Lena Rathjen

MSc. Thesis

„Effects of Management Practices on Carbon Allocation in the Semi-arid Savannahs of the Borana Region, Ethiopia“

Supervisors
Prof. Dr. Folkard Asch
Prof. Dr. Georg Cadisch

In Collaboration with the University of Agriculture, Hawassa, Ethiopia and the International Livestock Research Institute (ILRI), Nairobi, Kenya

July, 2012

University of Hohenheim
Institute of Plant Production and Agroecology in the Tropics and Subtropics
Department: Crop Water stress Management in the Tropics and Subtropics (380c)
Garbenstrasse 13, D-70599
Stuttgart – Germany

This Master Thesis was funded by a scholarship of the **Eiselen Foundation - fiat panis** “For a world without Hunger”, Ulm, Germany

Abstract

In the semi-arid savannahs of the Borana region in southern Ethiopia, the majority of people lives semi-sedentary and depends on their livestock, mainly cattle, goats and camels, for income generation. Traditional grazing systems are endangered and have been partly destroyed by rapid population growth, structural changes, governmental intervention and extreme weather events. Livestock-based pastoral and agro-pastoral livelihoods are no longer sufficient to sustain food security and living standards under these circumstances.

With climate change being one of the most important topics in the 21th century, reducing CO_2 in our atmosphere has become a primary goal of international efforts.

One idea to overcome the poverty and vulnerability of the pastoralist communities in southern Ethiopia is to establish a system of payment for environmental services (PES) based on the reduction of carbon emissions and the carbon sequestration potential of semi-arid savannahs linked to different rangeland management practices.

The aim of this study was to assess the impact of seasonal grazing, in so called enclosures, areas that are only grazed during the dry period, and continuous grazing on above- and belowground carbon allocation. Aboveground biomass production and carbon stocks, belowground carbon stocks, soil parameters such as bulk density and carbonate content, species composition and habitus and stocking rate and carrying capacity were examined in 20 plots in a 10X10 km^2 area; five plots each for the respective management and vegetation type. The following types were distinguished in the area: Enclosures in grassland, enclosures in tree savannahs, year-round grazed grassland, and year-round grazed tree savannah. An analysis of variance (ANOVA) was used to describe differences in above-and belowground carbon allocation depending on vegetation and management type. It was shown, that all parameters, except for the total aboveground biomass production and the organic carbon allocation over depth were significantly influenced by the management type. Belowground carbon stocks were higher under continuous grazing, while seasonal aboveground biomass accumulation was highest in enclosures. Palatability of species and soil cover was significantly better in enclosures than in continuously-grazed areas. Species composition and habitus changed to more dicot and annual species with increasing grazing intensity.

The results on the variability of carbon stocks under different management practices help to develop a sustainable rangeland management system in this region and give some indication on the carbon sequestration potential.

Key words: Carbon allocation, Enclosure, Vegetation Types, continuously-grazed areas, Savannah, Species composition

List of Acronyms

C	carbon
°C	degree Celsius
cm	centimeter
ECG	Enclosure in Grassland
ECT	Enclosure in Tree Savannah
G	Grassland
Gt	giga ton
ha	hectare
kg	kilogram
km^2	square kilometer
m	meter
mm	millimeter
mG	mega gram = ton
m^2	square meter
N	nitrogen
PES	Payment for environmental services
SOC	soil organic carbon
SOM	soil organic matter
t	ton
T	Tree Savannah
TLU	Tropical Livestock Unit (250 kg)
BD	bulk density

Author´s Declaration

Me, Lena Rathjen, (born on the 9th of April 1987,matriculation number: 416979, University of Hohenheim) hereby affirm that I have written this Master Thesis entitled “Effects of Management Practices on Carbon Allocation in Semi-arid Savannahs of the Borana region, Ethiopia”, independently and entirely by myself.

All authors mentioned or quoted in this work have been cited and no work has been included in this thesis without the authors being listed.

I further affirm that this Master Thesis was not submitted in the framework of any other examination process.

I declare, here within, that I have transferred the final digital text document (in the format doc, docx, odt, pdf, or rtf) to my mentoring supervisor and that the content and wording is entirely my own work. I am aware that the digital version of my document can and/or will be checked for plagiarism with the help of an analyses software program.

Supervisor: Prof. Dr. Folkard Asch
Prof. Dr. Georg Cadisch

Thesis topic: Effects of management practices on carbon allocation in the semi-arid savannahs of the Borana region, Ethiopia

Semester: 4

Stuttgart ____________________________ Signature____________________________

Acknowledgements

This study has been made possible by founding of the Hermann Eiselen –fiat panis foundation. I am very grateful for that.

Many thanks go to Prof. Dr. Folkard Asch for his supervising and his support during my master thesis research. He gave me a free hand in realizing my ideas.

Special thanks go to my “old” ☺ and new working group 380a, especially to Prof. Dr. Georg Cadisch, Dr. Thomas Hilger and Dr. Frank Rasche. They gave me the opportunity to become familiar with science; but more important confirmed me that my study subject and my choice to go to university were the right way to go.

Thanks to the people, who made our analyses possible: Stefan Becker- Fazekas, Natalia Egana and Holger Fischer.

Always a help in explaining rudimentary statistical questions ☺: Thanks to Juan Carlos Laso Bayas and Karin Hartung.

We did not know each other before, but I am sure that there is nobody else I know who I could have lived, worked, eaten, drunk, sung, danced, slept next door with and actually spent 24 hours a day, 120 days in row, together. I love you, OK? Amäsägnalähu to Sarah Glatzle, Beatrice (Patrick) Breuer and Jan Pfister.

I would like to thank my friends in Ethiopia for making me feel a little bit like home and help as in so many ways: translator, translator on the phone ☺, interviewer, “guides through the ministry jungle”: Dr. Jürgen Greiling, Alem Greiling, Hasan Yusuf, Haileyesus Agonafir, Addis Shiferaw, Ejigu Ejara and Nizam Husen. Special thanks to our driver Tamerate, the “King of the Road”.

My parents have always been my great example. I thank you so much for letting me live my life, but answer my calls from around the world at any time and for any reason; to listen to my problems, support me and make me laugh.

My Soeur de Coeur, Sinje, and my “little” brother Jan-Ole: Thank you for all highly-sophisticated technical support ☺ and listening to scientific problems you were never really interested in…

Ishi, bac´ca, amäsägnalähu.

Index

List of Figures

List of Tables

List of Pictures

Background

This study was conducted within the framework of the *"Livelihood diversifying potential of livestock based carbon sequestration options in pastoral and agro-pastoral systems in Africa"* Project, a joint project of the BMZ, the ILRI (International Livestock Research Institute), the DITSL in Kassel (German Institute for Agriculture in the Tropics and Subtropics), the University of Hawassa, Ethiopia and the University of Hohenheim, Germany. The goal of the project is to identify the role of large-scale, extensively managed land-based livestock systems on carbon sequestration and to exploit the potential of these systems to reduce greenhouse gas emissions and mitigate climate change.

Grassland systems cover 3.9 billion ha, which is ¼ of the earth´s terrestrial area, and could, according to FAO (2009), sequester up to 2 GT CO_2 equivalents worldwide if appropriate management of vegetation and soil resources would be applied. Carbon is sequestrated in different pools: dead and alive biomass in the soil and living biomass and litter aboveground. Soil organic carbon is composed of living roots, soil microbial biomass and dead organic residues while living aboveground biomass in tropical grasslands comprises annual and perennial grasses, shrubs and trees.

Livestock production has been a major source of income generation and food security in the semi-arid savannahs of the Borana region, Ethiopia ever since.
Population pressure, increasing competition from other land uses (spread of cropping area) and ecological changes such as more extreme weather events (floods and droughts) and erratic rainfall have negative impacts on the pastoral production systems located in this area. The dependency on traditional livestock-based pastoral and agro-pastoral livelihoods under these circumstances is no longer sufficient to sustain food security and the most basic standard of living.
Range management, herd management and size may have exceptional impacts on carbon fluxes in the grass- and bush-land savannahs of southern Ethiopia.
To overcome poverty and vulnerability of these communities, diversification of income is of crucial importance. Payment for environmental services (PES) based on reduction of carbon emissions and carbon sequestration linked to livestock and various rangeland management practices could be one tool to diversify income of the vulnerable group of Borana pastoralists (Reid et. al, 2004).

This master thesis gives information on how much carbon is currently allocated in different vegetation types of the semi-arid savannahs of the Borana in Ethiopia and how different management practices can have an impact on the carbon allocation potential of this area.

1. Introduction

The Borana region covers approximately 95000 km² in southern Ethiopia, bordering to Kenya and Somalia in the south. The area is characterized by a semi-arid climate with low, erratic rainfalls between 300-900 mm/year with high temporal and spatial variability (Kamara, Swallow, & Kirk, 2004). The main ethnic groups are the Borana, who use the area that suffers under recurrent droughts and fodder scarcity with a mobile livestock production system.

Pastoral systems rely on extensive land use and require a low population density (Homann et al., 2008).

The rangelands of the Borana region are characterized by a high patchiness of alternating grasslands and perennial woody shrub and tree savannahs due to high variabilities in rainfall. In the 1980s, dry matter production/ha varied between 1.5-2.7 t, allowing an average stocking density of 0,235 TLU/ha (Tropical Livestock Units = 250 kg) according to Cossins and Upton (1987) (cited in Homann et al., 2008). In 2004, 1.05 TLU/ha were measured, an increase of more than 400 %.

With increasing population density; the annual population growth has risen from 1-1.3% in the 70s to 2.5-3% in the late 80s and the pastoralists are nowadays facing problems like land scarcity through competition with cropping area, diminishing fodder resources especially in degraded and over-grazed areas, water scarcity and institutional changes (Homann et al., 2008).

The installation of additional watering ponds since the 1970s has led to the construction of permanent encampments in former seasonal grazing areas. Herd movement has been drastically reduced, resulting into severe overgrazing of areas around permanent water resources. Furthermore, the official ban of burning grasslands led to an increase from 40% to over 52% of forb vegetation in the 2000s (Homann et al., 2008).

The Borana that traditionally have mainly kept cattle are increasingly forced to raise sheep, goats and camels to meet the changing conditions of the area.

Extension services propagated crop cultivation in former grazing areas leading to a further decrease of valuable grazing land. Finally, the Ethiopian government transferred about one third of the Borana rangelands including two important permanent wells, to the Somali administrative. Thus, inter-ethnic war and skirmishes between the two different tribes of the Somali and the Borana make the area unsafe and end up in an insufficient use of the remaining resources.

Institutional changes have destroyed many of the traditional management strategies of the Borana tribe. The livestock-based pastoral livelihood cannot fulfill basic requirements and food security any more. In these days, the Borana are in transition from pastoralism to a semi-sedentary grazing system where most of the members live in permanent villages while a few people look after the herds in the surrounding grasslands of the encampments. To overcome severe droughts and fodder shortages, some areas, so-called “enclosures”, that can easily be reached, are fenced and grass is saved for the dry season, especially for young or weak animals.

Nevertheless, overgrazing, droughts and competition for resources endanger the Borana and let most of them live in poverty.

To diversify their income and simultaneously protect the region against further degradation, a payment for environmental services system could be installed as for example indicated by Lipper et al. (2010).

“The emergence of markets for mitigation of climate change offers new possibilities for economic and ecological returns to rangelands in developing countries”, cited from Lipper et al., 2010 .

Improved rangeland management by avoiding land degradation and rehabilitation of degraded areas will result into increased above-and belowground biomass production and a higher accumulation of organic carbon in the soil. Furthermore, carbon emissions from agricultural land can be significantly reduced by a sustainable rangeland and herd management. Carbon markets could play an important role to offer an additional income possibility for the Borana pastoralists and would further help to induce the adoption of improved rangeland management practices.

The objective of this study was to identify different grazing management types of a representative 10x10 km² area in the region regarding to vegetation type, aboveground biomass production and carbon stocks, species composition and soil cover, belowground carbon stocks as well as soil parameters like pH, texture and bulk density. Interviews were carried out in order to provide additional information on local grazing management, stocking densities, animals kept and grazing constraints.

The resulting data of this pilot study will help to characterize different grazing management types in terms of above- and belowground carbon allocation. The data collected about vegetation- and management-related carbon stocks will offer important information for the further project; indicating initial attempts under which management rangeland productivity and incomes could be improved. The data on various soil parameters and vegetation characteristics will help to characterize the landscape of the Borana region and could be used to describe a larger area in terms of potential carbon stocks.

2. Hypotheses

Carbon sequestration plays an important role in reducing greenhouse gas emissions and mitigating climate change. Grass-, bush- and tree lands of the sub-tropic savannahs have a great potential to sequestrate carbon. Increasing population, concurrence from other land-use systems (cropping area) and extreme weather events such as droughts have negative impacts on the pastoral production located in the Borana region. Range and herd management as well as herd size influence the carbon-fluxes and -storage within the various vegetation types of this region. Information on how much carbon is currently stored in different vegetation types and under different grazing management practices can be used to estimate the potential of this region to sequestrate carbon and help policy makers to evaluate, decide on and implement payment for environmental services systems (PES) to improve the living situation of the people of this area. In this context, the following hypotheses were tested:

- Regarding carbon densities (on a t/ha basis) and the biomass production aboveground, the following ranking of C-stocks between vegetation types was assumed, deduced from the increasing complexity and management:
  grassland < enclosures in grassland < tree-grassland < enclosures in tree-grassland. Furthermore, grass production will be increased in enclosed areas due to seasonal grazing and increased resting times.
- In terms of grazing management, a relatively higher carbon density (on a t/ha basis) in the soil was expected in the temporarily restricted to grazing, enclosed areas than in the continuously grazed zones:
  Grassland and tree-grassland < enclosures in grassland and enclosures in tree-grassland, while more carbon is stored in the respective tree savannah as the structure is more complex
- Organic carbon densities are supposed to decrease with increasing soil depths along a one meter deep auger sample. As enclosures are only grazed during the dry season, the vegetation can grow without hindrance during the rainy season. Therefore, the plant can develop better than a plant that is immediately grazed again. It is expected, that organic carbon fractions are higher in deeper soil layers in enclosed areas than in continuously-grazed areas.
- The grazing management (enclosed <-> continuously- grazed area) influences the species composition and the habitus and therefore the carbon stocks of the different vegetation types.

2.1. Objectives

The Borana region represents one of the last big connected grazing areas of the world and plays an important role in carbon storage and the mitigation of climate change. The region has been officially announced as an area only suitable for grazing; cropping has been forbidden by government. Nevertheless, population pressure and long drought periods often accompanied by animal deaths and famines force the pastoralists of the region to have fields and grow cereals to survive harsh periods and stay independent from food price increases and deliveries of relief supplies. In search of an alternative to protect this area from destruction and finally also to preserve the lifestyle and culture of the ethnic groups of the Borana region, the carbon allocation potential has to be analyzed in order to establish protection measures for this region and offer second income possibilities for the pastoralists. Yet, as a first step, the potential and the status-quo of the C-stocks in the Borana region have to be evaluated as knowledge about biomass and carbon stocks is of crucial importance for estimating carbon fluxes and establishing clean development mechanisms. Due to a lack of primary data, the main objective of this study was to differentiate between several vegetation types and evaluate their carbon sequestration potential under varying management practices.

Therefore, specific objectives of this study were to:

- Identify the most relevant vegetation types of this area
- Identify the most relevant grazing management types of this area
- Conduct interviews to describe differences in grazing management
- Describe these vegetation and grazing management types in terms of species composition and structure
- Determine input parameters required to estimate the aboveground and belowground carbon stocks of each vegetation and management type
- Destructively measure organic matter and carbon content of the soil
- Destructively measure aboveground biomass production
- Add up different carbon stocks (above- and belowground) and thus derive potential carbon stocks for each vegetation and management type

3. Literature Review

3.1. The Carbon Cycle

The Carbon cycle describes the fluxes of carbon between the various carbon sinks; namely the atmosphere, the oceans, the soil organic matter, the terrestrial plants, the marine sediments and sedimentary rocks and the fossil fuel deposits (Pidwirny, 2006).

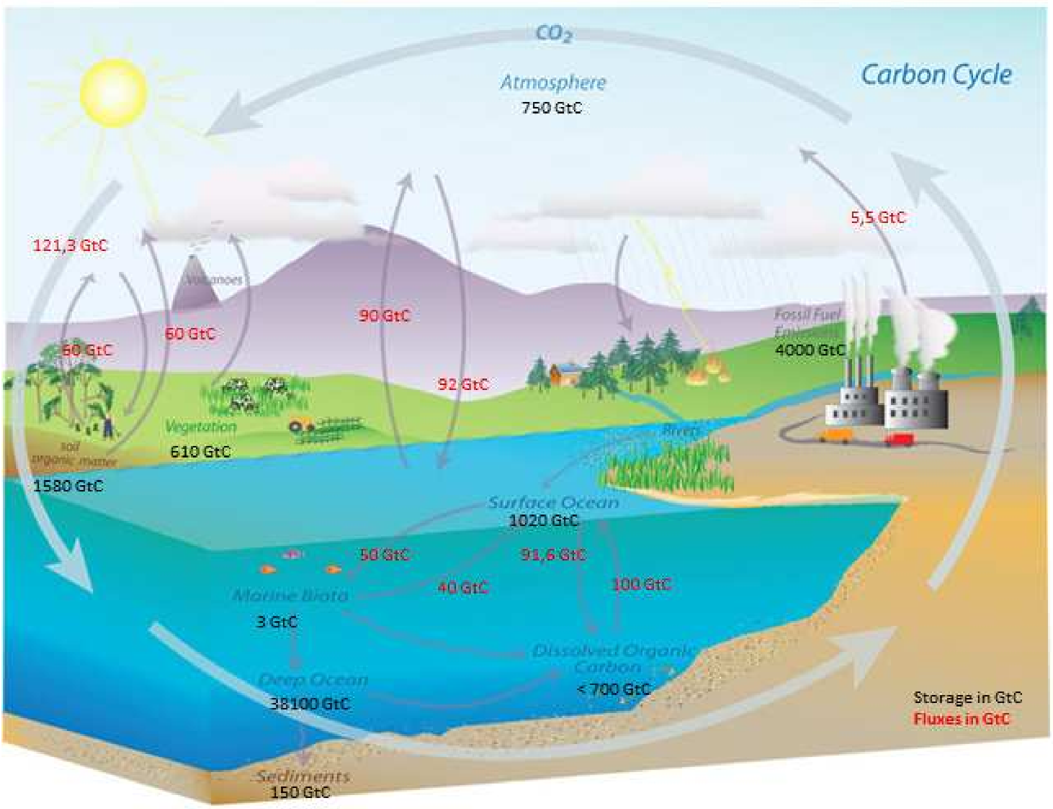


Fig. 1: **The Carbon Cycle**
changed after
http://www.esrl.noaa.gov/gmd/outreach/carbon_toolkit/images/carbon_cycle.jpg &
http://upload.wikimedia.org/wikipedia/commons/thumb/8/82/Carbon_cycle-cute_diagram.svg/460px-Carbon_cycle-cute_diagram.svg.png

In other words, it is a biogeochemical cycle among which carbon is exchanged between the biosphere, pedosphere, geosphere, hydrosphere and atmosphere of the earth. Carbon is the fourth most abundant element on earth, after Hydrogen, Helium and Oxygen and because of its ability to form many bonds, anchors all organic substances, from plants to DNA. There is a fixed amount of carbon in the earth system; annual and long-term fluxes do not change the amount of carbon but the distribution among the different pools.

One can distinguish between the slow and the fast carbon cycle: carbon takes 100-200 million years to move between rocks, soil, oceans and the atmosphere.

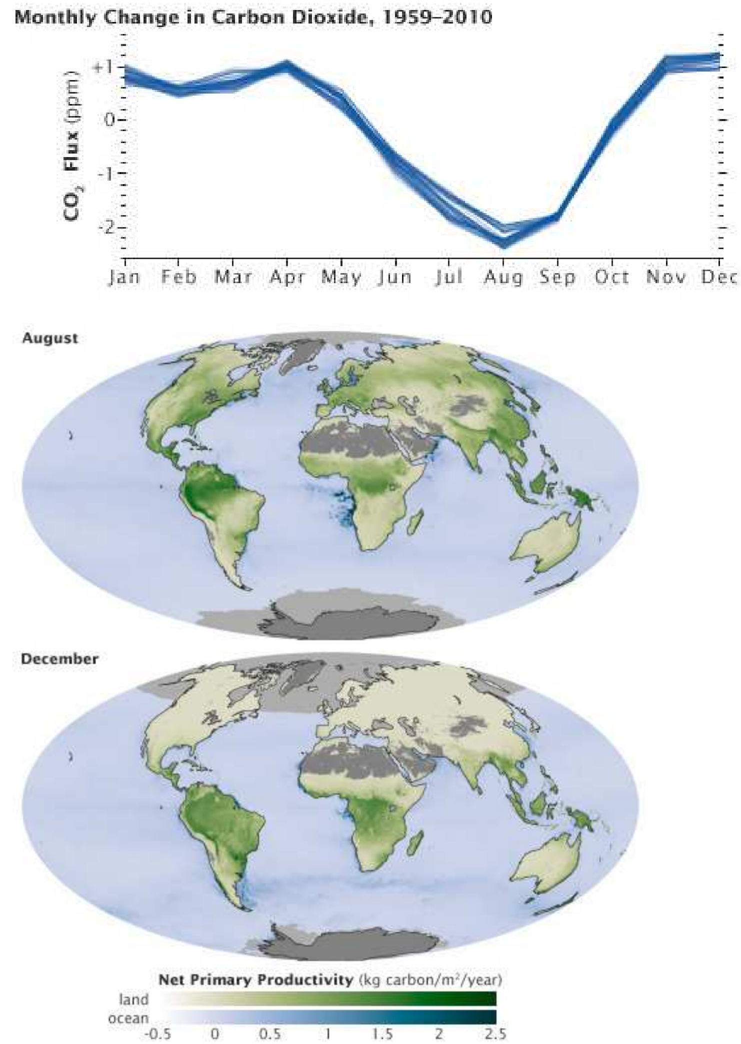


Fig. 2: World carbon flux over the year and net primary productivity (kg carbon/m²/year) of the earth in 2010 (http://earthobservatory.nasa.gov/Features/CarbonCycle/printall.php)

The fast carbon cycle is measured in a lifespan and describes the movement of carbon through the biosphere (Riebeek & Simmon, 2011). Photosynthesis plays a major role in these processes. Terrestrial plants and phytoplankton in the water use atmospheric carbon dioxide and water to form carbohydrates and oxygen (Fig. 3). If plants need energy to grow, they break down the carbohydrates. Animals and human-beings eat plants for the same reason. Furthermore, organic material like wood or charcoal is burned to gain energy. In the end of the growing season, plants and other living organisms die and decay.

In all four processes, carbon dioxide is released to the atmosphere. The fast carbon cycle is closely connected to plant life so that the growing season can be seen by the way carbon dioxide fluctuates in the atmosphere. During springtime in the northern hemisphere, plants start growing and the amount of carbon dioxide in the atmosphere decreases (Fig. 2). During wintertime, when plants decompose, carbon dioxide is released to the atmosphere again.

The amount of biomass produced in the northern hemisphere outweighs the seasonal

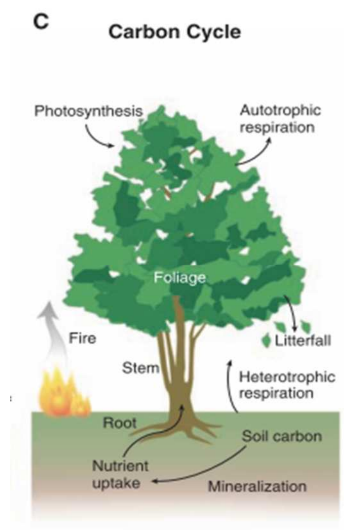


Fig. 3: The Carbon Cycle in Plants (changed after G. Bonan, 2008)

vegetation of the southern hemisphere by far so that carbon fluxes over the year are mainly determined by seasonal changes in the northern hemisphere.
Climate change, connected to global warming between 3-3.5°C on earth, will lead to increased plant productivity in some regions where growing season is positively affected and CO_2 fertilization might improve biomass production of many species. Whereas the semi-arid savannahs of Ethiopia will suffer from longer dry periods and shorter growing seasons respectively so that rangeland productivity may even decrease (Bunning, 2009). Additionally, global warming can even induce a faster decomposition of current carbon pools in the soil.

3.2. Carbon Pools in the Soil

Approximately 1580 Gt organic carbon and 950 Gt inorganic carbon are currently stored in the soils worldwide (Lal, 2008). The inorganic carbon pool consists of elemental carbon and carbonate minerals such as dolomite or gypsum. Primary carbonates are derived from weathering parent material such as the before-mentioned dolomite. Secondary carbonates develop when atmospheric CO_2 reacts with Ca_{2+} or Mg_{2+} brought into the system by fertilizer or irrigation water. A pH between 7.3- 8.5 favors these processes as well as decreasing water contents. Secondary carbonates occur mainly in semi-arid and arid areas.
Soil organic matter (SOM) describes the sum of all organic-carbon containing substances in the soil (Schnitzer, 1991). SOM has a chemical, biological and physical influence on the soil. In the soil structure, SOM plays and important role and provides soil aeration and moisture movement. Chemically, it can build metal-organic complexes with clay-minerals and therefore acts as a storing block for nitrogen, phosphorus and sulfur. N-fixing bacteria live off SOM, and it further enhances plant growth and plant nutrient uptake.
The soil organic carbon pool comprises of highly active humus and inert charcoal. Mainly three components form the soil organic carbon pool: plant and animal residues like roots or litter at different stages of decomposition, substances derived microbiologically and /or chemically from the breakdown products and the bodies of live micro-organisms and small animals and their decomposing products. Non-humic substances still contain carbohydrates, amino-acids or proteins and are relatively easily degraded in soils. Most of the soil organic matter consists of humic particles, that are partly aromatic, hydrophilic and do not have any recognizable chemical characteristics anymore. They are very resistant to chemical and biological degradation (Schnitzer, 1991). Hoyle et al. (2006) speak of the labile, the medium-term and the stable soil organic matter pool: The labile pool consists of fresh residues from plant roots and microbes and turns over in less than five years. Tiessen & Shang (1998) speak of

coarse, light material that is > 50µm that is still actively decomposed. The medium-term pool degrades within 20-40 years and results from chemically protected residues. Humus and charcoal belong to the stable carbon pool and need 100- 1000 years to degrade. This pool is important for long-term nutrient cycling and influences the cation exchange capacity, bulk density and water infiltration rate into the soil (Tiessen & Shang, 1998). The labile pool plays a major role when speaking of short-term soil fertility issues as the amount and the quality of labile carbon influences the mass and the activity of N-producing micro-organisms in the soil.

Plant biomass in the soil has a C:N:P ratio of 500:10:0.6. Decomposers mineralize the carbon, respire CO_2 and make nitrogen and phosphorus available for plants. Soil organic matter remains, consisting of plant material and dead decomposers, with a C:N:P ratio of 100:10:1 (Tiessen & Shang, 1998).

A C/N ratio below 22:1 supports the fast degradation of SOM by microbes. Higher ratios lead to net immobilization of nitrogen. With increasing state of decomposition, the C/N ratio decreases, so that the residues become more nutrient-rich. High C/N ratios at the beginning therefore also lead to slower decomposition rates (Hoyle et al., 2006) and influence the distribution of soil carbon into the stable or the easily degradable pool.

Tropical soils have much higher decomposition rates than temperate soils due to higher and more stable temperatures and activities of macro-fauna, i.e. termites (Tiessen & Shang, 1998).

In humid climates, plant production and soil organic matter content increase respectively. But also the decomposition rate is influenced positively and is relatively higher in humid climates than the SOM production. In sub-humid and semi-arid climates, precipitation is the limiting factor for plant production and decomposition, whereas the response of plant growth to precipitation is relatively greater than the response of decomposition (Jobbagy & Jackson, 2000). Therefore, carbon has a relatively longer resting –time in dry soils of semi.-arid regions than in wet areas (Bunning, 2009).

Additionally, soil organic carbon stocks can be influenced by the soil texture. The availability of Ca_{2+} cations in the soil leads to a significant accumulation of SOC. Especially fresh organic matter can be coated by the highly reactive $CaCO_3$ and mineralization is effectively slowed down (Krull et al., 2000). A similar mechanism has been observed in soils derived from volcanic ash, where Al_{3+} cations bound to organic carbon. Clayey soils as well tend to accumulate carbon (also stated by Jobbagy & Jackson, 2000) Saturated with multivalent cations, clay molecules flocculate and reduce the exposure of absorbed carbon to mineralization. Furthermore, the pore volume should exceed three mm to allow microbes to enter the organic matter to mineralize it. Therefore, SOM mineralization occurs much faster in sandy than in clayey soils or in compacted soil horizons. Thus, soils have a specific “protective capacity” and only after the soil is saturated, soil organic carbon will be available for degrading micro-organisms.

Soil respiration

Soil respiration includes plant root, rhizosphere, microbe and soil fauna respiration. It can either occur by plants, when they break down carbohydrates to release energy or by heterotroph microbes or soil organisms that feed on plant material to gain energy. Both processes release CO_2 (Taneva et al., 2006). Michelsen et al. (2004) state that soil respiration depends on water availability in seasonal, tropical savannahs.

During dry season, the microbial biomass plays a fundamental role in retaining nutrients when plant activity is low. To reduce competition with plants for nutrients during rainy season, soil fauna like nematodes, graze on the microbes and lead to increased soil respiration. Furthermore, plant root growth and the increased uptake of nitrogen in the form of NO_{3^-} lead to soil respiration (Mlambo et al., 2007).

The soil microbial respiration is controlled by the soil carbon pools (Fang & Moncrieff, 2005). With increasing soil depth, soil organic carbon becomes less decomposable; accordingly, the microbial population and activity decrease, negatively affecting soil respiration.

3.3. The Role of Vegetation Type in Organic Carbon Allocation

Approximately 20% of the world´s terrestrial surface is covered by savannahs. They are characterized by a dynamic mixture of woody and grassy species; there are dense tree and bush savannahs as well as grasslands and grassy areas with scattered or more evenly distributed trees (Bond & Midgley, 2000). Herbivory is influenced by the balance between grass and trees; grassland can be grazed by cattle while a woody area is preferably used to keep camels and goats. The change from a tree to a grass savannah and vice versa is associated with a change in carbon stocks as they are a result of the balance of in- and outflows to the carbon pool. Furthermore, each vegetation system has a "carbon-carrying-capacity", defined by the nature of vegetation, the precipitation and the temperature (cited from Gupta & Rao, 1994 in Guo & Gifford, 2002). Above- and belowground allocation patterns and vertical root distribution of different plant species and vegetation types may therefore have a big impact on relative distribution of soil carbon with depth (Jobbagy & Jackson, 2000).

Grasses have a dense, fibrous root system, which can locally explore the soil more intensively for nutrients than trees. On the other hand, trees have a deeper and more wide-spread rooting system that extensively finds high resource patches in the soil (Bond, 2008).

Grasses can achieve similar or even higher soil carbon stocks than forests as they have high productivity and turnover rates and continuously cover the soil so that soil temperature and accordingly decomposition of matter are reduced (Brown & Lugo, 1990). Grasses´ main rooting system is allocated to the 15 cm top layer of a soil (Snyman, H.A. 2005) and grasses´ average living root biomass under a pasture is 570 g/m^2, meaning 5.7 t/ha (Rao, 1996 cited in Cadisch et.al., 1998). Yakimenko (1998, cited in Guo & Gifford, 2002) states a high accumulation of soil organic matter in grasslands just after deforestation due to a more intensive humus formation by the fine grass roots in the top soil layers. Furthermore, the dense rooting system inhibits water and gaseous exchange so that decomposition rates are negatively affected. Also Bunning (2009) stresses that grasses store considerably more carbon in soils than in their vegetation respectively. Fisher et al. (1994) state that deep-rooting grasses play a major role in SOC allocation in soils. Savannahs in South America were improved by introducing deep-rooting, perennial *Brachiaria humidicola* species; these areas yielded 25 t/ha SOC more than conventional savannahs.
Opposite findings were published by Mlambo et al. (2007) about SOC allocation under trees in African savannah woodland. Soil organic carbon increased significantly under tree cover, probably due to annual litter fall and increased abundance of shade-tolerant grass and herb species. The findings of another study by Belsky & Amundson (1998) go along with these results.

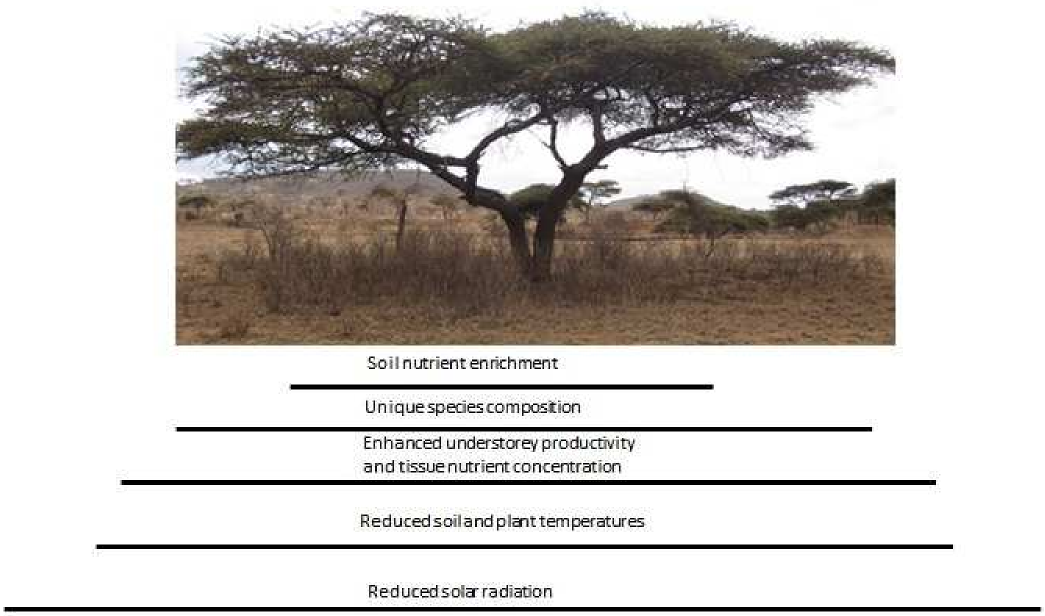


Fig. 4: Zones of altered characteristics surrounding an isolated *Acacia tortilis* tree in the Borana region (after Belsky and Canham, 1994)

Significant higher contents of organic matter, Ntot, calcium, potassium and phosphorus were observed in soils under trees than in interspaces (Fig. 4). Hudak et al.

(2003) found that litter of areas under woody vegetation in South Africa had higher N values and a lower C:N ratio, resulting in increased SOC allocation potential as residues could be easier decomposed.

Trees can take up nutrients from interspaces and subsoil layers and release them to below-crown soils via leaf and stem litter (Kennard & Walker, 1973; Vetaas, 1992; Campbell et. al., 1994). Furthermore, wind- and rain-borne particles can be deposited in tree crowns and stems and increase organic matter amounts under trees (Kellman, 1979; Alstad & Veetas, 1994). Wildlife and birds are attracted by the several benefits of trees, such as fruits and shade and their deposits allocate nutrients to the surroundings of the tree that have been gathered in a larger area (Christie, 1975; Weltzin & Coughenour, 1990). Trees also have several physiological features. Virginia & Jarrell (1983) stressed the symbiotic and associative nitrogen fixation function of trees, leading to higher nutrient mineralization rates and availability so that growth of associated plants was improved for the benefit of higher carbon allocation. Furthermore, the deep rooting systems of the trees enable a nutrient shift to deeper soil layers, leading to improved nutrient cycling. Often, the roots have lingo-tubers that enhance the root: shoot ratio of savannah trees (Grace et al., 2006). Finally, respiration and evapotranspiration under trees decrease, improving water retention and availability (Vetaas, 1992; Joffre & Ramball, 1988) and enhance herbaceous vegetation growth. Shading further leads to lower temperatures and less decomposition processes in woodlands (Morris et. al, 1982).

When it comes to quality of the carbon inputs, one factor that controls decomposition is lignin. Thus, long-term storage of SOM and SOC is better under tree areas as their residues contain larger amounts of lignin than grass residues respectively (Jobbagy & Jackson, 2000). Furthermore, species composition can influence carbon storage. As mentioned in Chapter 3.2., mineralization and decomposition of organic matter depends substantially on C:N ratios. Grasslands often contain varying amounts of legumes. Legumes derive N_2 from the atmosphere and their plant residues consist of high amounts of nitrogen (low C:N ratio), enhancing mineralization and nutrient availability for grasses. On the one hand, biomass production of grasses can noticeable increase while on the other hand, overall residues of the system mineralize more quickly and carbon losses increase as SOM is relatively fast decomposed. Legumes have a positive impact on the soil macrofauna; termites and earthworms mix the soil and translocate organic matter particles to deeper layers, leading to a shift of nutrients to subsoil regions (Cadisch et. al, 1998). Many trees in the Borana region also belong to the family of *Mimosideae* and can fix nitrogen. Therefore, litter and plant residues have similar effects on mineralization rates.

Simultanously, trees play a major role in aboveground carbon allocation. The high amount of aboveground biomass in tree vegetation stores approximately 45% of the terrestrial carbon (Bonan, 2008). In tropical savannahs worldwide, the aboveground carbon stocks vary from 1.8 t C/ha in grasslands to 30 t C/ha under a substantial tree cover (Grace et al., 2006). This findings were further verified by Jobbagy & Jackson (2000): Approximately 50% of the total belowground SOC in the first one meter of soil was found in the 20 cm top layer under tree vegetation, whereas only 33% of total SOC was allocated here under grassland. This can be explained by the root distribution of the different vegetation types: Trees have a relatively higher aboveground biomass allocation than grasses; the root: shoot ratio of grasses is 3-4 on average. Hence, the rooting system of trees are less important sources of organic matter than grass roots as most of the tree root system lives for many years and the annual turnover is low (Guo & Gifford, 2002). The substantial carbon stocks in grassland on the other hand are located belowground in the roots and in the soil (Jones & Donnelly, 2004).

As stated above, vegetation cover and species composition plays a substantial role in carbon and nutrient allocation in the soil. Grasslands have a very high productivity and fast turnover rates and contribute directly to the SOM pool. Trees enhance nutrient cycling across soil layers and improve microclimatic conditions and physiological traits in their surroundings, leading to a better growth performance of associated plants. Questions are whether grasslands or tree savannahs significantly influence organic carbon allocation under different management types?

3.4. The Influence of Grazing on Carbon Allocation and Storage in the Soil

“Rangelands are estimated to store up to 30 % of the world´s soil carbon in addition to the substantial amount of above-ground carbon stored in trees, bushes and grasses”, cited from Bunning (2009). Grazing can affect mineralization rates of soil organic matter and therefore influences soil carbon storage in rangelands. Through soil and vegetation restoration by a sustainable grazing management, carbon storage capacity can be positively influenced.

Grasslands store only a little amount of carbon in the aboveground vegetation while the most considerable amount is allocated in the soils (Fig. 5), as already mentioned in Chapter 3.3.

Biome	Area in Km^2	GT C in Vegetation	GT C in Soils	Total GT C
Tropical savanna	22.5	66	264	330
Temperate Grasslands	12.5	9	295	304
Desert-semi-desert	45.5	8	191	199

Fig. 5: Stocks in Vegetation and 1 meter depth of soil (Watson et al. in Bunning, 2009)

Tropical savannahs have a net primary productivity that ranges from 1 -12 t C/ha and year, on average 7.2 t C/ha/year, while the lower values are found in the semi-arid, extensively-used savannahs of Africa. If savannahs are used sustainably, they can accumulate considerable amounts of carbon in the soil (Grace et al., 2006).
Herbivores may alter above- as well as belowground biomass and carbon stocks in a savannah system. Grazers and browsers feed on grasses, bushes and trees and reduce growth, survival and fitness of most plants, leading to decreasing amounts of above-ground biomass and related carbon stocks (Sawadogo et al., 2005; Tanentzap & Coomes, 2011). Piñeiro et al. (2010) speak of changes in net primary productivity of vegetation under grazing.
Similarly, belowground biomass of plants might be reduced as it is closely linked to photosynthesis rate and assimilates of aboveground organs of the plant (Litton, Raich and Rayn, 2007 cited in Tanentzap & Coomes, 2011). Carbohydrates of the root system will be re-allocated to the aboveground organs to allow shoot re-growth and restoration of photosynthetically active tissue (Gao et al., 2008). Consequently, also less assimilates are allocated to the roots as aboveground biomass is disturbed and reduced (Wang& Ripley, 1997 cited in Chen et al., 2006) (Fig. 6).

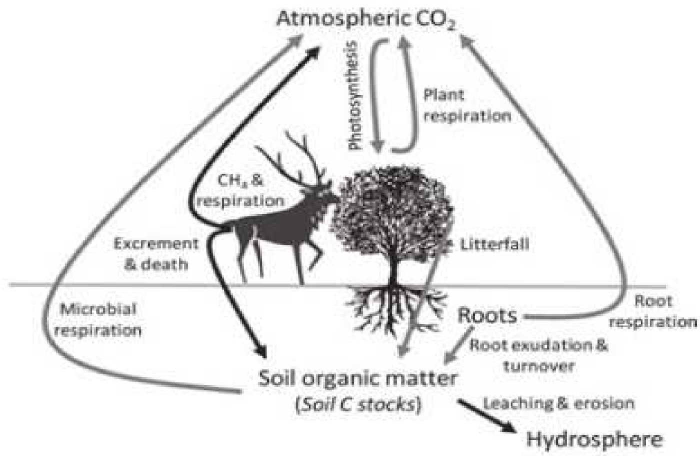


Fig. 6: Effects of herbivores on carbon cycling in terrestrial ecosystems. Lines show fluxes that are supposed to either increase (black) or decrease (grey) in response to herbivory. (after Tanentzap & Coomes, 2011)

Yet, grazing impacts on carbon stocks are much more complex than mentioned above.
Consumption of aboveground biomass not only leads to a decrease of living material but also to a reduction of plant litter quantity and quality (Tanentzap & Coomes, 2011). Plants being adapted to herbivory shift to low quality leaves that often are more lignified and less decomposable by microbes. Thus, soil organic matter pools and carbon allocation can rise under grazing. Contrary, Mc Naughton et. al (1984) (cited in Tanentzap & Coomes, 2011) found that plants can increase their tolerance to animal

feeding by changing their leaf structure into more blades and less sheaths. This plant litter has a high quality and is highly decomposable by micro-organisms resulting in smaller SOC stocks (Semmartin & Ghersa, 2006 cited in Tanentzap & Coomes, 2011).

Some grasses need moderate animal grazing to reach optimal productivity rates and therefore developed several mutualisms to attract herbivory on the one hand and be resistant towards grazing on the other hand. Mechanisms are: High palatability, increased shoot production, basal meristems and vegetation growth and reproduction (Owen, 1980; Owen and Wiegert, 1981,1982 cited in Belsky, 1986). Clipped grasses in a trial in Tanzania showed an even better growth performance and above-ground biomass production than unclipped grasses respectively (Belsky, 1986). In Panama, grazing enhanced the aboveground productivity of grasses; similarly, ecosystem respiration was reduced as aboveground biomass was regulated by herbivores (Wolf et al., 2011). Also Bunning (2009) observed that grasses grew more vigorously under continuous grazing and produced a healthy root system that fed the soil biota.

Belowground biomass production has been observed to increase under grazing pressure too. Li et al. (2011) found a significantly higher C and N storage with increasing grazing intensities in an alpine meadow. They observed an enhanced below-ground biomass allocation through excessive root growth.

Furthermore, grazing can alter soil respiration rates. Animal excretion can change soil nutrient cycling processes and locally leads to increased soil nitrogen amounts, altering the C/N ratio of SOM and resulting into higher SOM decomposition (Belsky, 1986; Olofsson & Oksanen, 2002, cited in Tanentzap & Coomes, 2011). Piñeiro et al. (2010) found contrary results as C/N ratios of SOM under grazed sites increased, limiting N resources and reducing SOM decomposition in grasslands.

Indirectly, herbivores also increase the activity and biomass of soil microbes. Grazing induces an increase in root exudation of adapted plants. Carbohydrates are transferred to microbes, increasing their activity and soil respiration respectively (Frank & Groffman, 1998, Ayres et. al, 2004 cited in Tanentzap & Coomes, 2011).

Also Olsen et al. (2011) observed enhanced microbial biomass and activity under grazing, similarly also more root turnover and root exudation rates. In the papers stated before these processes automatically led to more soil respiration, whereas CO_2 respiration rates did not significantly change under grazing in a temperate salt marsh. However, significantly more C was allocated to the microbial biomass pool, being immobilized and transferred to the medium to long C storage pools in the soil. Therefore, grazing slowed down the turnover of microbial biomass and significantly altered the longevity of C in the soil and the utilization of carbon in the microbial community.

Through reduction of soil cover and plant litter and increased soil compaction through trampling, herbivores accelerate soil erosion and leaching resulting into a further reduction of soil organic carbon stocks (Wood &Blackburn, 1981, cited in Tanentzap &

Coomes, 2011). Similarly, reduced soil cover also enhances soil temperatures and thus soil organic matter decomposition (Sawadogo et. al, 2007 cited in Piñeiro et al., 2010). Finally, less soil cover can also result into decreasing water levels in upper soil layers and encourage bush and tree invasion in former grasslands (Graz, 2008 cited in Tanentzap & Coomes, 2011).

Grazing impacts on soil organic carbon allocation and storage are various and sometimes contradictory. Grazing can either lead to higher aboveground and belowground vegetation growth or reduce biomass production. Consequently, also organic carbon allocation varies under herbivory. Simultaneously, grazing also changes soil respiration rate and cover, leading to changes in SOM decomposition and allocation. Whether grazing intensity and period of time can have an impact on carbon allocation and aboveground biomass composition and production will be investigated in this master thesis.

4. Materials and Methods

4.1. Study area

The study was carried out between August and December 2011 in the Oromia province, Borana region, Yabelo district in southern Ethiopia (Fig. 7).

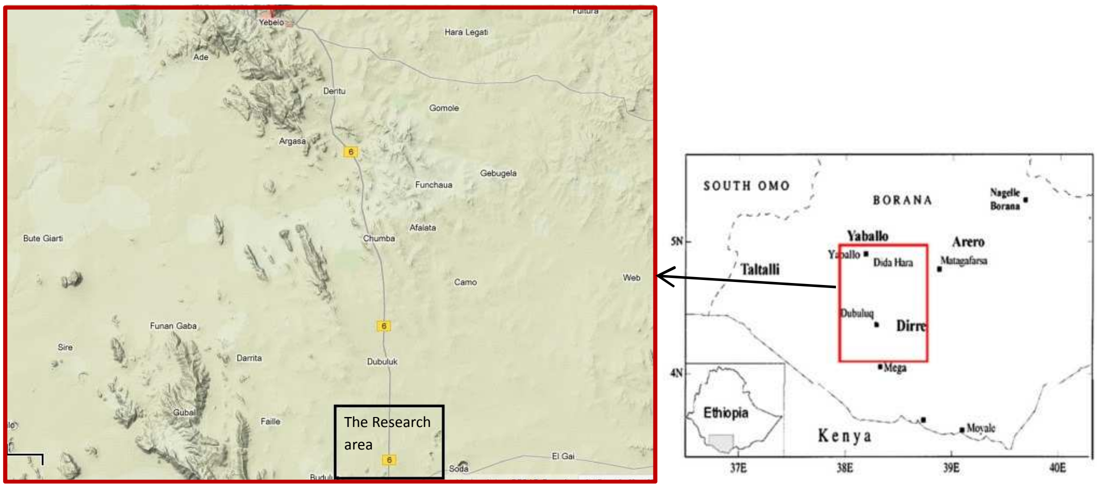


Fig. 7: Map of the Research Area in Southern Ethiopia, between Yabello and Mega in the Borana Region
http://www.ganeandmarshall.com/images/map/Ethiopia.jpg%3Bjsessionid=B5F42B7A0E9411EBE1CEC60B5E756EA6 & changed after www.google.de/maps

The research area was defined by a 10x10 km² square (NW: N4°16.682/E38°15.634; NE: N4°15.028/E38°20.853; SW: N4°11.491/E38°14.058; SE: N4°9.868/E38°19.220) between the cities of Dubuluk/Medecho in the north, Soda in the east and Mega in the south.

The Borana region covers 95000 km² of area in southern Ethiopia, having 350000 - 500000 inhabitants and providing grazing grounds for more than one million cattle, sheep, goats and camels (Homann et al., 2008).

The landscape is characterized by gently undulating hills and ranges at altitudes between 1000-1500 m. The savannahs are dominated by tropical vegetation; grasslands alternate with perennial herbaceous and woody plants.

The Borana pastoralists specialized on extensive cattle-keeping in a semi-sedentary grazing system and explore their rangelands in seasonal patterns. Permanent water is limited and can only be found in a cluster of deep wells distributed among the area. Although crop production is officially illegal (Appendix I, questionnaire), 92% of the Borana pastoralists rely on both crop and livestock production while 8% live from livestock production only (Solomon et al., 2007). Main crops cultivated are maize and haricot beans, more seldom are wheat, sorghum, barley and tef.

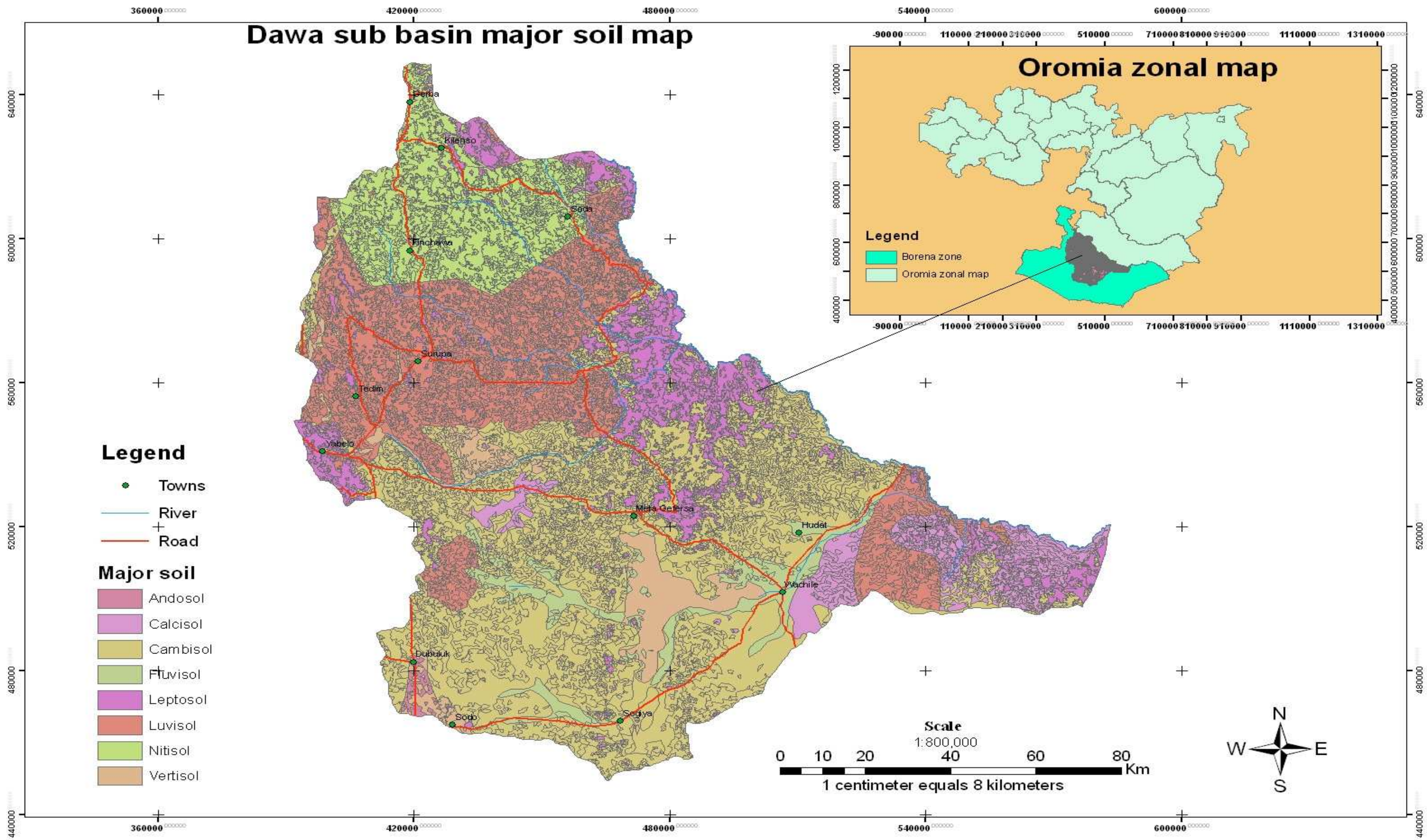
4.1.1. Soils

The research area was located within the Dawa sub basin area, found in the Borana zone, with a size of 1740370 ha.

Main geological formations in that area are volcanic basalt and tuff as well as quaternary deposits like alluvial deposit and alluvial in-situ weathering rock. Seldom, Precambrian basement complex rocks (consisting of granite, gneisses and magmatite) occur. Important for soil development is the parent material. Basaltic formations break down to clay minerals resulting into clayey textured soils. Granite and gneiss parent material consists of silizium molecules and results into more sandy and loamy soils (Oromia pastoral area development commission, Soil survey report).

The soils of the research area mainly consisted of Cambisols, Calcisols and Vertisols, whereas Vertisols were found in the depressions and Calcisols rather in higher located areas.

Vertisols are typical soils of the seasonal tropics and subtropics, especially in regions with erratic rainfalls and changing rainfall amounts. They have of high amounts of loam and are quite fertile, because they consist of easily degradable minerals and the high clay content leads to a good storage capacity of the soil. The natural vegetation is grasses and trees. Cambisols are relatively young soils at the beginning of soil formation. They are typical for the temperate zones, but can be found in the tropical regions associated by mature soils and under severe erosion incidents. They are quite fertile. Calcisols are wide-spread in arid and semi-arid environments of the tropics and subtropics on highly calcerous parent material. Under natural conditions, they are rather unfertile, because of a substantial secondary accumulation of lime. The natural vegetation consists of xerophytic shrubs and trees and they are mainly used for grazing.



Fig, 8: Map of soil types (Oromia Pastoral Area Development Commission: Borana Land Use Study Project, Soil Survey Report)

Soil types

Table 1: Soil types of the examined enclosures and continuously- grazed areas in the Borana region, Ethiopia (EC-G= Enclosure in Grassland, EC-T = Enclosure in Tree Savannah, G= Grassland, T= Tree Savannah; Numbers 1-5 explain the five repetitions respectively)

Plot	Coordinates	Soil Type	Soil Colour	Bulk Density (0-10/10-30cm)	pH (0-10/60-100cm)	Carbonate Content (%) (0-10/ 60-100 cm)
EC-G1	N4°11.569/ E38°17.108	Chromic Cambisol (vertic)	red	0.96/0.99	7.15/7.79	0.3 –11.3
EC-G2	N4°14.816/ E38°15.267	Vertisol	brown-black	0.93/0.81	7.68/7.89	2.3 - 2.9
EC-G3	N4°12.191/ E38°16.702	Chromic Cambisol (vertic)	red	0.88/0.92	6.77/7.53	0.3 - 11.3
EC-G4	N4°12.049/ E38°19.675	Cambisol (vertic)	brown	0.89/0.76	7.59/7.64	0.02 –3.2
EC-G5	N4°13.829/ E38°16.928	Calcisol/Cambisol	(white) brown	0.91/0.86	7.54/7.70	0.9 – 9.1
EC-T1	N4°10.350/ E38°18.934	Cambisol (vertic)	brown	0.98/0.98	7.13/7.61	0.02 –3.2
EC-T2	N4°10.322/ E38°18.549	Cambisol	reddish-brown	0.96/1.03	6.97/7.25	0.02 –3.2
EC-T3	N4°10.548/ E38°18.475	Cambisol (vertic)	brown	1.13/1.10	7.18/7.56	0.02 –3.2
EC-T4	N4°14.373/ E38°14.660	Chromic Cambisol (vertic)	red	1.16/1.11	7.19/7.82	0.3 – 11.3
EC-T5	N4°12.089/ E38°19.767	Cambisol	brown	0.72/0.71	6.89/7.88	0.02 –3.2
G1	N4°11.353/	Chromic Cambisol	red	1.36/1.30	6.76/7.82	0.3 – 11.3

	E38°17.027					
G2	N4°11.042/ E38°16.278	Vertisol	black	1.11/1.16	8.12/7.79	2.3 – 2.9
G3	N4°11.481/ E38°15.772	Vertisol	black	1.12/1.03	7.64/7.65	2.3 – 2.9
G5	N4°11.736/ E38°18.281	Chromic Cambisol	red	1.14/1.14	7.30/7.85	0.3 – 11.3
G7	N4°11.551/ E38°17.451	Calcisol (Cambisol)	white-brown	1.32/1.17	7.27/7.84	0.9 – 9.1
T1	N4°11.088/ E38°16.054	Vertisol	black	0.76/1.06	7.73/7.78	2.3 - 2.9
T2	N4°12.167/ E38°16.291	Calcic Cambisol	white-brown	1.19/1.01	7.16/7.79	0.9 – 9.1
T3	N4°10.749/ E38°18.737	(calcic) chromic Cambisol	red	1.23/1.24	6.85/7.89	0.3 - 11.3
T4	N4°11.724/ E38°18.565	Chromic Cambisol	red	1.30/1.20	7.17/7.78	0.3 - 11.3
T5	N4°11.705/ E38°15.802	Calcisol (Cambisol)	white-brown	1.38/1.27	7.52/7.82	0.9 – 9.1

4.1.2. Climate

The Borana rangelands are characterized by an arid to semi-arid climate with an annual rainfall amount between 110 mm in the south and 600 mm in the north and exceptional areas with rainfall amounts up to 900 mm (Tefera et al., 2007).

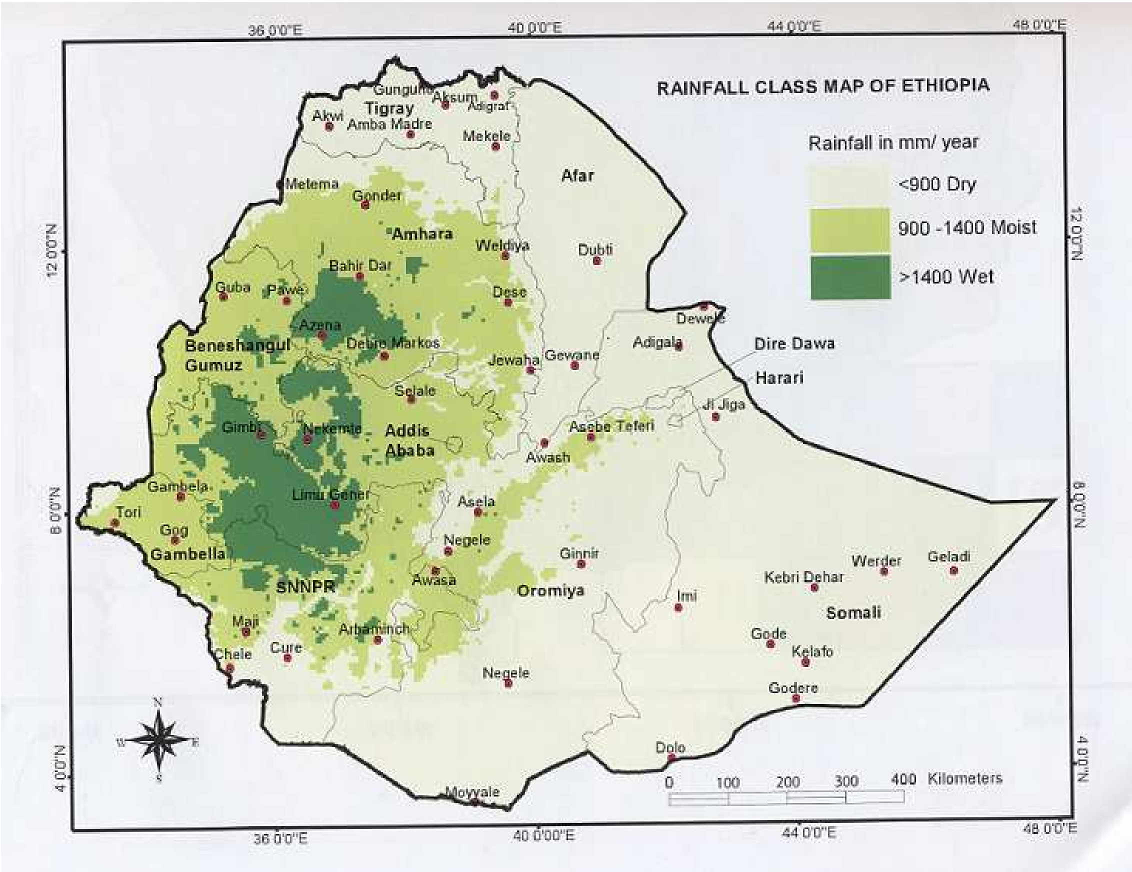


Fig. 9: Rainfall class map of Ethiopia (Managing land, Technical handbook No.36, RELMA in ICRAF, 2005, p. 7)

Rainfall has a considerable inter-annual variability of 21-68% and droughts occur every 5-10 years, although patterns have tightened and the latest drought (1999/2000) already occurred three years after the previous one (Homann et al., 2008). Rainfall patterns are bimodal; 60% of the rainfall occurs between March and May and variable rainfall has been observed between September and November. The mean annual temperature varies from 15-24°C and shows little changes across the seasons. Temperature peaks of 40°c or more have been observed during the dry periods.

4.1.3. Vegetation

Four vegetation types were distinguished: open grasslands, tree savannah, bush land and a mixture of tree and bush savannah (Pic. 1). Main tree species in this area are *A. tortilis, A. nilotica, Commiphora africana, A. bussei* and *A. seyal*; the last one especially on swampy grounds and clayey soils with good water-holding capacities. Bush lands were characterized by *A. nubica, A. mellifera* and *A. drepanolobium*, sometimes *Solanum* ssp. species and *Ossimum* ssp. were found. Grasslands varied in their composition. On

Pic. 1 (from left to right): Grassland, tree savannah, bush land and a mixture of trees and bushes

Vertisols and vertic Cambisols, perennial *Pennisetum* species dominated while a mixture of annual and perennial grasses and herbs was observed in rangelands located on Calcisols and Cambisol (Pic. 2). Dominating species here were *Cenchrus ciliaris*,L., *Cynodon dactylon,* L. (pers.) *Chrysopogon aucheri,* (Boss) Stapf., *Chloris myriostachya,* Horst. *Eragrostis cilianensis,* Link exlutati, *Sporobulus nervosus,* Hochst., *Lintonia nutans* Stapf. *, Commulina* ssp., *Setaria* ssp. and diverse forbs like *Indigofera spinosa, Crotalaria* ssp., *Artemisia annua, Beidens* ssp. and *Forbia* ssp.

Pic. 2 (from left to right): Grassland on a Vertisol and grassland on a Calcisol

4.1.4. Land Use

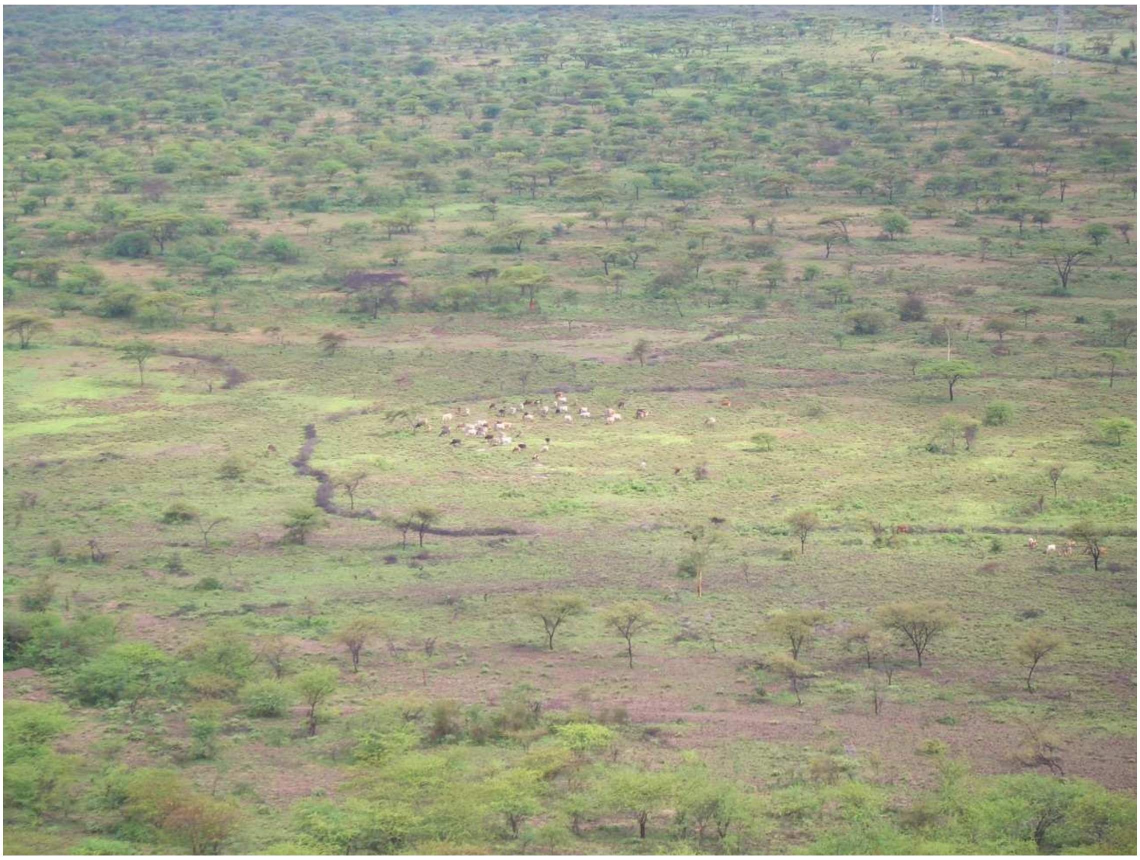
Traditionally, the Borana region was a pastoralist area with extensive cattle keeping and high seasonal herd mobility. The rangelands were ruled by various clans that were responsible for the scattered deep wells and social security and culture. The political system was the *gadda* system, providing the framework of the society by defining authorities and rules. The organization of the area was spatial: there were common seasonal grazing areas (*dheeda),* and areas related to permanent water sources (*madda*). The society was divided into stationary encampments with households of five to seven persons (*warra)* which were merged into encampment clusters (*ardaa)*, villages *(olla*) and neighbourhoods (*reera).* Herds were driven from dry to rainy season grazing areas along the year (Homann et al., 2008).

Today, the Borana pastoralists are in transition from traditional pastoralism to a semi-sedentary grazing system as a result of the ongoing governmental and structural changes since the 1970s. During that period, land was nationalized and due to increasing population pressure, enormous efforts were made to enhance the productivity of the Borana region. Additional water ponds were constructed, burning of bush land was forbidden, extension services favored crop production to make the area less vulnerable towards droughts and a new formal administration of peasant associations was established (Homann et al., 2008).

Nowadays, large-scale herd mobility is no longer necessary as permanent water ponds make a movement to dry season grazing grounds invalid. The former temporary rangelands were slowly converted into permanent continuous grazing areas. Since the 1980s, crop production is launched to improve food security during the dry season. Furthermore, livestock sales can be reduced as staple food stocks are available by the pastoralists themselves (Appendix I, questionnaire). On purpose of crop farming, communal grazing land has been converted into private crop land, eventually leading to conflicts with grazing and browsing purposes. Each household owns 1.3 ha of cropland on average (Solomon et al., 2007). Main livestock species kept in this area are cattle (100%), goats (89.8%), sheep (64.1%) and camels (46.2%). Camel keeping started in the 1980s after a row of severe droughts. Camels make a better use of available vegetation (grazer and browser), a more reliable milk production and additional transport services (Homann et al., 2008; Solomon et al., 2007). Animals are kept for milk production (food), income generation (sale), meat production (food), draft power and social prestige. Stocking densities vary with the season: in years with average rainfall, average stocking densities lie at 0.235 Tropical Livestock Units (1 TLU ~ 250 kg)/ha. 0.176 TLU/ha were calculated in dry years and 0.118 TLU/ha in drought years. Nevertheless, in regions with permanent water ponds, 1.73 TLU/ha were measured (Homann et al., 2008).

4.1.5. Enclosures and Continuously-grazed areas

Before the major policy changes in the 1970s, the Borana pastoralists land management was mainly driven by ecological aspects, namely water scarcity. The central area around the deep wells (*tula)* determined the mobile land use pattern. Permanent villages were clustered to a line on a distance of 10-15 km around the wells. The pastures between the village belt and the wells were prohibited for any other use then walking and grazing. The grass around the encampments and in the direction of the wells was reserved for smaller calves, lactating calves and weak animals. Some areas in this region were reserved for times of forage scarcity. The pastures for rainy and dry season grazing were found in the periphery of the central rangelands and were mainly used for non-lactating animals.
After the political changes in the 1970s, crop production and the installation of permanent water ponds on the one hand limited the grazing area and on the other hand made seasonal movement unnecessary. Herd mobility decreased drastically while population pressure increased and climatic variability led to erratic rainfall and droughts. Feed and water shortages, starvation and poverty led to the establishment of enclosures (*Kallo/Obru)* (Solomon et al., 2007).



Pic. 3: A communal Kallo used by cattle near Madhacho in the Research area

Kallo have been used in the last 50 years to conserve natural resources for a critical climatic period (i.e. drought). The *Kallo* is established by the community and has an average size of 12 ha with a range of 1-80ha.
The size is determined by the number of vulnerable animals (calves, lactating cows etc.) of the community. The fencing (bush) is done jointly by the village community and rules for use are set by the village as well (Appendix I, questionnaire). The *Kallo* are mostly used during the dry season for feeding immature livestock and lactating cows to reduce grazing pressure and fodder shortages during that season. *Kallo* are constructed close to the village. Some interviewees stated that water has to be available so that vegetation can grow up easily (Appendix I, questionnaire). Normally, *Kallo* are only used for cattle, as goats, sheep and camels are less vulnerable and feed on a higher amount of varieties.
Obru are used for the cultivation and harvest of crops and are a private area (Appendix I, questionnaire). After harvest of the crops, crop residues and grass are used for weak and young animals and lactating cows. Grass can be cut or animals are driven into the *Obru* to feed on the crop residues. *Obru* are smaller in size than *Kallo* (between 0.2- 5 ha) and are fenced with thorny bush by the owner. Sometimes, relatives are allowed to use the *Obru* as well. Compared to the *Kallo* practice, the *Obru* management has been established in the last 15-10 years in the research area. As *Obru* are used for crop cultivation, water occurence is very important. Hence, they are established in fertile bottomlands and on the foothills of mountains to secure water availability (Appendix I, questionnaire). This practice competes with the traditional grazing management as these areas were traditionally used for calf raising (Solomon et al., 2007).

4.2. Experimental Setup

4.2.1. Localization of Plots within the Study Area

Enclosures existed in the grasslands and in the tree savannahs of this area. Twenty plots were selected according to the two vegetation types and the two common management practices (Continuously- grazed vs. enclosures), so that four combinations were possible: Continuously- grazed grassland, continuously- grazed tree savannah, enclosures in grassland and enclosures in tree savannah. Five repetitions each were established (Appendix II shows pictures and graphic distribution of vegetation for each plot).

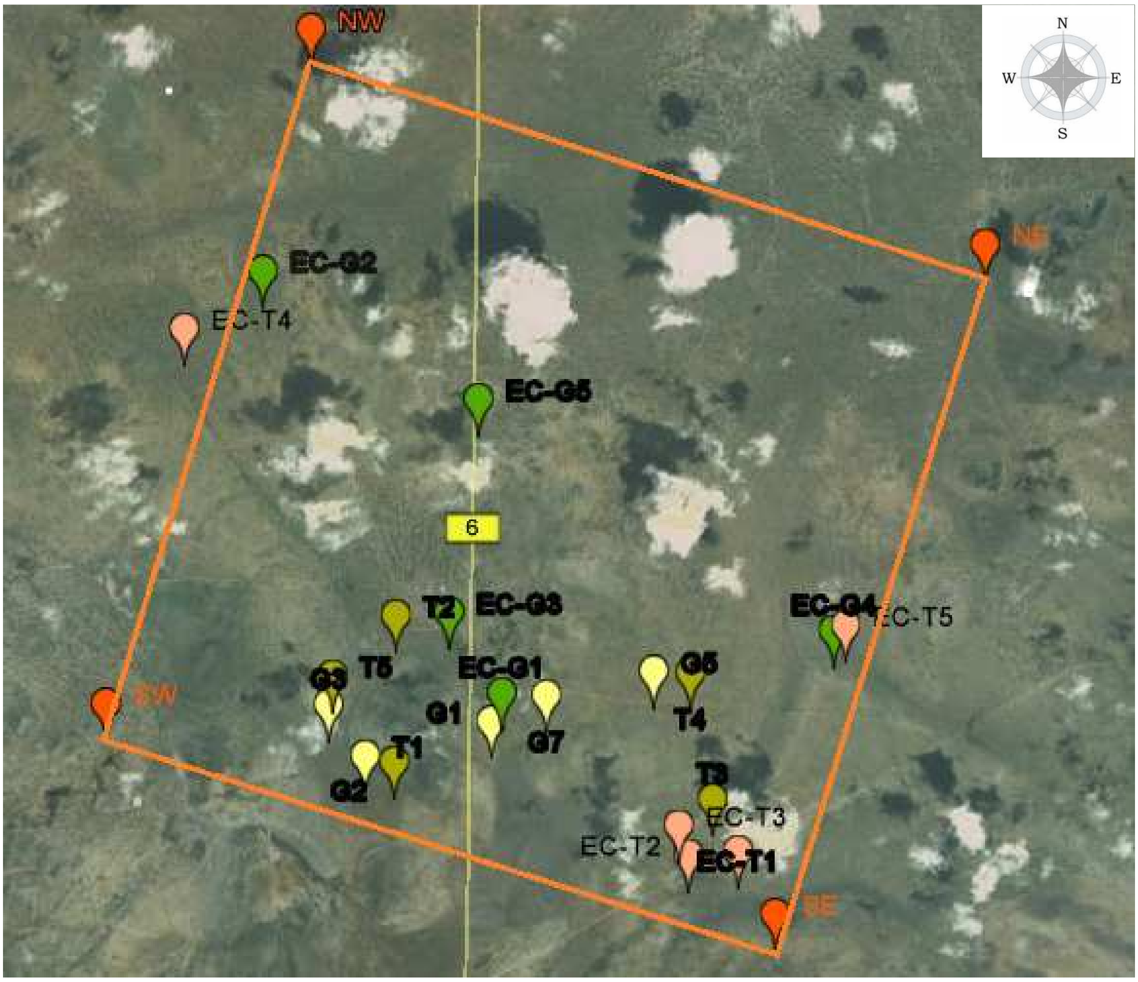


Fig 10: Satellite image of the research area: Localization of the plots (Source: google earth) **T= Tree savannah, G= Grassland, EC-G= Enclosure in grassland, EC-T= Enclosure in tree savannah; Number 1-5 indicate the repetitions respectively**

Continuously- grazed grassland

We distinguished between two types of grassland, as already stated in the chapter "Vegetation". Grassland was found in the bottomlands of the area, on Vertisols.

Here*,* *Pennisetum* species dominated. Grasslands on Cambisols and Calcisols showed a higher species variety of monocots as well as herbaceous vegetation. Five plots were established in the permanent, continuously- grazed grassland. Livestock in these areas were mainly cattle. The average stocking rate was 14.7 TLU/ha.

Continuously- grazed tree savannah

Tree savannah was mainly found on shallow, calcerous soils in the periphery of grasslands. Acacia species dominated in these areas.

Livestock species were cattle, camels and goats.
Five plots were established in the permanent, continuously-grazed tree savannah. The average stocking rate was 8.38 TLU/ha.

Enclosures in grassland

Enclosures were primarily found close to villages. *Obru* as well as *Kallo* enclosures were established in grassland. As rainy season had started, only few cattle were held in the enclosures. Grass grew between 30-130 cm high and species composition was mainly monocot. Enclosures were selected according to their fencing (strong and impermeable), a similar size, an even size and distribution of grass.

Enclosures of the same vegetation type had to have a distance of at least 1 km. Five enclosures were selected and five research plots were established accordingly. The average stocking rate was 1.5 TLU/ha.

Enclosures in tree-savannah

Obru as well as *Kallo* enclosures were established in tree savannah. Grass was less high than in grassland enclosures and distribution of nests was more uneven.

Under the trees, species composition was often higher and also herbaceous plants and small bushes could be found. Five tree enclosures were selected according to tree number, similar size and evenness of grass. The average stocking rate was 3.12 TLU/ha.

4.2.2. Site Selection Criteria

Sites were selected by visual observation and by using satellite images from www.googleearth.com. Pictures of the area were taken in all directions by climbing the hills located in and around the research site. The height of the hills varied between 100– 200m above the surrounding area. Tree, bush and grass areas were defined visually. After the picture analysis, results were compared to a map from www.googleearth.com. If defined areas in the pictures matched with the satellite image, plots were randomly located in the satellite image. By using a GPS handheld device, plots were visited in the research site. If representing the surrounding area in terms of soil type, vegetation type, species and stand density, the plot was chosen for further investigation. To define the surrounding area, transect walks were done in north-south and east-west direction. Augers were taken in regular distances to gain information on the soil type. If the plot from the satellite image did not match with the surrounding area, an appropriate site was selected after having done the transect walks.

4.2.3. Setup of Field Monitoring

After determining the two selected vegetation types, grassland and tree savannah, five representative 30x30m plots were established in each of the vegetation zones (Fig. 11).

Fig. 11: Setup of a field monitoring

Furthermore, ten enclosures, five in the tree and five in the grass savannah, were selected and 30x30m plots were established here as well. Ten soil samples of one meter depth were taken in a randomized pattern in this 900m² by the help of a Puerckhauer auger. Furthermore, soil bulk density was determined by digging 50 cm deep holes at two corners of the plot and using standardized cylinders for estimating the bulk density at 0-10cm and 10-30cm depth. To classify the plant species and harvest the aboveground biomass, three monitoring subplots of 1m² size were established along a diagonal in the plot. Species composition and density was determined by eye observation before harvesting all biomass in these sections. Tree biomass was calculated by using allometric (Chapter 4.2.4. (2)) equations. Therefore, tree height, stem height, crown height and width and stem diameter were measured in the field by using measuring tape and a slat.

4.2.4. Measurements

Non-destructive measurements

1. Species density and soil cover

Species were classified by visual observation within the three subplots with the help of a local expert. After that, the overall soil cover was estimated by visual examination. Main species were identified and soil cover of all occurring species was evaluated.

2. Tree measurements and biomass determination

Tree biomass was estimated by using allometric equations from literature. Therefore, tree parameters had to be measured (Pic. 4). By using a measuring tape, DBH, DBH_a , crown width and stem height were determined. Tree height and crown height were estimated with the help of a slat. Trees were numbered and information was recorded for each specific tree separately. Tree species were assessed with the help of a local expert.

Pic 4: Determination of tree parameters

Calculation of tree biomass
To calculate the tree biomass, the following allometric formula was used:

Biomass (kg DW/Tree) = 0.0096*($H+D_1+D_2$)/3,3015
(for *Acacia tortilis*)

Where H= total height of the tree, D_1 = the first diameter of the crown of the tree and D_2 = the second diameter of the crown of the tree

After (Henry et al., 2011; Hofstad, 2005)

The biomass of every tree of a plot was calculated separately and results were added to gain the overall tree biomass. Results were averaged for a square meter and extrapolated for a hectare.

3. Calculation of Stocking rate and Carrying Capacity
The amount of animals in the different grazing systems was estimated with the help of interviews with the owners of the enclosures and by counting the animals passing the plots while working in the field. The stocking rate and the carrying capacity were calculated according to the handbook "Managing Land" by ICRAF (2005):

Stocking rate = (TLU*number of animals)/ total area grazed (ha)
where by 1 TLU =250 kg (one Zebu cow) and 1 Camel=1.2 TLU, 1 Horse=0.8 TLU, 1 Donkey =0.8 TLU, 1 Goat =0.1 TLU and 1 Sheep= 0.1 TLU

Carrying capacity =(((total area grazed (ha)*total dry forage production (t/ha))/ 2 (usable forage))/ 3 (TLU/year)

The grazing pattern in the Borana region is influenced by the nomadic lifestyle of the people. Therefore, the animals do not stay at one place at a time, but move from one pasture to the next, also changing grazing patterns between dry and rainy season. Schlecht et al. (2004 monitored cattle activities in nomadic, western Niger with the help of GPS attached to cattle herds. They stated that animals spent on average 543 min/day on a pasture in the rainy season and 575 min/day in the hot, dry season. During this time period, they monitored grazing, resting and long distance walking activities. To calculate the actual stocking rate of the research area in the Borana, activities for each plot and the time consumed for each activity were considered in the calculation. The enclosures are only grazed during the dry period and main activities are grazing and resting, while the year-round grazed areas are highly used during the rainy season and main activities are grazing, resting and walking over longer distance.

Destructive measurements

1. Bulk density

Bulk density describes the mass of particles of a material in a specified volume. In soil, particle volume as well as pore volume are considered. Therefore, the degree of compaction and the mineral composition play a very important role. Bulk density is later on needed to calculate the potential organic carbon content of the soil. Two 40-50 cm deep holes were dug in two opposite corners of the respective plot.

Pic 5: Setup of bulk density determination site

Standardized metal cylinders with a volume of 100 cm^3 were sunk into the walls of the hole, at 0-10cm and 10-30 cm depth (Pic. 5). Three repetitions for each depth were carried out. The cylinders were cut out of the soil by the help of a spatula and jutting out soil was removed. The soil was oven-dried at 105°C for 48 hours.
Bulk density was calculated as follows:

$$\textbf{Soil bulk density } (g/m^3) = \frac{\textbf{weight of oven-dried soil } (g)}{\textbf{Volume of soil } (cm^3)}$$

2. Soil sampling

Soil samples were taken in the 30x30m plot. Ten auger points were selected randomly by throwing a stone over the shoulder. Samples were taken up to one meter depth (Pic. 6); at least until the parent material was reached. Soil material was separated into four different depths: 0-10 cm (a), 10-30 cm (b), 30-60 cm (c) and 60-100 cm (d). The samples were air-dried and will be used for laboratory analysis on total C, C_{org} , pH, texture and carbonate content. In the field, soil parameters like texture, carbonate content and colour were already estimated by using a Munsell chart and HCl acid.

Pic 6: Puerckhauer auger for soil sampling

3. Harvest of aboveground vegetation

After establishing the 30x30m plot, three 1m² subplots were marked along a diagonal. The plant species composition and soil cover were determined and after that, aboveground vegetation was harvested down to 7 cm grass height (Pic. 7).

Pic 7: Biomass determination in a grass plot; left: before harvest; middle: after harvest; right: air- and oven drying of the vegetation samples

The grass was collected and oven-dried at 65°C until the dry weight did not change anymore. The dry weight of the vegetation of the three subplots was recorded and averaged so that the potential dry matter production of one hectare of each vegetation and management type could be calculated. The data will be useful to estimate aboveground carbon pools and, therefore, the potential organic carbon stored in a vegetation respectively management type. Furthermore, the data give an overview on aboveground biomass production of the semi-arid savannahs in southern Ethiopia.

3. Laboratory analysis

1. Organic carbon in the soil

Loss-of-Ignition method

Soil samples were ball-milled for 3 minutes to homogenize the soil. Afterwards, 5 g of the air-dried soil were weighed into ceramic crucibles and oven-dried for 24 hours at 180°C. The soil contained a high amount of clay, often more than 40%. Therefore, the amount of crystalline water which is captured between the clay particles is relatively high. Drying the soil at 180°C removes the major part of crystalline water in the soil samples. After drying, the soil was weighed with an electric balance and the moisture loss was taken down. The ceramic crucibles were heated up in a muffle furnace for 4h at 550°C (after Kamau-Rewe et al., 2011). During that process, organic material is oxidized to carbon dioxide and ash. This can be detected by the weight loss of the sample. Above 900°C (some papers state 600°C), mineral carbonates in the soil volatize and can cover up the actual amount of soil organic carbon (Heiri et al., 2001; Konen et al., 1998).
After the burning the samples in the muffle furnace, they were cooled down in a desiccator to prevent the samples from a further oxygen enrichment and the ash was weighed.
The soil organic carbon and the soil organic matter content were calculated as follows:

1. **Soil organic matter content (SOM) (%) =** $\frac{(DW_{180}-DW_{550})}{DW_{180}} * 100$

(After Heiri et al., 2001)

2. **Soil organic carbon content (SOC) (%) = 0.58*SOM (%)**

(After Ouimet, 2008)

3. **Soil organic carbon content (SOC) (kg/ha)= SOC (%)*BD*Soil depth**

(After Guo et al., 2002)

2. Total carbon in plant material

The carbon content of the plant material was estimated by using an elemental analyzer (Leco).

In each plot, three subplots of 1m² in size were established along a diagonal and vegetation was harvested, oven-dried at 65°C and homogenized by using an electric grinder. A subsample of 10 g was taken to Germany. For the elemental analysis, 100 mg were weighed into tin capsules and burned in a combustion chamber at 1800°C. The carbon and nitrogen content were calculated in %. By calculating the carbon stock of the one-square-meter subplots, results could easily be extrapolated for one hectare of the respective vegetation type in the research area.

1. **Aboveground carbon stock (t/ha):** **(%C_{org} /sample (g)) → g C_{org}/ 1g**
   x g C_{org} = y DW vegetation subplot (g)
   → x g C_{org}/m²
   → x g C_{org}/m² * 10000 → t/ha

4. Soil pH

Soil pH was estimated by using 0.01 M $CaCl_2$ solution after the standard method DIN 19684-1 from the German Institute for Standardization.

In this method, cations that are bound to the mineral and organic compounds of a soil are replaced by the Ca^{2+} - ions of the calcium chloride solution. Cations like aluminium or manganese react as cationic acids and release protons (H^+). By releasing protons, the pH-value of the solution drops. The more acidic the soil is, the more protons are released and the lower the pH-value is.

The pH is mainly influenced by the mineral contents of a soil, the organic substances as well as by salts and bases (i.e. carbonate content of a soil).

To estimate the pH of the research site, three augers out of the ten taken were selected randomly. Each auger was divided into four depths (0-10, 10-30, 30-60, 60-100 cm). Therefore, twelve samples for each plot were analyzed and the average valuewas separately calculated for each depth and the vegetation/management type.

5. Carbonate Content

Soil Carbonates were analyzed by using a Scheibler apparatus after DIN ISO 10693. In this method, oven-dried (105°C) and 2 mm sieved soil was treated with 10% hydrochloric acid. Carbonates react with the acid and the amount of free CO_2 can be measured. To calculate the amount of carbonates in the soil, the following formula was used:

$$CaCO_3\ (\%) = \frac{\text{(Titrated acid* air pressure* 0.1605)}}{\text{(Room temperature*weight of the contents)}}$$

4.3. Questionnaire

A questionnaire about the local definition of enclosures, the history, the ownership relation, the management and the animal stocking density was developed and five pastoralists located in the research area were interviewed. The interviewees were the owners of five of the examined enclosures. The villages lay on an axis from south to north within the research region (Appendix I).

4.4. Data Analysis

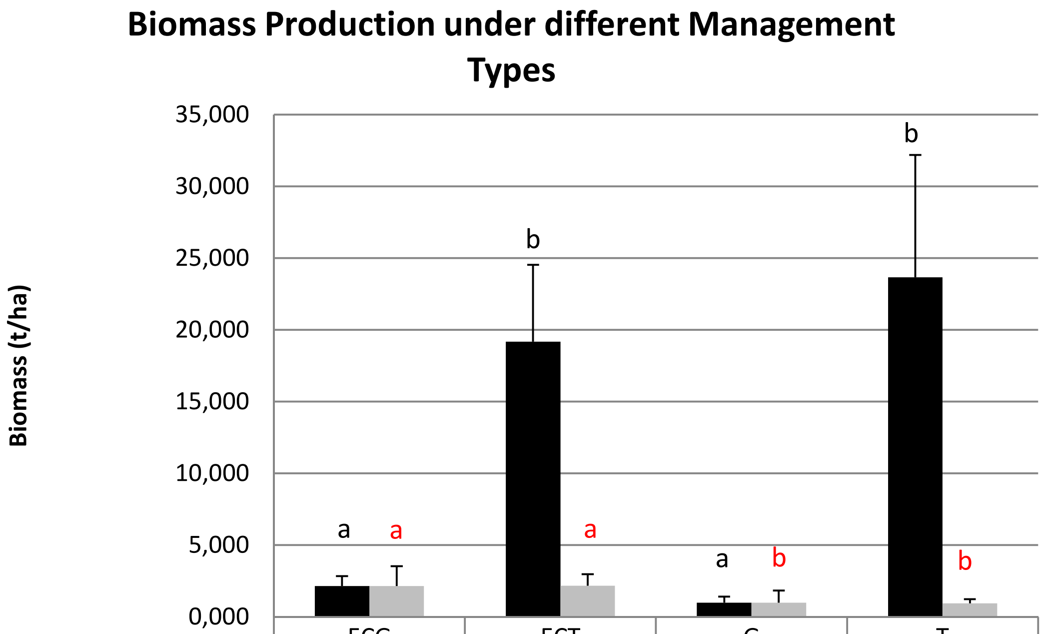
Data was analyzed with the statistical package SAS 9.3. A one-way ANOVA was carried out using the "Mixed" procedure, an extended form of the General Linear Model (GLM) to test for fixed and random effects. The model used was Var(Y) = Vegetation Type + Management Type + Vegetation Type*Management Type. To test for the differences of carbon stocks over soil depth, the model was changed to Var(Y)= Vegetation Type+ Management Type + Vegetation Type*Management Type + Depth. As data was not always normally distributed (Appendix III), datasets were tested for normality and, if necessary, transformed by using logarithms. Freak values were erased to achieve a normal distribution. Differences were considered significant at $P<0.05$. In case of individual changes in the model or the significance level, they were indicated beneath the graph. The statistical significance of the differences between means was tested by using a t-test.

Graphs and diagrams were produced using Microsoft Excel 2010. Detailed data on SAS calculations are found in Appendix IV.

5. Results

5.1. Aboveground Carbon Stocks- Biomass Production

Fig. 12 shows the aboveground biomass production under the different management types. The total aboveground biomass production (t/ha) was dependent on the vegetation type. Significantly more biomass ($P<0.05$) was produced in the tree savannahs than in the grasslands, no matter which management was used.

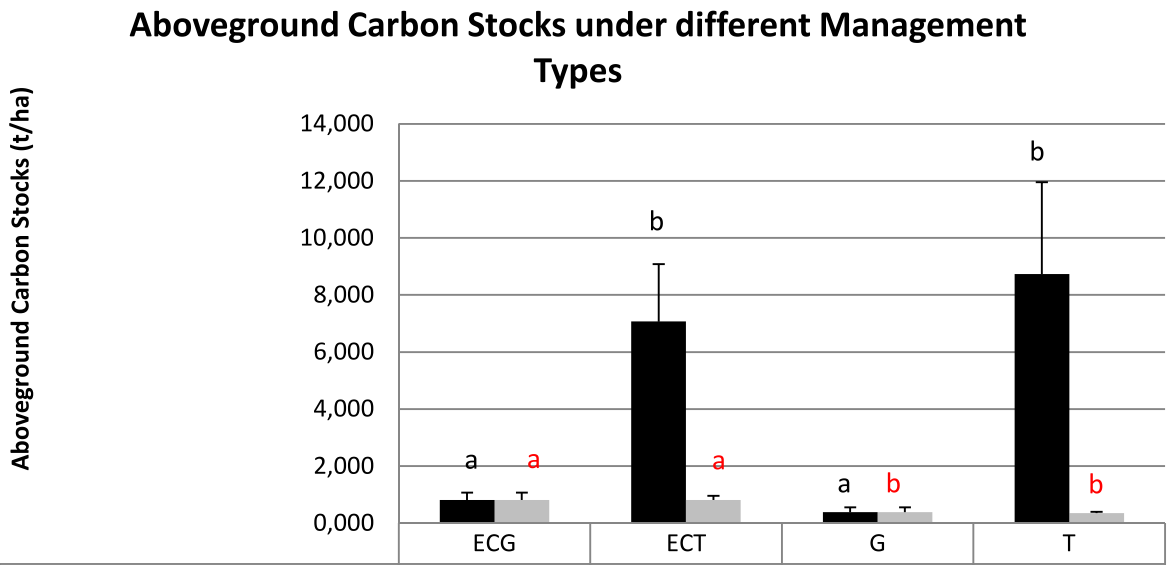


	ECG	ECT	G	T
■ Total Biomass (t/ha)	2,159	19,183	0,983	23,677
■ Grass Biomass (t/ha)	2,159	2,184	0,983	0,956

Fig. 12: Aboveground Biomass Production under Different Management Types (t/ha). Means followed by the same letter are not significantly different at $P<0.05$. Bars show the standard error over the repetitions. Colors indicate the significances for Grass and Total Biomass production. Data was not normally distributed and had to be transformed. ECG = Enclosure in Grassland; ECT= Enclosure in Tree Savannah; G= Year-round Grazed Grassland; T= Year-round Grazed Tree Savannah.

Management played a significant role ($P<0.05$) in the overall grass production of the different systems. Enclosures produced around 200 % more grass biomass than continuously- grazed systems. On average, enclosures yield 2 t/ha, while continuously-grazed areas produce less than 1 t/ha of grass dry matter.

In terms of aboveground carbon stocks, results reflect the data on aboveground biomass production (Fig. 13). Significantly ($p<0.05$) more carbon is stored in tree savannahs if speaking about the total aboveground matter.



	ECG	ECT	G	T
Total Aboveground Carbon Stock (t/ha)	0,813	7,075	0,379	8,732
Aboveground Carbon Stock Grass (t/ha)	0,813	0,805	0,379	0,346

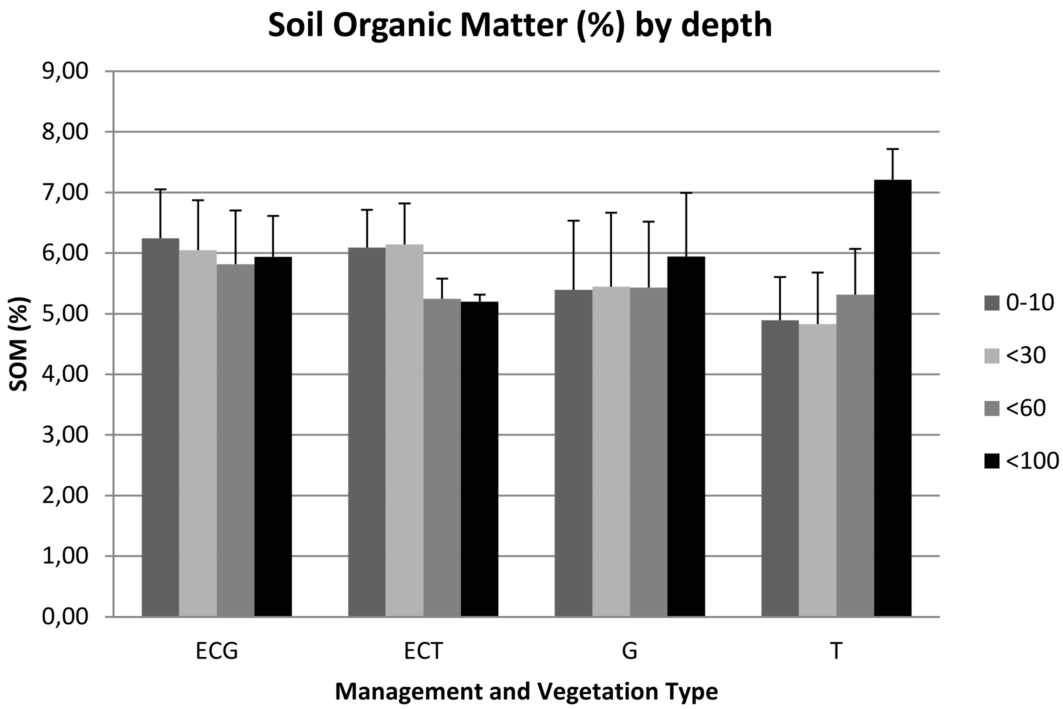
Fig. 13: Aboveground Carbon Stocks under Different Management Types (t/ha). Means followed by the same letter are not significantly different at $P<0.05$. Bars show the standard error over the repetitions. Colors indicate the significances for Grass and Total Carbon Stocks. Data was not normally distributed and had to be transformed. ECG = Enclosure in Grassland; ECT= Enclosure in Tree Savannah; G= Year-round Grazed Grassland; T= Year-round Grazed Tree Savannah.

On average, 7 t/ha of organic carbon are stored in tree enclosures while continuously-grazed tree areas even allocate 8.7 t/ha. Grasslands only store 0.4 to 0.8 t/ha respectively. Significant differences ($P<0.05$) in carbon allocation between management types could be observed when looking at the seasonal carbon stock, the grass production. In enclosures, significantly ($P<0.05$) more organic carbon is stored in grass biomass than in continuously- grazed areas.

5.2. Belowground Carbon Stocks

Soil organic matter (SOM) contents (%) varied on average between 4.8% and 7.2% across the different management systems and soil depths. There were no significant differences ($P<0.05$) in SOM content between vegetation type or management system

Fig. 14 shows that only soil depth had a significant influence on SOM matter.



Trait	Treatment	Depth	Mean (%)	Standard Error	Significance
SOM	Depth	0-10	5,66	0,3539	a,b
		<30	5,61	0,3539	a,b
		<60	5,43	0,3545	b
		<100	5,85	0,3583	a

Fig. 14: Soil Organic Matter (%) by Depth. Means followed by the same letter are not significantly different at P<0.05. Bars show the standard error over the repetitions. Only depth was significant after analysis with SAS 9.3., vegetation and management type have no effect on Soil Organic Matter over depths. ECG = Enclosure in Grassland; ECT= Enclosure in Tree Savannah; G= Year-round Grazed Grassland; T= Year-round Grazed Tree Savannah.

Across the management systems, there were no significant (P<0.05) differences in SOM in the first 60 cm. The soil layer 30-60 cm had significantly (P<0.05) less SOM than the layer 60-100 cm. Nevertheless, between the layers from 0-30 cm and the subsoil were no significant (P<0.05) differences.

Total belowground carbon stocks over one meter (t/ha) were significantly influenced by the management type (Fig. 15). Enclosures store significantly (P<0.05) less soil organic carbon (SOC) than continuously-grazed areas.

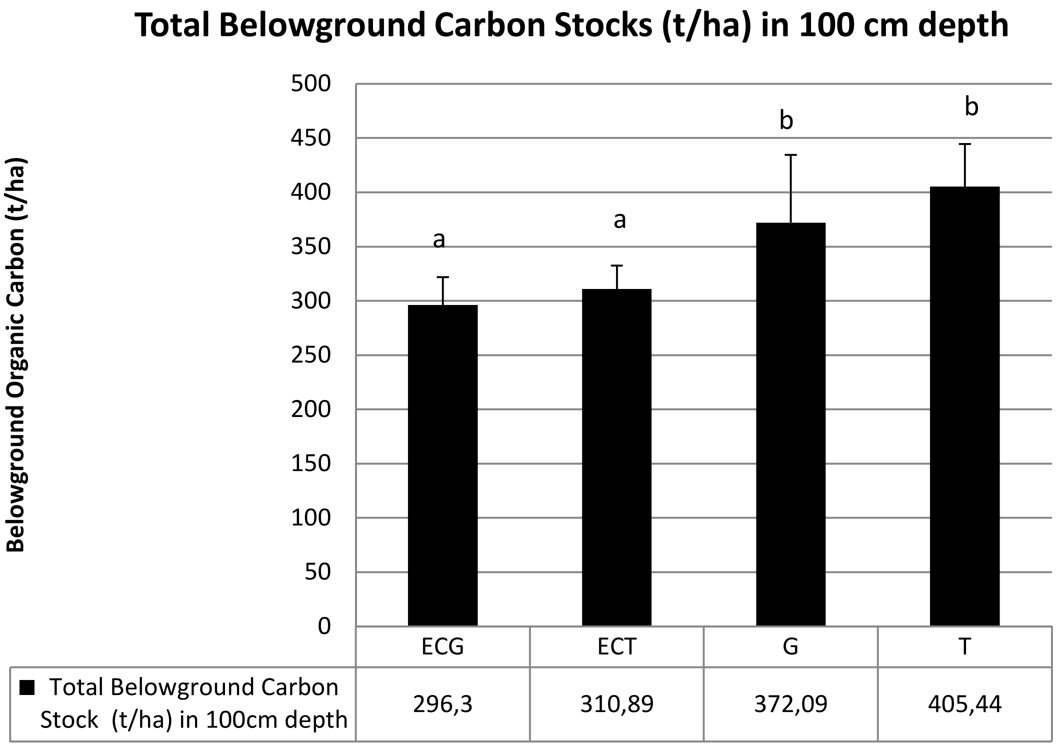
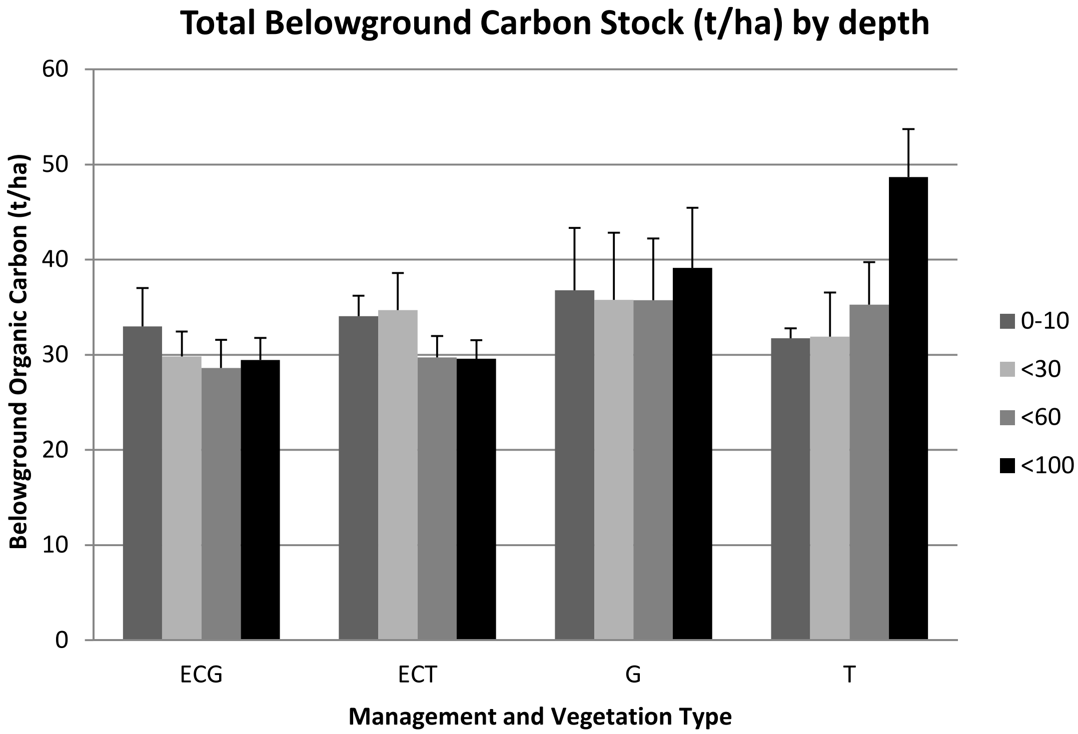


Fig. 15: Total Belowground Carbon Stocks (t/ha) in 100 cm depth. Means followed by the same letter are not significantly different at P<0.05. Bars show the standard error over the repetitions. Data was not normally distributed and had to be transformed. ECG = Enclosure in Grassland; ECT= Enclosure in Tree Savannah; G= Year-round Grazed Grassland; T= Year-round Grazed Tree Savannah.

370-400 t/ha SOC are stored in year-round managed areas while 295-310 t/ha SOC are allocated in the first meter of a soil under enclosed systems.

When describing the SOC allocation of the different management systems over depths, there is neither a significant (P<0.05) influence of the management nor the vegetation type (Fig. 16). Only soil depth plays a significant (P<0.05) role in carbon allocation. From the topsoil down to 60 cm depth, there are no significant (P<0.05) changes in carbon accumulation. The deeper subsoil stores 35.35 t/ha SOC on average, significantly (P<0.05) more than the upper soil layers. Over one meter soil depth, carbon accumulation ranges from 32.17- 35.35 t/ha SOC.



Trait	Treatment	Depth	Mean (t/ha)	Standard Error	Significance
SOC	Depth	0-10	33,97	1,7998	a
		<30	33,03	1,7992	a
		<60	32,17	1,8041	a
		<100	35,35	1,8336	b

Fig. 16: Total Belowground Carbon Stocks (t/ha) by depth. Means followed by the same letter are not significantly different at P<0.05. Bars show the standard error over the repetitions. Only depth was significant after analysis with SAS 9.3., vegetation and management type have no effect on carbon allocation over depths. ECG = Enclosure in Grassland; ECT= Enclosure in Tree Savannah; G= Year-round Grazed Grassland; T= Year-round Grazed Tree Savannah.

5.3. Soil Cover and Species Composition

In the research area, 71 different plant species of 24 different families were identified. 28 species belonged to the family of *Poaceae* , while 43 species were dicots of various families; four species were nitrogen-fixing legumes. Trees identified belonged to the *Mimosaceae* family and were all acacias (Fig.17).

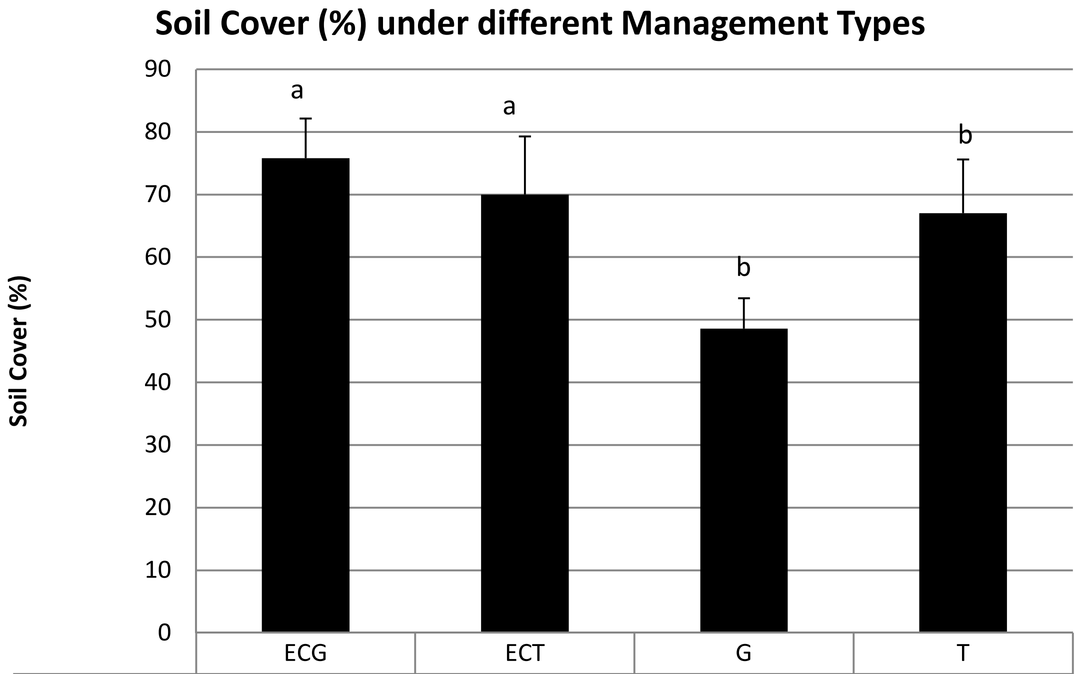
	Number	Scientific Name	Family
Grasses	1	*Aristida adscensionis* L.	Poaceae

	2	*Cenchrus ciliaris* L.	Poaceae
	3	*Cynodon dactylon* L.	Poaceae
	4	*Chrysopgon plumulosus* (L.) Pers.	Poaceae
	5	*Chloris roxburghiana* Schult.	Poaceae
	6	*Chloris virgata* sw.	Poaceae
	7	*Panicum coloratum* L.	Poaceae
	8	*Eragrostis papposa* Ruem & Schult. Steud	Poaceae
	9	*Eragrostis cilianensis* (All.) Lutati	Poaceae
	10	*Enneapogon cenchroides* Ruem & Schult. C.E. Hubbard	Poaceae
	11	*Leptothrium senegarense* (Kuth)	Poaceae
	12	*Microchloa kunthii* esv.	Poaceae
	13	*Sporobulus pyramidlis* P. Beauv.	Poaceae
	14	*Sporobulus festivus* A Rich.	Poaceae
	15	*Setaria varticillata* (L.) P. Beauv.	Poaceae
	16	*Tragus berteronianus* Schult.	Poaceae
	17	*Tragus heptaneuron* ciayton.	Poaceae
	18	*Brachiaria humidicola* (Rendle) Schweick.	Poaceae
	19	*Brachiaria eruciformis*	Poaceae
	20	*Pennisetum mezianum* Leek	Poaceae
	21	*Pennisetum stramineum* Pete V.	Poaceae
	22	*Commelina latifolia* A. Rich	Poaceae
	23	*Commelina subulata* Rott.	Poaceae
	24	*Bothrichloa radicans* Lehm. A. Camus.	Poaceae
	25	*Digitaria velutina* forsk P. Beauv.	Poaceae
	26	*Tetrapogon cenchriformis* (A. Rich) ciayton.	Poaceae
	27	*Lintonia nutans* stapf.	Poaceae
	28	*Dactyloctenium aegypticum* (1) Beauv.	Poaceae
Forbs	29	*Sida ovata* forsk	Malvaceae
	30	*Becium verticillifolium* beke cufed.	Lamiaceae
	31	*Ocimum basilicum* L.	Lamiaceae
	32	*Ocimum lamiifolium* Hocht.ex	Lamiaceae
	33	*Portulaca oleracea* L.	Portulaceae
	34	*Bidens pilosa* L.	Compositae
	35	*Launaea cormuta oliv.* Hiern.c. Jeffrey	Nyctalinaceae
	36	Boerhaaria *erecta* L.	Compositae
	37	*Amaranthus graecizons* L.	Amaranthaceae
	38	*Piantago lanceolata* L.	Plantaginaceae
	39	*Erucastrum arabicum* Fisch&Mey.	Compositae
	40	*Anthemis tigreensis* A. Rich	Compositae
	41	*Crotalaria incana* L.	Fabaceae
	42	*Crotalaria Greenway* Bak f.	Fabaceae

	43	*Indigofera spinos* Forssk	Fabaceae
	44	*Indigofer*a Volkensii Taub	Fabaceae
	45	*Helichrysum glumaceum* D.C.	Asteraceae
	46	*Dyschoriste hildebrandtii* S.Moore	Acanthaceae
	47	*Achyranthes apera* L.	Amnranihaceae
	48	*Kyllinga bulbosa* P. Beauv.	Cyperaceae
	49	*Cyperus amauropus* steud	Cyperaceae
	50	*Heliantropium cinrascens* D.C.	Boraginaceae
	51	*Tribulus terrestris* L.	Zygophyllaceae
	52	*Oxygonum sinuatum* (Meisner) Dammer	Zygophyllaceae
	53	*Psydrax schimperiana* (A.Rich)	Rubiceaea
	54	*Chenopaaium opolifolium* Koch.	Chenopodiaceae
	55	*Acacia mellifera* Vahl Benth.	Mimosaceae
	56	*Acacia nubica* Benth.	Mimosaceae
	57	*Grewia bicolor* Juss.	Tiliaceae
	58	*Grewia villosa* willd.	Tiliaceae
	59	*Lantana rhodesensis* moldenke.	Verbenaceae
	60	*Solanum incanum* L.	Solanaceae
	61	*Solanum giganteum* Jacq.	Solanaceae
	62	*Vernonia cinerascens* Sch.Bip.	Asteraceae
	63	*Solanum somarense* Franchet	Solanaceae
	64	*Acacia seyal* Del.	Mimosaceae
	65	*Acacia tortilis* (Forsk.) Hay.	Mimosaceae
	66	*Acacia nilotica* (L.) Del. Var. Nilotica	Mimosaceae
	67	*Acacia drepanologium* Harms.	Mimosaceae
	68	*Acacia bussei* Harms ex sjöstedt.	Mimosaceae
	69	*Balanites aegyptica* (L.) Del.	Balanitaceae
	70	*Ipomoea maarmoaata* Britt&Rendre	Convalvulaceae
	71	*Euphorbia nubica* n. Br.	Euphorbiaceae

Fig. 17: Species List of the Research Area in the Borana Region, South Ethiopia

Fig. 18 shows the soil coverage (%) under different management types. Soil cover varied between 48.6% and 75.8%. Management had a significant ($P<0.05$) influence on soil cover in the four observed grazing systems.



	ECG	ECT	G	T
■ Soil cover (%)	75,8	70	48,6	67

Fig. 18: Soil Cover (%) under different Management Types. Means followed by the same letter are not significantly different at P<0.05. Bars show the standard error over the repetitions. Data was not normally distributed and had to be transformed. ECG = Enclosure in Grassland; ECT= Enclosure in Tree Savannah; G= Year-round Grazed Grassland; T= Year-round Grazed Tree Savannah.

Enclosures had a significantly (P<0.05) better ground cover than year-round grazed areas, while vegetation type had no mentionable influence (Fig. 18). Soil cover varied from 49% in the continuously- grazed systems to 76% in the enclosures.

Species composition was further examined in terms of the monocot-dicot ratio (Fig. 19). Dicot coverage varied between 8-37% respectively. Significantly (P<0.05) more dicots were observed in continuously- grazed systems than in enclosed areas. Species variability was higher in permanently-grazed systems than in enclosures.

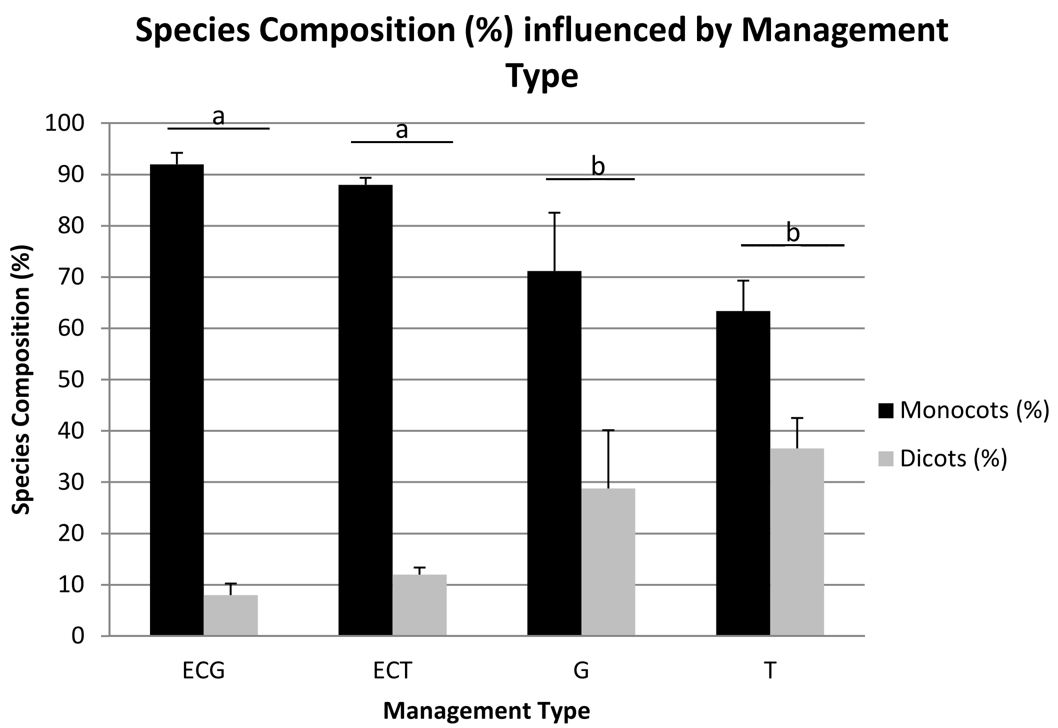


Fig. 19: Species Composition (%) influenced by Management Type. Means followed by the same letter are not significantly different at P<0.05. Bars show the standard error over the repetitions. Data was not normally distributed and had to be log-transformed. ECG = Enclosure in Grassland; ECT= Enclosure in Tree Savannah; G= Year-round Grazed Grassland; T= Year-round Grazed Tree Savannah.

Also the habitus of species changed under varying management practices (Fig. 20). Significantly (P<0.05) more perennial species were observed in enclosures than in permanently- grazed areas. Under seasonal management, 60-84% of the species identified were perennial while on average only 35% of the species growing in the continuously- grazed systems were perennial respectively.

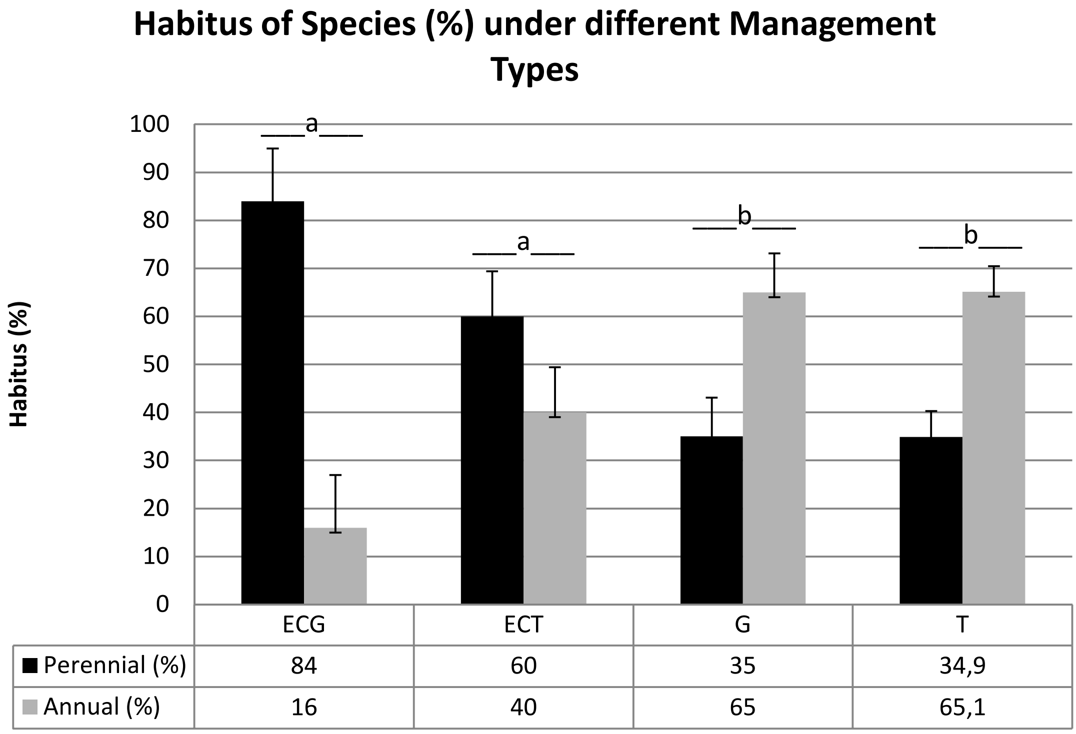


Fig. 20: Habitus of Species (%) under different Management Types. Means followed by the same letter are not significantly different at P<0.05. Bars show the standard error over the repetitions. ECG = Enclosure in Grassland; ECT= Enclosure in Tree Savannah; G= Year-round Grazed Grassland; T= Year-round Grazed Tree Savannah.

Thus, annual species predominated in permanently grazed regions.

Main species identified in enclosures were *Penisetum mezanium* Leek, *Penisetum stramineum* Pete V. and *Cenchrus ciliaris* L.. Species variability was low. Usually, 3-5 main species could be determined. Permanently- grazed areas had higher species variability. 5-8 main species were found in each research plot. Dominating species were *Cynodon dactylon* L., *Eragrostis* ssp., *Commelina latifolia* A. Rich, *Solanum incanum* L., *Crotalaria incana* L. and *Indigofera spinosa* Forssk.

On average, 25-43% of the species were highly palatable for cattle (Fig. 22). Although differences were not significant, neither for vegetation type nor management system, higher spot check numbers should definitely end up in significant differences between management and vegetation types (Fig. 21).

Effect	**DF Numerator**	**DF Denominator**	**F-Statistics**	**P>F**
Vegetation Type	1	9.81	4.49	0.0606
Management Type	1	9.38	4.96	0.0518

Fig. 21: Statistical Analysis for highly palatable Species

In all management systems, except for the grass enclosures, for cattle unpalatable species dominated (Fig. 22). On average, 8-50% of the species were not palatable for them. Significantly (P<0.05) more unpalatable species were counted in continuously-grazed areas than in enclosures.

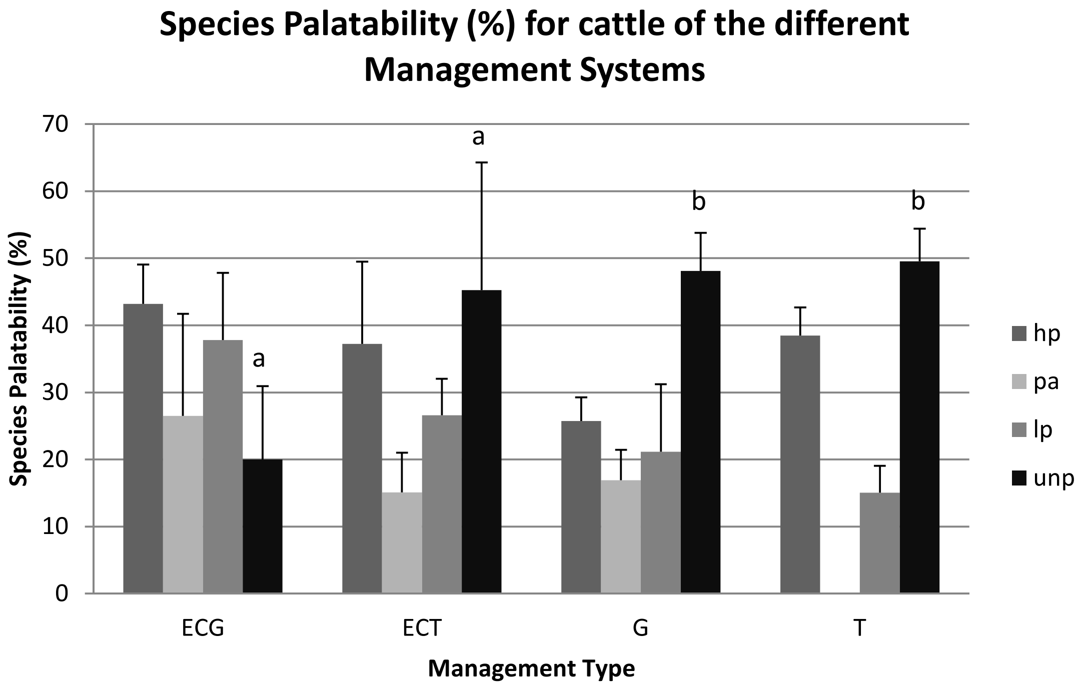


Fig. 22: Species Palatability (%) for cattle of the different Management Systems. Means followed by the same letter are not significantly different at P<0.05. Bars show the standard error over the repetitions. Significances were tested for hp and unp species. ECG = Enclosure in Grassland; ECT= Enclosure in Tree Savannah; G= Year-round Grazed Grassland; T= Year-round Grazed Tree Savannah. Hp= Highly palatable; Pa= palatable; Lp= less palatable; Unp= unpalatable.

92% respectively 72 % of the species in the enclosures were somehow palatable for cattle (hp, pa, lp), whereas only 50% of the species in the year-round grazed systems could be eaten by them.

5.4. Stocking Densities and Carrying Capacity influenced by Management

Stocking rates varied highly across the different management systems (Fig. 23). Between 1.5 TLU/ha to 14.7 TLU/ha were kept, whereas management type played a significant (P<0.05) role for stocking densities. In enclosures, significantly (P<0.05) less cattle were counted, on average 1.5 -3.1 TLU/ha. In continuously- grazed systems, variability of stocking densities was a lot higher respectively. Furthermore, stocking densities varied between 8.4-14.7 TLU/ha and were, therefore, five to six times higher than in enclosed areas.

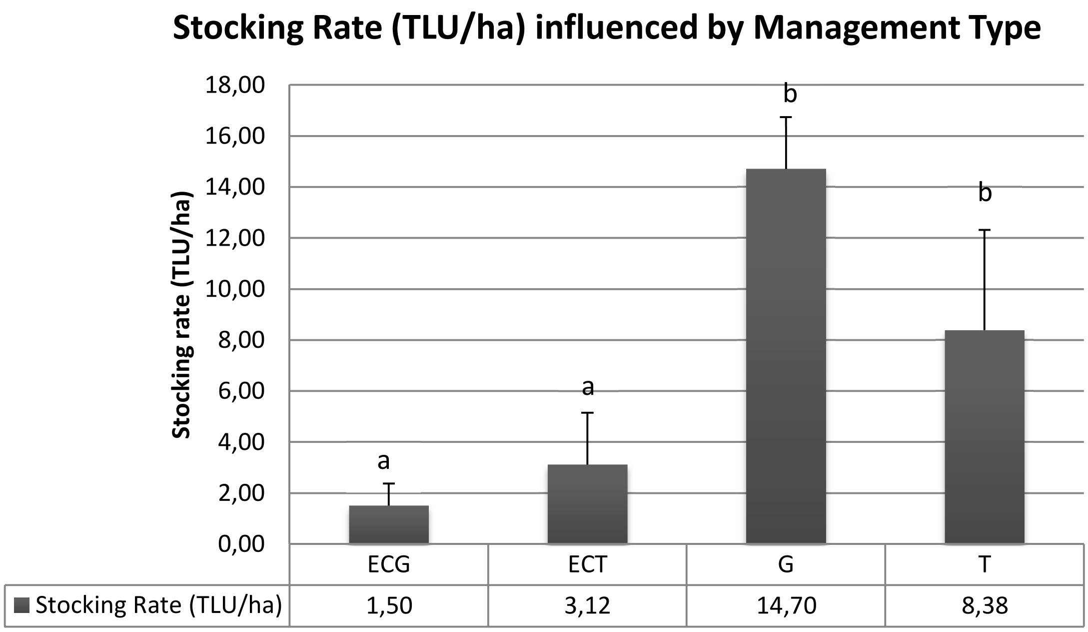


Fig. 23: Stocking Rate (TLU/ha) influenced by Management Type. Means followed by the same letter are not significantly different at P<0.05. Bars show the standard error over the repetitions. Data was not normally distributed and had to be transformed. ECG = Enclosure in Grassland; ECT= Enclosure in Tree Savannah; G= Year-round Grazed Grassland; T= Year-round Grazed Tree Savannah.

All systems could not carry the amount of animals that were observed on them (Fig. 24), in which enclosures could on average carry twice the amount of livestock (TLU/ha) of continuously- areas.

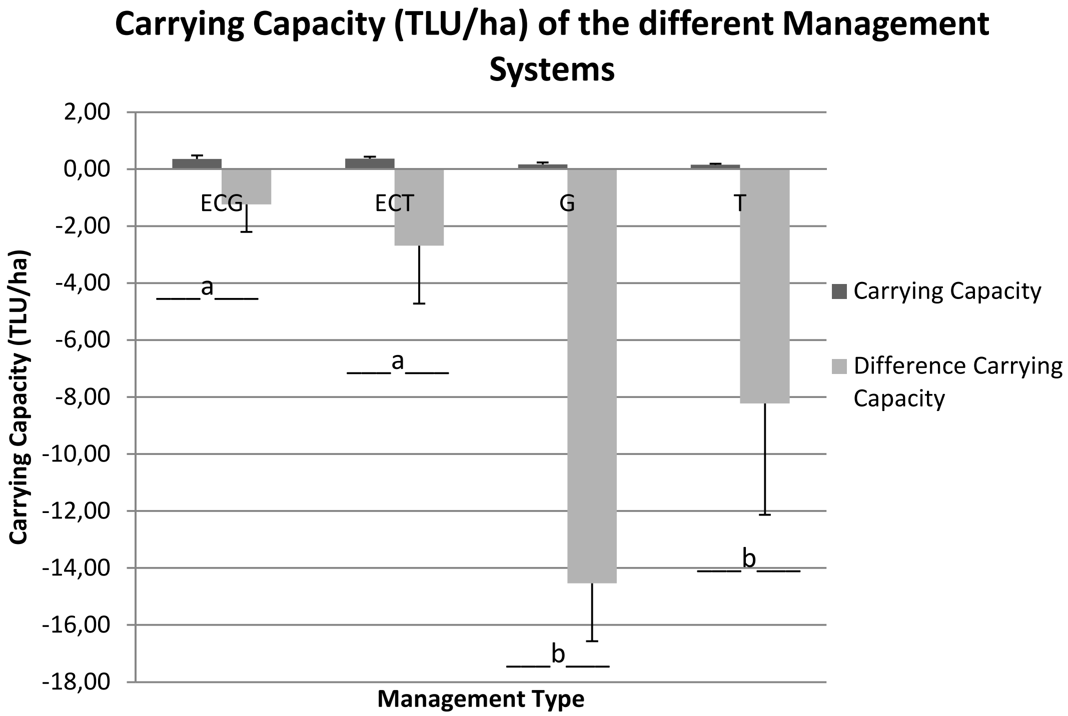


Fig. 24: Carrying Capacity (TLU/ha) of the different Management Systems. Means followed by the same letter are not significantly different at P<0.05. Bars show the standard error over the repetitions. "Difference Carrying Capacity" describes the difference between the possible carrying capacity of the area and the actual stocking densities in the area at the moment. Data was not normally distributed and had to be transformed. ECG = Enclosure in Grassland; ECT= Enclosure in Tree Savannah; G= Year-round Grazed Grassland; T= Year-round Grazed Tree Savannah.

Management type had a significant (P<0.05) influence on carrying capacity in this case. Enclosures could carry significantly (P<0.05) more animals than permanently grazed regions (0.36 TLU/ha). Furthermore, the grazing pressure in continuously- grazed areas was significantly (P<0.05) higher than in enclosures. 1-2.7 TLU/ha too much fed on the resources in seasonal grazing places while severe overgrazing was observed in permanently grazed areas, where 8-14.5 TLU/ha too much were observed.

6. Discussion

6.1. Impact of Grazing on Aboveground Biomass Production and Carbon Stocks

One of the main hypotheses of this master thesis was that the different grazing managements (enclosure vs. continuously- grazed) have a significant impact on above- and belowground carbon allocation. Furthermore, it was expected that aboveground biomass production and carbon stocks respectively would increase with increasing complexity of the system, meaning that most carbon (Fig. 13) was expected in the tree-savannahs (more under seasonal management) and less in the grasslands (more under seasonal management). In terms of total aboveground biomass production (Fig. 12), management system did not play a major role. Significantly ($P<0.05$) more biomass was accumulated in tree savannahs than in grasslands as expected in the hypotheses. Among other parameters, the root:shoot ratio of trees is a lot lower than that of grasses so that relatively more biomass is allocated to the aboveground biomass in trees than to the roots (Bonan, 2008; Grace et al., 2006; Jobbagy & Jackson, 2000).

Nonetheless, the grass production of the four management systems depended significantly ($P<0.05$) on the management type. More than double the amount of grass was accumulated and measured in enclosures compared to open-grazed systems (Fig. 12). This finding is supported by Oba et al. (2001) who state that significantly more aboveground biomass has been produced in enclosures than in open-grazed areas in Northern Kenya. Biomass production varied between 440 g/m^2 under seasonal grazing and 172 g/m^2 in year-round grazed areas in Moyale District. Another trial in Southern Ethiopia showed similar results. Angassa & Oba (2010a) state that herbaceous biomass was higher in enclosed than in open-grazed areas due to less grazing pressure. Contrary are the results of Bunning (2009) who found out that grazing stimulates vegetation to grow more vigorously. These results are tempered by Conant & Paustian (2002) who state that excessive grazing always leads to a reduction in herbaceous biomass accumulation if grazing impact is stronger than the plant growth capacity. Also Kölbl et al. (2011) found a significant reduction in aboveground biomass under intensive grazing in Mongolia. Similar results were published by Sawadogo et al. (2005) in Burkina Faso, where aboveground biomass declined under intensive grazing management. Aboveground biomass accumulation further decreased under increasing grazing pressure in studies by Li et al. (2011) and Angassa et al. (2010b).

In semi-arid savannah systems, land degradation due to overgrazing often constitutes a severe threat to sustainable grassland management. The FAO defines overgrazing as "the practice of grazing too many livestock for too long a period on land unable to recover its vegetation. Furthermore, overgrazing exceeds the carrying capacity of a pasture (www.fao.org, 2012)."

Fig. 23 shows that the stocking rate (TLU/ha) in the enclosed areas was significantly ($P<0.05$) lower than in the continuously- grazed areas, although it exceeded by far the stocking rate in this area in 2004, when Homann et al. (2008) observed 1.05 TLU/ha. Furthermore, they calculated a carrying capacity of 0.235 TLU/ha, if aboveground biomass production ranged between 1.5-2.7 t/ha. These results coincide with the findings of this thesis. Carrying capacities calculated for enclosures were 0.36 TLU/ha and for continuously- grazed areas 0.16 TLU/ha (Fig. 24). The actual stocking rates were three to ninety times higher than grass biomass could sustainably feed. Thus, overgrazing is severe in this region, although remarkably less in seasonally grazed, enclosed areas.

Snyman (2005) observed that aboveground biomass accumulation declined with rangeland degradation, due to several factors like reduced soil cover, changed species composition and decreased root biomass. A rangeland under good conditions yielded 3.1 t/ha grass on average, a medium area 1.6 t/ha and a severely overgrazed region 0.695 t/ha. Under these circumstances, the enclosed areas in the research region are between good to medium conditions, while the permanently-grazed areas are highly degraded. Also Wolf et al. (2011) noticed substantial reductions of aboveground biomass during periods of overgrazing in Panama which additionally led to a reduction in topsoil carbon pools. Especially in semi-arid regions, overgrazing during the dry season reduced aboveground biomass with no recovery as water was limited until the rainy season started. Continuous overgrazing may lead to a permanent reduction in biomass production. Similar results were also observed by Skornik et al. (2010) in Adriatic Karst pastures. Highest aboveground biomass accumulation was observed under decreased grazing, vice versa, aboveground biomass was reduced in overgrazed areas.

In case of aboveground biomass production and carbon stocks, the vegetation type played a significant role in terms of total biomass production, but grazing management altered the seasonal grass production substantially, showing that grazing intensity has a major impact on aboveground carbon allocation.

6.2. The Influence of Grazing on Belowground Carbon Allocation

Hypotheses also indicated that grazing management considerably alters belowground carbon allocation. It was expected that seasonally grazed enclosures could store more carbon in the soil due to higher biomass production rates, less disturbances by grazers and browsers, less overgrazing and slower mineralization rates. Additionally, carbon accumulation would be enhanced along soil depths compared to year-round grazed management systems.

Belowground carbon pools consist to a substantial amount of fresh and decomposed plant roots and residues (Hoyle et al., 2006). C/N ratio has a crucial influence on the mineralization process of fresh plant material and SOM.
Snyman (2005) not only observed decreased aboveground biomass production under enhanced grazing pressure, but also reduced root biomass. Roots grew worse in degraded rangelands, leading to less SOM accumulation and a smaller labile SOC pool. Furthermore, the root distribution was altered and shallower; most of the roots only grew in the first 15 cm of the topsoil.
Also Chen et al. (2006) recorded decreasing belowground biomass accumulation related to increasing stocking rates in Mongolia. As the photosynthetically active area of the plant was reduced by grazing, less assimilates went to the root, ending up in reduced belowground biomass. Gao et al. (2008) as well observed less root biomass under heavy grazing due to reallocation of the carbon in the roots to the plant leaves and stems to rebuild assimilation tissue.
Abril & Bucher (2001) observed a decrease in SOC from moderately to heavily overgrazed regions on Argentina. Mineralization rates of soil organic carbon increased with the level of overgrazing, leading to a reduction of the SOC pool from 7 kg/m² in the restored to 0.13 kg/m² in the overgrazed region. Soil temperatures increased as soil cover decreased under grazing, enhancing microbial activity and SOM degradation (Amelung et al., 1998, cited in Abril & Bucher, 2001). Furthermore, less soil cover favored a rapid desiccation after rains, leading to a breakdown of the soil aggregates and further SOM degradation (Kay, 1998, cited in Abril & Bucher, 2001). Also Sousa et al. (2012) measured higher total organic carbon and nitrogen amounts in areas where grazing was excluded than in grazed regions.
Results are contradictory to the hypotheses. Significantly ($P<0.05$) more organic carbon has been accumulated in the continuously- grazed areas than in the enclosures (Fig. 15). Similar processes have been observed by Pucheta et. al (2004) in Argentina. They measured the organic carbon accumulation in a grazed and a neighbouring un-grazed exclosure. In this case, exclosure describes an area that is fenced and protected from grazing for a longer period. The grazed site had twice the amount of dead biomass accumulated in the soil than the exclosure. The fine-root biomass production was 1200 g/m² under grazing and only 700 g/m² in the un-grazed exclosure. Additionally, 95% of the fine roots in the year-round grazed plot were renewed each year, whereas only 56% of the roots in the exclosure regrew yearly. Also Li et al. (2011) observed that grazing had a significant positive impact on soil properties. C and N storage increased in grazed sites in an alpine meadow as belowground biomass allocation was enhanced and roots grew vigorously.
In these cases, grazing stimulated the belowground biomass production. Some grasses need moderate grazing to achieve their optimal production rates and have developed

several mutualisms to attract grazers; like high palatability and basal meristems (Owen, 1980; Owen and Wiegert, 1981,1982 cited in Belsky, 1986).
Grazing can improve the soil cover and the plant biomass and diversity in grasslands. Furthermore, grazers can influence soil compaction through trampling and enhance nutrient cycling by distributing dung and urine (Bunning, 2009). Improved water-holding capacity and nutrient availability, i.e. ammonium through faeces, provide habitats for soil biota, such as free-living N-fixing bacteria.
Also Ammann et al. (2007) state that extensive grazing management leads to a decrease in SOC pools. Compared to other important nutrients, a large amount of carbon is supplied. Microbes intensify the decomposition of the active SOC pool in the soil and stimulate the microbial activity for further nutrient mobilization. This leads to a high heterotrophic release of CO_2 and a reduction of the belowground labile SOC pool (Fontaine et al., 2004, Fenchel et al., 1998 cited in Ammann et al., 2007).
Other authors claim that grazing alters the decomposability of plant residues, leading to changes in the labile and stabile SOC pool. Plants that are adapted to herbivory produce more lignified leaves under heavy grazing, that are less decomposable by microbes. Thus, more carbon is accumulated in the stabile SOC pool under grazing (Tanentzap & Coomes, 2011). Piñeiro et al. (2010) measured increased C/N ratios of plant residues under grazing, resulting into limited N resources and reduced SOM decomposition.
Also Olsen et al. (2011) measured an increase of the stabile SOC pool compared to the labile pool under grazing. Anyway, this was not due to a change in residue degradation potential, but to a change in soil respiration. Grazing enhanced plant root exudation and turnover and simultaneously supported higher microbial activity. But instead of an increase in soil respiration, significantly more C was allocated to the microbial biomass pool and transferred to the medium to long storage C pool. Therefore, grazing alters the longevity of C in the soil and the utilization of carbon in the microbial community, which is supported by Fontaine et al. (2004) and Fenchel et.al (1998) cited in Amman et al. (2007) as they measured increased microbial soil respiration under no grazing.

Although management practice had the only significant ($P<0.05$) impact on the total amount of carbon allocated to the soil (Fig. 15), still more organic carbon was measured in tree savannahs of the respective management system than in the grasslands. This is due to several effects of trees on matter cycling and micro-climate. Scurlock & Hall (1998) measured increased SOC levels under trees compared to grasslands. Dalle et al. (2006) observed a soil nutrient enrichment with increasing amount of woody species. Harms et al.(2005) noticed declining SOC values after tree-clearing a semi-arid savannah in Queensland, Australia.
Trees can improve nutrient cycling. Lateral roots withdraw nutrients from surrounding topsoil and vertical roots from deeper soil layers. The tree litter raises the soil organic

matter content (Chivaura-Mususa et al., 1998). Furthermore, all trees in the research region were acacias, that could fix nitrogen from the atmosphere, enhancing N amounts under trees and improving soil nutrient composition so that herbaceous growth and biomass accumulation was increased. Belsky & Amundson (1998) found significant higher contents of OM, Ntot, calcium, potassium and phosphorus under trees than in interspaces.
Additionally, respiration and transpiration under trees decrease, improving the water availability and support herbaceous plant growth (Vetaas et al, 1992, Joffre & Ramball, 1988). Morris et al. (1982) measured lower temperatures and concomitant less SOM decomposition under woody canopies.

Belowground carbon storage potential of semi-arid savannahs has been measured by Watson et al. (2000) (cited in Bunning, 2009). Average amounts in one meter depth are 265 t/ha (Chapter 3.4). Fig. 15 shows that SOC pools varied between 290-400 t/ha in the research site. Bunning (2009) and Jobbagy & Jackson (2000) stated that carbon has a longer resting-time in dry than in wet soils. During the period of the study, the first considerable rainfalls after a three years drought period in Eastern Africa occurred. Probably, the drought slowed down mineralization processes of SOM and plant residues in the soil. This has also been proved by Warren and Meredith (1998). They measured considerably higher decomposition rates of SOM in regions with bimodal than with unimodal rainfall.
Also texture and mineral composition can have a major impact on belowground carbon allocation. The highest concentration of organic carbon was measured in clay-rich soils by Warren and Meredith (1998). Clay builds up strong humus complexes that are hardly degradable by microorganisms. Soils in the research area were exclusively Cambisols and Vertisols with clay contents between 20-60% (Materials and Methods). Clayey soils are saturated with multivalent cations; the clay molecules flocculate and reduce the exposure of absorbed carbon to mineralization (Jobbagy & Jackson, 2000). Furthermore, the pore volume of clay-rich soils is very small. It should exceed at least three millimeter to allow microbes to enter the organic matter and degrade it.
Finally, the carbonate content of the soils fluctuated between 0.2- 11.3 % $CaCO_3$, usually increasing with depth. Especially fresh organic matter can be coated with highly reactive carbonates and mineralization is effectively slowed down (Krull et al., 2000). The Borana region has been created in many areas by volcanic activity. Soils derived from volcanic ash often have a high Al^{3+} content that can have similar effects on carbon fixation in the soil as carbonates.
It was expected, that carbon accumulation in the soil would increase with depth. Furthermore, more organic carbon was expected in the lower soil layers of the enclosures. Organic carbon contents varied between 32-35 t/ha over one meter depth, neither vegetation nor management type played a significant role in carbon allocation,

only depth (Fig. 16). In the lowest soil layer, from 60 to 100 cm, significantly (P<0.05) more carbon was allocated than in the top soil layers. This is probably due to several factors: With increasing depth, carbonate content of the soils increased and could bind organic matter, as mentioned above (Krull et al., 2000). Furthermore, soil respiration and microbial activity is reduced with increasing depth (Ammann et al., 2007), enhancing SOM and residue accumulation.
In clayey soils, pelo-turbation plays a major role in nutrient shifting across layers. Wet and dry periods lead to shrinking and expansion of the soil, so that deep cracks can occur. Plant residues and SOM particles can easily be shifted to deeper layers during expansion of the soil, while they are relatively stuck there in periods of shrinking. Therefore, high amounts of organic matter can be stored in the lower layers of the soil.
Results show, that management practice and vegetation type have a relatively low influence on carbon allocation across soil depths in the research region. It is expected, that soil type plays a prominent role when talking about vertical carbon storage potential of the region.

In case of total belowground carbon pools, management practice had a significant impact on carbon allocation; more carbon was stored in year-round grazed areas. Nevertheless, carbon storage potential and allocation across soil depths were mainly influenced by soil parameters and climatic factors and not by management practices.

6.3. Effect of Grazing on Soil Cover, Species Composition and Habitus

Grazing intensity has considerable effects on the soil cover, the species composition and the habitus as well.
In Fig. 18 one can see, that soil cover was significantly (P<0.05) influenced by the management type. In enclosures, ground cover varied from 70 to 76% in the respective vegetation type, while more than half of the continuously-grazed area was bare soil. Similar observations have been recorded by Snyman (2005). Under severe grazing, soil cover was reduced. Also in an alpine meadow, grazing pressure reduced the soil cover substantially (Li et al., 2011). Besides, Angassa et Al. (2010a, 2010b) mentioned a considerable better grass basal cover in enclosures, due to less grazing pressure. As stated before, Abril & Bucher (2001) found reduced SOM pools in overgrazed areas, also due to increased soil temperatures. Consequently, they observed more bare soil in highly degraded, intensively-grazed regions.
Species composition and habitus were significantly (P<0.05) influenced by the management type. Dicots varied from 29-37% under continuous grazing (Fig. 19), while only 8-12% of the species in the enclosures were dicots. The species variability between the different repetitions was very high in continuously-grazed areas. Furthermore, the habitus of species changed with grazing management (Fig. 20).

Significantly (P<0.05) more perennials were observed in enclosures; on average, 70% of the species under seasonal grazing were perennial, whereas only 36% grew over perennial in the continuously- managed areas.
Sustained grazing alters the botanical composition of semi-arid grasslands from long-lived perennials to short-lived annuals, leading to a decrease in biomass production and an increase in production variability (Snyman, 2005).
Less aboveground biomass production in year-round grazed areas compared to seasonal grazing has also been observed in his study (Fig. 12).
Under high grazing pressure, perennial grasses cannot reach the water in deeper layers and are easily suppressed by annual grasses and forbs that are unpalatable and have less biomass is stated by Rietkerk et al. (1996) cited in Tanentzap & Coomes (2011). Asefa, Oba, Weladji, & Colman (2003) observed a change from annual to perennial species after a three years rest from grazing in Northern Ethiopia as well. Annual species also increased in intensively-managed grasslands in a study from Niger (Hiernaux, 1998). In South Africa, perennial grass growth was enhanced in enclosures while overgrazing resulted into more annuals (Kraaij & Milton, 2006).
Oba et al. (2000) observed a connection between the species composition of an area and the soil cover. As also noticed in this study, in areas with a high percentage of perennials, the soil cover increased compared to areas where mostly annuals grew.
Species composition also changed in terms of diversity, type and palatability between seasonally and year-round grazed areas. Species diversity was lower in enclosures than in continuously-grazed areas (Fig. 20). Mainly *Pennisetum* ssp. and *Cenchrus ciliaris* grasses were found in enclosures, while *Cynodon dactylon, Eragrostis* ssp. types, *Commelina latifolia* and some legumes dominated the continuously- grazed regions. Furthermore, significantly (P<0.05) more unpalatable species were found in the open-grazed areas (Fig. 22). 8-27% of the species in the enclosures were unpalatable to cattle, contrary to approximately 50% unpalatable species under continuous grazing.
Oba et al. (2001) found out that species richness was reduced in enclosures due to less grazing and higher biomass production so that the number of less competitive species decreased. Li et al. (2011) observed increasing species richness with increasing grazing intensity.
Contrary were the results by Schlesinger et al. (1990) (cited in Conant & Paustian, 2002) and Abebe et al. (2006). They found that enclosures had a higher species variety than open-grazed areas. Besides, Angassa & Oba (2010a, b) observed increasing species diversity in enclosures due to less grazing pressure which is contradictory to the results of Oba et al. (2001) who stated that less grazing pressure would result into more biomass and less species variety in seasonally grazed areas (cited above). Species abundance and diversity is, therefore, also dependent on the grazing tolerance (Oba et al., 2001).

Nevertheless, more standing, erect biomass was observed in the enclosures than in the year-round grazed regions (Fig. 19), as it has also been stated in Oba et al. (2001). Peco et al. (2012) recorded a change from short, creeping grazing-tolerant species to more tall and erect species under no grazing in the mediterranean grasslands as well. This can be verified by the dominant species of the different management systems. *Pennisetum* species are tall and erect, while *Cynodon dactylon* and legume species like *Crotalaria incana* L. have a short, creeping growth style.
Palatability decreased significantly (P<0.05) with increasing grazing pressure. *Cenchrus ciliaris* is a key forage species in the Borana, especially for calf feeding (Coppock et al., 1994 cited in Angassa & Baars, 2000). Moderate grazing in the enclosures supports its growth while it has been removed in areas under severe overgrazing. Many of the dicot plants observed in the open-grazed areas are unpalatable to cattle like *Solanum incanum* L., *Euphorbia nubica* n. Br., *Indigofera spinosa* and *Ocimum basilicum.* Palatable species like *Cynodon dactylon, Commelina latifolia* and *Lintonia nutans* Stapf are highly overgrazed and have been considerably reduced by more competitive, unpalatable species.

Pic. 8: Difference in Species Composition between year-round and seasonal grazing management. Left: Plot G5, year-round grazed; right: Plot EC-G5, seasonally grazed.

Abebe et al. (2006) found that the majority of herbaceous species in grazed areas were unpalatable. Unpalatable species were increasing with grazing intensity and valuable grasses were on a downward trend in a trial by Angassa & Beyene (2003) in Ethiopia and also Kraaij & Milton (2006) came to similar results in South Africa.

Continuous grazing resulted into more dicot and annual species than seasonal grazing. Furthermore, unpalatable species increased under increased grazing pressure. Enclosures had less species diversity but species palatability and soil cover were high.

7. Conclusion

To gain results on the differences in biomass production, above-and belowground carbon allocation, species composition and habitus between enclosures and year-round managed areas, five repetitions each were selected according to the four existing systems in the research area: enclosure in grassland, enclosure in tree savannah, continuously-grazed grassland and continuously-grazed tree savannah.
In terms of aboveground biomass production, vegetation type had a significant influence on total biomass accumulation. In tree savannahs, aboveground biomass production was higher than in grasslands. Regarding seasonal grass biomass accumulation, management type influenced the results. Significantly more aboveground grass biomass was accumulated in enclosures than in continuously-grazed areas. These results prove the first hypothesis.
Belowground carbon allocation was significantly higher in the continuously- grazed areas than in the enclosures and contradict the second hypothesis after that longer resting times and higher biomass production, less grazing pressure and slower mineralization rates in the enclosures should result into more soil organic carbon accumulation than under open-grazed management. Due to better nutrient cycling and positive influences of trees, more organic carbon was stored in tree savannahs than in grasslands, although results were not significant.
Results prove the third hypothesis false after which management type should have a significant impact on carbon allocation across soil depths.
Carbon accumulation along soil depth was neither influenced by the vegetation nor the management type; only soil depth played a significant role in carbon storage in the different systems. More organic carbon was stored in deeper soil layers than in the topsoil, probably due to several soil parameters such as clay concentration and carbonate content.
It was expected, that management type would influence soil cover, species composition and habitus in hypothesis four. Significantly more annual, dicot species were observed under constant grazing than in enclosures. Soil cover improved under seasonal grazing. Additionally, palatability of species for cattle declined with increasing grazing pressure. Enclosures had a positive impact on species growth and biomass accumulation and supported high aboveground biomass allocation compared to year-round grazed areas.
Under the aspect of carbon sequestration potential under different management practices to establish a PES system and improve pastoralists income, the year-round grazed systems store significantly more organic carbon than the protected, seasonally grazed areas. Nevertheless, these areas are highly overgrazed and species composition has been changed towards mainly unpalatable species for cattle. Furthermore, soil

cover has been drastically reduced, enhancing soil degradation due to erosion incidents after erratic rainfalls and storms. Aboveground biomass production under seasonal grazing is significantly higher than under constant grazing, so that carrying capacity of the enclosed areas is better, allowing pastoralists to feed more cattle and improve their own living conditions.

In this study, many questions remain unanswered. To gain information on the nutrient turnover of the region, which might be highly seasonal, due to erratic rainfalls, studies on soil respiration potential and microbial activity would be highly valuable. Furthermore, C/N ratios of the residues in the different management systems should be calculated to get results about the potential matter decomposition rate under seasonal or continuous grazing. Also the water household might influence SOM degradation and plays an important role in semi-arid systems.

Additionally, the variability of root growth over seasons is crucial to know to give answers on the potential variability of belowground carbon stocks and gain information on labile and stabile carbon pools.

Finally, also soil parameters seem to play an important role in belowground carbon storage and allocation. Further laboratory analyses could prove the role of carbonates and clay particles in carbon accumulation in the soil.

References

FAO: http://www.fao.org/corp/google_result/en/?cx=018170620143701104933%3Aqq82jsfba7w&q=definition+overgrazing&x=0&y=0&cof=FORID%3A9&siteurl=www.fao.org%2F&ref= June, 14th 2012; 10.58h

Abebe, M. H., Oba, G., Angassa, A., & Weladji, R. B. (2006). The role of area enclosures and fallow age in the restoration of plant diversity in northern Ethiopia. *African Journal of Ecology*, *44*, 507-514.

Abril, A., & Bucher, E. H. (2001). Overgrazing and soil carbon dynamics in the western Chaco of Argentina. *Applied Soil Ecology*, *16*, 243-249.

Alstad, G., Vetaas, O.R. (1994): The influence of *Acacia tortilis* stands on soil properties in arid northeastern Sudan. *Acta Oecologica* 15, 449-460.

Ammann, C., Flechard, C. R., Leifeld, J., Neftel, A., & Fuhrer, J. (2007). The carbon budget of newly established temperate grassland depends on management intensity. *Agriculture, Ecosystems and Environment*, *121*, 5-20.

Angassa, A, & Oba, G. (2010a). Effects of grazing pressure , age of enclosures and seasonality on bush cover dynamics and vegetation composition in southern Ethiopia. *Journal of Arid Environments*, *74*, 111-120.

Angassa, A., Oba, G., Treydte, A.C., Weladj, R.B. (2010b): The Role of traditional enclosures on the diversity of herbaceous vegetation in a semi-arid rangeland, Southern Ethiopia. L*ivestock Research for Rural Development* 22 (9).

Angassa, Ayana, & Baars, R. M. T. (2000). Ecological condition of encroached and non- encroached rangelands in Borana , Ethiopia. *East*, 321-328.

Angassa, Ayana, & Beyene, F. (2003). Current range condition in southern Ethiopia in relation to traditional management strategies : The perceptions of Borana pastoralists. *Tropical Grasslands*, *37*, 53-59.

Asefa, D. T., Oba, G., Weladji, R. B., & Colman, J. E. (2003). An assessment of restoration of biodiversity in degraded high mountain grazing lands in northern Ethiopia. *Land Degradation & Development*, *14*(1), 25-38.

Belsky, A. J. (1986). Does Herbivory Benefit Plants ? A Review of the Evidence. *The American Naturalist*, *127*(6), 870-892.

Belsky, A.J., Amundson, R.G. (1998): Influence of savannah trees and shrubs on understorey grasses and soils: new directions in research. CAB International 1998. *Carbon and Nutrient Dynamics in Natural and Agricultural Tropical Ecosystems*. Wallingford, United Kingdom

Bonan, G. B. (2008). Climate Benefits of Forests. *Science*, *320*, 1444-1449.

Bond, W. J. (2008). What Limits Trees in C 4 Grasslands and Savannas ? *Annual Review of Ecology, Evolution and Systematics*, *39*, 641-59. 411

Bond, W. J., & Midgley, G. F. (2000). A proposed CO 2 -controlled mechanism of woody plant invasion in grasslands and savannas. *Global Change Biology*, *6*, 865-869.

Brown, S., & Lugo, A. E. (1990). Effects of forest clearing and succession on the carbon and nitrogen content of soils in Puerto Rico and US Virgin Islands. *Plant and Soil*, *164*, 53-64.

Bunning, S. (2009). Review of evidence on drylands pastoral systems and climate change. *Organization*.

Cadisch, G., de Oliviera, O.C., Cantarutti,R., Carvalho, E., Urquiaga, S. (1998): The role of legume quality in soil carbon dynamics in savannah ecosystems. CAB International 1998. *Carbon and Nutrient Dynamics in Natural and Agricultural Tropical Ecosystems.* Wallingford, United Kingdom

Campbell, B.M, Frost, P., King, J.A., Mawanza, M., Mhlanga, L. (1994): The influence of trees on soil fertility on two contrasting semi-arid soil types at Matopos, Zimbabwe. *Agroforestry Systems* 28, 159-172

Chen, Y., Lee, P., Lee, G., Mariko, S., & Oikawa, T. (2006). Simulating root responses to grazing of a Mongolian grassland ecosystem. *Plant Ecology*, *183*, 265 -275.

Chivaura-Mususa, C.C., Campbell, B.M. (1998): The influence of scattered Parinari curatellifolia and Acacia sieberana trees on soil nutrients in a grassland pasture and in arable fields. CAB International 1998. *Carbon and Nutrient Dynamics in Natural and Agricultural Tropical Ecosystems*. Wallingford, United Kingdom

Conant, R. T., & Paustian, K. (2002). Potential soil carbon sequestration in overgrazed grassland ecosystems. *Global Biogeochemical Cycles*, *16*(4), 91-99.

Christie, E.K. (1975): A note on the significance of *Eucalyptus populnea* for buffel grass production in infertile semi-arid rangelands. T*ropical grasslands* 9, 243-246

Dalle, G., Maass, B. L., & Isselstein, J. (2006). Encroachment of woody plants and its impact on pastoral livestock production in the Borana lowlands , southern. *African Journal of Ecology*, *44*, 237-246.

Fang, C., & Moncrieff, J. B. (2005). The variation of soil microbial respiration with depth in relation to soil carbon composition. *Plant and Soil*, *268*, 243-253.

Fisher, M. J., Rao, I. M., Ayarza, M. A., Lascano, C. E., Sanz, J. I., Thomas, R. J., & Vera, R. R. (1994). Carbon Storage by Introduced deep-rooted grasses in the South American Savannahs. *Nature*, *371*, 236-238.

Gao, Y. Z., Giese, M., Lin, S., Sattelmacher, B., Zhao, Y., & Brueck, H. (2008). Belowground net primary productivity and biomass allocation of a grassland in Inner Mongolia is affected by grazing intensity. *Plant and Soil*, *307*, 41-50.

Grace, J., Jose, J. S., Meir, P., Miranda, H. S., & Montes, R. A. (2006). Productivity and carbon fluxes of tropical savannas. *Journal of Biogeography*, *33*, 387-400.

Guo, L. B., & Gifford, R. M. (2002a). Soil carbon stocks and land use change : a meta analysis. *Global Change Biology*, *8*, 345-360.

Guo, L. B., & Gifford, R. M. (2002b). Soil carbon stocks and land use change : a meta analysis. *Global Change Biology*, 345-360.

Harms, B. P. A., Dalal, R. C. A., & Cramp, A. P. C. (2005). Changes in soil carbon and soil nitrogen after tree clearing in the semi-arid rangelands of Queensland. *Australian Journal of Botany*, *53*, 639-650.

Heiri, O., Lotter, A. F., & Lemcke, G. (2001). Loss on ignition as a method for estimating organic and carbonate content in sediments : reproducibility and comparability of results. *Science And Technology*, 101-110.

Henry, M., Picard, N., Trotta, C., Manlay, R. J., Valentini, R., Bernoux, M., & Saint-andré, L. (2011). Estimating Tree Biomass of Sub-Saharan African Forests : a Review of Available Allometric Equations. *Silva Fennica*, *45*(January).

Hiernaux, P. (1998). Effects of grazing on plant species composition and spatial distribution in rangelands of the Sahel. *Plant Ecology*, *138*, 191-202.

Hofstad, O. (2005). Review of biomass and volume functions for individual trees and shrubs in southeast Africa . *Review Literature And Arts Of The Americas*, *17*(1), 151-163.

Homann, S, Rischkowsky, B., & Steinbach, J. (2008a). The effect of development interventions on the use of indigenous range management strategies in the Borana lowlands in Ethiopia. *Land degradation and Development*, *19*, 368-387.

Homann, Sabine, Rischkowsky, B., Steinbach, J., Kirk, M., & Mathias, E. (2008b). Towards Endogenous Livestock Development : Borana Pastoralists ’ Responses to Environmental and Institutional Changes. *Human Ecology*, *36*, 503-520.

Hoyle, B. F., Murphy, D., Sheppard, J., & Council, A. C. (2006). *Labile carbon*. Internet Source April 2012

Hudak, A. T., Wessman, C. A., & Seastedt, T. R. (2003). Woody overstorey effects on soil carbon and nitrogen pools in South African savanna. *Austral Ecology*, *28*, 173-181.

ICRAF and Ministry of Agriculture and Rural Development, Ethiopia (2005): Managing Land. A practical guidebook for development agents in Ethiopia. No. 36, Nairobi, Kenya and Addis Abeba, Ethiopia (received at ILRI in Addis Abeba)

Jobbagy, E. G., & Jackson, R. B. (2000). The vertical Distribution of Soil Organic Carbon and its Relation to Climate and Vegetation. *Ecological Applications*, *10*(2), 423-436.

Jones, M. B., & Donnelly, A. (2004). Carbon sequestration in temperate grassland ecosystems and the influence of management , climate and elevated CO 2. *New Phytologist*, 423-439.

Kamara, A. B., Swallow, B., & Kirk, M. (2004). Policies , Interventions and Institutional Change in Pastoral Resource Management in Borana , Southern Ethiopia. *Development Policy Review*, *22*(4), 381-403.

Kamau-Rewe, M., Rasche, F., Cobo, J. G., Shepherd, K. D., & Cadisch, G. (2011). Generic Prediction of Soil Organic Carbon in Alfisols Using Diffuse Reflectance Fourier-Transform Mid-Infrared Spectroscopy. *Carbon*, *75*(6), 2358-2360.

Kellman, M. (1979): Soil enrichment by neotropical savanna trees. J*ournal of Ecology 67*, 565-577.

Kennard, D.G, Walker, B.H. (1973): Relationships between tree canopy cover and *Panicum maximum* in the vicinity of Fort Victoria. *Rhodesian Journal of Agricultural Research* 11, 145-153

Konen, M. E., Jacobs, P. M., Burras, C. L., Talaga, B. J., & Mason, J. A. (1998). Equations for Predicting Soil Organic Carbon Using Loss-on-Ignition, 1878-1881.

Kraaij, T., & Milton, S. J. (2006). Vegetation changes (1995 – 2004) in semi-arid Karoo shrubland , South Africa : Effects of rainfall , wild herbivores and change in land use. *Journal of Arid Environments*, *64*, 174-192.

Krull, E., Baldock, J., & Skjemstad, J. (2000). Soil Texture Effects on Decomposition and Soil Carbon Storage. *NEE Workshop Proceedings* (pp. 103-110).

Kölbl, A., Steffens, M., Wiesmeier, M., Hoffmann, C., Funk, R., Krümmelbein, J., Reszkowska, A., et al. (2011). Grazing changes topography-controlled topsoil properties and their interaction on different spatial scales in a semi-arid. *Plant abd Soil*, *340*, 35-58.

Lal, R. (2008). Carbon sequestration. *The Royal Society*, 815-830.

Li, W., Huang, H.Z., Zhang, Z.N., Wu, G.L. (2011): Effects of grazing on the soil properties and C and N storage in relation to biomass allocation in an alpine meadow. *Journal of Soil Science and Plant Nutrition* 11(4), 27-39

Lipper, L., Dutilly-diane, C., & Mccarthy, N. (2010). Supplying Carbon Sequestration From West African Rangelands : Opportunities and Barriers Supplying Carbon Sequestration From West African Rangelands : Opportunities and Barriers. *Ecology*, *63*(1), 155-166.

Michelsen, A., Andersson, M., Jensen, M., Kjøller, A., & Gashew, M. (2004). Carbon stocks , soil respiration and microbial biomass in fire-prone tropical grassland , woodland and forest ecosystems. *Soil Biology*, *36*, 1707-1717.

Mlambo, D., Mwenje, E., & Nyathi, P. (2007). Effects of tree cover and season on soil nitrogen dynamics and microbial biomass in an African savanna woodland dominated by Colophospermum mopane. *Journal of Tropical Ecology*, *23*, 437-448.

Morris, J., Bezuidenhout, J.J., Furniss, P.R. (1982): Litter Decomposition. In Huntley, B.J. and Walker, B.H. (eds) *Ecology of Tropical Savannahs.* Springer Verlag, New York, USA, pp. 535-553

Oba, G., Post, E., Syvertsen, P. O., & Stenseth, N. C. (2000). Bush cover and range condition assessments in relation to landscape and grazing in southern Ethiopia. *Landscape Ecology*, *15*, 535-546.

Oba, G., Vetaas, O. L. E. R., & Stenseth, N. C. (2001). Relationships between biomass and plant species richness in arid-zone grazing lands. *Journal of Applied Ecology*, *38*, 836 - 845.

Olsen, Y. S., Dausse, A., Garbutt, A., Ford, H., Thomas, D. N., & Jones, D. L. (2011). Cattle grazing drives nitrogen and carbon cycling in a temperate salt marsh. *Soil Biology and Biochemistry*, *43*(3), 531-541. Elsevier Ltd.

Ouimet, R. (2008). Organic carbon , organic matter and bulk density relationships in boreal forest soils.

Peco, B., Carmona, C. P., de Pablos, I., & Azcárate, F. M. (2012). Effects of grazing abandonment on functional and taxonomic diversity of Mediterranean grasslands. *Agriculture, Ecosystems & Environment*, *152*, 27-32. Elsevier B.V.

Piñeiro, G., Paruelo, J. M., Oesterheld, M., & Jobbágy, E. G. (2010). Pathways of Grazing Effects on Soil Organic Carbon and Nitrogen Pathways of Grazing Effects on Soil Organic Carbon and Nitrogen Gervasio Pin. *Rangeland Ecology Management*, *63*(1), 109-119.

Pucheta, E., Bonamici, I., Cabido, M., & Díaz, S. (2004). Below-ground biomass and productivity of a grazed site and a neighbouring ungrazed exclosure in a grassland in central Argentina. *Austral Ecology*, *29*, 201-208.

Reid, R.S., et al. (2009): *Evolution of models to support community and policy action with science: Balancing pastoral livelihoods and wildlife conservation in savannas of East Africa.* PNAS.

Riebeek, H., & Simmon, R. (n.d.). The Carbon Cycle. *Nasa Earth Observatory, 2011*.

Sawadogo, L., Tiveau, D., & Nygård, R. (2005). Influence of selective tree cutting , livestock and prescribed fire on herbaceous biomass in the savannah woodlands of Burkina Faso , West Africa. *Agriculture, Ecosystems and Environment*, *105*, 335-345.

Schlecht, E., Hülsebusch, C., Mahler, F., & Becker, K. (2004). The use of differentially corrected global positioning system to monitor activities of cattle at pasture. *Applied Animal Behaviour Science*, *85*, 185-202.

Schnitzer, M. (1991). Soil Organic Matter-the next 75 years. *Soil Science*, *151*(1), 41-58.

Scurlock, J. M. O., & Hall, D. O. (1998). The global carbon sink : a grassland perspective. *Global Change Biology*, *4*, 229-233.

Skornik, S., Vidrih, M., Kaligaric, M. (2010): The effect of grazing pressure on species richness, composition and productivity in North Adriatic Karst pastures. *Plant Biosystems* 144 (2), 355-364

Snyman, H. A. (2005). Rangeland degradation in a semi-arid South Africa: influence on seasonal root distribution , root / shoot ratios and water-use efficiency. *Journal of semi-arid Environments*, *60*, 457-481.

Solomon, T. B., Snyman, H. A., & Smit, G. N. (2007). Cattle-rangeland management practices and perceptions of pastoralists towards rangeland degradation in the Borana zone of southern Ethiopia. *Journal of Environmental Management*, *82*, 481-494.

Sousa, F. P., Ferreira, T. O., Mendonc, E. S., Romero, R. E., & Oliveira, J. G. B. (2012). Agriculture , Ecosystems and Environment Carbon and nitrogen in degraded Brazilian semi-arid soils undergoing desertification. *Agriculture, Ecosystems and Environment*, *148*, 11-21.

Tanentzap, A. J., & Coomes, D. A. (2011). Carbon storage in terrestrial ecosystems : do browsing and grazing herbivores matter ? *Biological Reviews*, 1-23.

Taneva, L., Pippen, J. S., Schlesinger, W. H., & Gonzalez-Meler, M. A. (2006). The turnover of carbon pools contributing to soil CO 2 and soil respiration in a temperate forest exposed to elevated CO 2 concentration. *Global Change Biology*, *12*, 983-994.

Tefera, S., Snyman, H. A., & Smit, G. N. (2007). Rangeland dynamics in southern Ethiopia : (1) Botanical composition of grasses and soil characteristics in relation to land-use and distance from water in semi-arid Borana rangelands. *Journal of Environmental Management*, *85*, 429-442.

Tiessen, H., Shang, C. (1998): Organic matter turn-over in tropical land-use systems. CAB International 1998. *Carbon and Nutrient Dynamics in Natural and Agricultural Ecosystems.* Wallingford, United Kingdom

Vetaas, O.R. (1992): Micro-site effects of trees and shrubs in dry savannahs. *Journal of Vegetation Science* 3, 337-344

Virginia, R.A., Jarrell, W.M. (1983): Soil properties in a mesquite dominated Sonoran desert ecosystem. *Soil Science Society of America Journal* 47, 138-144.

Warren, G.P, Meredith, J.A. (1998): Isotopic composition of organic carbon in some soils of semi-arid Africa. CAB International 1998. *Carbon and Nutrient Dynamics in Natural and Agricultural Ecosystems.* Wallingford, United Kingdom

Weltzin, J.F., Coughenour, M.B. (1990): Savanna tree influence on understorey vegetation and soil nutrients in northwestern Kenya. *Journal of Vegetation Science* 1, 325-332

Wolf, S., Eugster, W., Potvin, C., Turner, B. L., & Buchmann, N. (2011). Carbon sequestration potential of tropical pasture compared with afforestation in Panama. *Global Change Biology*, 1-18.