grazing land as compared to cultivated and fallow lands could be attributed to the long term soil compaction caused by the grazing cattle. These results are similar to those found by Nyangito et al. (2009) who found higher soil bulk densities in grazed lands compared to ungrazed lands, while investigating soil physical properties of various perennial grass swards in grazed and ungrazed sites in the semi-arid rangelands of Kibwezi district, Kenya. Once bare ground is exposed, grazing livestock can cause soil compaction and reduce soil aggregate stability (Kinyua et al., 2010). Eventually, such structural degradation can lead to a formation of a surface seal that further reduces infiltration and hinders seed germination (Beukes and Cowling, 2003). Trampling by grazing animals is a primary reason for lower water infiltration in heavily grazed land thus increased rates of erosion leading to loss in soil nutrients. Long-term trampling by grazing livestock, especially in the semi-arid rangelands often characterised by limited amounts of vegetation coverage, can create a hard-pan in the sub-soils of open grazing areas. Lack of enough vegetation cover and shortage of litter being deposited on the soil surface, not only makes the soils more vulnerable to wind and water erosion but also accelerates the formation of the hardpan layer (Chaichi et al., 2005).

Soil moisture content (SMC %) in the semi-arid rangelands is a function of soil type and rainfall. The differences in soil moisture contents in the three land use types could be attributed to percentage of clay content in the soils. Higher soil moisture content in the cultivated and grazing lands can be attributed to the sandy clay soil textures with a higher percentage of clay content compared to sandy clay loam textured soils in the fallow land. Munaifu and Kinyamario (2007) also found similar results while working in the same study area. Soil moisture content (SMC %) increased with an increase in percent clay in the soil. Additionally, the lower soil moisture content in the fallow land can partly be attributed to the high rates of hydraulic conductivity characteristic of the sandy clay loam soil textured soils, compared to the sandy clay soils in the cultivated and grazing lands. High rates of hydraulic conductivity facilitate the free movement of water beyond the sampling horizon.

## Conclusion

The semi-arid rangelands in Kenya were predominantly used as pastureland for both domestic livestock and wildlife. However, as a result of the increased livestock and human populations in these semi-arid rangelands of Kenya in recent past, these ecosystems have experienced changes in land use. This has lead to increased pressure on the fragile ecosystems as a result of cultivation of crops mainly for subsistence and overgrazing by livestock. Our results suggest that the land use types currently practised in the semi-arid rangelands of Kenya influence soil physical and chemical properties.

## ACKNOWLEDGEMENTS

The authors acknowledge the Department of Land Resource Management and Agricultural Technology, University of Nairobi for allowing us use their laboratories for soil analysis. We gratefully acknowledge the Agricultural Innovations for Drylands Africa (AIDA) Project (Grant Number 043863-SSA Africa-2006) for funding this research. The lead author would sincerely like to thank the Tropical Biology Association (TBA) for sponsoring and inviting him to participate in the TBA-NK-NMK-DRECA Specialist Training Workshop on Communicating and Disseminating Research Results, 2011.

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