Examensarbeten 2014:9

Fakulteten för skogsvetenskap
Institutionen för skogens ekologi och skötsel

Carbon sequestration in the pastoral area of Chepareria, western Kenya

– A comparison between open-grazing, fenced pastures and maize cultivations

Allokering av kol i Cheparerias betesmarker, västra Kenya

– En jämförelse mellan allmänningar, inhägnader och odlingsmark

Foto: Sara Svanlund

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Sveriges Lantbruksuniversitet
Examensarbete i biologi, 30 hp, avancerad nivå A2E
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ABBREVIATIONS

A(OG): Agriculture, starting from unfenced pasture-land

A(FENCE): Agriculture, starting from fenced pasture-land

ANOVA: ANalysis Of VAriance

BC: Bush Control

BD: Bulk Density

FENCED(1): Pasture, young category (1-5 yrs. since fencing)

FENCED(2): Pasture, middle age category (7-10)

FENCED(3): Pasture, old category (>15 yrs. since fencing)

MC: Micro-Catchment

NGO: Non-Governmental Organization

OD: Open Grazing, e.g. land that is grazed continuously without restrictions.

PL: Plowed

PT: Planted trees

SOC: Soil Organic Carbon

ABSTRACT

Carbon sequestration through restoration of degraded pastoral soils is an advocated way of mitigating global warming, and simultaneously alleviating poverty. An often proposed rehabilitation strategy is fencing of pastures, a method that was introduced to the farmers of Chepareria by the Vi-Agroforestry organization in 1987. The landscape of Chepareria changed from eroded, over-grazed grasslands, to a mixture of open-grazed commons, pastoral enclosures and cultivations. The aim of this study was to investigate (1) if the soil organic carbon (SOC) is higher inside the enclosures than on the open-grazed commons, (2) if SOC is affected by duration of fencing and (3) what effect cultivation of pastures has on the SOC. Estimations of vegetation cover and deep profile (100cm) soil sampling was performed on six clusters containing; (1) open-grazing (OG) (2) 1-5 years of fencing (FENCED(1)), (3) 7-10 years of fencing (FENCED(2)), (4) 15-23 years of fencing (FENCED(3)), (5) maize from OG (A(OG)), (6) maize from fenced pasture (A(FENCED)). Spectrometric analysis of SOC was performed and the results were statistically tested with correlations and ANOVA's. The average mass of SOC in the 100cm soil profile was 77,76 ± 22,73 t/ha, or 0,68 ± 0,13%, ranging from 61,12 ±15,44 t/ha (0,55 ± 0,08%) on OG to 87,21 ±29,77 t/ha (0,78 ± 0,16%) on FENCED(2). A significant difference in SOC(%) could be distinguished on 0-20 cm were FENCED(1) and FENCED(2) exceeded the OG, and on 20-40 cm where FENCED(2) > OG. No significant difference was found when comparing SOC(t/ha). This was explained by high variation of SOC and BD, deriving from diverse management and environment. The SOC(%) in FENCED(3) was (insignificantly) lower than in FENCED(1) and FENCED(2). This was proposed as original differences in soil conditions, due to a consistent (insignificant) pattern of SOC and BD throughout the 100cm profile, with OG ≤ FENCED(3) ≤ FENCED(1) ≤ FENCED(2). The ground vegetation cover increased significantly from OG to FENCED(2) and FENCED(3). The maize-cultivations contained similar levels of SOC as the fenced pastures, e.g. more than OG. Fertilization, and farming of soils with initially high SOC contents, was used as explanations to why SOC did not decrease after plowing and harvest. The study area and method were considered as suitable for analysis of carbon sequestration on rehabilitated land, but more information about present and previous management, soil properties and vegetation is requested.

SAMMANFATTNING

Restaurering av degenererad betesmark leder till ökad inlagring av koldioxid och har blivit en etablerad strategi för att bromsa den globala uppvärmningen, samtidigt som fattigdom bekämpas. En rekommenderad restaureringsåtgärd är inhägnande av betesmark, en metod som Vi-skogen introducerade i den kenyanska byn Chepareria, år 1987. Cheparerias landsbygd förändrades från ett eroderat och utarmat beteslandskap till en blandning av allmänningar, inhägnade hagar och odlingsmark. Syftet med den här studien var att undersöka (1) om mängden organiskt kol var högre i jorden på inhägnaderna än på allmänningarna, (2) om kolmängden påverkades av hur länge betet varit hägnat och (3) vilken effekt odling har på jordens kolinnehåll. På sex områden identifierades närliggande ytor med; (1) fri betestillgång, (2) 1-5 års hägn, (3) 7-10 års hägn, (4) 15-23 års hägn, (5) majsodling på f.d. allmänning, (6) majsodling på f.d. hägn. På samtliga ytor togs jordprover ner till 100cm djup och vegetationstäckningen uppskattades. Kolmängden erhölls genom spektometeranalys, varpå statistiska korrelationer och variationsanalyser (ANOVA) genomfördes. Det fanns, utslaget på alla provytor och hela jordprofilen, i medel 77,76 ± 22,73 t/ha, eller 0,68 ± 0,13% kol i marken, med en variation från 61,12 ±15,44 t/ha (0,55 ± 0,08%) på allmänningarna till 87,21 ±29,77 t/ha (0,78 ± 0,16%) på stängslad mark (10år). En signifikant skillnad i kolmängd kunde urskiljas i markens översta 20cm, där unga och medelålders hägn hade högre kolhalt (%) än allmänningarna, samt på 20-40cm där endast kolhalten på medelålders hägn översteg kolhalten på allmänningarna. Det fanns inga signifikanta skillnader kol (t/ha), vilket förklarades med en hög variation i kol och bulkdensitet, grundad i varierande skötsel- och miljöfaktorer. Kolhalten i gamla hägn var lägre (ej signifikant) än i unga och medelålders. Ursprungliga skillnader i jordegenskaper mellan provytornas föreslogs, då skillnaderna i kolmängd, med allmänningar ≤ unga ≤ medelålders ≤ gamla, återfanns ända ner på 100cm jorddjup. Vegetationstäckningen var signifikant högre på medelålders och gamla hägn än på allmänningarna. Odlingarna innehöll liknande mängd kol som inhägnaderna, dvs. mer än allmänningarna. Gödsling och brukande av jord med hög initial kolhalt ansågs vara trovärdiga anledningar till att kolmängden inte minskat efter plöjning och skörd. Både studieområde och metod bedömdes vara lämpliga för att analysera inlagringen av kol i restaurerad betesmark. Dock efterfrågas mer information om skötselhistorik, jordegenskaper och vegetation.

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1. INTRODUCTION

Over the last few decades increased atmospheric concentrations of greenhouse gases have induced global warming which, if no actions are taken, is expected to raise the average temperature on earth by 4ºC within the next century (Albrecht & Kandji 2003; Larson et al. 2008). This change of climate can be mitigated by sequestration of atmospheric carbon dioxide into biomass and soil carbon.

1.1. The sequestration of carbon

Carbon is a dynamic element. It cycles between the atmosphere, biosphere and lithosphere, alternating from gaseous to solid states through different processes of fixation and release. In photosynthesis, carbon dioxide is incorporated into plant biomass (Reynaldo et al. 2012). Carbon is temporarily stored as organic compounds in living organisms, and as debris in the soil. During the decomposition of organic matter, the bonds that connect these compounds are cut and the carbon returns to the atmosphere as carbon dioxide. The soil organic carbon (SOC) content depends mainly on the current balance between primary production and microbial respiration and is therefore immediately affected by land-use changes (Paustian et al. 2006). Ploughing, for example, enhances the respiratory activities of decomposers, and harvest of crops removes significant amounts of organic carbon compounds that would otherwise remain as soil organic matter (FAO 2010; Reynaldo et al. 2012). When grasslands are cultivated, the carbon concentrations close to the surface might therefore decrease. A degraded soil that is rehabilitated through promotion of grassland vegetation, with an increased input of debris to the soil, will instead act as a carbon sink. Restoration of degraded land in development countries is often prescribed as a way to increase carbon sequestration, while simultaneously alleviate poverty (Reynaldo et al. 2012).

1.2 Enclosure of over-grazed pastures

Pastoral enclosure is a common practice to improve biomass production through reduction of grazing pressure (Damene et al. 2013; Hao et al. 2013; Li et al. 2007). Grazing affects the vulnerability of soils through changing the quality, quantity and structure of soil organic input, altering the vegetation cover and root network and physically compacting the soil.

When large herds of livestock are restricted to limited areas of marginalized land, the treading and grazing will impoverish the soil (Hillel 2004). Surface sealing, soil exposure and loss of organic matter are common consequences that reduce the infiltrability, fertility and stability of the soil (Hillel 2004; Oldeman 1992). Together, these factors increase the risk of erosion, including potentially severe and sometimes irreversible damages of essential soil functions. Many pastoral areas in Africa are currently heavily eroded, and land degradation is sometimes explained with the ”tragedy of the commons”. This expression, coined by Hardin (1968), describes a situation where the private gain of increased number of livestock always exceeds the following private loss of resources. Hence, the rational action of every herdsman is to maximize their livestock, which ultimately depletes the common resources - i.e. overgrazing. The causes of degradation may be more complex however, and depend on political or international rather than individual actions. When the area accessible for common herding is reduced by agriculture or urbanization, or the production capacity decreases due to climatic change, traditional livestock management may become unsustainable (FAO 2012).

1.2. Rehabilitation in Chepareria, western Kenya

The dry-land of sub-Saharan Africa is home to many of the poorest people on earth (Stringer et al. 2012). It is also a globally important region for carbon sequestration with high potential, and an urgent need, to increase the biomass production on degraded land. In western Kenya, over-grazing on common pastures has generated serious depletion of soils and left the ground bare and erodible (Touber 1992). However, since 1987 groups of farmers around the village of Chepareria in West Pokot have joined a rehabilitation program, designed to reduce the intensity of grazing and simultaneously improve human livelihoods (Makokha et al. 1999). The program, which was initiated by the Swedish non-governmental organization (NGO) Vi-Agroforestry, encourages usage of live-fences to control the density of livestock, and promotes rotational grazing as sustainable management. For this effort the farmers are awarded with ecosystem services such as improved infiltrability and water holding capacity, erosion control and improved soil fertility, as well as future possibilities of carbon sequestration and compensation (Luedeling & Neufeldt 2012; Stringer et al. 2012). The interest among farmers has increased substantially, from only a few dedicated participants, to most of the farmers in the area. Today, there is an ongoing development from a predominantly pastoral lifestyle to mixed agro-pastoral management.

1.3. The need for further investigations

The project in Chepareria creates a win-win situation for local farmers and the global climate, which is highly encouraged by the Kyoto Protocol (Larson et al. 2008). This international agreement obliges industrial countries to reduce their emissions and enhance sequestration of greenhouse gases, either on a national level or through development projects in areas of poverty. The latter, working through well regulated funding systems, is often a profitable cooperation for both payer and receiver, since enhancement of carbon sequestration requires less effort in highly degraded areas. Trade of carbon emission rights requires solid knowledge about the levels of carbon sequestration in various soils and management systems. Stringer et al. (2012) report an absence of both scientific data and accurate monitoring systems in the sub-Saharan dry-lands. In their review article, the authors stress the importance of studying different aspects of the land-use changes.

In early 2013, a multidisciplinary research was initiated by scientists in Sweden and Kenya, with the aim of analyzing several aspects of improved management in Chepareria (e.g. economics, animal husbandry, soil science, human ecology, geography and remote sensing). My master thesis is intended as a pilot study to this initiative, focusing on changes in the pool of soil organic carbon (SOC) after fencing of pastoral land.

1.5 Objectives

The overall aim of my paper is to test the hypothesis that soil carbon sequestration in sub-tropical soils is enhanced, resulting in increased levels of soil organic carbon, when open-grazed pastures are fenced and the regrowth of vegetation inside the enclosures is promoted with a rotational grazing regime. This will be accomplished by quantifying the amount of carbon in the soil of (1) grazed enclosures of different ages; (2) maize cultivations; and (3) unfenced, continuously grazed control plots. I will answer the questions:

- How is the amount of carbon in a pastoral soil affected when the density of grazers is controlled with a fence, and how does the carbon content change with duration of treatment?
- How are the primary producers of SOC (trees and vegetation) affected by fencing?
- What happens with the carbon content when an open-grazing system is replaced with maize cultivation, and is the effect on carbon different if a fenced pasture is cultivated?

My research is a pilot-study for a multidisciplinary initiative, evaluating the land-use change in Chepareria, West Pokot. The study objectives therefore include evaluating my method and providing a directive to decide the future aim and methodology. For this purpose the following specific questions are addressed:

- To what extent did the plots inside a cluster meet the criteria of being geographically close and sharing similar site conditions?
- How did the bulk density differ between the treatments and how accurate were the bulk density measurements?
- What was the rate of success in collecting samples from the layers 0-20cm, 20-40cm, 40-60cm, 60-80cm, 80-100cm depth?

2. MATERIALS AND METHODS

2.1. Study area

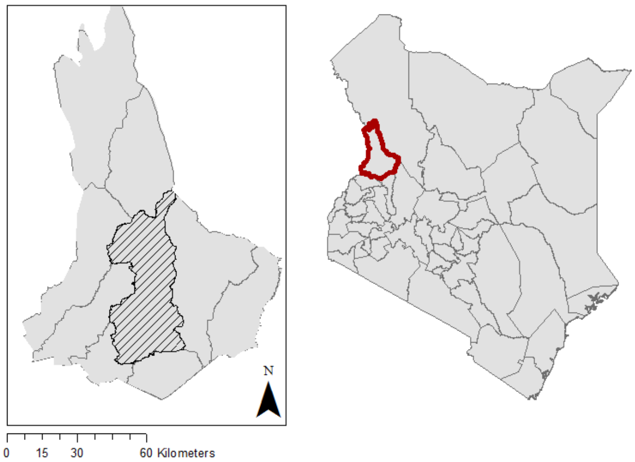

Fig.1. Map of Kenya (to the right) with magnification of West-Pokot District (to the left). West-Pokot district is marked with red borders in the map of Kenya. Chepareria ward is dashed in the map of West-Pokot District.

My study was conducted in Chepareria ward, situated in western Kenya at 1º19'N, 35º12'0E (Nyberg & Högberg 1995). This region is located on a gently undulating plain, reaching altitudes of 1200-1600 meters above sea level, with mountain peaks of up to 3000 meters towering in the horizons (Touber 1992). It is an area of metamorphic bedrock, rich in ferromagnesian minerals, from which moderately shallow, well drained and locally rocky soil has developed. As part of the semi-arid sub-Saharan region, Chepareria experiences a profoundly seasonal climate. The precipitation averages 800-1000 mm, with rainy seasons in April-July (short rains) and October-November (long rains) and temperatures ranging between 24-38°C (FEWSnet 2011; Nyberg & Högberg 1995). The vegetation is steppe-like and dominated by grasslands, with interspersed occurrence of both native trees (*Acacia spp., Terminalia brownii, Balanites aegytiaca, Kigelia Africana)* and introduced tree species (*Croton spp., Azadirachta indica, Grevillea robusta, Ficus spp.*)[1]. The landscape is substantially influenced by human activities and has a modern history of erosion and land degradation.

Chepareria ward is mainly inhabited by the Pokots, a widely distributed tribe with a long tradition of livestock management. The Pokots were originally nomadic people, moving with

[1] Information from local guide.

the seasons to let their land recover from grazing. During the colonial era, 1920-1963, the introduction of new borders intervened with this migratory lifestyle (Nangulu 2009). The herds were constricted to limited areas during prolonged periods, which generated over-grazing. Attempts by the administration officers to prevent land degradation through introduction of livestock taxes were perceived as yet another way to master the locals. They therefore failed to attract supporters. In 1987, a land rehabilitation program was set up in Chepareria by the Vi-Agroforestry organization (Makokha et al. 1999). West Pokot was by then sparsely vegetated and mainly used by livestock-herding farmers under communal land tenure. Overgrazing was extensive and the soils were depleted of organic matter, which contributed to severe gully erosion. Vi-Agroforestry worked together with schools, churches and farmers to demonstrate the advantages of planting live fences, consisting of sisal, euphorbia and thorny shrubs, to periodically exclude grazers from a pasture. Since then, there has been a prolonged change in land management.

At present, most farmers in Chepareria keep their livestock enclosed and although animal husbandry remains as the main land-use practice the adoption of agriculture, with maize as the primary crop, has increased (Makokha et al. 1999). The enclosures are usually rotationally grazed by a controlled amount of livestock. This rotation cycle is individually determined and varies greatly between the farms, from daily rotations to periods of weeks or months without livestock disturbance (table 1- appendix I). During the non-grazing seasons some farmers cultivate grasses for fodder or thatching.

2.2. Site selection

With the guidance of a locally experienced field advisor, I identified six clusters in Chepareria Ward, each containing:

- One unfenced control with open grazing (OG)
- One pasture that was fenced 2-5 years ago; FENCED(1)
- One pasture that was fenced 7-12 years ago; FENCED(2)
- One pasture that was fenced >15 years ago; FENCED(3)
- One maize field, cultivated on already enclosed pastoral land; A(FENCED)

Four of the clusters also contained:

- One maize field, cultivated on unfenced open-grazed land; A(OG)

This equals 34 plots. The target was to find clusters in which each of these plots was located at walking distance (< 2km) from the others to minimize differences in soil and climatic features (fig.2).

2.3. Plot description

Geographic references and estimates of ground vegetation cover, tree density, crop vitality and soil texture was collected on all plots to (1) enable scientists to relocate or visualize the sample sites and (2) guide me in my interpretation of the soil analysis. I calculated stems >1,5m, with single trunks, inside an area of 0,5 ha, and made an approximate, subjective estimation of ground cover. The texture was tested with a standardized rolling test acc. Troedsson & Nykvist (1973). I additionally denoted information and management history of each plot either from direct interviews with the farmer or indirectly through my interpreter and guide (table 2 appendix I).

2.4. Soil sampling and analysis

I extracted soil from 0-20, 20-40, 40-60, 60-80 and 80-100cm depth from three sub-sites on every plot, using either an open auger (similar to the Edelman combination auger) or one with a smaller opening, according to Aynekulu et al. (2011). This method was modified on; (1) very stony soil where the auger was frequently hindered by obstacles and (2) soil that was too densely packed to core in. In these conditions I used a 5x5x5 cm bulk-density (BD) sampler to extract the soil from three sides of a 1 m deep pit. The sub-samples were pooled and weighed. Close to the center of each plot I used a 5x5cm BD sampler to collect soil from the uppermost 5cm. This sample was intended as a reference to determine the accuracy of BD, calculated from the cored sampling sites. 500g of soil from each layer on every plot was dried for more than 3 days. I registered the air-dried weight within 1g of accuracy. A 50g sample was oven-dried for 48 hours in 105ºC to receive gravimetric water content. The remaining soil was sieved to 2mm. A representative sample of 100g was selected for laboratory analysis (Aynekulu et al. 2011). The SOC content was predicted from analysis in a Mid Infra-Red (MIR) spectrometer (Bruker Tensa 27) at the ICRAF laboratory in Nairobi (Aynekulu et al. 2011).

The estimated carbon contents (g/cm^3/ha) was used to (1) compare the carbon stocks under pastoral enclosures land of different ages (fig. 2) and (2) display how cultivation of fenced pastoral land affects the carbon stocks.

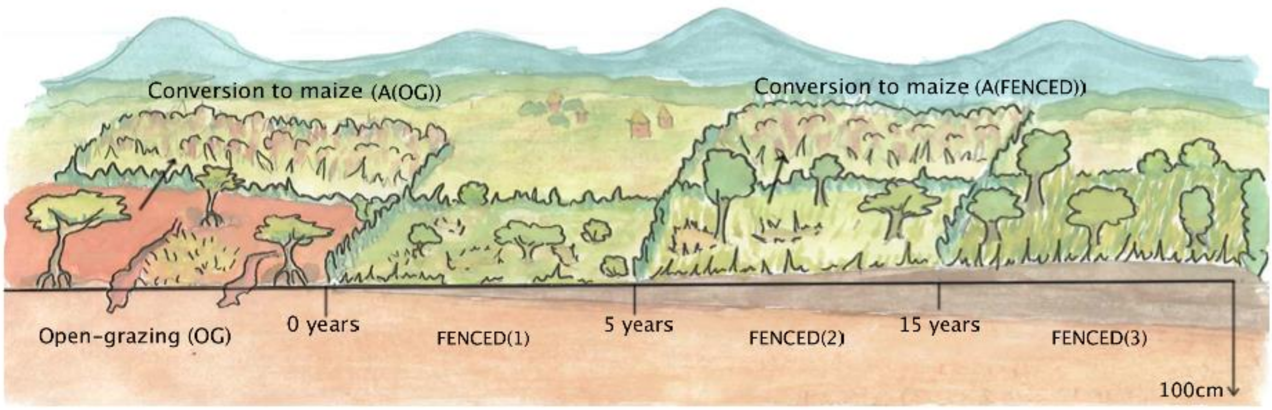

Fig.2. Duration of enclosure, with each square being one of my plots.

2.5. Calculations and Statistics

Using equation 1 & 2 (appendix II), I calculated BD and carbon mass/area from measured values of dry and wet soil mass, sampling volume and SOC (%), in Microsoft Excel. The values of BD from cluster 4, which were sampled with a different method than the rest, stood out in the data analyze and were excluded from the calculations. I used MiniTab 16 for the statistical analyzes. After confirming the normal or nearly-normal assumptions of various parameters in my data set, I performed general linear model analyses of variance (ANOVAs) (on unbalanced data-sets) and one-way ANOVAs (on balanced data-sets) to test the impact of fencing on (1) bulk density, (2) carbon content, (3) ground vegetation cover and (4) tree density. I worked by the theory that BD would decrease with duration of fencing (OG > FENCED(1) ≥ FENCED(2) ≥ FENCED(3)) and that SOC, vegetation cover and tree density would follow a reversed pattern. Significantly varying analyzes were followed by Tukey's test to identify the pattern of variation. The BD and SOC statistics were performed both on an average (soil g/cm3, carbon %) and total (carbon t/ha) values of the profile and on every specified level through the soil. Pairwise correlations between BD or SOC and tree density, vegetation cover and surface content of clay were performed with Pearsons Correlation and visualized in boxplots (categorical data of vegetation cover) or scatter plots (continuous data of tree density and clay content).

3. RESULTAT

3.1. Analysis of study area and method

3.1.1 Sample design and site conditions

The plots were spread across an area of approximately 18 km^2 (fig. 3). The clusters were situated 1,6 to 2,4 km from each other and the maximum distance between two plots inside a cluster amounted to 1,7 km.

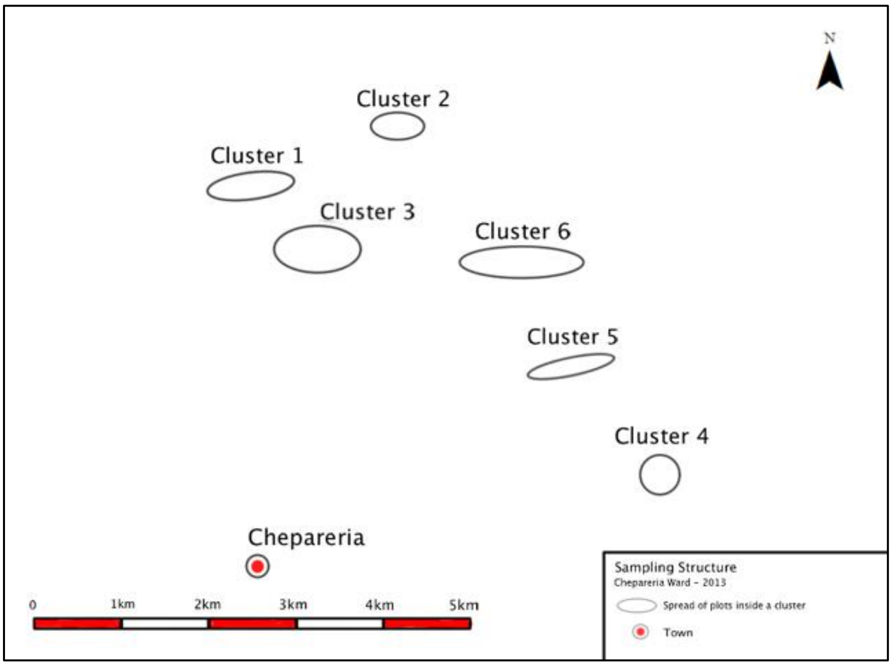

Fig.3. Simple illustration of sample design with clusters containing five or six plots.

The soil texture was highly variable both inside and between the clusters. Clay, silt and sand was found in the area. The texture also differed within individual profiles. This vertical change was denoted but not measured.

3.1.2 Bulk density

An average BD of 1,27 ± 0,34 g/cm3 (slightly increased to 1,28 ± 0,35 g/cm3 when cluster 4 was excluded) was recorded, using the cored volume and mass of soil.

The BD significantly increased with soil depth in FENCED(2) (P=0,05) and FENCED(3) (P=0,025). A slight tendency of increment with depth may be identified, but not statistically confirmed, in FENCED(1) while BD in the control peaked at 20-40cm.

The BD was not consistently reduced with duration of fencing (fig. 4). In the two uppermost layers (0-20cm, 20-40cm) a tendency of decrease from control to fenced areas may be identified, while the pattern is remarkably different, even reversed, in deeper layers of soil.

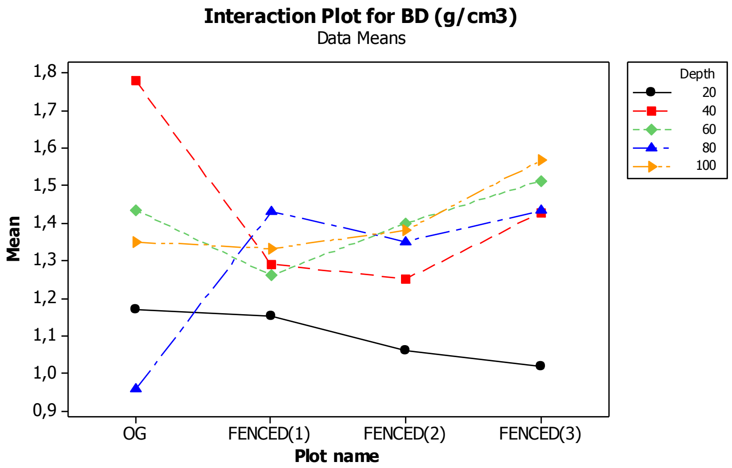

Fig.4. Changes in bulk density over different durations for all soil layers, where mean is expressed in g/cm^3 and the depths represent ranges from 0-20cm, 20-40cm etc.

The BD was highly variable within each group of duration and each soil layer, with internal variation often exceeding the differences between groups. The slight decrease of BD in the uppermost (0-20cm) layer of soil was hence insignificant (fig. 6). The difference on 20-40cm depth, with OG (BD=1,82±0,22 g/cm^3) exceeding the fenced areas ($BD_{FENCED(1)}$=1,33±0,15 g/cm^3, $BD_{FENCED(2)}$=1,28±0,33 g/cm^3, $BD_{FENCED(3)}$=1,46±0,13 g/cm^3), could however be confirmed (P = 0,006).

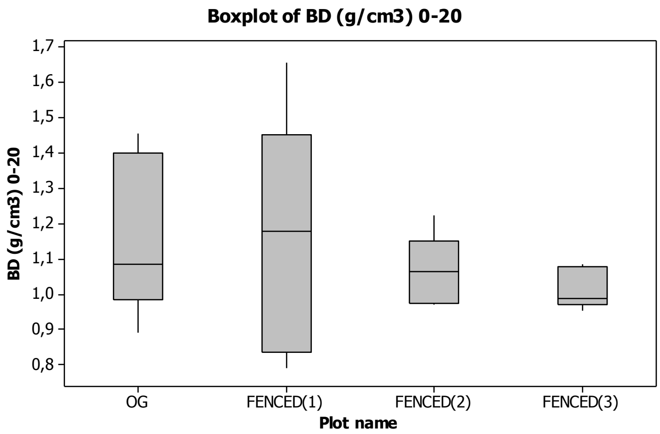

Fig.5. Illustration of the large internal spread of BD in the uppermost layer 0-20cm, exceeding the variation over different durations.

3.1.3. Sampling success

Using the coring method, complemented with sampling from pit on stony soil, soil was extracted down to 60cm in 100%, to 80cm in 92% and to 100cm in 71% of the sites.

3.2. Analysis of the fencing effect on SOC

3.2.1 Pastoral land

Across the study area, the average mass of SOC in the 100cm soil profile was 77,76 ± 22,73 t/ha, or 0,68 ± 0,13% of the soil. On pastoral land it ranged from 61,12 ±15,44 t/ha (0,55 ± 0,08%) on OG to 87,21 ±29,77 t/ha (0,78 ± 0,16%) on FENCED(2) (table 3 – 4 appendix I).

The variation of SOC (fig. 6), could be described as weak linear correlations with time of fencing:

Average SOC (%) = 0,5855 + 0,02543 Time of Fencing.
S= 0,134601, R-Sq = 30,8%, R-Sq(adj) = 26,4%

Total SOC (t/ha) = 65,91 + 2,828 Time of Fencing.
S = 25,7351, R-sq = 13,1%, R-Sq(adj) = 7,6%

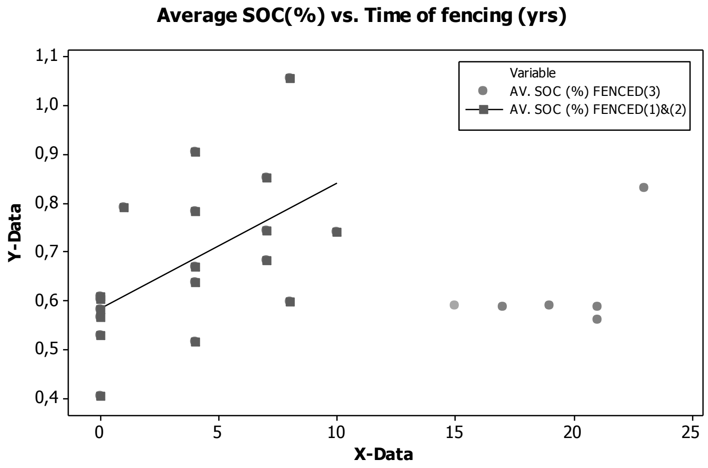

Fig.6. The percentage of SOC increased with time of fencing from 0-10 years of practice, but where returned to lower values after 15-20 years. X- represents time of fencing, expressed in years. Y represents content of SOC expressed in %.

The tendency of increased amounts of SOC from open-grazed controls (OG) to the fenced pastures could be distinguished on most levels in the soil (fig. 7).

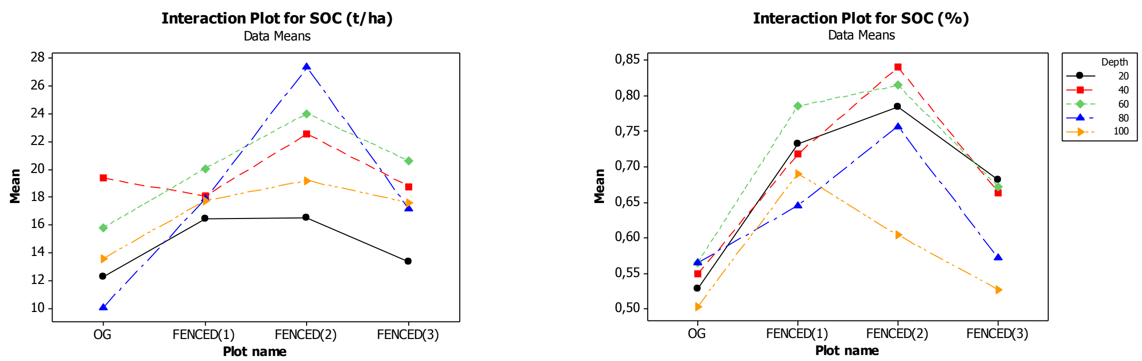

Fig.7. Interaction plots displaying the changing content of SOC over time, on different depth in the soil. Values of depth represents ranges from 0-20cm, 20-40cm, 40-60cm etc.

The effect was clearest in the top 0-20cm, were there was a found significantly (P=0,04) lower percentage of SOC in OG than in the recently fenced (FENCED(1)) and middle-aged (FENCED(2)) enclosures (fig. 8 & table 3). At deeper layers only FENCED(2) contained a significantly higher percentage SOC than C, and below 40cm no significant differences could be proved. The old enclosures (FENCED(3)) approached the low SOC values found in OG, both regarding percentage and mass of carbon (t/ha) (fig 8 - 9). No significant increases could be distinguished when SOC was expressed in t/ha (fig. 9 & table 4).

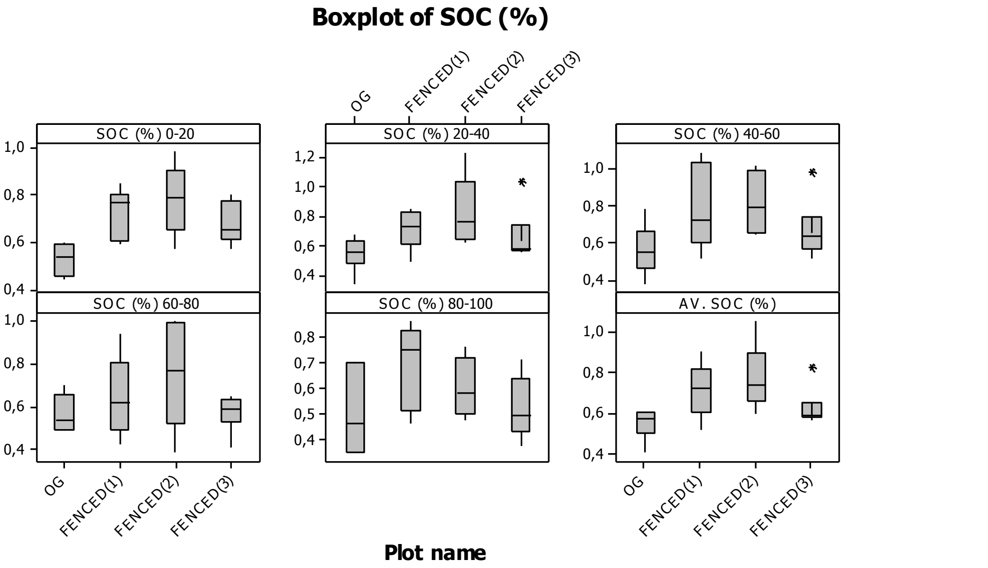

Fig.8. Side by side comparison of SOC (%) over different durations of fencing.

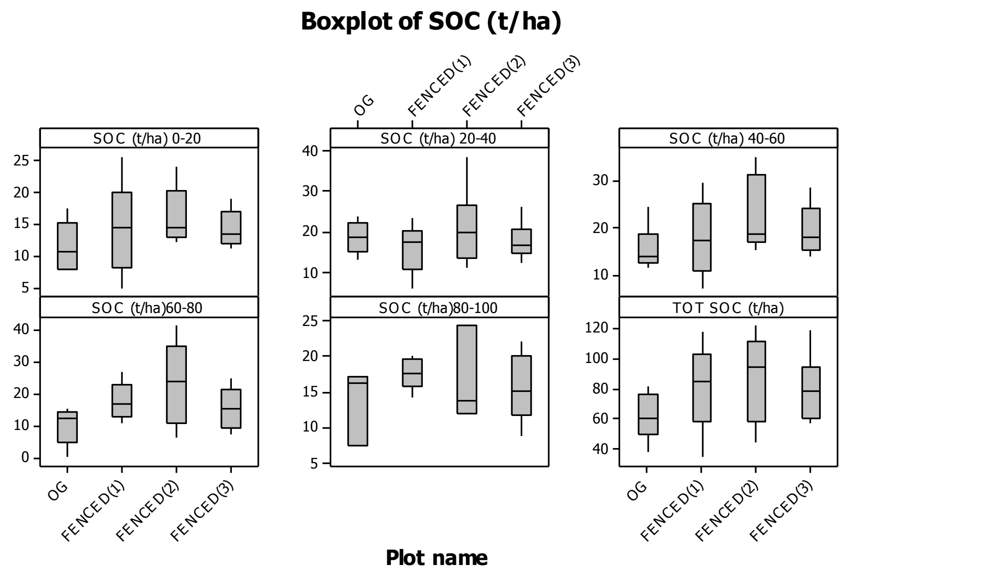

Fig. 9. Side by side comparison of the SOC (t/ha) over different duration.

3.2.2. Primary producers

During the study, I registered clear differences between open-grazed areas and enclosures. OG plots were in 50% of the cases almost bare and heavily eroded, whereas the fenced areas varied from patchy short-grassed lanes to forests with high but unevenly spread grass-vegetation and thriving meadows with high coverage. The pictures (fig. 10) show the differences in vegetation cover among all plots and durations.

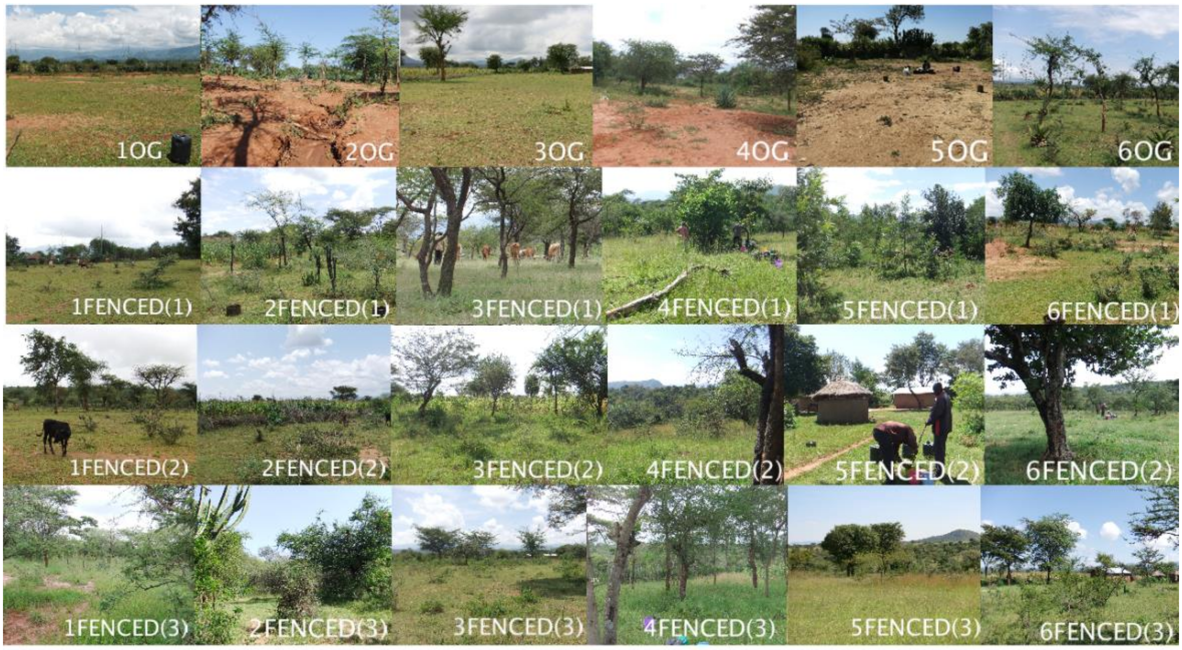

Fig.10. Photographs of all plots, illustrating the vegetation cover and tree density with numbers (1-6) determining cluster and letters the group of duration.

The ground vegetation cover was significantly higher (P = 0,021) on an average of the fenced areas than on OG. FENCED(1) had slightly less vegetation cover than FENCED(2) and FENCED(3), which both exceeded OG (P=0,25), but the difference between the three categories of enclosures was not significant (fig. 11).

There was, with almost 90% probability (P=0,084), a positive interaction between vegetation cover and SOC content in the uppermost soil layers, where the percentage of SOC on areas with 75-100% vegetation exceeded the levels on areas with 0-25% coverage (fig. 12).

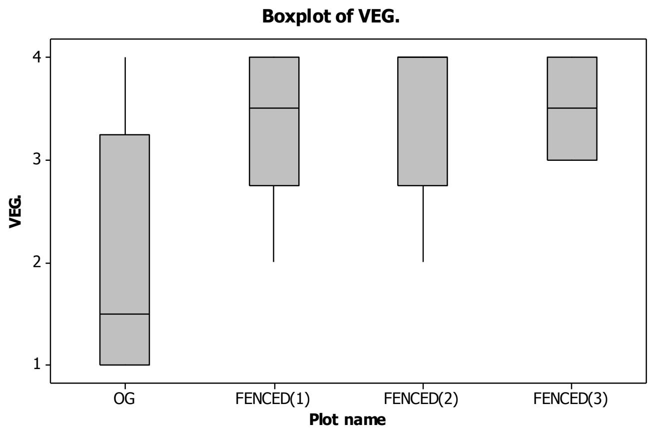

Fig.11. Levels of ground vegetation cover between open grazing (OG) and fenced pastures, with values expressed in % representing four categories of coverage:1= 0-25%, 2=25-50%, 3=50-75%, 4=75-100%.

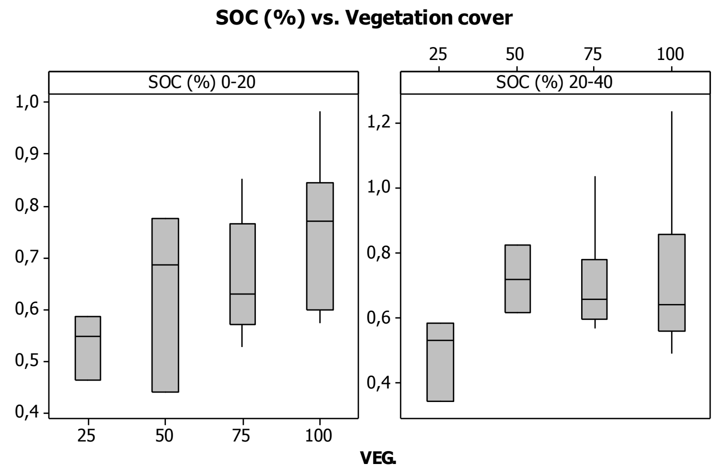

Fig.12. Almost significant (P=0,084) positive interactions between SOC (%) and vegetation cover (%) in the uppermost 0-20cm and 20-40cm soil.

There was no apparent correlation between tree density and SOC content on any level in the soil, neither when including all plots, nor when excluding those with unusually high densities of trees. The number of trees had furthermore no relationship to the duration of fencing.

3.2.3 Cultivation of pastures

The SOC content on the maize fields were of the same magnitude as the SOC on fenced pastoral land, both in the entire soil profile and on individual levels in the soil (fig. 13-14). Due to low values of bulk density in the plowed layers on maize-fields, the surface levels of SOC were lower when displayed in t/ha than in percent, compared to the SOC in pastoral soils (fig. 14). The difference between OG and A(OG) was thus reduced.

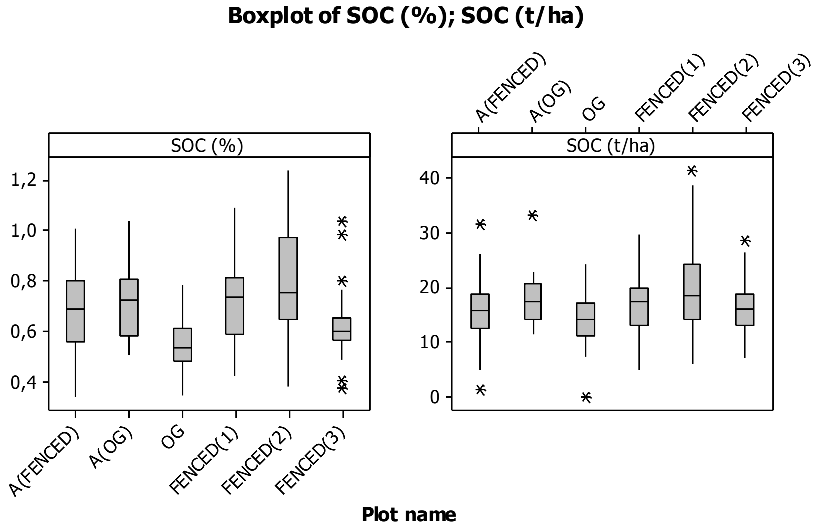

Fig.13. Boxplot of the variation and mean values of average (%) and total (t/ha) contents of SOC in the 100cm profile on; agricultural land (A(OG) & A(FENCED) compared to open-grazed areas (OG) and fenced pastures of different ages (FENCED (1), (2), (3)).

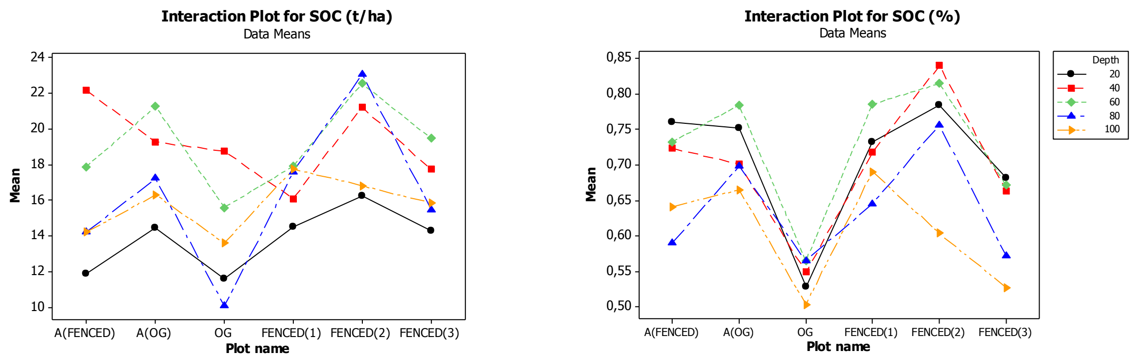

Fig.14. Interaction plots displaying content of SOC (% & t/ha) on agricultural land (A(OG), A(FENCED) compared to open-grazed areas (OG) and fenced pastures of different ages (FENCED), on different depth in the soil. Values of depth represent ranges from 0-20cm, 20-40cm, 40-60cm etc.

The SOC content did not change with age of cultivation on neither of the categories. A(OG) displayed higher mean values of SOC than A(FENCED) but the difference was highly insignificant (P=0,501 for SOC % and P=0,297 for SOC t/ha). In a pairwise comparison the average percentage of SOC on A(OG) significantly exceeded that of OG 0,7198 ± 0,1466% > (0,5455 ± 0,1076%) with P=0,017.

4. DISCUSSION

4.1. Study area and sampling methods

4.1.1. Site selection

My study was conducted in an area where farmers have voluntarily improved their land management by fencing, planting trees, creating micro-catchments and converting grasslands into cultivations (Makokha et al. 1999). Individual preferences for management practices have generated a diverse cultural landscape, with enclosures of various sizes, ages, grazing regimes and vegetation patterns (table 1-2 appendix I). The diversity is reinforced by a heterogeneous soil structure, with large textural variation over short distances. I aimed to design my sample so that the distance, and thereby the probability of equal soil conditions, was minimized between different categories of treatment (Open-Grazing, FENCED, Agriculture) and duration (FENCED(1), FENCED(2), FENCED(3)). Every choice of cluster implied a compromise between fulfillment of plot criteria and minimization of plot dispersal. In the end, both soil texture and bulk density proved to be surprisingly variable, not only within clusters but inside individual plots. A further reduction of data ranges through placement of plots was hence unreasonable within the frames of my study.

4.1.2. Bulk density

The BD is used for mass/area calculation of SOC and must therefore be estimated with approvable accuracy. A BD of 1,26 ± 0,37 g/cm3 is very reasonable in a sub-tropical soil and similar but less variable ranges have been reported by other scientists (Don et al. 2007; Hedemyr 2012; Verdoodt et al 2009). BD is a naturally shifting soil property, which normally increases with depth and decreases with duration of treatment (Don et al. 2007; Gifford & Roderick 2003; Baer et al. 2002). I found a seemingly random pattern of variation (fig. 4 & 5), which is likely to derive from environmental- and management diversity. It could, however, be partly due to discrepancies in the sampling method. In an article on soil sampling errors, Kulmatiski & Beard (2004) report significant deviations in BD values when different people sampled a soil, using the same method (coring). They also conclude that certain techniques, such as composite coring and quantitative pit, have a high tendency of sampling errors. I used three common techniques of BD sampling; the ”coring method” (but with a square sampler), the ”quantitative pit” and the ”augering method” (Blake & Hartge 1986;

Kulmatiski & Beard 2004; Aynekulu et al. 2011). Three people performed the augering, with occasional help from local farmers, while the square cores and quantitative pit were sampled by me alone. The cored BD in the top 5cm was consistently higher than in the first augered layer. This could indicate that the auger disturbed the upper part of the soil and lowering the BD (Aynekulu et al. 2011). The use of a sampling plate should have reduced this risk. The discrepancy can also derive from compaction of the soil inside the 5cm BD sampler, or be an effect of a hard surface crust that has a greater impact on the top 5cm than the augured 0-20cm layer. None of these problems can fully explain the BD-variation with depth and duration. My choice of method should not affect the liability of my results.

4.1.3. Sampling success

The soil auger proved to be an appropriate tool for soil sampling in my study area. This is also the method used in the same region by Touber (1992) and by the Africa Soils Information Service (AfSIS) (Aynekulu et al. 2011). My rate of sampling success was 100% down to 60cm. Below this level the auger was sometimes hindered by a dense layer of gravel, occasionally stones or bedrock/hardpan. I reached 80cm in 92% and 100cm in 71% of the sub-sampling sites. The reduced sample-size beneath 60cm does not essentially affect my final results, even when the bedrock was below 100cm, since deep SOC can be presumed to reflect historical conditions rather than recent fencing events. The auger sometimes hit stones above 60cm, in which the sample was retaken in accordance with Aynekulu (2011). In cluster 4 the soil was too rocky to use the auger. This is a known problem, recognized by e.g. Blake & Hartge (1986). I extracted the samples from a pit instead, in all plots except FENCED(1). The BD-values from cluster 4 averted from the others and were excluded in my calculations.

4.2. Fencing effect on SOC

4.2.2. Pastoral land

I obtained a SOC percentage of 0,68 ± 0,13%, averaged from all plots down to 100cm. These values slightly exceed those identified by Hedemyr Joelsson (2012), in an inventory of parklands in Burkina Faso. Her values of SOC, measured in a 10cm soil layer, increased from 0,43 to 0,68% with decreasing distance to trees. In my study, a clear difference in SOC percentage could be distinguished between open-grazed (OG) areas and the enclosures (FENCED) in the upper 0-20cm soil layer (table 4 appendix 1). Hence, a fencing effect can be expected. The variation was consistently high, however, and the pattern did not sustain when the data was transformed into t/ha (fig 9; table 3 appendix 1). Large ranges of SOC is likely a reflection of the observed diversity in my study area (discussed in 4.1.1.), and the variation is amplified in the mass/area unit, which was calculated using the BD. One or several of the following statements might be adequate as explanations:

1. *The SOC and BD are affected by the structural heterogeneity of the soil*. Burke et al. (1999) conclude, in an article about spatial variability of soil properties, that topography and microsite conditions explain more of the variation in BD than vegetation type and livestock management, if soil has been transported by wind, water or gravity. This is a likely scenario in my heavily eroded study area. The vertical variation in BD correlate in many cases with my notes about soil texture, which in some profiles changes from clay to sand or gravel in an unpredictable pattern. A clay-rich soil may additionally enhance the SOC content (Don et al. 2007). No such correlation was determined in my study.
2. *The SOC and BD are affected by other management practices than fencing*. The abundance of trees and shrubs are not significantly affected by fencing in my study area (Makokha et al. 1999). The root activity and decomposing debris of trees and shrubs provide SOC, and decrease the BD (Albrecht & Kandji 2003; Sanchez et al. 1989). This effect is enhanced by the presence of termites (Hedemyr Joelsson 2012).
3. *The SOC and BD reflect diversity in grazing intensity between the plots*. I failed to receive reliable data on the density of stock, grazing each sampled enclosure. However, the information about rotation strategies (table. 1 appendix I) indicates that the management strategy differs essentially between farms. The stock density on my plots is likely to reflect this individual management. The grazing pressure may additionally vary on a small scale, with parts of an enclosure (e.g. pathways and shadows beneath canopies) being extra exposed to trampling and treating (Greenwood & McKenzie 2001). I tried to avoid sampling apparent paths but included other variation.
4. *The SOC and BD reflect a patch-wise recovery of ground vegetation*. The BD in fig. 5 is more spread in FENCED(1), where the vegetation has recently started to recover, than in the older and more vegetated enclosures. It is plausible that patchiness in vegetation cover had a small-scale impact on the BD measurements.

I anticipated higher levels of SOC in the old enclosures than in the recently fenced. This is a development previously described by e.g. Verdoodt et al. (2009). According to VandenBygaart & Angers (2005), it is it difficult to distinguish management induced changes in SOC over less than five years, but I expected to at least detect an increase from young to old enclosures. My expectation was not met. I could not prove significant differences between any of the fenced plots. My middle-aged enclosures contained most SOC, followed by the recent. The old enclosures contrasted (although not significantly) with unexpectedly low levels of SOC, approaching the open-grazed areas. The results indicate a fencing-effect but cannot substantiate the hypothesis that SOC increases with duration of treatment. This does not mean that a correlation is unlikely. When the old plots (FENCED(3)) were excluded, I could distinguish a weak but positive regression between carbon and duration, indicating that duration of treatment has an impact (fig. 6).

I suspect that the plots in FENCED(3) have; (1) been mismanaged and degenerated due to e.g. generation switch, lack of attendance to the fence or overconfident use of the land, or (2) initially suffered from worse degradation of soil than the plots used in FENCED(1) & (2). During the field inventory I noticed signs of impaired management in some of the old plots. The vegetation cover was very patchy in cluster 1 (fig. 10). In cluster 1 and 5, animals grazed the land despite information to me about current period of relief. Both observations were however made on some plots in the other categories as well (fig. 10). A few old enclosures might hence be mistreated but that is unlikely to fully explain their low content of SOC. If the variation in SOC derives from original differences in site condition, this should be reflected in the deep layers of the soil profile (Hedemyr Joelsson 2012). My pattern of carbon variation is indeed consistent all the way to 100cm (fig. 9), although the impact of rehabilitation practice is usually restricted to the upper 10-20cm in similar studies (Don et al. 2007, Baer et al. 2002). Carbon can be transported deep into the profile by tree-roots, ants/termites or through cracks in the soil (Sanchez et al. 1989; Don et al. 2007). My SOC data did not correlate with tree density at any depth, and I find it hard to believe that these modes of transport affect the soil to a depth of 100cm in less than five years (fig. 7). In 1987, when the rehabilitation program was initiated, fencing was met by suspicion. The organization was offered highly degraded areas, which were improved with good result (Makokha et al. 1999). It is plausible that the subsequent enclosures were created on higher potential land to improve the carrying capacity of that land, and that fencing have been performed on the best unenclosed pastures since then.

4.2.2. Primary producers

If the significant difference between OG and enclosures is an effect of fencing, and not due to historical differences, this effect should be reflected in the biomass of primary producers as well. SOC is, as described in the background, incorporated into the soil through the growth and decline of photosynthesizing plants (Reynaldo et al. 2012). Increased sequestration of carbon thereby relies on improved production of vegetation biomass. The differences in vegetation cover in my study area are apparent in fig. 10, with bare ground in several OG plots.

The ground vegetation cover appears to be more affected by pastoral management than by duration of fencing (fig. 11). According to Verdoodt et al. (2009), the increase in vegetation cover is quickest during the first 6 years after fencing. This can explain why the vegetation in my study appears to have reacted to initial fencing, but not to the development from young to middle-aged and old enclosures.

The tree density was not affected by fencing, neither in my study nor in the evaluation performed by Makokha et al. (1999), and is likely to depend more on other actions, such as planting and cutting. It is more surprising that the tree density did not correlate with the SOC content. Studies by e.g. Nyberg & Högberg (1995), Hedemyr Joelsson (2012) and Albrecht & Kandji (2003) indicate positive relationships between SOC and closeness to trees. My plots might be affected by the production of grasses, rather than by trees. Nyberg & Högberg (1995) found that dense undergrowth of grass, in an area where grazers were excluded by fencing, could have a greater impact on the SOC content than some tree species. The contribution of carbon from trees in our area may be counteracted by canopy shadowing, which reduces the carbon sequestration performed by ground vegetation. Another possibility is that the abundance of shrubs was high in plots with few trees. This aspect was not considered in my study.

4.2.3. Cultivation of pastures

When grasslands are plowed and converted into agriculture the SOC content generally decreases (Reynaldo et al. 2012). This is due to a combination of enhanced aeration of the soil which increases the respiration of soil living organisms, and reduced input of organic matter since biomass is harvested. There are considerations, however, of whether fertilized cultivations on the contrary improve the soil organic input, on impoverished pastoral land in semi-arid Africa (Sanchez et al. 1989). Further studies in this area of research are inquired. In my study, both categories of maize-fields, (A(OG) and A(FENCED), contained equal ranges of SOC as the fenced areas, i.e. more than the OG-plots (fig. 14-15). This was true for both units of SOC (% & t/ha), but the difference was only significant in percent, and only in the upper parts of the soil. There was no significant difference between the maize-fields derived from fenced pastures (A(FENCED)) and those created on open-grazed areas (A(OG)). If the maize-fields, as I anticipated when designing my study, originate from areas with equal soil properties as OG and FENCED, then the A(OG) must have gained carbon during the years of cultivation while the SOC content in A(FENCED) has remained constant.

In the interviews about history of management the farmers reported that dung and/or DAP were added to all four A(OG) but only 4/6 of the A(FENCED). The fertilization can explain why the carbon content has not decreased with cultivation (Cebula 2013; Sanchez et al. 1989), especially when dung, containing both nutrients and organic carbon, was added. The farmers further informed about pro-harvest grazing, i.e. cattle grazing the stubble fields when the crops have been collected. Their manure adds supplement carbon to the soil. The addition of nutrients has probably affected the impoverished OG soils more than the improved soils inside the enclosures. More frequent fertilization of A(OG) fields might be the clue to why their SOC increased to the same level (or even higher) as in the A(FENCED) (fig. 12-13). It is however likely that the maize-fields were created on better soils than the pastoral enclosures and open-grazed areas. During the field study, the agricultural soil was consistently easy to sample, with few stones hindering the auger. A farmer presumably chooses the best possible soil when converting from rangeland to maize-cultivation. This hypothesis is supported by the fact that the average carbon content on A(OG) and A(FENCED) followed the same pattern through the entire soil profile (fig. 14). Cultivation of today's pastures might therefore result in reduction of SOC, if it is not prevented by addition of organic matter.

5. CONCLUSIONS

5.3.1. Choice of study area and method

- The study area is interesting for analysis of carbon sequestration under natural circumstances, but was diverse, with heterogeneous soil conditions and varying land-management. This variation was reflected in the results but might be reduced if confounding factors are included in the statistical calculations. I therefore suggest that further investigations of past and present management, and detailed inventories of vegetation and soil properties, are performed in the area.
- A sampling depth of 100cm is recommended, as the information about deep SOC was valuable for understanding previous soil conditions. The auguring-method was suitable for deep soil sampling, with a 100% sampling success to 60cm depth, 92% to 80cm and 71% to 100cm.

5.3.2. Sequestration of SOC

- The young and middle-aged enclosures contained a significantly higher percentage of SOC than the open-grazed areas, in the upper part of the soil. This, together with an observed increase of ground vegetation cover after fencing, indicates that more carbon is sequestered in the soil when a pasture is fenced. It is difficult to specify the extent of SOC increment, or how the sequestration capacity develops with duration of fencing, due to large variation in the data.
- The management categories I studied (OG; A(OG); A(FENCED); FENCED(1); FENCED(2); FENCED(3)) may have developed from unequal soil conditions. The oldest enclosures (FENCED(3)) were, according to Makokha et al. (1999), created on severely degraded soils. Successful rehabilitation may have led to subsequent fencing on the best available land, so that FENCED(2) and FENCED(1) had better initial conditions than FENCED(3). The remaining areas left are currently used for OG. Fertile and stone-free soils were presumably chosen as agricultural land.
- Fertilization of maize-fields is likely to counteract significant loss of SOC after conversion from pasture to cultivated land.

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2014:6 Författare: Björn Karlsson
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2014:7 Författare: Martin Karlsson
Jordbrukets och järnframställningens påverkan på skogsutvecklingen vid Eskilshult, en by med medeltida anor. – En studie baserad på pollenanalys

2014:8 Författare: Ragna Lestander
En utvärdering av de skogliga vattenplaneringsverktygen NPK+ och Blå målklassning med avseende på vattenkvalitet och vattenkemi

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