EVALUATION OF SELECTED SOIL PROPERTIES IN SEMI-ARID COMMUNAL RANGELANDS IN THE WESTERN BOPHIRIMA DISTRICT, SOUTH AFRICA

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"DESS - Ingénieur Agronome"

Thesis submitted in fulfillment of the requirements for the degree Philisophiae Doctor in Environmental Sciences at the Potchefstroom Campus of the North-West University

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"In the name of God, the Most Gracious, the Most Merciful"

In loving memory of my father.

To my mother, my family, Abdoul Jabbar and Yasira

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Declaration

The work described in this thesis was conducted at the School of Environmental Sciences and Development, Potchefstroom Campus of the North-West University. I, hereby, declare that this work is the fruit of personal labor. To the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institutes of higher learning, except where due acknowledgment has been made in the text.

Abdoulaye Saley Moussa
January 22nd 2007

FOREWORD

Land degradation is a major concern worldwide, although its true extent remains a source of debate, and the contributions of human and climatic factors to the phenomenon are not understood well enough. In South Africa, concerns were raised about land degradation, which threatens environmental sustainability and the livelihood of poor rural communities. Rangelands, which represent almost 80% of the land surface, and the single most dominant land use type, are reportedly suffering of degradation. Severe rangeland degradation was described in areas under communal land tenure than under commercial management. Understanding resource degradation through research, information and capacity building is important and a prerequisite to help develop sustainable resources use. The need of monitoring, baseline information and assessment has been strongly emphasized by the Millennium Ecosystem Assessment in the sense that "*without a scientifically robust and consistent baseline of desertification, identifying priorities and monitoring the consequences of actions are seriously constrained*".

This work was initiated within the framework of the Desert Margins Program (DMP). The DMP is a collaborative initiative among nine African countries (Botswana, Burkina Faso, Kenya, Mali, Namibia, Niger, Senegal, South Africa, and Zimbabwe). The overall objective is to combat land degradation through demonstrations and capacity building activities. The purpose is to develop and implement strategies for conservation, restoration and sustainable use of drylands biodiversity. One major DMP's component is to improve understanding of ecosystem status and dynamics. In South Africa, the DMP aims to conserve and restore biodiversity in the desert margins through sustainable utilization and specifically, to develop strategies to enhance ecosystem function and sustainable use in arid and semi-arid areas that are degraded and have reduced biodiversity associated with human and climatic impacts. The aim of this work was to characterize and provide baseline soil indicators, and assess the effects of grazing and exclusion management on selected soil properties that could be used for reporting on rangeland degradation. This work needs to be viewed in perspective of the search of indicators to characterize rangeland health and assess degradation processes in selected communal areas.

Three manuscripts referred by their Roman numeral, constitute the core of this thesis:

I. Characterization of soil quality and effects of grazing and exclusion management in semi-arid communally managed rangelands in South Africa (Manuscript).
II. Soil microbial biomass in semi-arid communal rangelands in the western Bophirima District, South Africa (accepted pending revisions Journal Applied Ecology and Environmental Research).
III. A comparative assay of rangeland under different management systems in semi-arid South Africa: species composition *vs.* soil quality indicators (Manuscript).

Findings from this research have received exposure at several scientific forums at both national and international levels since the onset of the research. The following presentations (oral and poster) have been delivered:

1. Grazing effects on soil properties under communal semi-arid rangelands in the North-West Province. *Oral presentation - Arid Zone Ecology Forum (AZEF), Victoria West, Northern Cape Aug 30th - Sep 2nd 2004*
2. Impact of communal grazing on soil and vegetation properties and their relations in semi-arid rangelands in the North-West Province, South Africa. *Oral presentation - LandCare/DMP Symposium (North-West Department of Agriculture, Conservation, Environment and Tourism, Potchefstroom Jun 22nd 2005).*
3. Livestock grazing and rangeland degradation in semi-arid communal areas: effects on selected soil quality indicators. *Oral presentation - 40th Congress of the Grassland Society of Southern Africa (GSSA), Port Shepstone Jul 19th 2005.*
4. Patterns of soil organic carbon and nitrogen in grazed and ungrazed exclosure of semi-arid rangelands in South Africa. *Poster - First International Symposium on Management of Tropical Sandy Soils for Sustainable Agriculture (Khon Kaen, Thailand Nov 28th - Dec 2nd 2005).*
5. Soil indicators of rangeland degradation in a semi-arid communal district in South Africa. *Oral and poster presentations - International Scientific Conference "Future of Drylands" (Tunis Tunisia, 19th - 21st June 2006). The manuscript of this presentation has been accepted in the proceedings of the conference.*

ABSTRACT

Concerns were raised over the past decades, on the degradation condition of arid and semi-arid rangelands in South Africa, mainly in areas under communal land management. Baseline information on soil quality is essential to monitor changes in land conditions and assess impacts of land uses and management over time. The objectives of this study, initiated within the framework of the Desert Margins Program, were to characterize and establish baseline indicators of soil quality/health, and to investigate the potential effects of grazing and exclusion management (hypothesized as grazing effect) on selected soil properties in the western Bophirima District in South Africa.

Soils were characterized for physical, chemical, enzymatic activity and microbial biomass properties, and grazing effects were evaluated on selected properties. The aboveground herbaceous species composition and biomass production were also determined. Sandy, poor fertile soils (low organic carbon and phosphorus) characterized all sites. Various levels of enzymatic and microbial biomass were recorded at the sites. Grazing had no significant effects on most of soil chemical properties, but did affect selected enzymatic activities, site-specifically. No significant differences of grazing effects were observed on soil microbial biomass. The inconsistent responses of soil properties across the sites prompt to caution regarding the generalization and/or extrapolation of grazing effects to other areas, without consideration of the prevailing environmental and management characteristics to each site. Notwithstanding the alarming plea about degradation at these communal sites, indicators of soil quality did not significantly differ between communal and surrounding commercial and/or game managed areas, despite their apparent vegetation degradation. The results showed that rangeland under the communal management were characterized by *increaser* species of low grazing value, but this situation did not necessarily interpret severe soil degradation as tacitly described. Soil degradation depends on land use, management and environmental conditions, and references are needed to assess degradation. Important interrelationships between the aboveground vegetation and soil belowground activity were observed. This emphasized the need to integrate both soil and vegetation into rangeland monitoring, as these interrelationships and associated ecological processes sustain rangeland health. Further research is needed to re-examine the "inferred" degradation of rangelands in communal areas, taking into consideration their history, and using appropriate baselines and references sites. Only then, can degradation trends and hotspots be identified and thereof, appropriate management decisions (through participatory research) taken locally to combat degradation and sustain long-term rangeland resources uses.

Keywords: soil characterization; baseline indicators; monitoring; soil quality; communal rangeland management; rangeland degradation; grazing effects; sustainable rangeland management.

OPSOMMING

Besorgdheid bestaan die laaste paar dekades betreffende die toestand van degradasie van ariede en semi-ariede weivelde in Suid Afrika, hoofsaaklik in kommunaal bestuurde gebiede. Goeie basiese data van grondkwaliteit word benodig om veranderinge in toestand te moniteer en die impak van landgebruike en bestuur oor tyd te evalueer. Die doelwitte van hierdie studie, wat binne die raamwerk van die Desert Margins Program val, was om basiese indikatore van grond kwaliteit/gesondheid te karakteriseer en te bepaal, en om die potentiele effek van beweiding en uitsluitingsbestuur (as 'n beweidingseffek) op geselekteerde grond eienskappe in die westelike Bophirima distrik van Suid Afrika, te ondersoek.

Gronde is op met betrekking tot fisiese, chemiese, ensiematiese aktiwiteit en mikrobiese biomassaeienskappe gekarakteriseer, en die effek van beweiding is op sekere eienskappe geevalueer. Die bogrondse kruidagtige spesiekomponent en biomassaproduksie is ook bepaal. Sanderige, arm fertiele gronde (lae organiese koolstof en fosfaat) is in alle persele gekarakteriseer. Verskeie vlakke van ensiematiese en mikrobiese biomassas is vir die persele bepaal. Beweiding het geen betekenisvolle effek op meeste grondchemiese eienskappe gehad nie, maar het wel sekere ensiematiese aktiwiteite in sekere persele geaffekteer. Geen betekenisvolle verskille ten opsigte van beweiding is op die grondmikrobiese aktiwiteit waargeneem nie. Die onkonsekwente respons van grondeienskappe oor al die persele beklemtoon die gevaar van veralgemening en/of ekstrapolasie van die effek van beweiding na ander areas sonder om die heersende omgewings- en bestuurstoestande van elke perseel in aanmerking te neem. Ondanks die waarskuwende pleidooi betreffende die degradasie van kommunaalbestuurde gebiede, is daar geen betekenisvolle verskil in indikatore wat die grondtoestand aandui, tussen kommunale- en kommersiële- en/of wildbestuurde areas nie, ten spyte van die duidelike plantegroeidegradasie. Die resultate toon dat weiveld oner kommunale bestuur deur *toenemer* spesies met lae weidingswaarde gekenmerk is, maar dat hierdie situasie nie noodwendig drastiese gronddegradasie weerspiëel soos dikwels beskryf word nie. Gronddegradasie hang van die landgebruik, bestuur en omgewingstoestande af, en verwysings is nodig om hierdie degradasie te evalueer. Belangrike verhoudinge tussen die plantegroei in die bogrond en aktiwiteite in die ondergrond is waargeneem. Dit beklemtoon die noodsaaklikheid om beide grond en plantegroei in weiveldmonitering te integreer, angesien hierdie verhouding en geassosieerde ekologies prosesse die gesondheid van die weiveld onderhou. Verdere navorsing word benodig om die "afleidende" degradasie van kommunale weiveldareas verder te evalueer en dat historiese, asook toepaslike basislyndata met verwysingspersele in aanmerking geneem word. Slegs dan kan die verloop van degradasie en brandpunte geindentifiseer word en toepaslike bestuursbesluite (deur samewerkende besluitneming en navorsing) op grondvlak geneem word om degradasie te bekamp en die hulpbronne van die weiveld oor die langtermyn volhoubaar gebruik word.

Kernwoorde: grondkarakterisering basislynindikatore monitering; grondkwaliteit; kommunale weiveldbestuur; weivelddegradasie; effek van beweiding, volhoubare weiveldbestuur.

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I am greatly indebted for the funding from the Desert Margins Program (DMP South Africa) to conduct this research. I wish to extend my sincere gratitude to the DMP Coordination Unit and the African Network for Soil Biology and Fertility (Tropical Soil Biology and Fertility, Institute of CIAT, Kenya) for the financial assistance to carry this work.

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I owe a deep gratitude to my parents for your love, prayers, blessings, and support. To my sister Mrs. Issa Fati Moussa, thank you very much with all my heart. To my wife and children, thank you very much for your love, the happiness you brought in my life and your unfailing patience during the years of separation imposed by this work. Your support has provided the incentive for the successful completion of this work.

Thank you very much to all.

LIST OF ACRONYMS AND ABBREVIATIONS

ß-gluco	ß-glucosidase
ACP	Acid phosphatase
AfNet	African Network for soil biology and fertility
ANOVA	Analysis of variance
CCA	Canonical Correspondence Analysis
CEC	Cation Exchange Capacity
DEAT	Department of Environmental Affairs and Tourism
DHA	Dehydrogenase
DMP	Desert Margins Program
EXC	Exclosure plot
FAMEs	Fatty Acids Methyl Esters
FAO	Food and Agriculture Organization of the United Nations
GEF	Global Environment Facility
GLASOD	Global Assessment of Soil Degradation
GRZ	Grazed plot
IFS	International Foundation for Science
INF	Iodonitrotetrazolium chloride-formazan
IPCC	Intergovernmental Panel on Climate Change
MEA	Millennium Ecosystem Assessment
NAP	National Action Program
NRC	National Research Council
NWP	North-West Province
NWDACET	North-West Department of Agriculture, Conservation, Environment, and Tourism
OC	Organic Carbon
P	Phosphorus
PCA	Principal Component Analysis
PLFA	Phospholipids Fatty Acids
pmol	Pico mole
pNP	p-nitrophenol
SA	South Africa
STSS	Scientific and Technical Support Services
TSBF-CIAT	Tropical Soil Biology and Fertility (Institute of the International Center for Tropical Agriculture)
UNCCD	United Nations Convention to Combat Desertification
UNCBD	United Nations Convention on Biological Diversity
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
UNU	United Nations University

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NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

January 8th 2007

To Whom It May Concern:

Dear Sir, Madam,

SUBJECT: CO-AUTHORSHIP OF MANUSCRIPTS

The undersigned, as co-authors of the research manuscripts listed below, hereby give permission to Mr. Abdoulaye Saley Moussa to submit the below mentioned manuscripts as part of the Philosophiae Doctor degree in Environmental Sciences at the North-West University.

I. A.S. Moussa, L. Van Rensburg, K. Kellner and A. Bationo. Characterization of soil quality and effects of grazing and exclusion management in semi-arid communally managed rangelands in South Africa.

II. A.S. Moussa, L. Van Rensburg, K. Kellner, and A. Bationo. Soil microbial biomass in semi-arid communal rangelands in the western Bophirima District, South Africa.

III. Abdoulaye S. Moussa, Leon Van Rensburg, Klaus Kellner, and André Bationo. A comparative assay of rangelands under different management systems in semi-arid South Africa: species composition *vs*. soil quality indicators.

Yours truly,

Prof. Leon Van Rensburg — Prof. Klaus Kellner — Dr. André Bationo

CHAPTER 1.

INTRODUCTION AND LITERATURE REVIEW

This chapter provides a broad literature review on concepts of relevance, and background information to help understand the rationale of the study. The institutional framework within which, the study was undertaken and the objectives follow the literature review. The outlines and format of the thesis, which serve as an introduction to the rest of the document, conclude the chapter.

1.1. DESERTIFICATION AND LAND DEGRADATION

1.1.1. Generalities

Drylands cover nearly 41% of the earth's surface; more than two billion people (UNEP, 1997) inhabit them. They represent ecosystems limited by soil moisture, the result of low rainfall and high evaporation, and show a gradient of increasing primary productivity, ranging from hyper-arid, arid, and semiarid to dry sub-humid areas (Millennium Ecosystem Assessment, 2005). Drylands face severe land degradation, the consequences of which are estimated to affect the livelihoods of more than 250 million people in the developing world (Reynolds *et al.*, 2007). Rangelands, which cover 88% of the drylands areas, are most affected by desertification (UNEP, 1997).

Desertification has emerged as a global environmental crisis threatening the livelihoods of million of poor living in drylands, through its effects on ecosystem services (provisioning, regulating, supporting, and cultural) (Millennium Ecosystem Assessment, 2005). Desertification is defined as "land degradation in arid, semi-arid, and dry sub-humid areas resulting from climatic variations and human activities" (UNCCD, 1995). The relative importance of climatic and anthropogenic factors in causing desertification remains a source of debates; some scientists judge that anthropogenic factors outweigh climatic factors, though others maintain that extended droughts remain the key factor (IPCC, 2001). According to Hambly (1996), two of the most crucial requirements for desertification abatement are (i) the improvement of information systems to review and measure ecological, economic, and social consequences of desertification, and (ii) the transformation of results and recommendations to policy-makers into action-oriented programs.

Land degradation is defined as "the reduction or loss of the biological or economic productivity and complexity of terrestrial ecosystems, including soils, vegetation, other biota and the ecological, biogeochemical and hydrological processes that operate therein" (UNCCD, 1995). Land degradation transcends the deterioration of the land *per se*, particularly because of its influence on several critical issues such as food security, diminished quality and quantity of water resources, loss of biodiversity, and global climate change (Aneecksamphant *et al.*, 1999). The most commonly quoted degradation processes are vegetation degradation, water and wind erosion, salinization, soil compaction and crusting, and soil nutrient depletion. The causes and consequences of land degradation vary from region to region, mainly in terms of localized intensity, ecosystem characteristics, culture, economics, and political will (Reynolds and Stafford Smith, 2002). There is a need of scientifically robust and consistent baseline indicators to monitor land degradation in order to anticipate and/or prevent further degradation and improve livelihoods condition in drylands. Of the various forms of land degradation, this study focuses on soil condition/health and degradation in semi-arid rangelands.

1.1.2. Soil quality and degradation

1.1.2.1. Soil quality: concepts, definitions and indicators

Soils support plant growth, modulate water and nutrients, and play functions essential to the global sustainability of the earth as a living system, and basis for human survival and well-being (Arshad and Martin, 2002; Hurni *et al.*, 2006; Bastida *et al.*, 2006). Concern about soil resource needs to expand beyond soil productivity, to include a broader concept of soil quality that encompasses all the functions that soils perform in natural and agro-ecosystems (National Research Council, 1993). The concept of soil quality has been developed in response to public demand for an increased emphasis on sustainability, and to the recognition that soil management could be improved by taking a more holistic and integrative approach to soils (Herrick *et al.*, 2002). The term quality implies value judgment (degree of excellence), thus soil quality is concerned with measures of property or function of soil (good/bad, low/high) (Schjønning *et al.*, 2004). Soil quality is defined as "the capacity of a kind of soil to function within ecosystem boundaries, to sustain biological productivity, maintain environmental quality, and to promote plant and animal health" (Doran and Parkin, 1996). Karlen *et al.*, (2003) defined soil quality as "the fitness of a specific kind of soil to function within its capacity and within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain, or enhance water and air quality and support human health and habitation". Andrews *et al.*, (2004) emphasized that any specific definition of soil quality for a particular soil, is dependent on its inherent capabilities, the intended land use, and the management goals. The soil quality concept has however been criticized for its lack of sufficient quantification and scientific rigor (Sanchez *et al.*, 2003). Effort should rather be directed towards available technical information to motivate and educate farmers on quality soil management with regard to high crop production, low environmental degradation and sustained resource use (Sojka *et al.*, 2003).

The concept of soil quality is often associated to that of soil health. Soil health is defined as ''the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, maintain the quality of air and water environments, and promote plant, animal, and human health'' (Doran *et al.*, 1996). The limits of the two concepts are not particularly clear, but it is currently acknowledged that the term "quality" refers to the aptitude of the soil to carry out a specific function, while "health" refers to its overall condition (Doran and Safley, 1997). Whatsoever the definition, healthy or good quality soils are essential for the integrity of terrestrial ecosystems to resist (resistance) or to recover (resilience) from disturbances such as climate change and/or human pressures (Ellert *et al.*, 1997). Assessing soil quality implies measuring physical, chemical, and biological soil properties (indicators) (Schjønning *et al.*, 2004), and using these measured values to detect changes resulting from land use change and/or management practices (Campos *et al.*, 2007). Tugel *et al.*, (2005) proposed a process-based relational framework to assess soil changes (Table 1.1.), and to organize and disseminate soil change hypotheses, data, interpretation pertaining to human time scale, and protocols that should lead to the collection of soil properties (indicators) and quantifying changes.

Table 1.1. Soil survey user inquiry that addresses soil condition or level of function (functional capacity) and the corresponding soil change attribute necessary for response

Inquiry	Change attributes within a state	Change attributes within a transition
What is the condition of the soil or level of function?	State variable (actual and potential)	
Is it degrading, improving, or maintaining?		Trends of change
What should it be for the intended or sustained use?	State variable (potential or standard)	
What can be used to detect soil degradation before it occurs?		Early warning indicators
If degraded, can it be restored or improved?		Reversibility
What will it take to restore or improve it?		Drivers of change
How long will it take?		Rate of change
How long will soil changes affect future management options?		Pathways of change (feedbacks)

The need for indicators is reflected by the question posed by producers, researchers, and conservationists: "*which measurements should I make or what can I observe that will help me evaluate the effects of management on soil function now and in the future?*" (Doran and Safley, 1997). The criteria for indicators of soil quality selection relates mainly to their utility in defining ecosystem processes, their sensitivity to management and climatic variations, and their accessibility and utility to land users and policy-makers (Doran and Parkin, 1996). Indicators are measurable soil properties that influence the capacity of the soil to perform a function (Carter, 2002; Pathak *et al.*, 2005). The type and number of indicators depend on the scale of the evaluation (i.e., field, farm, watershed, or region) and the soil functions of interest. They should show observable and significant changes between 1-3 years, with 5 years being an upper limit to usefulness (Pathak *et al.*, 2005). Herrick *et al.*, (2002) proposed that soil indicators should be predictive, to the extent possible reflect early changes in ecological processes, and indicate if a significant change is likely to occur or not. Doran and Safley (1997) suggested that soil quality indicators should:

- Correlate well with ecosystem processes.
- Integrate soil physical, chemical, and biological properties and processes.

- Be relatively easy to use under field conditions and be assessable by both specialists and producers.
- Be sensitive to reflect the influence of management and climate.
- Be components of existing soil databases where possible.

Numerous soil physical, chemical, biological and microbiological properties have been proposed as indicators to assess the effects of human activities on soil quality (Table 1.2.) (Larson and Pierce, 1994; Doran and Parkin, 1994; Doran *et al.*, 1996).

Table 1.2. Minimum data set of physical, chemical and biological indicators for determining soil quality

Indicator	Rationale for its use
Physical	
Texture	Retention and transport of water and chemical
Depth of soil and rooting	Estimate of productivity potential and erosion
Infiltration and soil bulk density	Potential for leaching, productivity, and erosion
Water holding capacity	Water retention, transport, and erosivity
Chemical	
Toil soil organic matter	Carbon storage, potential fertility, and stability
Active organic matter	Structural stability and food for microbes
pH	Biological and chemical activity thresholds
Electrical conductivity	Defines plant and microbial activity thresholds
Extractable N, P, and K	Plant available nutrients and potential for N loss; productivity and environmental quality indicators
Biological	
Microbial biomass C and N	Microbial catalytic potential and early warning of
Potentially mineralizable N	management effect on organic matter
Specific respiration	Soil productivity and N supply potential
Macro-organism number	Microbial activity per unit of microbial biomass
	Potential influence of such organisms as earthworms

Soil physical and chemical have been used to measure soil quality, but these parameters change very slowly, and many years are required to measure significant changes (Pascual *et al.*, 2000). There is a growing interest in the use of soil biological and microbiological properties to assess soil quality (Pascual *et al.*, 2000; Bending *et* *al.*, 2000; Filip, 2002; Ros *et al.*, 2003; Gil-Sotres *et al.*, 2005). Biological processes respond more sensitively to environmental changes than chemical and physical properties (Tscherko *et al.*, 2007). However, the use of biochemical properties as soil quality indicators is hampered by the lack of reference values, the contradictory behavior shown by these properties when a soil is degraded, and the regional variations in expression levels (Gil-Stores *et al.*, 2005; Tscherko *et al.*, 2007).

A single minimum data set will probably remain undefined because of the inherent variability among soils, but it may be feasible to identify a suite of physical, chemical, and biological indicators that are useful for evaluating site-specific, temporal trends in soil quality (Campos *et al.*, 2007). Because different soil conditions are desired depending on land uses and management within different climatic conditions (Schipper and Sparling, 2000), there are no universal sets of indicators that are equally applicable, nor references or threshold values for comparative purposes (Pathak *et al.*, 2005). For soil indicators to be useful, standards or references values must first, be established as baseline from which, comparisons can be made to assess the status and degree of change (Mausbach and Seybold, 1998). References can however be given as specific limits or ranges for each indicator for a particular soil or groups of similar soils. These ranges or limits are based on the values for indicators, which define a condition representative of a soil functioning at full potential.

1.1.2.2. Soil degradation

Soil degradation is one major form of desertification, and constitutes a serious threat in drylands (Doran and Safley, 1997; FAO, 2004; Tugel *et al.*, 2005). Soil degradation proceeds from physical, chemical and biological degradation, driven by socioeconomic and political forces, and accentuated by inappropriate land use systems (Lal, 1998). Drylands soils are vulnerable to degradation through physical erosion and to chemical and biological degradation because of their low organic carbon (Reynolds and Stafford Smith, 2002). According to Pascual *et al.*, (2000), soils from arid and semi-arid regions are not resilient to the effects of inappropriate land-use and management that lead to permanent degradation and loss of productivity. A key factor in the degradation of these soils is the loss of natural plant cover which, aggravates the effects of semi-arid conditions (Garcia *et al.*, 1996), leading to loss of soil quality and fertility. Nortcliff (2002) stressed that soil may be easily lost in a relatively short period with very limited opportunity for restoration when it is inappropriately used and managed. Inappropriate uses and management such as overgrazing, deforestation, agricultural activities, overexploitation of vegetation, as well as industrial activities are among the most important factors leading to soil degradation (Oldeman, 1994).

Soil degradation is however a relative concept, depending on the land use type, management, and environmental conditions. It is not degraded as long as some land use is possible and some functions are achievable, or as long as soil responds to improved management or inputs. Furthermore, soil degradation is always relative to a reference soil, and that soil is degraded if improved management cannot restore its potential utility (Lal, 1998).

For each particular resource management situation, one should conduct in-depth analysis of what factors may cause environmental degradation and impede the adoption of more sustainable management practices (Lambin, 2005). Despite the relative concept of soil degradation and the limited available information on its extent, preserving soils from degradation is, in financial terms, more cost effective than attempting to remediate the environmental, social and economic consequences of not doing so (Bastida *et al.*, 2006). Reliable information is therefore required to understand processes, establish the cause-effect relationships and develop appropriate methods of constraint/stress alleviation, soil restoration and quality management (Lal, 1998).

1.1.3. Land degradation in South Africa

1.1.3.1. Overview

Over 90% of South Africa falls within the United Nations' definition of "affected drylands" which are extraordinarily dry areas where rainfall is low and potential evaporation high (Hoffman and Ashwell, 2001). Roughly, 80% of the land surface in South Africa is used for agricultural purposes, but only about 13.5% is considered arable. Nearly 70% of the country is "commercial" farmland under freehold tenure, 14% is state land that is communally managed, 10% is formally conserved by the State as National and other parks, and the remaining 6% is freehold land used for mining, urban and industrial development (Hoffman and Ashwell, 2001; Palmer and Ainslie, 2005). The communal areas are located mainly in the former homelands of Transkei, Ciskei, Bophutatswana, Lebowa, Kwa-Zulu, Venda, and Gazankulu in the north and east of the country, while the commercial areas occupy most of the western, central, and southern regions. Two widely disparate land tenure systems can be distinguished: (i) commercial land tenure characterized by clear boundaries, exclusive rights for the individual properties, and commercial farming objectives; (ii) communal land tenure with often unclear boundaries, generally with open access rights to grazing areas and subsistence-oriented farming (Hoffman and Ashwell, 2001; Palmer and Ainslie, 2005).

Desertification, a major form of land degradation, is a concern in the drylands of South Africa (Hoffman and Todd, 2000; Hoffman and Ashwell, 2001). Decades of inequitable land and development policies have shaped land use patterns, and have resulted in severe land degradation. Because of these policies, large numbers of people were forced into subsistence lifestyles, and many are still highly dependent on natural resources to meet their nutritional, medicinal, housing and energy needs. The causes of land degradation are very complex, combining climatic and human impacts interacting with the natural and social environment within a region (DEAT, 2004). The consequences include declining productivity and diversity of resources to support human livelihoods, biodiversity and ecosystem services losses (DEAT, 2002).

1.1.3.2. Forms and extent of land degradation

South Africa has a long history of research into land degradation (Hoffman and Todd, 2000), but before 1997, the literature on land degradation was scattered and poorly synthesized (Hoffman and Ashwell, 2001). The first national synthesis[1] of land degradation (Hoffman *et al.*, 1999) was completed in 1999, as part of the South African National Action Program (NAP) of the United Nations Convention to Combat Desertification (UNCCD). The synthesis was based on the expertise and perceptions of agricultural research technicians, extension officers and resource conservation technicians on land degradation (Hoffman and Todd, 2000; Hoffman and Ashwell, 2001; DEAT, 2004). The main forms of land degradation identified include:

- Soil degradation (wind and water erosion, loss of fertility, and acidification).

[1] For further information, visit http://www.sanbi.org/landdeg

- Rangeland (veld) degradation (loss of plant cover, woody species encroachment, change in the composition of plant species, deforestation, and alien plants invasion).
- Loss of biodiversity.

Soil, rangeland and combined degradation indices were calculated for all the nine provinces of South Africa (Table 1.3.). All provinces showed increasing signs of land degradation, and findings pointed more severe degradation in districts under communal management than commercial management (Hoffman and Ashwell, 2001). Although degradation also occurs in smaller patches on commercial land and not all parts of the communal lands are degraded, large contiguous degraded areas are confined to the communal lands (Wessels *et al.*, 2007). In the North West Province (NWP), Mangold *et al.*, (2002) reported increasing signs of land degradation. All the magisterial districts showed signs of soil degradation. The highest degraded areas are located in districts under communal than commercial management.

Table 1.3. Comparative land degradation statistics for the nine provinces of South Africa

Provinces	Soil Degradation Index	Rangeland Degradation Index	Combined Degradation Index
Eastern Cape	200	116	316
Free State	48	86	134
Gauteng	113	31	144
KwaZulu Natal	253	187	440
Mpumalanga	143	81	224
Northern Cape	92	140	232
Northern Province	255	189	444
North-West	149	122	271
Western Cape	77	93	170
Commercial districts	*102*	*96*	*198*
Communal districts	*292*	*183*	*475*

South African soils are not particularly fertile and their spatial diversity and variability is considerable (Anonymous, 2000). They are characterized by low resilience, and any mismanagement in land use can be devastating with little chance of recovery once the degradation had begun (Laker, 2005). The major forms of soil degradation threatening the soil-resource base, food security and consequently increasing poverty, are soil acidification, soil organic matter and nutrient depletion, soil sterilization and the loss of soil biodiversity, soil compaction/crusting, runoff and erosion and soil pollution, all conducive ultimately to desertification (Hoffman and Ashwell, 2001; De Villiers *et al.*, 2002). The threats to soils are the consequences of high population densities, unsustainable farming systems such as overgrazing, overstocking, and catastrophic natural disasters. Each year, soil erosion causes losses of 30 000 tons of nitrogen (N), 26 400 tons of phosphorus (P), 363 000 tons of potassium (K) and the cost of replacing these nutrients exceeds R1.5 billion per annum (Hoffman and Ashwell, 2001). The highest levels of soil degradation were reported in both cropland and rangeland. Soil degradation was depicted as being more severe in districts under communal management than commercial land management although the degradation was not necessarily related to the land tenure (Hoffman and Ashwell, 2001).

Studies on soil degradation have attempted to assess erosive forms such as rills, and gully, with very little on the quality of the soil that has remained (Mills and Fey, 2003). In a study of soil quality indicators, Brejda *et al.*, (2000) reported that soil could be degraded by other means than erosion, such as a decline in organic matter, compaction, nutrient depletion, reduced biodiversity, and activity of soil microorganisms. Assessment must therefore go beyond estimating erosion and consider other soil qualities that may be altered. De Villiers *et al.*, (2002) proposed that regular monitoring of benchmark sites based on reliable data acquisition and storage is essential to quantify trends and changes. Despite the concern about soil degradation, there is limited information or data collected systematically over time to assess the extent of soil degradation in communally managed areas (mainly in rangelands). For example, Henning and Kellner (1994) emphasized the serious lack of information on the influence of soil factors on rangeland degradation. Likewise, Snyman and Du Preez (2005) stressed the need of information on the effects of grazing on soil as well as to assess the effects of degradation on soil quality.

1.2. RANGELAND DEGRADATION

Rangelands cover a great variety of vegetation types, and occupy from 30% to 50% of the earth's land surface (Mannetje, 2002). They are defined as "land on which the native vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs, or shrubs" (The Society of Range Management, 1989). They include natural grasslands, savannas, shrub lands, most deserts, tundra, alpine communities, coastal marshes, and wet meadows. They represent ecosystems and landforms unsuitable for intensive agriculture or forestry because of limitations imposed by climate, soils and topography. They are the main feeding resources for traditional livestock systems, contributing to the livelihoods of millions of people living in drylands (Mannetje, 2002).

1.2.1. Rangeland condition/health

1.2.1.1. Concepts and definitions

The concept of rangeland condition was used to denote the changes in the vegetation composition, productivity, and land stability that occur when rangelands are grazed by domestic livestock (Wilson and Tupper, 1982). Rangeland condition is the most important cornerstone of any management system (Tainton, 1988). Harrington *et al.*, (1984) defined rangeland condition as the sum of various attributes (vegetation composition and biomass, soil stability and nutrients status), relative to a maximum production potential for a particular land use. Many factors or attributes are used in the concept of rangeland condition: (i) changes of the vegetation components, (ii) changes of soil attributes, and (iii) changes in production characteristics of the land such as animal production, water yield and wildlife habitat (Wilson and Tupper, 1982).

The concept of rangeland condition was however criticized, particularly its assessment methods, because of confusion as to which factors are of relevance for meaningfully assessing rangeland condition (Wilson and Tupper, 1982), and how these factors should be assessed and interpreted (Friedel, 1991; Jordaan *et al.*, 1997). The difficulty in assessing rangeland condition was reported also by Van der Westhuizen *et al.*, (1999). According to these authors, the accuracy in determining rangeland condition and trends, depend on the assessors' ability to measure changes as well as the correct interpretation thereof. The concept of rangeland health was therefore adopted to overcome these limitations. Rangeland health is defined as "the degree to which the integrity of the soil and the ecological processes of rangeland ecosystems are balanced and sustained" (National Research Council, 1994). This approach of rangeland health willingly abandons the conceptual weakness of the rangeland condition concept and embraces the profound but inscrutable ecological processes of rangeland ecosystem management (Scarnecchia, 1995).

1.2.1.2. Assessing rangeland health

Rangeland ecosystems are continually responding to temporal changes in the physical and biotic environments. Any system that assesses rangeland health must be able to distinguish between changes that result in the crossing of a threshold from those that are temporary because of fluctuations in physical or biotic factors (National Research Council, 1994). Assessing rangeland health is essential to identify ecological problems before the condition of the rangeland degrades (Manske, 2004) and to help develop and facilitate adaptive management practices (Rezaei *et al.*, 2006). The purpose of measuring these changes relates to the concern for long-term productivity and stability (Wilson and Tupper, 1982). Rangeland health evaluation requires the collection of data, which should reflect the diverse processes of rangeland ecosystem. This evaluation should be based on sound ecological principles (Task Group, 1995) and done using indicators and benchmarks (Snyman, 1998). Several interactive components such as the status of the above and belowground vegetation, the status of soil development processes and the status of ecological processes should be considered when assessing the condition of rangelands (Wilson and Tupper, 1982; National Research Council, 1993). The National Research Council (1994) considered rangelands as:

- Health "if an evaluation of soil and ecological processes indicates that the capacity to satisfy values (wildlife habitat, scenic beauty) and produce commodities (meat, wool, milk) is being sustained".
- At risk "if the assessment indicates an increased, but reversible, vulnerability to degradation".
- Unhealthy "if the assessment indicates that degradation has resulted in an irreversible loss of capacity to provide values and commodities".

Traditional rangeland condition assessment methods have often used changes of vegetation parameters (e.g. loss or diminution of palatable perennial grasses and/or a shift to unpalatable species, loss of plant cover, woody species encroachment) to describe degradation (Bosch and Theunissen, 1991; Havstad *et al.*, 2000). Vegetation changes however, may be an unreliable indicator of changes in the functioning and resilience of rangelands, especially in arid regions where large fluctuations in species composition, plant biomass, and cover are common due to erratic rainfall patterns (Miller, 2000; Vetter, 2005). Soil properties and processes have rarely been included in rangeland monitoring and assessment (Herrick *et al.*, 2002) despite their potential as early warning indicators in the susceptibility of rangelands to change (Herrick and Whitford, 1999). The growing recognition of the importance of soil-vegetation feedbacks in structuring rangelands (Schlesinger *et al.*, 1990; Tongway and Ludwig, 1994) and the interest in rangeland health have led to a renewed interest in integrating soil information into rangeland monitoring and management (Herrick *et al.*, 2002).

Many indicators have been proposed for evaluating rangeland health (Herrick *et al.*, 2002; Pyke *et al.*, 2002), but without a range of values as a standard for management, managers will not know the status of their rangeland (Pyke *et al.*, 2003).

1.2.2. Rangeland degradation

1.2.2.1. Definition and forms

Arid and semi-arid rangeland degradation is a worldwide known phenomenon (Milton and Dean, 1995; Heitschmidt *et al.*, 2004; Steinfeld *et al.*, 2006). Rangeland degradation is defined as "an effectively permanent decline in the rate at which land produces forage for a given input of rainfall under a given system of management" (Abel and Behnke, 1996). Effectively means that natural processes will not rehabilitate the land within a time scale relevant to humans, and that capital or labor invested in rehabilitation are not justified. This definition excludes reversible vegetation changes, even if these lead to temporary declines in secondary productivity. It includes effectively irreversible changes in both soils and vegetation (Abel and Behnke, 1996), and has direct bearing on the capacity of the rangeland to support grazing animals and to provide sustainable income to landowners (Beukes and Cowling, 2003).

Rangeland degradation takes many forms depending on the soil type, the natural vegetation and the grazing management imposed. The process of rangeland degradation is complex and involves the interaction of changes in the physical, chemical, and biological properties of soils, as well as changes in plant vigor, species composition, litter accumulation and distribution, seed germination and seedling recruitment, total biomass production, and other ecological processes (National Research Council, 1994). Degradation of vegetation (Hiernaux, 1998; Hoffman and Ashwell, 2001), woody species encroachment (Snyman, 2003), loss of biodiversity (Steinfeld et *al*., 2006), soil erosion (Illius and O'Connor, 1991; Snyman, 1999) and soil nutrient depletion are some of the environmental problems associated with rangeland degradation.

Rangelands adapt to changes from management and environmental conditions through modifications of their characteristics such as plant species composition, biomass production, and nutrients cycling. Many changes in the ecological state may not have long-term effects on rangeland productive capacity (National Research Council, 1994). Other changes, however, can be destructive although some of their effects might be reversible when management is changed or improvement in environmental conditions, such as climate occurs. Changes such as serious soil degradation (properties and processes) and the loss of species and/or seed resources can lead to irreversible changes (National Research Council, 1994). Degraded rangeland soils have reduced water infiltration rates given rise to increase runoff and erosion (Snyman, 2000). Most rangeland soils are nutrients deficient, particularly nitrogen and phosphorus and characterized by uneven distribution of nutrients across the soil surface (Mannetje, 2002). Rangeland deterioration occurs mainly through deterioration of the soil's capacity to capture and store water (erosion), loss of the ability of the soil to supply nutrients or the accumulation of salts or other toxic substances in the soil. Friedel (1991) indicated that rangeland deterioration is best indicated by irreversible changes in the soil, and that assessment of soil is a critical element in the identification of thresholds of change on rangelands.

Rangeland degradation is not easily seen and farmers only realize that the land is deteriorating when drastic changes occur (Kellner and Bosch, 1992), and because its takes place over time-scales much greater than those at which, management decisions are made (Reynolds and Stafford Smith, 2002). However, it is widely acknowledged that, while many assessments of degradation were overestimated and their attributed causes oversimplified, degradation has occurred in many semi-arid rangelands (Vetter, 2005; Reed, 2005; Steinfield *et al.*, 2006). Numerous local scale studies have identified changes in species composition (shifting towards unpalatable (often thorn-bush) species), vegetation cover and erosion features as indicators of degradation, but many of the assessments have been contested. Finding an accurate and reliable way to assess land degradation is still a major research challenge (Reed, 2005).

1.2.2.2. Causes of rangeland degradation

The most commonly quoted sources of rangeland degradation worldwide are overgrazing and overstocking (Le Hourérou, 1976; Dregne and Chou, 1992; Milton *et al.*, 1994). The term overgrazing is usually value-laden as it implies grazing at high level than wanted relative to a specific management objective (Mysterud, 2006). Coughenour and Singer (2000) defined overgrazing as "an excess of herbivory that leads to degradation of plant and soil resources. The term applies where humans define the excess of herbivory, but it has been used to describe any kind of negative impact of grazing. Overstocking is regarded as "the maintenance of excessive livestock numbers, which will cause a permanent reduction in the production capacity of the rangeland" (Livingstone, 1991). Overgrazing and overstocking affect rangeland ecosystem in several ways that can be either positive or negative (Fleischner, 1994; Miller, 2000). The effects can be seen at individual plants or species, plant communities and soils, and proceed from three hardly separable processes i.e. plant defoliation due to animal foraging, soil and litter trampling and deposition of faeces and urine (Hiernaux *et al.*, 1999).

There is a wealth of literature on the effects of livestock grazing and overgrazing on rangeland ecosystem across a wide range of climatic conditions and rangeland management (Milchunas and Lauenroth, 1993). Grazing affects herbaceous species composition (Hiernaux, 1998; Shackleton, 2000; Abule *et al.*, 2005), density and plant cover (Washington-Allen *et al.*, 2004), plant biomass (Hiernaux and Tuner, 1996; Oztas *et al.*, 2003) and soil seed banks (Bertiller, 1996; Hérault and Hiernaux, 2004). Grazing effects on soil physical and chemical properties and nutrients cycling have been documented (Hiernaux *et al.*, 1999; Baron *et al.*, 2002; Oztas *et al.*, 2003; Henderson *et al.*, 2004; Neef *et al.*, 2005; Liebig *et al.*, 2006). Soil biochemical and microbiological properties responses to grazing have been reported worldwide

(Haynes and Williams, 1999; Abril and Bucher, 1999; Northup *et al.*, 1999; Bardgett *et al.*, 2001; Bardgett and Wardle, 2003; Raiesi and Asadi, 2006; Wang *et al.*, 2006). Various and often contradicting results have been found because of differences in climatic factors, grazing treatments and management, soil types, depth of sampling and analytical methods. These contrasting results make generalization of livestock grazing effects difficult, and that the effects should be restricted to the inherent characteristics of the study sites and grazing management studied.

1.2.3. Rangeland degradation in South Africa

1.2.3.1. Rangeland management systems

Rangelands (veld) cover nearly 80% of the land surface, and constitute the single most dominant land use type for livestock production (Hoffman and Ashwell, 2001). Three rangeland management systems namely commercial, communal, and game exist in South Africa (Table 1.4.) (Smet and Ward, 2006). Commercial management is a well-developed industry and largely export-oriented (Palmer and Ainslie, 2005) whereas communal management is mainly subsistence-oriented (Everson and Hatch, 1999). Game ranching primary objective is tourism-related activities and income generation (e.g. hunting), but also includes some biological and ecological facets (Joubert *et al.*, 2006).

Table 1.4. Rangeland management systems in South Africa

	Communal	Commercial	Game ranching
Management	Multiple managers	Single manager	Single manager
Animal diversity	Different species	Single species	Different species
Management of grazing resource	Continuous grazing - diverse vegetation	Rotational grazing - uniform vegetation	Continuous grazing - diverse vegetation
Products	High quantity, diversity of products mostly for personal use	High quality, single product for domestic and international markets	High variety, strong health, big animals for trophies or eco-tourism

1.2.3.2. Characterization of rangeland degradation

Rangeland degradation has been reported over the past decades in South Africa (Snyman, 1998; Hoffman and Todd, 2000; Hoffman and Ashwell, 2001). Snyman

(2003) quoting Scheppers and Kellner (1995) indicated that nearly 66% of the total rangeland area has been degraded, because of poor management practices and recurrent droughts (Kellner and Bosch, 1992). Hoffman and Ashwell (2001) reported six main types of rangeland (veld) degradation from the national review of land degradation in South Africa, namely:

- Loss of plant cover, resulting in increase erosion and runoff.
- Change in the composition of plant species, mainly from palatable to unpalatable species.
- Woody species (bush) encroachment (increase bush density).
- Alien plant invasion
- Deforestation
- Other forms such as clearing of veld for crops or mining pollution.

The land degradation synthesis (Hoffman and Ashwell, 2001) pointed that overall veld (rangeland) degradation was higher in districts under communal than commercial management (Table 1.3).

1.2.3.3. Communal rangeland degradation

Communal rangelands cover nearly 6 million ha and are home to nearly 2.4 million rural households (Shackleton *et al.*, 2001). They are used mainly by rural communities not only for supporting livestock, but also for harvesting a wide range of natural resources (Twine, 2005). Livestock ownership and production in communal areas is multipurpose in character, with both cattle and goats serving a greater diversity of functions than in a typical commercial production system (Shackleton *et al.*, 2001). Communal rangelands in particular and communal areas in general in South Africa have a long history of environmental and political neglect (Hoffman and Todd, 2000). They have been subjected to over-utilization owing to the high human populations that were involuntarily resettled and confined to these relatively small areas (Wessels *et al.*, 2004). There are described as open access areas, frequently associated with over-utilization and poor management of the natural resources therein (Dovie *et al.*, 2006).

Comparisons between communal and commercial managed rangelands have often been used to investigate rangeland degradation (e.g. Parsons *et al.*, 1997; Duma, 2000;

Smet and Ward, 2005; Vetter *et al.*, 2006; Anderson and Hoffman, 2006) (Figure 1.1c.).

Figure 1.1. Rangeland in different vegetation conditional states (communal (a), commercial (b), and fence line contrast (c) between a commercial (left side) and communal (right) managed rangelands in the Bophirima District

Many communal rangelands have been described as degraded based on the structural differences of vegetation attributes (cover, species ecological and grazing status, importance of bush encroachment) compare to commercial rangelands or game ranching. In communal managed rangelands, studies have reported increasing unpalatable grass species, loss of plant cover favoring erosion processes, increasing bush density (bush encroachment). In contrast, in commercial managed areas, a uniform layer of vegetation is often observed with better soil cover and less of bush encroachment (Figure 1.1.). These contrasting vegetation patterns have led to the overwhelming perception that communal rangeland management is unsustainable, leading to irreversible rangeland degradation (Shackleton, 1993). This degradation results from:

- The absence of programmes to control alien plants.
- The removal of plants for traditional medicines and the cutting of trees for firewood.
- Increase in livestock numbers.
- A decrease in the extent of the grazing lands with the number of animals either remaining constant or increasing (leading to overgrazing and overstocking).
- Limitation of watering points and large numbers of animals concentrated around few watering points.
- Historical impact of overgrazing.
- Poor infrastructures, theft of infrastructure and poor management practices.
- Incorrect veld burning programmes (Hoffman and Ashwell, 2001).

In communal rangelands, interventions concerning the development and conservation of natural resources are still dominated by the belief that communal herders have little technical skills and cause destruction of natural resources (Allsopp *et al.*, 2007). The view that communal tenure leads to rangeland degradation has recently been challenged (Shackleton, 1993; Sullivan and Rhode, 2002). Harrison and Shackleton (1999) found that communal rangelands have a relatively high resilience after removal of high grazing pressure. Studies which attempted to compare communal to commercial and/or game management have revealed an array of contradicting results regarding the effects of communal grazing, i.e. degradation in communal rangelands. Questions remain therefore as to whether all communal areas are severely degraded or if certain areas remain productive under this management scheme (Shackleton, 1993;

Evans, 2000; Sullivan and Rohde, 2002; Vetter *et al.*, 2006). For example, Vetter *et al.*, (2006) questioned what constitutes degradation and overgrazing in communal rangelands.

South Africa has a long tradition of rangeland monitoring. Monitoring was intended to: (i) serve decision-making through providing information required for amending management actions in order to improve production goals or other management objectives; (ii) to serve decision-making of regulatory bodies and policy-makers; and (iii) to serve scientific purposes, in which case, it has traditionally been most widely practiced on conservation properties (O'Connor, 2007). Changes of the vegetation components (shift in species composition, and palatability, increased bush encroachment, loss of plant cover) have been often used over the past decades in rangeland monitoring. Soil properties and processes have received less attention (Henning and Kellner, 1994; Herrick and Whitford, 1999; Snyman and Du Preez, 2005). In South Africa, soil has been considered as a "poor indicator" of community change (Hoffman and Cowling, 1990), and generally the use of soil data has been inappropriate as it is based on a soil type by soil type approach (Palmer *et al.*, 2001). An implicit assumption of most management programs is that soil properties are correlated with vegetation, so it is only necessary to manage and monitor the plant community (Herrick and Whitford, 1999). Furthermore, soil information is rarely included in rangeland monitoring programs because of problems associated with sampling, interpreting and applying information about soils in the context of highly spatially and temporally variable environment (Herrick and Whitford, 1999).

Integrating soil information into rangeland monitoring has become imperative with regard to rangeland health (Herrick *et al.*, 2002) and the growing recognition of the importance of soil-vegetation feedbacks in structuring rangelands (Schlesinger *et al.*, 1990; Tongway and Ludwig, 1994). Soil is the most important and basic physical resource of rangeland (Stringham *et al.*, 2001); therefore, maintaining and improving the quality of the soil resource base is essential for sustainable rangeland use and management (Du Preez and Snyman, 1993; Society of Range Management, 1995; Snyman and Du Preez, 2005). In a study of rangeland under different conditional states (good, moderate and poor) which, could arise because of different grazing histories, Snyman (2000) showed that rangeland in poor condition (degraded) has decreased plant-available water because of increased runoff. Soil compaction and temperature increased, whereas soil organic carbon and total nitrogen were significantly lower than under good condition rangeland (Snyman and Du Preez, 2005). Herrick *et al.*, (2002) proposed the following guidelines for soil-vegetation monitoring and management systems on rangelands:

1. Identify a suite of indicators that are consistently correlated with the functional status of one or more critical ecosystem processes.
2. Base indicator selection on site or project specific resource concerns and inherent soil and site characteristics.
3. Use spatial variability in developing and interpreting indicators to make them more representative of ecological processes.
4. Interpret indicators in the context of an understanding of dynamic, nonlinear ecological processes.

1.3. CONTEXT OF THE STUDY: THE DESERT MARGINS PROGRAM

This study forms part of the Desert Margins Program (DMP) research activities in South Africa. The DMP is a collaborative initiative between nine countries (Botswana, Burkina Faso, Kenya, Mali, Namibia, Niger, Senegal, South Africa and Zimbabwe) aiming at combating desertification. The goal is to improve rural livelihoods and food security of smallholders in Africa's desert margins by arresting land degradation and conserving biodiversity. The overall objective is to arrest land degradation in Africa's desert margins through demonstrations and capacity building activities (Koala and Tabo, 2004). The broader objectives include:

- Develop a better understanding of the causes, extent, severity, and physical processes of land degradation in traditional crop, tree, and livestock production systems in the desert margins, and the impact, relative importance and relationships between natural and human factors.
- Document and evaluate with the participation of farmers, non-governmental organizations and national agricultural research systems, current indigenous soil, water, nutrient, vegetation and livestock management practices for arresting land degradation and to identify socioeconomic constraints for the adoption of improved management practices.

- Develop and foster improved and integrated soil, water, nutrient, vegetation and livestock management technologies and policies to achieve greater productivity of crop, trees, and animal, to enhance food security, income generation, and ecosystem resilience in the desert margins.
- Evaluate the impact and assist in designing policies, programs, and institutional options that influence the incentives for farmers and communities to adopt improved resource management practices.
- Promote more efficient drought-management policies and strategies.
- Enhance the institutional capacity of countries participating in the DMP to undertake land degradation research and the extension of improved technologies, with particular regard to multidisciplinary and participative socioeconomic research.
- Facilitate the exchange of technologies and information among farmers, communities, scientists, development practitioners and policy makers.
- Use climate change scenarios to predict shifts in resource base and incorporate these into land use planning strategies (Koala and Tabo, 2004).

In South Africa, the aim of the DMP to conserve and restore biodiversity in the desert margins through sustainable utilization, and specifically to develop strategies to enhance ecosystem function and sustainable use in arid and semi-arid areas that are degraded and have reduced biodiversity associated with human and climatic impact (K. Kellner[2], pers. comm. 2004).

1.4. AIM AND OBJECTIVES

Research into land degradation particularly in communal areas is a priority in South Africa. Study cases are needed to deepen understanding of the complex issue of land degradation and to help develop locally appropriate solutions (Hoffman and Ashwell, 2001). South African's rangelands have been described as degraded because of combined effects of climatic and human (management) factors. Because rangeland degradation occurs as a slow decline in resource quality over decades, and not as

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sudden, cataclysmic event, monitoring is essential to ascertain if resources are degrading (O'Connor, 2007).

Sustainable utilization of grazing lands requires management strategies that do not compromise the capacity of the soil to function over the long-term (Liebig *et al.*, 2006). There is a need to early identify and prevent degradation, because management inputs and costs increase for every step in the degradation process (Milton *et al.*, 1994). Indicators of temporal changes, as well as benchmarks, are necessary to quantify soil degradation processes, and to define reference and/or threshold values for repeated monitoring activities.

With the increasing concern of rangeland degradation in communal areas, there is a need for monitoring to provide scientifically sound information on the condition of rangeland resources, and investigate the degree and extent of degradation. For monitoring to be locally and globally useful, it must provide information to local users in a timely and usable form and simultaneously provide data on which deleterious environmental impact can be assessed independently of the users (Western, 2004). The highest priority for integrated monitoring lies in creating user awareness of monitoring and demand for information and applying the results to improve livelihoods and the state of the environment (Western, 2004). The challenge will be to maintain the quality of the land in areas where degradation has been addressed, while attending to the problems threatening ecological processes, food security and livelihoods in the communal areas (Hoffman and Ashwell, 2001). In the western Bophirima District in the North-West Province (NWP), there is a lack of information on soil characteristics and the effects of communal grazing management on soil properties. The aim of this research is to characterize and establish some baseline indicators of soil health/quality, and to investigate the effects of grazing and exclusion management that could be used for reporting on rangeland degradation. It is intended to serve as a reference point for future research aiming at understanding and assessing land degradation processes in communal managed rangelands. Specific objectives include:

1) Establish baseline indicators (references) of soil quality.
2) Assess potential effects of grazing and exclusion management on selected soil at the communal sites.

3) Compare selected soil properties under different rangeland management systems.
4) Serve as benchmarks for long-term monitoring of land degradation.
5) Awareness, training, and capacity building regarding soil information integration into rangeland monitoring and assessment.

1.5. OUTLINES AND FORMAT OF THE THESIS

The research reported in this thesis is structured in four chapters with findings presented in manuscript format (Chapter 3). The above Chapter 1 is a broad literature review on concepts of relevance and states the objectives of the study. Chapter 2 refers to a general description of the study area and sites with emphasis on some biotic and abiotic components, as well as the methods of soil and vegetation sampling and analyses and data processing used during the study. Chapter 3 refers to the research manuscripts elaborated. Three research manuscripts have been elaborated (one has been accepted at the date of submission). As recommended in the manual for post-graduate studies[3] of the North-West University (Potchefstroom Campus), the guidelines for authors of the journals where submissions have been made or will be made precede each manuscript. Chapter 4 is a synthesis of the main findings of the research and conclusions. Since the onset of this project, various results have been presented at several scientific conferences at both national and international levels. The titles, abstracts of these presentations and posters are attached in appendix. A pamphlet entitled "soil quality management: the key to rangeland sustainability" was produced and distributed to various stakeholders.

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CHAPTER 2.
GENERAL MATERIALS AND METHODS

This chapter provides a detailed description of the study area and sites, the experimental design and the methods of soil and vegetation sampling, analyses as well as data processing methods. Repetitions between this chapter and the research manuscripts were unavoidable because of the format in manuscript of the thesis.

2.1. GENERALITIES OF THE STUDY AREA

2.1.1. Location

The study was conducted in the Bophirima District in the western region of the North-West Province (NWP) in South Africa (Figure 2.1.). The Bophirima District covers nearly 40.82% (48 192 ha) of the province area. The population was estimated at 502 607 (1996), with a density of 10.43 inhabitants/km^2 (Tladi *et al.*, 2002).

The NWP is the sixth largest province in South Africa (116 320 km^2), with a population estimated at 3.7 million (8% of the national), of which, 65% live in rural areas (Mangold *et al.*, 2002). Nearly 85% of the land surface is used for agricultural purposes; 34% is considered potentially arable and 66% consists of grazing land. The majority of the land is privately owned, 10% is state-owned and large areas are under tribal administration (in the former "Bophuthatswana" homeland) (Mangold *et al.*, 2002). The communal district (3242 million ha) and commercial district (4749 million ha) are similar in terms of their biophysical and climatic attributes, but differences emerge when land use, human population, labor, employment and economic indicators are compared (Meyer *et al.*, 2002). Communal districts are mainly located in the formerly Bophuthatswana area (Figure 2.2.); they are described characterized by *a)* injudicious land uses, *b)* inappropriate cultivation practices, and *c)* increasing erosion as a result of overgrazing, and soil surface exposure with increasingly diminish soil fertility. Most communal grazing areas are overstocked 40 times more than their carrying capacity (Mangold *et al.*, 2002).

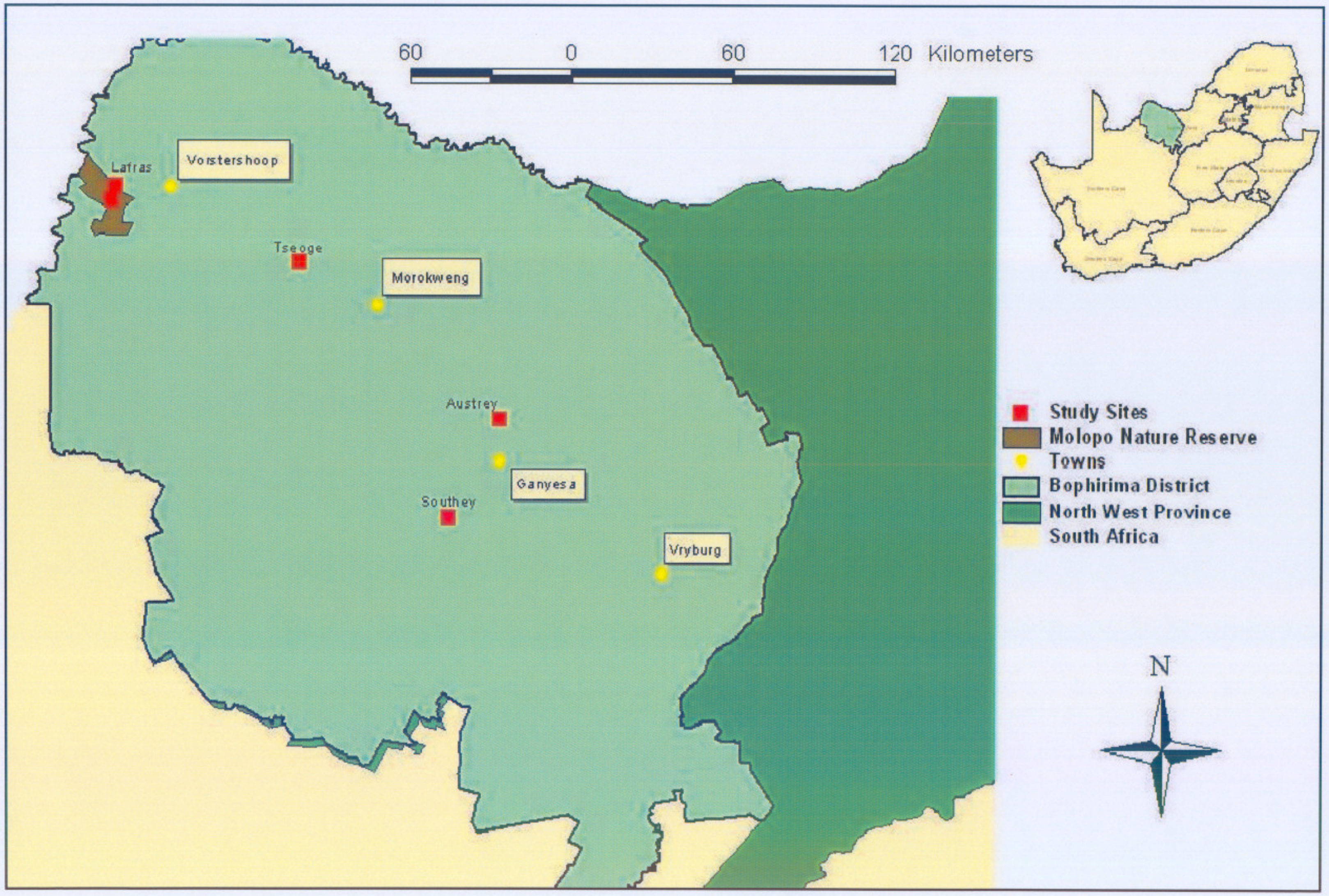

Figure 2.1. The Bophirima District with the study sites in the North-West Province

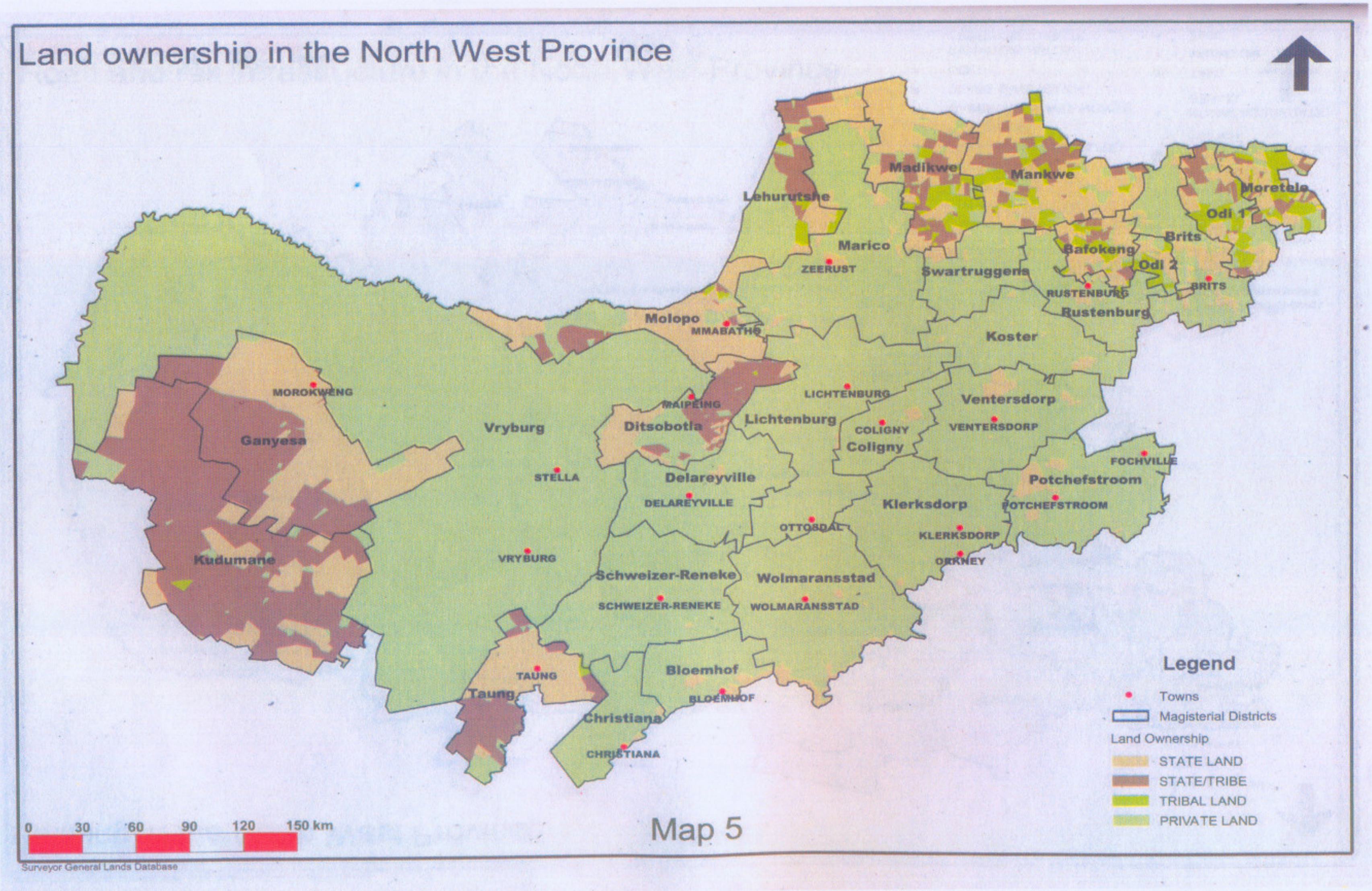

Figure 2.2. Land ownership in the North-West Province

2.1.2. Climate

Climatic conditions vary significantly from the West to the East. The far western region is arid, the central region is semi-arid and the eastern region is predominantly sub-tropical (De Villiers and Mangold, 2002). The rainfall pattern is highly variable spatially and temporally, with an annual average rainfall varying from 300 mm in the western region, to 550 mm in the central region and over 600 mm in the eastern region. The dominant rainfall season in the central region is mid-summer (peak in January); the western part receives late summer rain (peak in February), whereas the eastern part typically peaks in early summer (December). The province is characterized by a great seasonal and daily variations in temperature, from very hot in summer (daily average temperatures of 32° in January) and mild to cold in winter (daily minimum temperature is 0.9°) (De Villiers and Mangold, 2002).

2.1.3. Soils and geology

Large areas of yellow shifting sands occur in the northwestern region, while plinthic catena of yellowish-brown sandy loams characterize the south and eastern regions. Red or brown non-shifting sands with rock dominate the central region, as well as weakly developed lime soils associated with the dolomite limestone formation. The southwestern region is characterized by undifferentiated rock and lithosols, shallow, soils containing coarse fragments and solid rock at depths less than 30 cm. The northeastern region shows lithosols of arenaceous sediments. The southern and central regions are dominated by black and red clay as well as ferrisiallitic soils of sands, loams, and clay. The drier western region is characterized by red and yellow arenosols, while the southwest has calcareous sands and loams and arenaceous lithosols (De Villiers and Mangold, 2002). In the Eastern Kalahari bushveld, which includes the study area, the following soil groups are found:

- A4 (27%) - Red, massive or weakly structured soils with high base status (association of well-drained Lixisols, Cambisols, Luvisols). Land type: Ae.
- A5 (1%) - Red, massive or weakly structured soils with high base status (association of well-drained Lixisols, Cambisols, Luvisols and one or more of Regosols, Leptosols, Calcisols and Durisols). Land types: Ag and Ah.

- AR (49%) - Red, yellow and grayish excessively drained sandy soils (Arenosols). Land types include Af and Ha.
- C1 (2%) - Soils with a marked clay accumulation (association of Luvisols, Planosols and Solonetz. In addition, one or more of Plinthosols, Vertisols and Cambisols may be present). Land types: Da, Db and Dc.
- E1 (17%) - Soils with minimal development, usually shallow on hard or weathering rock, with or without intermittent diverse soils (association of Leptosols, Regosols, Calcisols and Durisols. In addition, one or more of Cambisols, Luvisols and Phaeozems may be present). Land types: Fa, Fb, Fc
- G1 (5%) - Rock with limited soils (association of Leptosols, Regosols, Durisols, Calcisols and Plinthosols). Land types include Ib and Ic (Mucina and Rutherford, 2006).

The NWP has an ancient geological heritage, rich in minerals and palaeontological artefacts. The northeastern and north-central regions are largely dominated by igneous rock formations. Ancient igneous volcanic rocks dating back to the Ventersdorp age appear to be the dominant formations in the western, eastern and southern regions of the Province, whereas sedimentary rocks of the Quaternary period occur in the northwestern part (Mangold et al., 2002).

2.1.4. Vegetation

The vegetation consists of the savanna (71.35%) and the grassland biomes (28.65%) (Acocks, 1988; Low and Rebelo, 1996). The savanna biome includes six bioregions (the Mopane, the Central bushveld, the Lowveld, the Sub-Escarpment savanna, the Eastern Kalahari, and the Kalahari Duneveld), and the grassland biome includes four bioregions (the Drakensberg, the Dry Highveld, the Mesic High veld and the Sub-Escarpment bioregions). The study area falls within the Eastern Kalahari Bushveld vegetation unit (Mucina and Rutherford, 2006).

Increasing signs of land (soil and vegetation) degradation have been reported in the province (Hoffman and Ashwell, 2001; Mangold *et al.*, 2002). Degradation driving forces include population growth, national policy and legislation, and natural disturbances (floods, droughts, winds, and fire) (Meyer *et al.*, 2002). Soil degradation is a problem across all land use types and is depicted as being more severe in districts under communal management (almost three times higher) than under commercial management (Figure 2.3.).

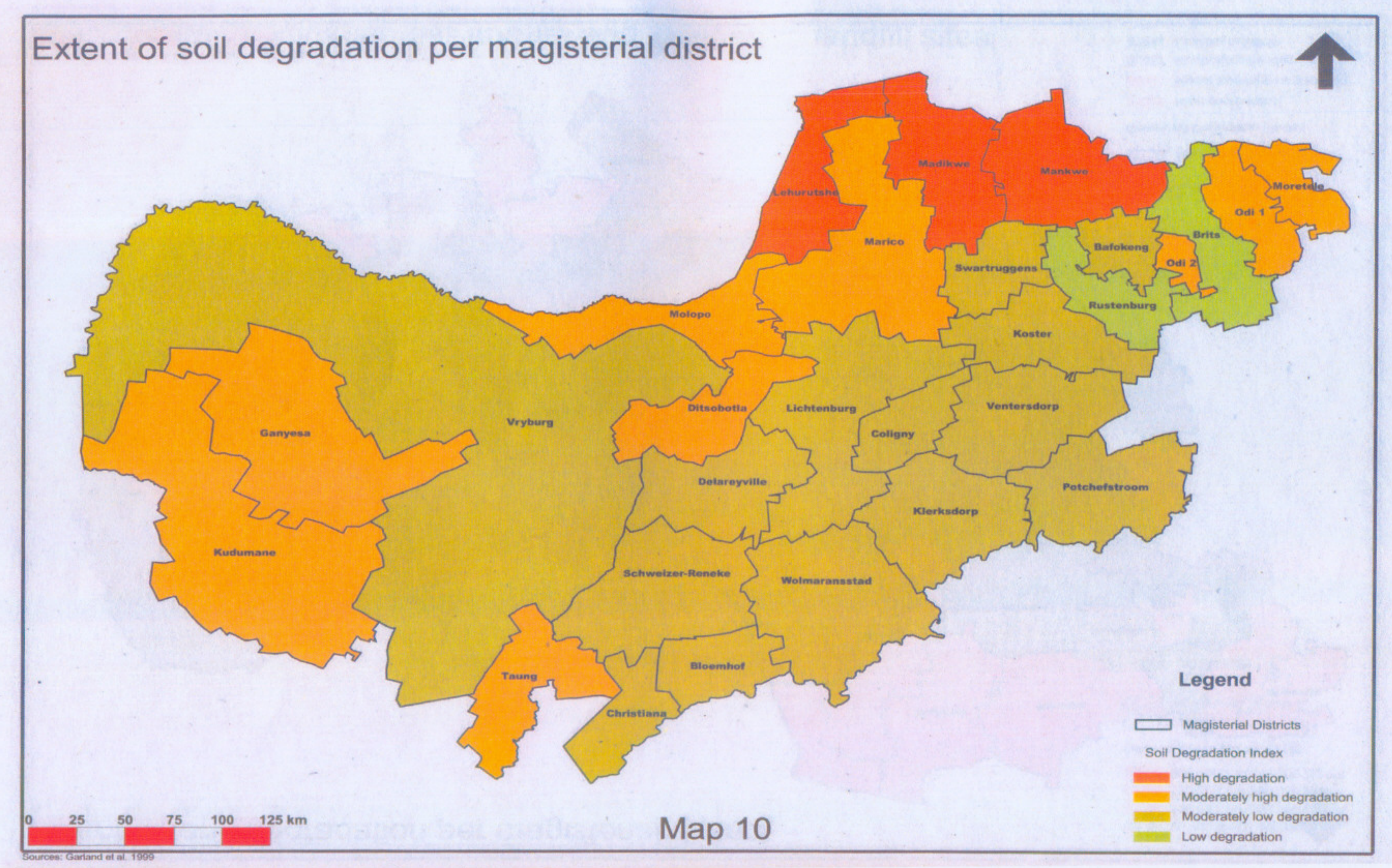

Figure 2.3. Severity of soil degradation in the North-West Province

2.2. RESEARCH SITES AND EXPERIMENTAL DESIGN

2.2.1. Sites description

2.2.1.1. Sites selection approach

Sites were selected on grounds of LandCare projects in areas already supported by the National Department of Agriculture (M. Coetzee[4] pers. comm., Coetzee, 2006). LandCare is a community-based program of the National Department of Agriculture aiming at optimizing the productivity and sustainable use of resources (DEAT, 2004). The provincial LanCare programme aims to develop and implement integrated approaches to natural resources management, which are efficient, sustainable, equitable and consistent with the principles of ecological sustainable development (Van Heerden, 2002). The sites were selected as part of the Desert Margins Program to build on existing knowledge (Koala and Tabo, 2004). They were intended to serve as field laboratories for demonstrations activities related to monitoring and assessment of biodiversity status, improving the understanding of ecosystem status and dynamics, testing of most promising natural resource management options, developing sustainable alternative livelihoods and policy guidelines (DEAT, 2004).

2.2.1.2. Sites characteristics

Three communally managed sites located in the Kagisano Local Municipality were chosen: Austrey (26°28'S - 24°14'E), Southey (Eska/Newham) (26°38'S - 23°51'E), and Tseoge (25°57'S - E23°31'E). To address specific objectives 3, the Lafras commercial farm (25°48'S - 23°49'E) and a site within the Molopo Nature Reserve (25°48'S - 23°49'E) were included (Figure 2.4.).

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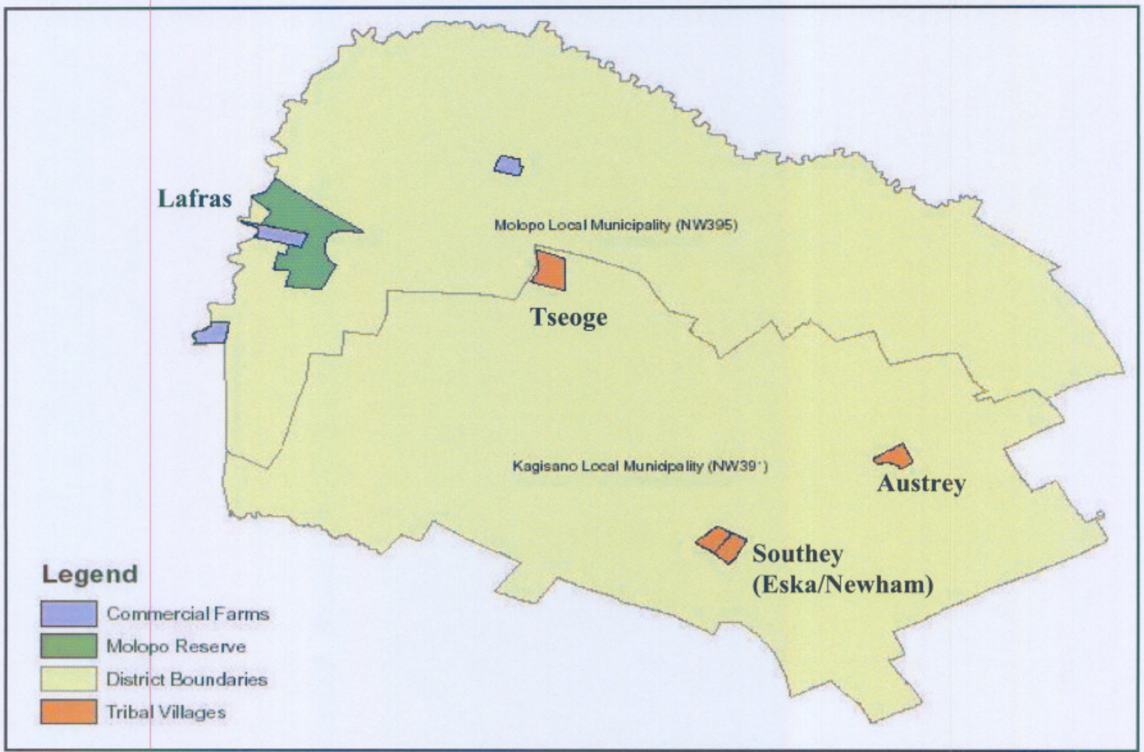

Figure 2.4. Study sites location *(adapted after Coetzee, 2006)*

The climate at the study sites is semi-arid with annual rainfall falling mostly in summer (80% - October to March) and in winter (20% - April to September) (Mangold *et al.*, 2002). Summer rainfall with very dry winters characterizes the Austrey site. Mean annual precipitation varies from about 350 mm in the west to about 520 mm in the east. At the Tseoge, Southey, Lafras and Molopo sites, the climate is characterized by summer and autumn rainfall with very dry winters. Mean annual precipitation varies between 250 and 400 mm. Frost is frequent in winter. Figure 2.5. gives an overview of climatic diagram of the Eastern Kalahari Bushveld with the Mafikeng and Molopo Bushveld types in which fall the study sites (Mucina and Rutherford, 2006).

The geology at the Austrey site is characterized by an Aeolian Kalahari sand of tertiary to recent age on flat sandy plains. Yellow sands of the Clovelly Form and red sands of the Hutton Form both with 3-10% clay content, 0.9-1.2m deep onto calcrete dominate the soils. Soils of the Clovelly Form are characterized by an orthic A topsoil horizon and a yellow-brown apedal B subsoil, whereas the Hutton Form has an orthic A topsoil and a red apedal B subsoil. The Orthic A topsoil is a surface horizon soil that does not qualify as organic, humic, vertic or melanic topsoil, although it may have been darkened by organic matter (Soil Classification Working Group, 1991). Land types are Ah, Ai, and Ae.

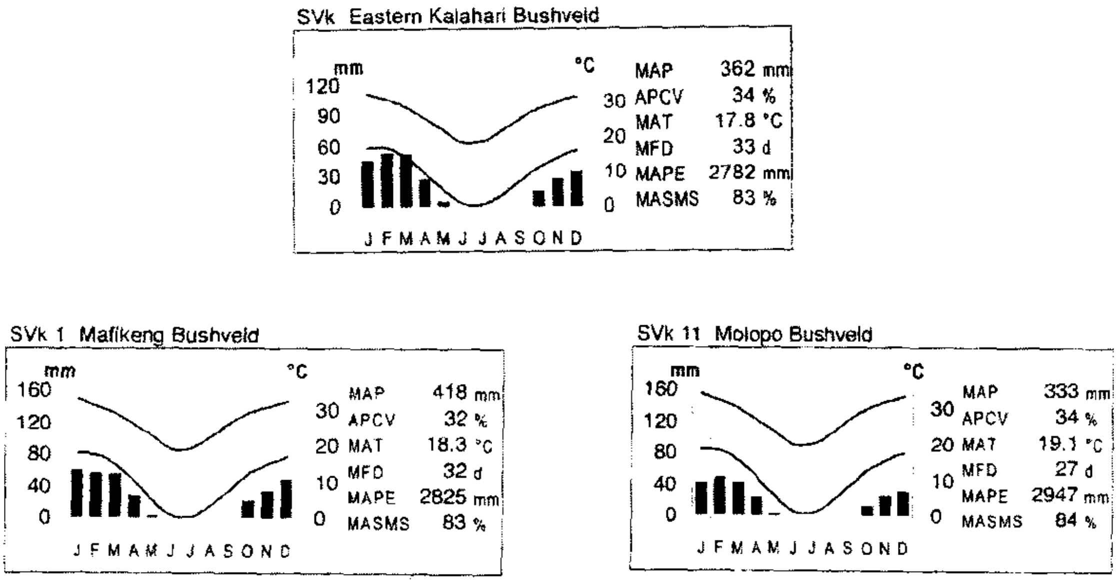

Figure 2.5. Climatic diagrams of the Eastern Kalahari Bushveld with the Mafikeng and Molopo Bushveld types. *Bars show the median monthly precipitation. The upper and lower black lines show the mean daily maximum and minimum temperature respectively. MAP: mean annual precipitation; APCV: annual precipitation coefficient of variation; MAT: mean annual temperature; MFD: mean frost days (days when the temperature was below 0°C); MAPE: mean annual potential evaporation; MASMS: mean annual soil moisture stress (% of days evaporative demand was more than double the soil moisture supply)* (Mucina and Rutherford, 2006).

The geology at the Tseoge, Southey, Lafras and Molopo sites consists of a Red Aeolian sand of recent age with surface calcrete and silcrete. At the Southey site, the soils are similar to those at the Austrey site, but deeper (generally >1.5m). At the Tseoge site, the soils are shallow (< 0.25m), with 4-10% clay and belong to the Mispah form (G. Paterson[5], pers. comm.). The Mispah Form is characterized by an orthic topsoil horizon on a hard rock (Soil Classification Working Group, 1991). The soils at the Molopo and Lafras sites are predominantly sandy depositions with

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calcretes along the riverbed of the fossilized Phepane and the Molopo river (Anonymous, undated). Land types: Ah with a little of Fc.

The vegetation in the area was classified as the savanna biome, dominated by the Kalahari thornveld and shrub bushveld vegetation type (A16) (Low and Rebelo, 1996; Tainton, 1999). It was recently described as the Eastern Kalahari Bushveld (Mucina and Rutherford, 2006). It is characterized by a fairly well developed tree stratum with *Acacia erioloba* and *Boscia albitrunca* as the dominant trees, along with scattered individuals of *Acacia luederitzii* and *Terminalia sericea*, which may be locally conspicuous. The shrub layer is moderately developed and individuals of *Acacia mellifera, Acacia hebeclada, Lycium hirsutum, Grewia flava* and *Acacia haematoxylon* dominate this layer. The grass cover depends on the amount of rainfall during the growing season. Species such as *Eragrostis lehmanniana, Schmidtia kalahariensis* and *Stripagrotis uniplumis* are conspicuous (Low and Rebelo, 1996). The low rainfall and grazing by livestock influence the structure of this vegetation (Low and Rebelo, 1996). In this part of the province, the ecological transition of grass-dominated rangelands into more uniform shrub-encroached communities dominated by *Acacia mellifera*, constitutes a threat to agricultural sustainability (Mangold *et al.*, 2002; Thomas and Dougill, 2006). The Austrey site falls within the Mafikeng Bushveld (SVk 1) characterized by a well-developed tree and shrub layer, dense stands of *Terminalia sericea, Acacia luedenritzii* and *Acacia erioloba* in certain areas. Shrubs include *Acacia karroo, Acacia hebeclada* and *Acacia mellifera, Dichrostachys cinera, Grewia flava, Grewia retinervis, Rhus tenuinervis* and *Ziziphus mucronata.* The grass layer is also developed. The Tseoge, Southey, Lafras and Molopo sites fall within the Molopo Bushveld (SVk 11) characterized by an open woodland to a closed shrubland with the trees *Acacia erioloba* and *Boscia albitrunca* and shrubs *Lycium cinereum, Lycium hirsutum* and *Rhigozum trichotomum*. The grass layer is well developed (Mucina and Rutherford, 2006).

2.2.2. Experimental design

Within each site, single plots representative of a relative good *vs.* poor rangeland condition respectively, and adjacent benchmarks (exclosures) were selected. At each site and within each of the vegetation degradation gradient, the open-grazed and benchmark plots were located on the same soil type, less than 10 m apart. The size of the plots was 110 m x 20 m at the three communal sites and 120 m x 30 m size at the commercial and the Molopo sites. The plots were subjectively chosen by agricultural extension officers based upon their knowledge of the area and expertise to represent the extremes of a degradation gradient or rangeland health within each survey area (Coetzee, 2006). Criteria such as the composition, cover and density of the aboveground herbaceous layer were used (Van Heerden, 2002). The plots at the communal sites were erected in 1999 for the purpose of the LandCare projects (Coetzee, 2006), and in 2003 at the commercial and Molopo sites. The benchmarks plots were fenced to prevent grazing by large and small livestock while the open plots were grazed either continuously (communal management) or rotational (commercial management). The limitations of the experimental design were acknowledged.

2.2.2.1. Soil sampling and analysis

Soil sampling

Soil samples were collected once every year at the end of the rainy season (April/May 2004, 2005 and 2006) in all the plots. Because the methods of soil sampling differed between 2004 and 2005/6, the 2004 data was only used to assess soil particle size distribution. Pseudo-replicate sampling was performed in 2005 and 2006. Each plot was divided in three sub-plots and soil samples were collected within each sub-plot. Ten soil samples were taken from the upper 0-20cm in each sub-plot, and mixed thoroughly with dead coarse organic materials and stones discarded to obtain a composite sample. A sub-sample of each composite sample (n=3 per plot, considered as "replicates" for statistical purposes) was collected for analytical purposes. Part of the soil sub-sample was kept moist in sealed plastic bags and transported in an icebox to prevent exposure to elevated temperatures, preserve the integrity of the biological community, and maintain its functions at a level representative of *in-situ* rates (i.e. level of activities previously existing in the field) (Alef and Nannipieri, 1995; Tate III, 2000). It was analyzed for biochemical (dehydrogenase, acid phosphatase and β-glucosidase) and microbiological (soil microbial biomass) properties. Another part was air-dried and stored at room temperature for physical (texture) and chemical (soil pH, organic carbon, phosphorus, and cation exchange capacity) analyses.

Soil analysis

Physical and chemical analyses

Soil texture was determined at the three communally managed sites in 2004 following the method described by Gee and Bauder (1986). Soil pH was determined in a 1:2 water-extract with a calibrated pH/conductivity meter (Radiometer PHM 80, Copenhagen) at 25°C. Phosphorus (P) was analyzed using the Bray 1 method (Bray and Kurtz, 1945). Soil organic carbon (OC) was measured by the Walkley-Black method (Walkley, 1935). The cation exchange capacity (CEC) was determined by a stepwise replacement of the cation from exchange sites by adding sodium acetate followed by ammonium acetate extraction as described thoroughly by Morgenthal and Van Rensburg (2004).

Biochemical and microbiological analyses

(i) Dehydrogenase (DHA) activity was assayed following the method of Von Mersi and Schinner (1991) as described in Alef and Nannipieri (1995). The method is based on the incubation of soil with the substrate iodonitrotetrazolium chloride (INT) at 40°C for 2h followed by colorimetric estimation of the reaction product iodonitrotetrazolium chloride-formazan (INF). Field moist soil (1 g) was mixed with 1.5 ml THAM buffer and 2 ml INT solution. Test tubes were sealed and incubated at 40°C in the dark for 2h. After the incubation, samples were mixed with 10 ml of extraction solution and kept in the dark. All measurements were carried out in triplicate. The soil suspension was filtered through Whatman no. 2 paper and the absorbance was measured spectrophotometrically at 464 nm against the blank. (ii) β-glucosidase assay was based on the released *p*-nitrophenol after the incubation of soil with *p*-nitrophenyl glucoside solution for 1h at 37°C as described in Alef and Nannipieri (1995). Soil (1 g) was placed in a 50 ml flask, with 0.25 ml of toluene, 4 ml of MUB pH 6.0, and 1 ml of PNG solution. The flask was swirled to mix the contents, and then incubated at 37°C. After 1h, 1 ml of 0.5 M $CaCl_2$ and 4 ml of 0.1 M THAM buffer pH 12.0 were added and the solution was swirled for a few seconds and filtered immediately through a Whatman no. 2. The yellow color development intensity of the filtrate was read with a spectrophotometer set at 410 nm. All measurements were carried out in triplicate with a blank. (iii) Acid phosphatase (ACP) assay was based on the determination of *p*-nitrophenol released after the incubation of soil with *p*-

nitrophenyl phosphate for 1h at 37°C. Soil (1 g) was placed in a 50 ml flask with 0.2 ml of toluene, 4 ml of MUB (pH 6.5) and 1 ml PNP solution made in the same buffer. The solution was swirled for a few seconds to mix the contents, and then incubated at 37°C. After 1h, the stopper was removed; 1 ml of 0.5 M $CaCl_2$ and 4 ml of 0.5 M NaOH were added. The flask was swirled for few seconds and the soil suspension filtered through a Whatman no. 2 paper. The yellow color development intensity of the filtrate was read with a spectrophotometer set at 410 nm. (iv) Soil microbial biomass and community structure were characterized by analyzing the ester-linked phospholipids fatty acids (PLFA) composition of the soil. Total lipids were extracted from a 5 g lyophilized soil according to a modified method (Bligh and Dyer, 1959) as described by White and Ringelberg (1998). Silicic acid column chromatography was used to fractionate the total lipid extract into neutral lipids, glycolipids and polar lipids. The polar lipid fraction was transesterified to the fatty acid methyl esters (FAMEs) by a mild alkaline methanolysis (Guckert *et al.*, 1985). The FAMEs were analyzed by capillary gas chromatography with flame ionization detection on a Hewlett-Packard 6890 series 2 chromatograph fitted with a 60 m SPB-1 column (0.250 mm I.D., 0.250 μm film thickness). Identification of peaks was done by gas chromatography/mass spectrometry of selected samples using a Hewlett-Packard 6890 interfaced with a Hewlett-Packard 5973 mass selective detector. Methyl nonadecanonate (C19:0) was used as the internal standard and the PLFA were expressed as equivalent peak responses to the internal standard.

2.2.2.2. Vegetation surveys

The vegetation surveys were conducted with the technical assistance of the Pasture Division of the North-West Department of Agriculture, Conservation, Environment, and Tourism. The surveys were performed at the end of the rainy season at maximum vegetation growth, at the same period that the soil samples were collected. Species composition, frequency, and biomass production were determined.

Species composition and frequency

Species composition was determined using the wheel point method (Tidmarsh and Havenga, 1955) along parallel transects running the length in each of the grazed and adjacent exclosure plots (Figure 2.6.). The wheel point method uses an apparatus with a rimless wheel that rolls over the ground on its spokes. The position where a point touches the ground or a plant vertically above a point on the ground is considered an intercept point for data recording (Griffin, 1989). Both annual and perennial grass species were recorded. The nearest grass plant in a 45 cm radius of the spoke was visually identified and recorded. When no grass was observed in the 45 cm vicinity, it was considered as bare ground. Data were directly entered into a Psion Monitor, which statistically determines the number of points to survey in each plot in order to give a significant reflection of the species composition. The survey was stopped when 98% of the total variation in species composition had been sampled (Coetzee, 2006). Similarities in herbaceous composition between the grazed and exclosure plots were determined using the Z-index value:

$$Z (\%) = [(b/a*100)*(a+b)]/\sum (a+b)$$

where a and b represent respectively, the highest and the lowest frequency values of each grass identified (Du Toit, 1998). Where needed, species were grouped based on their ecological status, which, refers to the grass reaction to different intensity of grazing. A grass species reacts to grazing either by increasing in number (*increaser*) or becoming less (*decreaser*). Increaser I represents grasses that are abundant in underutilized veld; they are usually unpalatable, robust climax grasses species that can grow without any defoliation. Increaser II refers to grasses that are abundant in overgrazed veld, and which increase due to the disturbing effect of overgrazing and include mostly pioneer and subclimax species. Increaser III includes grasses that are commonly found in overgrazed veld; they are usually unpalatable, dense climax grasses. They are strong competitors and increase because the palatable grasses have become weakened through overgrazing (van Oudtshoorn, 1999). Decreaser group includes grasses that are abundant in good veld, but that decrease in number when the veld is overgrazed or undergrazed; these grasses are palatable climax grasses. The grouping of the species was based also on research technicians' knowledge and expertise of the study area (Coetzee, 2006). The grazing status (palatability classes) was also used whenever needed, following the classification by van Oudtshoorn (1999).

Biomass production

The aboveground biomass production was determined using the dry weight rank method (t'Mannetje and Haydock, 1963) (Figure 2.7.). Within each experimental plot, 30 quadrates (0.60 x 0.60 cm^2) were placed alternatively along a 90 m long transect running the length of the plot. Grasses species were first identified, visually weight-estimated, dry-weight-ranked, and harvested by species group. The grass material cut for ranking estimated was dried to a constant mass, weighed and production per hectare was calculated on a dry mass basis (Coetzee, 2006).

Figure 2.6. The wheel point method for the determination of the composition of the herbaceous layer and frequency

Figure 2.7. The dry weight rank method for the determination of the aboveground biomass production

2.2.3. Statistical analyses

Soil data were analyzed as described in each of the manuscripts using appropriate statistical procedures based upon the objectives and research questions set in each of the manuscripts. A full description of the statistical methods can be found in the section materials and methods of each manuscript. All significance tests were reported at a probability level of $p < 0.05$. The following statistical software packages STATISTICA 7 and SPSS 14 were used. Multivariate analyses were also conducted using CANOCO 4.5 software package (Ter Braak and Šmilauer, 2002).

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CHAPTER 3.

RESEARCH MANUSCRIPTS

This chapter refers to the manuscripts elaborated. The guidelines for authors of the journals where the manuscripts were submitted or will be submitted, precede each manuscript as recommended in the manual for postgraduate studies[6]. The following manuscripts referred in the thesis by their Roman number have been elaborated:

I. Characterization of soil quality and effects of grazing and exclusion management in semi-arid communally managed rangelands in South Africa (Manuscript).

II. Soil microbial biomass in semi-arid communal rangelands in the western Bophirima District, South Africa (accepted pending revisions Journal Applied Ecology and Environmental Research).

III. A comparative assay of rangelands under different management systems in semi-arid South Africa: species composition *vs.* soil quality indicators (Manuscript).

[6] Manual for postgraduate studies. Revised and updated 46 p. http://www.nwu.ac.za/.../Manual-November2005-Web.pdf

3.1. CHARACTERIZATION OF SOIL QUALITY AND EFFECTS OF GRAZING AND EXCLUSION MANAGEMENT IN SEMI-ARID COMMUNALLY MANAGED RANGELANDS IN SOUTH AFRICA

(Short communication will be submitted to the Journal South African Journal of Plant and Soil)

South African Journal of Plant and Soil

Guidelines for authors

Editorial Policy: Original papers, short communication, book reviews, comments on papers recently published and exceptionally, reviews on research in fields of soil science and applied plant science will be considered for publication in this Journal. All papers will be referred, with mutual anonymity, to at least two referees. All articles published by the S. Afr. J. Plant & Soil will be considered for the Sanachem award.

Authors bear sole responsibility for the factual accuracy of their publication. Copyright for all published material is vested jointly in the South African Society of Crop Production, the Soil Science Society of South Africa and the Southern African Weed Science Society. The original typewritten manuscript and three clear copies complete with tables and figures should be submitted in double-spaced typescript on one side of A4 paper, leaving a margin of 2.5 cm on the left hand side. The use of pages with numbered lines greatly facilitates reviewing and is strongly recommended. The language medium used may be English of Afrikaans. As a general guide to manuscript preparation, authors are referred to the Publications Handbook and Style Manual (1988) of the American Society of Agronomy, 677 South Segoe Rd, Madison, WI 53711, USA.

Full-length original papers: contributions submitted should be written concisely and, generally must not be more than 3000 words in length (i.e. nine to ten size A4 pages typed in double spacing). Special attention is directed to the sections below concerning the preparation of the typescript. Typescripts that are not concise or do not conform to the convention of the Journal will be returned to the authors for revision.

Short communications: contributions reporting new techniques, work still in progress or lesser-completed investigations should not exceed two pages of printed text about 1000 words, including brief abstracts, tables, text, figures and references. No subheadings are to be included and where feasible discussion should be omitted or be as brief as possible. Tables and figures must be submitted according to the conventions of the Journal.

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2. An abstract in both English and Afrikaans should be included in the text. The abstract should convey essential information such as rationale, objectives, methods, results and conclusions. It should not exceed 200 words. Afrikaans papers should carry a translated title and the English abstract should be extended (up to 300 words) to facilitate information retrieval by international abstracting agencies.
3. A maximum of five keywords must be provided in English in alphabetical order
4. The contents must be arranged in an orderly way with suitable headings (not for short communications) for each subsection. The following sub-division is recommended:

   A separate title page (title, authors, institutional affiliations and acknowledgements, if any)
   Title, abstracts, keywords (devoid of author names)
   Introduction
   Materials and methods or procedures
   Results or results and discussion
   Discussion and/or conclusions
   References
   Tables
   List of figures
   Figures
5. Standard rules concerning nomenclature apply to certain topics. The common name, followed by Latin binomials with the relevant authority in parenthesis, must be shown for plants, insects and pathogens when first used in the abstract and text. Thereafter use only the common name. At the first mention of a pesticide, except in the title and the body of the abstract, give its approved common mane first and follow it with the full chemical name. Use only the common name thereafter.
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7. Tables are numbered consecutively in Arabic numerals (Table 1) and should bear a short adequate descriptive caption. Units are to be clearly shown. Footnotes to tables are designated by lower-case letters, which appear as superscripts to appropriate entries. Tables should be presented on separate sheets and grouped together at the end of the manuscript. Their appropriate positions in the text should be indicated and all tables should be referred to in the text.
8. Illustrations and diagrams should be prepared on separate A4 sheets. One set of original illustrations on good quality drawing paper, or glossy photo prints, and three sets of copies should accompany each submission. All original illustrations must be fully identified on the

back. Authors should use proper drawing equipment giving uniform lines and lettering of a size, which will be clearly legible after reduction (1.2-2.2 mm). Freehand or typewritten lettering and lines are not acceptable. The ASA Manual referred to in paragraph 6 provides useful tips on preparing figures. Axis labeling should run parallel to the axis. Unnecessary three dimensionality should be avoided. Authors are requested to pay particular attention to the proportions of the illustrations so that they can be accommodated in single (87 mm) or double (180 mm) columns after reduction, without wastage of space. Figures are numbered consecutively in Arabic numerals (Figure 1), and descriptive captions are listed on separate sheet. Where necessary drawings and photographs should have a statement of magnification. Illustrations should be used with the greatest economy. Indicate the approximate position of the figures by a note in the margin and refer to all figures in the text.

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   BROMMETT, J.M., 1975. Isotope-ratio analysis in tracer investigations. In J.B. White (ed.). Methods of soil analysis. Am. Soc. Of Agron., Madison, Wis.

   BUNCE, J.A., 1977. Leaf elongation in relation to leaf water potential in soybean. *J. Exp. Bot.* 28, 156-161

   PATRICK, A.C., 1974. Root growth and development, 2nd ed., McGraw-Hill, New York

   ALLEN, S.G., TAYLOR, G.A., & MARTIN, J.M., 1986. Agronomic characterization of 'Yogo" hard red winter wheat plant height isolines. *Agron. J.* 78, 63-66

   Journal names must be abbreviated according to the World List of Scientific Periodicals and underlined. Articles that are 'in press' and have been accepted for publication may be so designated in the listing of references.

10. Final proofs will be sent to contributors for minor corrections and should be returned to the Scientific Editor within three days of receipt. A careful check should be made of the reference numbers of tables and figures and of the magnifications of half tone illustrations if these have been reduced in block making. Major alterations to the text will be accepted only at the author's expense.

11. Reprints: 50 reprints of a full-length paper will be supplied free of charge. All short communications in one issue will be treated as one full-length paper. Additional reprints can be ordered directly from the printers (see address on inside front cover). Manuscripts for publication should be submitted to The Scientific Editor, Dr J.B.J. van Rensburg, Summer Grain Centre, Private Bag X1251, Potchefstroom, 2520.

MANUSCRIPT I:

CHARACTERIZATION OF SOIL QUALITY AND EFFECTS OF GRAZING AND EXCLUSION MANAGEMENT IN SEMI-ARID COMMUNALLY MANAGED RANGELANDS IN SOUTH AFRICA

Short communication

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CHARACTERIZATION OF SOIL QUALITY AND EFFECTS OF GRAZING AND EXCLUSION MANAGEMENT IN SEMI-ARID COMMUNALLY MANAGED RANGELANDS IN SOUTH AFRICA

Abstract

Concerns have developed in southern Africa over the health/condition of semi-arid communally managed rangelands, described as degraded because of overgrazing and overstocking. The objectives of this study were to characterize rangeland soil quality/health and to investigate the potential effects of grazing and exclusion management that could serve as baselines for further monitoring of rangeland health. Three communally managed sites (Austrey, Southey and Tseoge) in the western Bophirima District (North-West, South Africa) were characterized for soil and vegetation parameters in open-grazed and adjacent 5 years exclusion plots. Low fertile sandy soils were characteristics of all sites. Organic carbon was low (0.08 ± 0.007%) and phosphorus averaged 7.83 ± 0.44 mg kg^{-1}. Various levels of enzymatic activities were observed. Site-specific differences of grazing effects were observed on soil properties. Soil enzymatic activities appeared most sensitive to management effects than soil chemical properties. High percentage of Increaser II and low biomass (72.07 kg ha^{-1}) were characteristics of all the sites. The low biomass and bare ground might constrain enzymatic activity as plant biomass and residue provide the substrates for enzymatic metabolism. These interrelations between below and aboveground components are important in sustaining rangeland health, and should therefore be integrated in monitoring. Further research is needed to validate these preliminary findings because of landscape soil variability.

Keywords: Soil health/quality; Baseline characterization; Communal rangelands; Chemical properties; Enzymatic activity; Grazing and exclusion management.

INTRODUCTION

In South Africa, the effects of inappropriate land use practices have resulted in various forms of soil degradation (Mills and Fey, 2003) in both cropland and grazing lands. Approximately 80% of the land surface in South Africa is used as grazing land (Hoffman and Ashwell, 2001). Scheepers and Kellner (1995) quoted by Snyman (2003), reported that nearly 66% of the total rangeland surface has been degraded, mainly because of improper grazing management practices, deforestation, incorrect use of fire, encroachment of other land use types, and climate change. Rangeland degradation has been described more of a problem in districts under communal tenure in the former homelands than under commercial farming (Hoffman and Ashwell, 2001). Indeed, for decades, communal rangelands have been depicted as degraded because of overgrazing and overstocking (Shackleton, 1993). The view that communal tenure leads to rangeland degradation has however, recently been challenged (Shackleton, 1993; Sullivan and Rhode, 2002). Studies which attempted to compare communal to commercial and/or game management have revealed an array of contradicting results regarding the effects of communal grazing, i.e. degradation in communal rangelands. Questions remain therefore as to whether all communal rangelands are severely degraded or if certain areas remain productive under this management (Shackleton, 1993; Evans, 2000; Sullivan and Rohde, 2002; Vetter *et al.*, 2006), and how to define degradation and overgrazing (Vetter *et al.*, 2006).

Rangeland degradation has often been described through loss of plant cover, change in the composition of grass species, increasing buch density (bush encroachment), and alien plant invasions (Hoffman and Ashwell, 2001). Relatively little information exist on soil properties and degradation processes, particularly in communally managed rangelands (Henning and Kellner, 1994). Rangeland degradation occurs mainly through deterioration of the soil's capacity to capture and store water (erosion), loss of the ability of the soil to supply nutrients or the accumulation of salts or other toxic substances in the soil. Friedel (1991) indicated that rangeland deterioration is best indicated by irreversible changes in the soil, and that assessment of soil is a critical element in the identification of thresholds of change on rangelands. Recent interest in rangeland health and the growing recognition of the importance of soil-vegetation feedbacks in structuring rangelands (Schlesinger *et al.*, 1990; Tongway and Ludwig, 1994) have led to a renewed interest in integrating soil information into rangeland monitoring and management (Herrick *et al.*, 2002).

Soil quality is defined as "the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality" (Doran and Safley, 1997). Maintaining and improving the quality of the soil resource is an integral part of sustainable agriculture (Doran, 2002; Arshad and Martin, 2002), and ongoing assessment of the condition and health of soil is fundamental in determining the sustainability of land use and management practices (Aon and Colaneri, 2001; Doran and Safley, 1997). Du Preez and Snyman (1993) found that when soil quality deteriorates to the extent that plant growth and germination are affected, a shift in ecosystem state may occur and range (veld) recovery might become extremely difficult to achieve.

The selection of indicators that enable the quantification of soil quality is very important (Gil-Sotres *et al.*, 2005). Soil physical and chemical properties have been used to assess soil quality, but they are of little use as they alter only when the soil undergo drastic changes (Filip, 2002). On the contrary, soil biological and biochemical properties are sensitive to small changes (Yakovchenko *et al.*, 1996). Enzyme activities play key roles in the biochemical functioning of soils, including soil organic matter formation and degradation, nutrient cycling, and decomposition of xenobiotics. Soil enzyme assays are processes-level indicators and are presented as a means of determining the potential of a soil to degrade or to transform substrates (Sarapatka, 2003). The rationale for the use of soil enzyme activity as soil quality indicator is that they (i) are closely related to important soil quality parameters, (ii) they can begin to change much sooner than other properties, (iii) they can be an integrative soil biological index of past soil management, and (iv) they involve procedures that are relatively simple compared to other important soil quality properties (Dick *et al.*, 1996). Therefore, knowledge of enzyme activities can be used to describe changes in soil quality due to land use and management (Acosta-Martínes *et al.*, 2003, 2007). The objectives of the study were to characterize soil quality (baseline condition) and to investigate potential differences between grazing and exclusion management (hypothesized as grazing effect). This study forms part of a wider program (the Desert Margins Program) which aims to address issues of global environmental importance in the desert margins of sub-Saharan Africa, in particular the loss of biological diversity and reduced carbon sequestration associated with land degradation.

MATERIALS AND METHODS

Study sites

Three communally managed sites located in the Kagisano Local Municipality (western Bophirima District, Ganyesa region) were chosen: Austrey (26°28'S - 24°14'E), Southey (Eska/Newham, 26°38'S - 23°51'E), and Tseoge (25°57'S - E23°31'E) (Figure 1). The sites were part of the Provincial LandCare program. The climate at the study sites is semi-arid with rainfall falling in summer (October to March - 80%) and in winter (April to September - 20%) (Mangold *et al.*, 2002). Summer rainfall with very dry winters characterizes the Austrey site; mean annual precipitation varies from about 350 mm in the west to about 520 mm in the east. At the Tseoge and Southey, the climate is characterized by summer and autumn rainfall with very dry winters. Mean annual precipitation is between 250-400 mm (Mucina and Rutherford, 2006). The geology is dominated by an Aeolian Kalahari sand of tertiary to recent age on flat sandy plains at the Austrey site (Mucina and Rutherford, 2006). The soils are deep (>1.2 m) of the Clovelly and Hutton forms, characterized by an orthic A top soil underlain by a yellow-brown apedal B and a red apedal B horizon, respectively. The Orthic A topsoil is a surface horizon soil that does not qualify as organic, humic, vertic or melanic topsoil, although it may have been darkened by organic matter (Soil Classification Working Group, 1991). The Tseoge and Southey sites are characterized by a Red Aeolian sand of recent age with surface calcrete and secrete (Mucina and Rutherford, 2006). The soils are deep (>1.2), belong to the Mispath form, which is characterized by an orthic A top soil horizon overlying hard rock (G. Paterson, pers. comm., 2005; Soil Classification Working Group, 1991). The vegetation in the area was classified as savanna biome dominated by the Kalahari thornveld and shrub bushveld vegetation types (Low and Rebelo, 1996; Tainton, 1999). It was recently described as the Eastern Kalahari Bushveld (Mucina and Rutherford, 2006). The Austrey site falls within the Mafikeng Bushveld (SVk 1) characterized by a well developed tree and shrub layer, dense stands of *Terminalia sericea*, *Acacia luedenritzii* and *Acacia erioloba* in certain areas. Shrubs include *Acacia karroo, Acacia hebeclada* and *Acacia mellifera, Dichrostachys cinera, Grewia flava, G. retinervis, Rhus tenuinervis* and *Ziziphus mucronata.* The grass layer is also developed. The Tseoge and Southey sites fall within the Molopo Bushveld (SVk 11) characterized by an open woodland to a closed shrubland with *Acacia erioloba* and *Boscia albitrunca* and shrubs *Lycium cinereum, Lycium hirsutum* and *Rhigozum trichotomum.* Grass layer is well developed (Mucina and Rutherford, 2006).

Experimental design

At each site, plots representative of a relative "good *vs.* poor" condition open-grazed and adjacent benchmark (exclosure) were selected. These plots were erected for the purpose of the provincial LandCare projects in 1999. The open-grazed and benchmark plots were chosen to be similar as possible i.e. located on the same soil type, parental material, and grazing history. They were approximately 10 m apart at each of the degradation gradient (good *vs.* poor). These plots were subjectively selected by research technicians and resource conservation officers to represent the "extremes" of a degradation gradient or rangeland health within each survey area (Coetzee, 2006). According to Van Herdeen (2002), criteria such as the composition, cover and density of the aboveground herbaceous layer were used to assess degradation gradient. The benchmarks (exclosure) plots were subjected to zero grazing/browsing (Coetzee, 2006). Grazing and exclusion management effects were determined on the poor gradient of degradation plots. This was motivated by the fact that these plots were located near the villages and therefore subjected to intense grazing. On the contrary, on the far good gradient plots, grazing was little to non-existent. Because of possible differences in grazing management (number of animals, seasonality of grazing, stocking rates, frequency of grazing, etc), a site-specific approach was used to investigate the effects of grazing and exclusion management.

Soil sampling and analysis

For the baseline soil characterization, samples were collected in both the good and poor condition plots to reflect as much as possible the soil quality at the sites. Samples were taken from the soil upper 20 cm in 2005. Pseudo-replicate sampling method was used. Each plot was divided in three sub-plots considered as "replicates" for statistical purposes. Ten soil samples were collected using a soil auger within each sub-plot, and mixed thoroughly with coarse organic materials and stones discarded. From the composite sample of each sub-plot, a sub-sample was collected. A part of the sub-sample was put in sealed plastic bag and transported in an icebox to the laboratory for the determination of enzymatic activities. Another part of the soil sub-sample was air-dried and stored at room temperature for the physical (particle size distribution) and chemical analyses. Results are given as mean ± standard error.

Physical and chemical analyses

Soil texture was determined as described by Gee and Bauder (1986). Soil pH was determined in 1:2 w/v soil-water extract with a calibrated pH (Radiometer PHM 80, Copenhagen) at 25°C as described in Morgenthal and Van Rensburg (2004). Total phosphorus (P-Bray 1) was determined by the Bray 1 method (Bray and Kurtz, 1945) and organic carbon (OC) by the Walkley-Black method (Walkley, 1935).

Enzymatic assays

Dehydrogenase, ß-glucosidase and acid phosphatase activities were assayed following methods described in Alef and Nannipieri (1995). Dehydrogenase activity was assayed by incubating 1 g moist soil for 2h at 40°C with 1.5 ml Tris (hydroxymethyl)-aminomethane buffer and 2 ml iodonitrotetrazolium chloride (INT) (5 mg ml^{-1} in 2% v/v N,N-dimethylformamide). β-glucosidase (β-glucosidase EC 3.2.1.21) assay was based on p-nitrophenol release after cleavage of *p*-nitrophenyl glucoside substrate. Acid phosphatase (EC 3.1.3.2, pH 6.5) assay was based on the determination of *p*-nitrophenol released after the incubation of soil with *p*-nitrophenyl phosphate for 1 h at 37°C. All enzymes assays were done in triplicate per sample and controls were included. Claassens (2004) provided the full enzymatic assays description.

Species composition and biomass

The species composition was determined during soil sampling. The wheel-point method (Tidmarsh and Havenga, 1955) was used along parallel transects running the length in each plot. The wheel point method uses an apparatus with a rimless wheel that rolls over the ground on its spokes. The position where a point touches the ground or a plant vertically above a point on the ground is considered an intercept point for data recording (Griffin, 1989). Both annual and perennial grass species were recorded. The nearest grass plant in a 45 cm radius of the spoke was visually identified and recorded. When no grass was observed in the 45 cm vicinity, it was considered as bare ground. Data were directly entered into a Psion Monitor, which statistically determines the number of points to survey in each plot in order to give a significant reflection of the species composition. The survey was stopped when 98% of the total variation in species composition was sampled (Coetzee, 2006). Species were grouped based on their ecological status, which, refers to the grass reaction to different intensity of grazing, following the classification by Van Oudtshoorn (1999) and Coetzee (2006). Species reacts to grazing either by increasing in number (increaser) or becoming less (decreaser). Increaser I represents grasses abundant in underutilized veld; they are usually unpalatable, robust climax grasses species that can grow without any defoliation. Increaser II refers to grasses that are abundant in overgrazed veld, and which increase due to the disturbing effect of overgrazing and include mostly pioneer and subclimax species. Increaser III includes grasses that are commonly found in overgrazed veld; they are usually unpalatable, dense climax grasses. They are strong competitors and increase because the palatable grasses have become weakened through overgrazing (van Oudtshoorn, 1999). Decreaser group includes grasses that are abundant in good veld, but that decrease in number when the veld is overgrazed or undergrazed; these grasses are palatable climax grasses. The grouping of the species was also based on research technicians' knowledge and expertise of the study area (Coetzee, 2006). The aboveground biomass was determined using the dry weight rank method (t'Mannetje and Haydock, 1963). Within each plot, thirty quadrates were placed alternatively along a 90 m long transect running the length of the plot. Grasses species were visually identified, ranked, and harvested by species group. The grass material cut for ranking estimated was dried to a constant mass, weighed and production per hectare calculated on a dry mass basis (Coetzee, 2006).

Statistical analysis

Differences between the three sites and the effects of grazing and exclusion management (site-specific) were tested by one-way analysis of variance (ANOVA), and in case of significance, differentiated by Fisher test at $p < 0.05$ probability level. All statistical tests were conducted using STATISTICA 7 software package.

RESULTS

Soil baseline characterization

Physical and chemical indicators

All the soils were categorized as sandy (± 95.2%) with low clay and silt contents (3.05% and 1.09% respectively) (Table 1). Selected soil chemical properties are presented in Table 2. Soil pH ranged from 5.51 to 7.11; it was significant different between the three sites (*$F=1997$, $p=0.000001$*). Total phosphorus ranged from 6.3 mg kg^{-1} to 8.66 mg kg^{-1}. It was statistically different (*$F=9.6$, $p=0.01$*) between the three sites. Soil organic carbon ranged from 0.06 to 0.1% and was statistically different between the three sites (*$F=11.64$, $p=0.008$*), with the Tseoge site showing lower organic carbon (0.06%) compared to the Austrey and Southey sites (0.1%) (Table 2).

Enzymatic activities

Selected enzymatic activities are presented in Table 3. The activity of dehydrogenase ranged from 18.41 µg INF g^{-1} $2h^{-1}$ to 70.28 µg INF g^{-1} $2h^{-1}$. There was a significant difference between the three sites for the activity of dehydrogenase (*$F=39.44$, $p=0.0003$*). β-glucosidase ranged from 0.09 *p*NP $g^{-1}h^{-1}$ to 0.17 g *p*NP $g^{-1}h^{-1}$, but did not differ between the sites (*$F=1.18$, $p=0.38$*). The activity of ACP ranged from 1.08 *p*NP $g^{-1}h^{-1}$ to 2.69 g *p*NP $g^{-1}h^{-1}$; it was significantly different between the three sites (*$F=245$, $p=0.000002$*).

Effects of grazing and exclusion management: "grazing effects"

Soil chemical properties in the open-grazed and adjacent exclosure plots per site are given in Figure 2. Soil pH was not significantly different between the open-grazed and exclosure plots at any of the three sites (*$F=0.07$, $p=0.8$; $F=4.8$, $p=0.09$*, and *$F=3.6$, $p=0.12$* at the Austrey, Southey and Tseoge sites respectively). Phosphorus was significantly different between the open-grazed and exclosure plots at the Tseoge site only (*$F=88.5$, $p=0.0007$*), but not at the Austrey and Southey sites (*$F=4.8$, $p=0.09$* and *$F=5.4$, $p=0.5$* respectively). Soil organic carbon was not different at any of the three sites (*$F=1.5$, $p=0.27$; $F=1.2$, $p=0.33$*, and *$F=3.6$, $p=0.12$* at the Austrey, Southey and Tseoge sites respectively).

Soil enzymatic activities are given in Figure 3. Of the three enzymes, β-glucosidase was significantly different between the open-grazed and exclosure management at all the three sites (*F=92.9, p=0.0006*; *F=11.5, p=0.02*, and *F=10.9, p=0.02* at the Austrey, Southey and Tseoge sites respectively). No significant difference was found for the activity of acid phosphatase (*F=4.9, p=0.08*; *F=3.4, p=0.13*, and *F=2.5, p=0.18* at the Austrey, Southey and Tseoge sites respectively). Dehydrogenase wasn't different between the two management schemes at the Austrey and Tseoge sites (*F=2.5, p=0.18* and *F=1.11, p=0.35* respectively), but it was significantly different at the Southey site (*F=46.9, p=0.002*) (Figure 3).

Species composition and biomass

Sixteen species were identified and recorded (Table 4). Of the sixteen species, thirteen (81.25%) were perennial and three (18.75%) were annual species (*Aristida congesta, Tragus berteronianus, and Urochloa brachyuran).* The ecological status revealed a high percentage of Increaser II species across all the three sites. Increaser II refers to species that are abundant in overgrazed veld, and which increase due to the disturbing effect of overgrazing. The decreaser group was represented by high palatable species (*Digitaria eriantha, Schmidtia pappophoroides* and *Stripagrostis uniplumis).* These species occurred in relatively low frequency in all plots. The proportion of Increaser II species was higher at the Southey site (in both the open-grazed and exclosure plots) than at the Austrey and Tseoge sites. The relative abundance (percentage) of species based on their palatability classes is given in Figure 4. Desirable (DE) and highly desirable (HD) species dominated to some extent at the Austrey site (both in the open-grazed and exclosure plots). Species were unevenly distribution across the sites. Species such as *Aristida congesta, Aristida stipitata* and *Eragrotis lehmanniana* showed a fairly distribution across all the sites. Because of this unevenly distribution, no single species could be described as the most dominant across the sites. The percentage of bare ground was higher at the Tseoge site (both in the open-grazed and exclosure plots) than at the Southey and Austrey sites. The aboveground biomass was higher in the exclosure than the open-grazed plots across all the three sites (Table 4).

DISCUSSION

The objectives of this study were to characterize soil condition/health and investigate the potential effects of grazing and exclusion management on selected chemical and biological properties. The assessing of soil quality assessment has been proposed as a tool for evaluating the effects of agricultural management practices (Doran and Safley, 1997). However, to be helpful, reference or baseline value is required. This reference condition and subsequent soil health assessments should be made within areas of specific soil series and land use (Mausbach and Seybold, 1998). All the sites were characterized by low fertility (expressed by low organic carbon and phosphorus contents) with a pH moderately acidic (6.05 ± 0.26) at all the three sites. All the sites were characterized by sandy soil (± 95.2%) with low clay and silt contents (3.05% and 1.09% respectively). Soil organic carbon is considered as a sensitive soil quality indicator, which may serve as suitable indicator of soil fertility change (Murage *et al.*, 2000). Degens *et al.*, (2000) indicated that land use resulting in loss of organic carbon might generate soils that are less resilient to stresses or disturbances. Therefore, it is important to maintain good level of organic carbon. The characterization of soil enzymes showed different levels of enzymatic activities between the three sites. In the lack of previous data or reference, soil characterization from a biochemical point of view was difficult. These results can however serve as baseline for further monitoring of soil degradation in these rangeland sites.

No clear pattern of grazing and exclusion management effects could be described for all the soil properties. Except phosphorus at the Tseoge site, organic carbon and pH did not show significant difference between management (open-grazed and exclusion). Our results support previous findings from Lavado *et al.*, (1996), Berg *et al.*, (1997), Hiernaux *et al.*, (1999), Henderson *et al.*, (2004), Reeder *et al.*, (2004), Cui *et al.*, (2005), Yong-Zhong *et al.*, (2005) who also found no impact of grazing on soil organic carbon in sandy rangeland. Other studies on contrast showed significant increase in organic carbon in grazed treatments compared to ungrazed treatments (Schuman *et al.*, 1999; Manley *et al.*, 1999). Reeder and Schuman (2002) indicated that differences in the response of ecosystem carbon to grazing are the result of different climate, inherent soil properties, landscape position, plant community composition, and grazing management practices. Soil enzymes assays provide a useful indicator to evaluate effects of land use change on soil microbial activities (Raiesi, 2007). In this study, the levels of enzymatic activity between the open-grazed and exclosure plots were significantly different for the activity of ß-glucosidase across all three sites, and to a lesser extent the activity of dehydrogenase at the Southey site only (Figure 3). There was a pattern of increasing the activity of β-glucosidase in the exclosure compared to the grazed plots (Figure 3). This was expected because β-glucosidase is controlled by carbon supply (Knight and Dick, 2004; Aon and Colaneri, 2001; Gianfreda *et al.*, 2005). Any variation in organic carbon supply between the grazed and exclosure plots would therefore influence the activity of this enzyme.

In this study, all the exclosure plots had higher biomass than the open-grazed plots. Plant defoliation and removal by livestock grazing lead to lower inputs of organic matter and nutrients returned to the soil. In the exclosure plots on the contrary, the slow recovery of the vegetation is expected to increase litter inputs and organic carbon to the soil (Bardgett *et al.*, 1997). Plant cover and biomass are important as they provide protection against soil erosion and contribute to organic matter that enhances soil water holding capacity (Garcia *et al.*, 1994; 2002). Studying links between plant diversity and soil microbial communities, Zak *et al.*, (2003) suggested that the loss of plant species may have the greatest impact on microbial communities in ecosystems containing infertile soils poor in organic matter. At the Tseoge site, the low enzyme activity could be the result of lower biomass production and low plant cover as shown in Table 4. Garcia *et al.*, (2002) found that a lower quantity of plant residues contributes to a lesser degree of enzymes synthesis reported similar results. This was also confirmed by Raeisi and asadi (2006). These authors found in semi-arid rangeland in Iran that a decrease in residue inputs (residue quantity) and changes in species composition (residue quality) might affect microbial activity. Across all the three sites, the percentage of Increaser (II and III) was higher than that of Decreaser species. Increaser II and III species refers to grass that are abundant in overgrazed veld, usually unpalatable (Van Oudtshoorn, 1999; Abule *et al.*, 2007), and they are used as indicators of poor rangeland condition. This could apply for these sites. The low biomass and cover as shown at the Tseoge site might influence the soil quality through reduce cover and organic inputs to the soil. This is in line with Snyman and Du Preez (2005) who found that in semi-arid areas, plant cover and biomass have major effects on soil resources, and the decline in plant cover usually accompanies rangeland degradation. This emphasizes the importance of maintaining good soil cover to protect soil from erosion and loss of quality, as well as investigating the relationships between soil and vegetation parameters to ensure rangeland sustainability.

CONCLUSION

Soils at the sites could be described as low fertile because of low organic carbon and phosphorus contents. Various levels of enzymatic activity were observed. However, in the absence of previous or reference soil status, whether degradation has occurred or not was difficult to assess as well as the causes of degradation. This emphasizes the importance of baseline and regular monitoring to detect changes in rangeland ecosystem. The species composition dominated by increaser species of low grazing, indicative of overgrazing management at these sites. Interrelationships between soil and vegetation were observed. This highlights the important of maintaining good balance between soil and vegetation to sustain good rangeland condition. Comparison of these baseline data with long-term monitoring, will provide further insights into rangeland health as well as the effects of grazing management in these sites.

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Table 1 Particle size distribution at the study sites

Soil properties	Sites			Means
	Austrey	Southey	Tseoge	
Sand (%)	94.3 (0.6)	94 (1.04)	97.3 (0.01)	95.2
Clay (%)	3.47 (0.61)	3.9 (0.01)	1.78 (0.01)	3.05
Silt (%)	2.21 (0.002)	2.08 (1.06)	0.99 (0.006)	1.09

Values are means (n=6) and standard error in brackets.

Table 2 Soil chemical properties at the study sites

Soil properties	Sites			Mean	ANOVA Results	
	Austrey	Southey	Tseoge		*F*	*p*
pH (H_2O)	5.51 (0.03) [a]	5.54 (0.01) [a]	7.11 (0.01) [b]	6.05 (0.26)	*1996*	*0.000001*
OC (%)	0.10 (0.001) [a]	0.10 (0.001) [a]	0.06 (0.0001) [b]	0.08 (0.07)	*11.64*	*0.008*
P (mg kg^{-1})	6.30 (0.13) [a]	8.55 (0.69) [b]	8.66 (0.24) [b]	7.83 (0.44)	*9.6*	*0.01*

P: total phosphorus; OC: organic carbon. Subscript similar letter indicates no significant difference between the corresponding sites at p<0.05 probability level. Values are means (n=3) and standard error in brackets.

Table 3 Soil enzymatic activities at the study sites

Soil enzymes	Sites			Mean	ANOVA Results	
	Austrey	Southey	Tseoge		*F*	*p*
DHA (μg INF g^{-1} $2h^{-1}$)	70.28	18.41	35.47	41.38	*39.4*	*0.0003*
	(2.12) [a]	(0.28) [b]	(6.97) [c]	(7.91)		
ß-gluco (g*p*NP g^{-1} h^{-1})	0.18	0.12	0.09	0.13	*1.18*	*0.38*
	(0.01) [a]	(0.07) [a]	(0.02) [a]	(0.02)		
ACP (g *p*NP g^{-1} h^{-1})	2.69	0.82	1.08	1.53	*245*	*0.000005*
	(0.08) [a]	(0.03) [b]	(0.07) [c]	(0.29)		

DHA: dehydrogenase; ACP: acid phosphatase; ß-gluco: ß-glucosidase. INF: iodonitrotetrazolium chloride-formazan; pNP: p-nitrophenol. Subscript similar letter indicates no significant difference between the three sites at $p<0.05$ probability level. Values are means (n=3) and standard error in brackets.

Table 4 Species composition, life form, ecological status, frequency (%), and biomass production in the open-grazed and benchmark (exclosure) plots at the study sites

Species composition	Life form	Austrey		Southey		Tseoge	
		GR	EX	GR	EX	GR	EX
Digitaria eriantha	p/hd	1.1	18.5	-	-	-	3.4
Schmidtia pappophoroides	p/hd	4.5	11.1	1.8	4.7	-	-
Stripagrostis uniplumis	p/de	-	-	8.5	0.7	-	-
Total Decreaser		5.6	29.5	10.3	5.4	-	3.4
Triraphis andropogonoides	p/ld	-	0.8	1.8	6.7	-	-
Eragrostis lehmanniana	p/de	8.3	14.1	5.5	6	-	8.9
Eragrostis trichophora	p/de	21.7	5.9	-	-	-	-
Aristida stipitata	p/ld	18.9	20	26.1	8.7	-	3.3
Melinis repens	p/ld	1.1	-	3	-	-	-
Eragrostis rigidior	p/ld	0.6	5.2	-	-	-	-
Pogonarthria squarrosa	p/ld	-	1.5	33.8	48.6	-	-
Perotis patens	a/ud	1.2	1.5	-	-	-	-
Brachiaria marlothii	a/ud	1.7	-	-	-	20.65	13.3
Eragrostis pallens	p/ld	-	-	*5.5*	*1.3*	-	-
Total Increaser II		53.5	49	75.7	71.3	20.65	25.5
Aristida congesta	a/ud	22.2	12.6	7.9	7.3	-	7.8
Tragus berteronianus	a/ud	12.2	1.5	-	-	-	-
Urochloa brachyura	a/ud	-	-	-	*1.3*	-	-
Total Increaser III		*34.4*	*14.1*	*7.9*	*8.6*	-	*7.8*
Bare ground		6.5	7.4	6.1	14.7	79.35	63.3
Biomass (kg ha^{-1})		69.98	1384.6	70.84	179.29	75.75	134.4

Life form: "a" = annual, "p" = perennial; hd: highly desirable; de: desirable; ld: less desirable; ud: undesirable; GR: open-grazed plot; EX: benchmark (exclosure) plot.

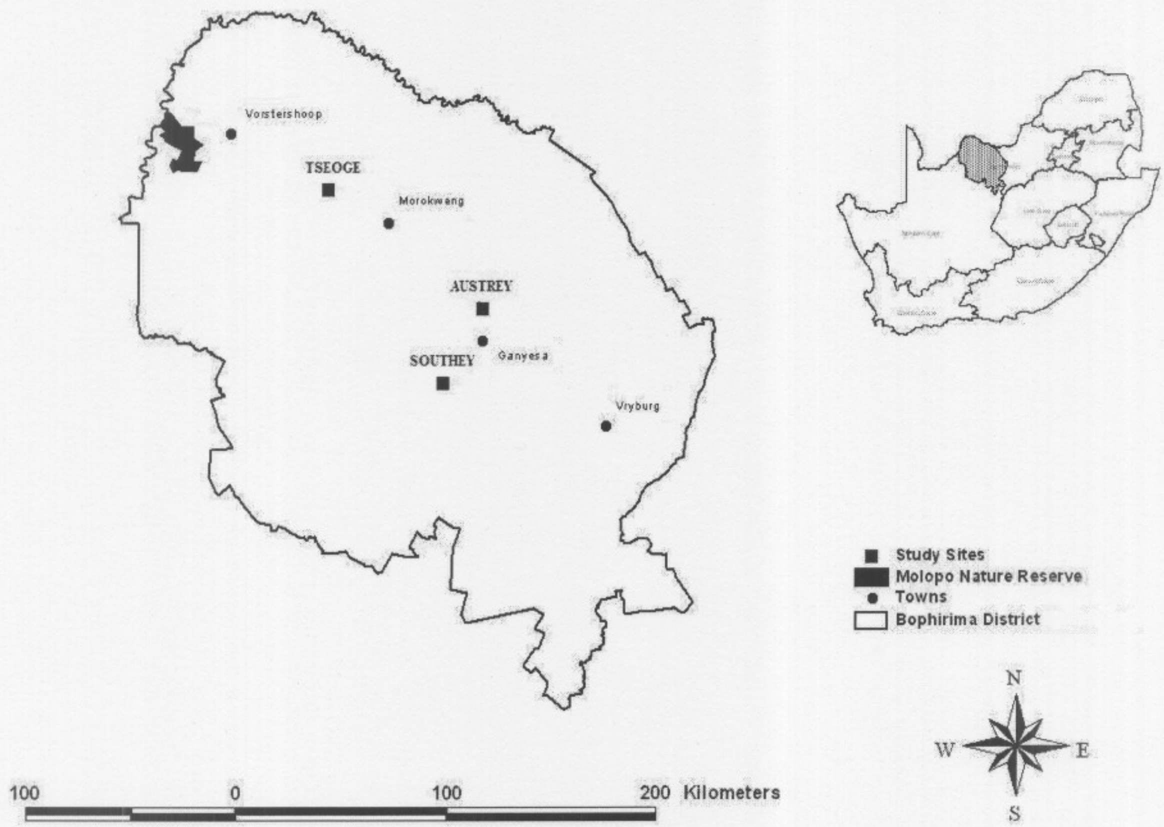

Figure 1 Location of the study sites in the western Bophirima District

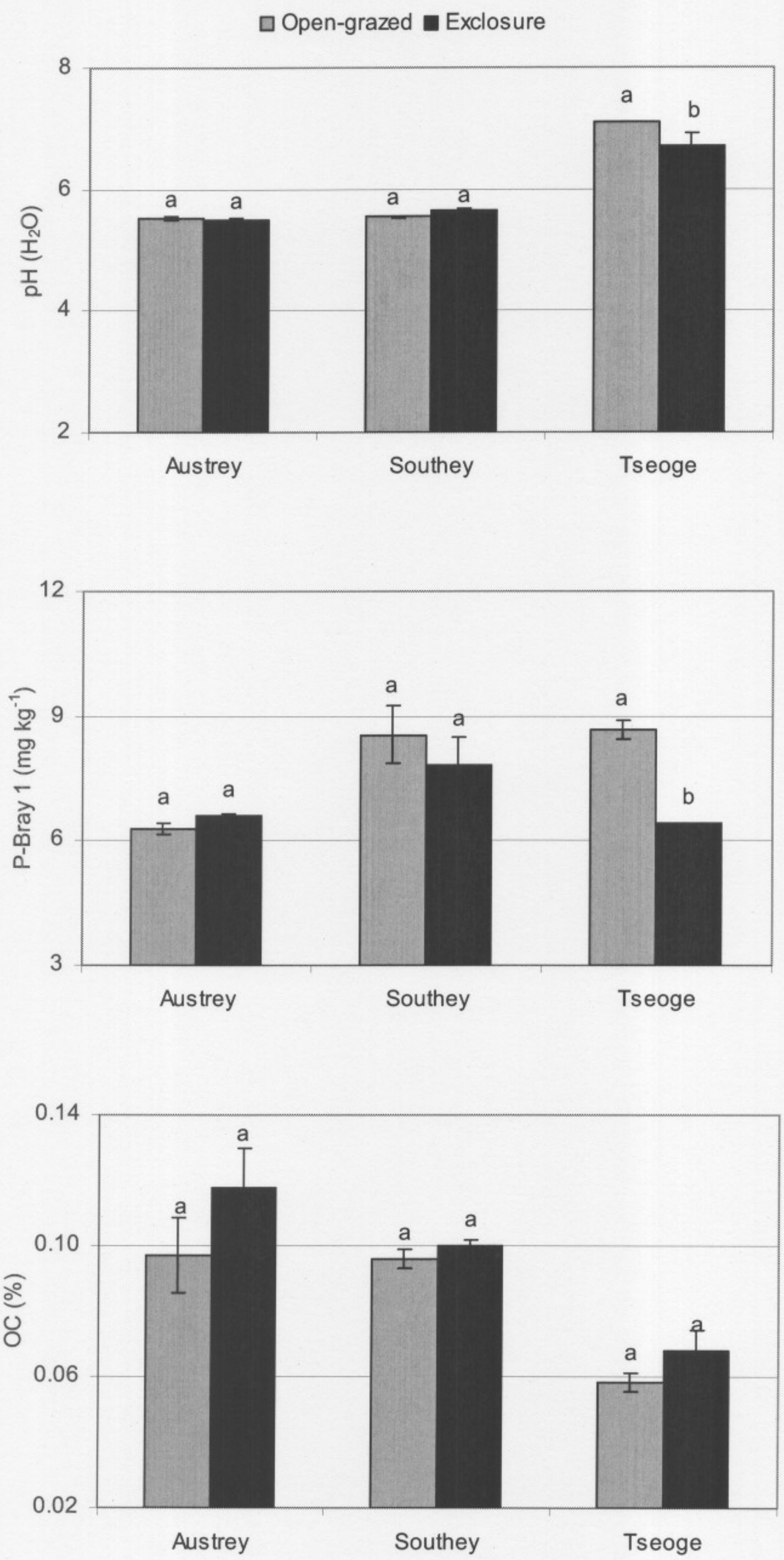

Figure 2 Soil chemical properties in the open-grazed and exclosure plots at the study sites. Values represent means (n=3) and bars are standard error

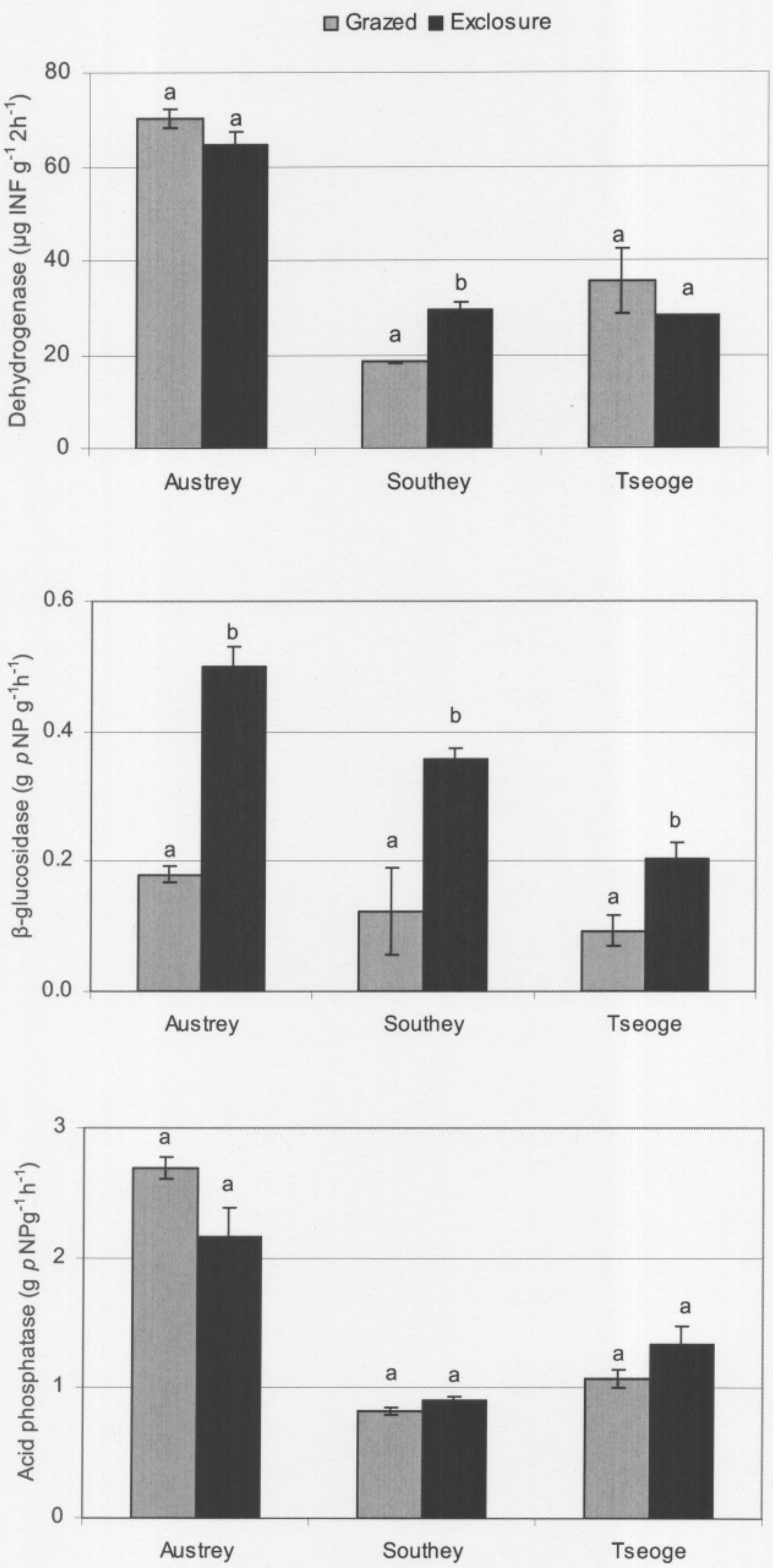

Figure 3 Soil enzymatic activities in the open-grazed and exclosure plots at the study sites
Values represent means (n=3) and bars are standard error

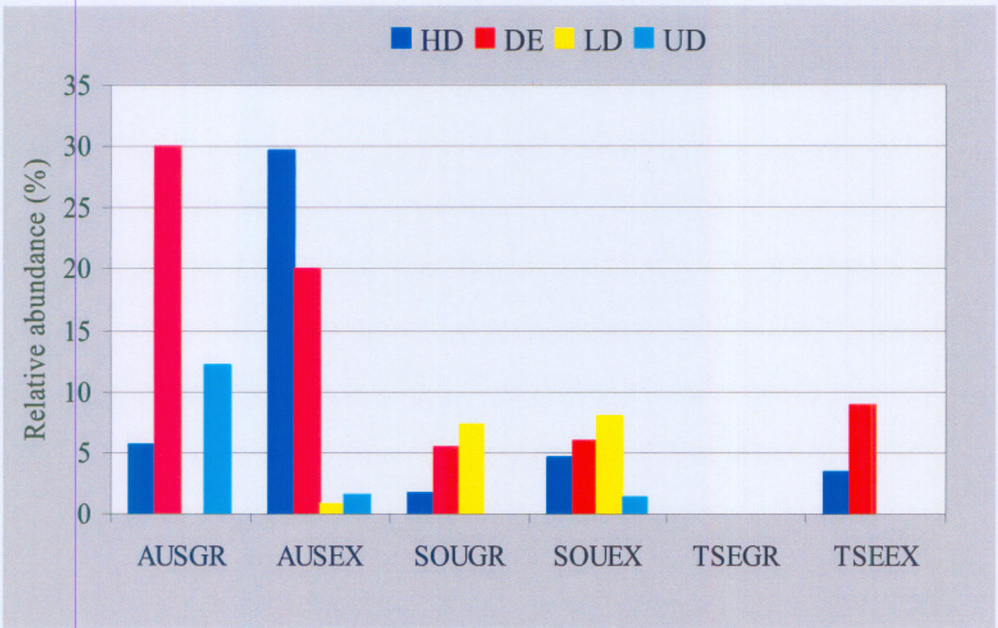

Figure 4 Species palatability in the open-grazed (GR) and exclosure (EX) plots at the study sites. HD: highly desirable; DE: desirable; LD: less desirable and UD: undesirable species

3.2. SOIL MICROBIAL BIOMASS IN SEMI-ARID COMMUNAL RANGELANDS IN THE WESTERN BOPHIRIMA DISTRICT, SOUTH AFRICA

(*Accepted pending revisions Journal Applied Ecology and Environmental Research*)

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MANUSCRIPT II:

SOIL MICROBIAL BIOMASS IN SEMI-ARID COMMUNAL RANGELANDS IN THE WESTERN BOPHIRIMA DISTRICT, SOUTH AFRICA

Abstract

Soil microbial biomass is considered as an early indicator of changes that may occur in the long-term with regard to soil fertility, and it is used to evaluate land use changes and management effects. In South Africa, soil microbial biomass dynamics and responses to grazing remain less investigated in semi-arid rangelands. In this study, soil microbial biomass and responses to grazing effects were investigated in three communally rangelands sites in the Bophirima District in South Africa. Soil organic carbon and phosphorus contents were low at all sites. Microbial biomass ranged from 489.28 pmol g^{-1} to 1823.04 pmol g^{-1}. No significant differences were observed for both microbial biomass and organic carbon between the grazed and 5 years exclosure. Results showed that soil microbial biomass may be constrained by organic carbon and indirectly plant biomass production and cover. Further investigations are required for in-depth understanding of the underlying processes that regulate the dynamic of soil microbial biomass at these sites.

Keywords: *Soil microbial biomass; microbial community structure; biomass production; grazing and exclusion; soil quality.*

1.1. INTRODUCTION

Soil quality evaluation has emerged as a critical component of agricultural sustainability [66], [36], [65]. The increasing concern of soil degradation has led to a renewed attention to characterize soil quality [14]. When soil degradation takes place, soil properties change, particularly the soil microbial activity; and high level of microbial activity is fundamental to maintain soil quality [19]. Because of the relatively direct linkage between soil biological activity and ecosystem-level processes, soil microorganisms provide good opportunities for investigating ecosystem-level responses to disturbances and stress gradients [64]. Microorganisms that live belowground regulate major ecosystem processes, and because of feedbacks between aboveground and belowground communities, they play a key role in governing ecosystem functioning [20]. They play key roles in grassland ecosystems through regulating the dynamics of organic matter decomposition and plant nutrient availability [16], and are important for the functioning and stability of ecosystems [43].

Soil microbiological properties such as the microbial biomass may be used as early and sensitive indicators of soil quality [9]. Soil microbial biomass is the primary catalyst of biogeochemical reaction as well as energy and nutrient reservoir [54], [22], [23], [57], [71], [26], [27], [34]. It is regarded as an early indicator of changes in soil fertility [30], as it controls the flows of carbon, nitrogen and phosphorus in terrestrial ecosystems [41]. It is critical in regulating soil ecosystem-level processes, such as nutrient cycling and organic matter decomposition [23]. In low fertile soils with a high proportion of nutrients immobilized in the belowground living biomass, standard soil fertility tests are of little value. It makes more sense to measure the living soil microbial biomass and microbial activity [51], although the quantitative description of microbial diversity remains one of the most difficult tasks facing microbial ecologists [71]. Microbial biomass more sensitive to changes in soil properties than the total C content [50]; it may provide earlier indication of changes in organic matter status than total carbon [29].

Most of the research of grazing and soil microbial biomass interactions was conducted in temperate grasslands [62]. [46] reported variable effects of grazers on microbial populations: reduced microbial biomass [53], increased microbial biomass [3], [8] and no effects of grazing [57]. Studying soil microbial biomass in temperate grasslands, [2], [3], found that the size and activity of soil microbial biomass are higher in grazed than ungrazed treatments. [44] observed in a semi-arid rangeland, that overgrazing may most likely depresses microbial activity through, either reduced input of fresh plant residue into the surface soil or lack of living roots and exudates for stimulating microbial activity. Grazer effects on soil microbial populations are contingent on how they alter the quantity and quality of resources inputs to the soils [46]. In nutrient-poor sites, grazers depress microbial biomass because of their decrease plant production, while in nutrient-rich sites, the effects are likely to be positive [1].

In South Africa characterized by three rangeland management systems (communal, commercial and game) [48], [42], relatively little is known on soil quality from a microbiological perspective, and how grazing affects soil microbial biomass in semi-arid rangelands. The objective of this study was to investigate soil microbial biomass and dynamics in responses to grazing and exclusion management in semi-arid communally managed rangelands. This study forms part of the Desert Margins Program (DMP), which, aims to conserve and restore biodiversity in the desert margins through sustainable utilization, and to develop strategies to enhance ecosystem function and sustainable use in arid and semi-arid areas that are degraded and have reduced biodiversity associated with human and climate impact.

1.2. MATERIALS AND METHODS

1.2.1. Study sites

Three communally managed sites located in the Kagisano Local Municipality (western Bophirima District, Ganyesa region) were chosen: Austrey (26°28'S - 24°14'E), Southey (Eska/Newham - 26°38'S - 23°51'E), and Tseoge (25°57'S - E23°31'E) (Figure 1). The sites were part of the Provincial LandCare program. The climate in the area is semi-arid; annual rainfall falls mostly in summer (October to March - 80%) and in winter (April to September - 20%) [32].

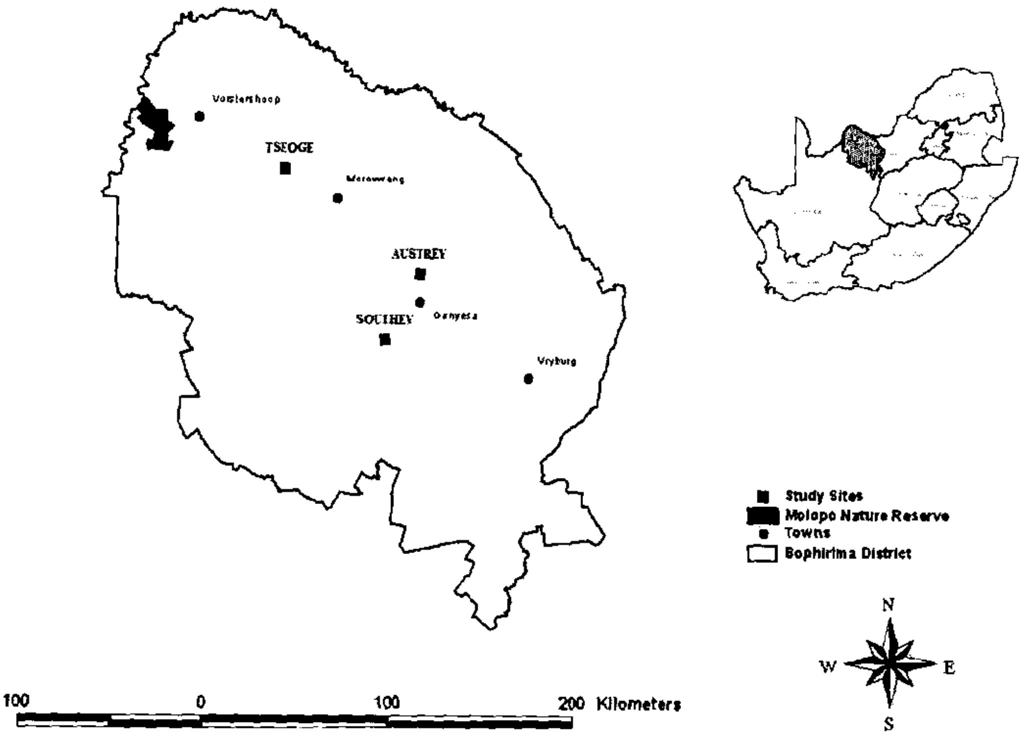

***Figure 1** Location of the study sites in the western Bophirima District*

Summer rainfall with dry winters characterizes Austrey site. Average annual precipitation varies from about 350 mm in the west to about 520 mm in the east. At the Tseoge and Southey, the climate is characterized by summer and autumn rainfall with very dry winters. Mean annual precipitation is between 250-400 mm. At the Austrey site, an Aeolian Kalahari sand of tertiary to recent age on flat sandy plains [38] dominates the geology. The soils are deep (>1.2 m) of the Clovelly and Hutton forms, characterized by an orthic A top soil underlain by a yellow-brown apedal B and a red apedal B horizon, respectively. Tseoge and Southey sites fall within a Red Aeolian sand of recent age with surface calcrete and secrete (Mucina and Rutherford, 2006). The soils are also deep (>1.2), and belong to the Mispath form, characterized by an orthic A top soil horizon overlying hard rock (G. Paterson, pers. comm., 2005), [49]. The vegetation in the area was recently described as the Eastern Kalahari Bushveld [38]. The Austrey site falls within the Mafikeng Bushveld (SVk 1) characterized by a well developed tree and shrub layer, dense stands of *Terminalia sericea, Acacia luedenritzii* and *Acacia erioloba* in certain areas. Shrubs include *A. karroo, A. hebeclada* and *A. mellifera, Dichrostachys cinera, Grewia flava, G. retinervis, Rhus* *tenuinervis* and *Ziziphus mucronata.* The grass layer is also developed. The Tseoge and Southey sites fall within the Molopo Bushveld (SVk 11) characterized by an open woodland to a closed shrubland with the trees *Acacia erioloba* and *Boscia albitrunca* and shrubs *Lycium cinereum, L. hirsutum* and *Rhigozum trichotomum*. Grass layer is well developed [38]. At the onset of this study, low vegetation cover was observed at the sites (Figure 2. Austrey site).

Figure 2 *Vegetation condition at the Austrey site*

1.2.2 Experimental design

At each site, plots representative of a relative "good *vs*. poor" condition open-grazed and adjacent benchmark (exclosure) were selected. These plots were erected for the purpose of the provincial LandCare projects in 1999. The open-grazed and benchmark plots were chosen as possible on similar same soil type, parental material, and same grazing history. Although information on grazing history was lacking, it was hypothesized that they have same grazing history, and that soil properties were similar before the exclosure plots were established. The plots were subjectively selected by research technicians and resource conservation officers to represent the "extremes" of a degradation gradient or rangeland health within each survey area [17]. According to [58], criteria such as the composition, cover and density of the aboveground herbaceous layer were used to assess degradation gradient. The benchmarks (exclosure) plots were subjected to zero grazing/browsing [17]. Grazing and exclusion management effects were exclusively determined on the open-grazed plots located near the villages. This was motivated by the absence or relatively little grazing influence on the plots located on the good vegetation gradient, which was far from the villages. Because of possible differences in grazing management (number and type of animals, seasonality and frequency of grazing, stocking rates, etc), a site-specific approach was considered to investigate the effects of grazing and exclusion management on soil microbial biomass.

1.2.2.1 Soil sampling and analyses

For the baseline soil characterization, samples were collected in both the good and poor condition plots to reflect as much as possible soil quality at the sites. Samples were taken from the soil upper 20 cm in 2005. Pseudo-replicate sampling method was used. Each plot was divided in three sub-plots considered as "replicates" for statistical purposes. Ten soil samples were collected using a soil auger within each sub-plot, and mixed thoroughly with coarse organic materials and stones discarded. From the composite sample of each sub-plot, a sub-sample was collected. A part of the sub-sample was put in sealed plastic bag and transported in an icebox to the laboratory to determine the soil microbial biomass and community structure. Another part of the soil sub-sample was air-dried and stored at room temperature for pH, organic carbon and phosphorus analyses. Results are given as mean ± standard error.

Soil analyses

Soil pH (H_2O) was determined in 1:2.5 v/v water-extract with a calibrated pH (Radiometer PHM 80, Copenhagen) at 25°C, as described by [37]. Total phosphorus (P-Bray 1) was determined by the Bray and Kurt method [12] and soil organic carbon (OC) was measured by the Walkley-Black method [61]. Soil microbial biomass was characterized by analyzing the ester-linked phospholipids fatty acid (PLFA) composition of the soil. The soil microbial biomass was determined as described by [15]. Total lipids were extracted from a 5 g lyophilised soil according to a modified method [11] as described by [67]. Silicic acid column chromatography was used to fractionate the total lipid extract into neutral lipids, glycolipids and polar lipids. The polar lipid fraction was transesterified to the fatty acid methyl esters (FAMEs) by a mild alkaline methanolysis [25]. The FAMEs were analyzed by capillary gas chromatography with flame ionisation detection on a Hewlett-Packard 6890 series 2 chromatograph fitted with a 60 m SPB-1 column (0.250 mm I.D., 0.250 μm film thickness). Identification of peaks was done by gas chromatography/mass spectrometry of selected samples using a Hewlett-Packard 6890 interfaced with a Hewlett-Packard 5973 mass selective detector. Methyl nonadecanonate (C19:0) was used as the internal standard and the PLFAs were expressed as equivalent peak responses to the internal standard. The total microbial biomass was expressed as pmol PLFA g^{-1} dry soil.

1.2.2.2 Species composition

The species composition was determined using the wheel-point method. The wheel-point method [55] was used along parallel transects running the length in each plot. The wheel point method uses an apparatus with a rimless wheel that rolls over the ground on its spokes. The position where a point touches the ground or a plant vertically above a point on the ground is considered an intercept point for data recording [24]. Both annual and perennial grass species were recorded. The nearest grass plant in a 45 cm radius of the spoke was visually identified and recorded. When no grass was observed in the 45 cm vicinity, it was considered as bare ground. Data were directly entered into a Psion Monitor, which statistically determines the number of points to survey in each plot in order to give a significant reflection of the species composition. The survey was stopped when 98% of the total variation in species composition was sampled [17]. Species were grouped based on their ecological status, which, refers to the grass reaction to different intensity of grazing. A grass species reacts to grazing either by increasing in number (*increaser*) or becoming less (*decreaser*). Increaser I represents grasses that are abundant in underutilized veld; they are usually unpalatable, robust climax grasses species that can grow without any defoliation. Increaser II refers to grasses that are abundant in overgrazed veld, and which increase due to the disturbing effect of overgrazing and include mostly pioneer and subclimax species. Increaser III includes grasses that are commonly found in overgrazed veld; they are usually unpalatable, dense climax grasses. They are strong competitors and increase because the palatable grasses have become weakened through overgrazing [59]. Decreaser group includes grasses that are abundant in good veld, but that decrease in number when the veld is overgrazed or undergrazed; these grasses are palatable climax grasses. The aboveground biomass was determined using the dry weight rank method [56]. Within each plot, thirty quadrates were placed alternatively along a 90 m long transect running the length of the plot. Grasses species were visually identified, ranked, and harvested by species group. The grass material cut for ranking estimated was dried to a constant mass, weighed and production per hectare calculated on a dry mass basis [17].

1.2.2.3. Data analysis

Soil chemical and microbiological properties were analyzed by means of analysis of variance (ANOVA), and statistically significant differences were tested by Fisher Least Significant Difference (Fisher LSD) at $P < 0.05$ probability level. STATISTICA 7 (Stat Soft ®) was used for all statistics.

3.1. RESULTS

3.1.1. Soil chemical properties

Table 1 summarizes the soil chemical properties in open-grazed and exclosure plots at three sites. Soil organic carbon ranged from 0.06 to 0.12% and phosphorus from 6.33 to 8.66 mg kg^{-1}. Soil pH was moderately acidic to neutral. Soil organic carbon and pH did not show any statistically significant difference between the open-grazed and exclosure plots at the study sites. Only phosphorus was significantly affected by grazing and exclusion differences at the Tseoge site only (p=0.03).

Table 1 *Soil chemical properties in open-grazed and exclosure plots at the sites*

Sites	Plots	pH (H_2O)	Organic Carbon (%)	P-Bray 1 (mg kg^{-1})
Austrey	Open-Grazed	5.52 (0.03)	0.1 (0.01)	6.3 (0.13)
	Exclosure	5.51 (0.02)	0.12 (0.01)	6.61 (0.04)
Southey	Open-Grazed	5.55 (0.02)	0.1 (0.0009)	8.55 (0.69)
	Exclosure	5.65 (0.04)	0.11 (0.002)	7.84 (0.67)
Tseoge	Open-Grazed	7.11 (0.01)	0.06 (0.001)	8.66 (0.24)*
	Exclosure	6.69 (0.22)	0.07 (0.01)	6.41 (0.02)*

** Significantly different at $p < 0.05$. Values are means (n=3) and standard error in brackets*

3.1.2. Soil microbial biomass

The total phospholipids fatty acids (PLFA), a measure of the viable microbial biomass in the open-grazed and exclosure plots is given in Fig. 3. Total PLFA ranged from 489.28 pmol g^{-1} to 1823.04 pmol g^{-1} in the open-grazed plot. It was not statistically different between the open-grazed and exclosure plots at any of the study sites. When comparing exclusively the open-grazed plots across the three sites, total PLFA showed statistically significant differences between the three sites (p=0.03, Fig. 3).

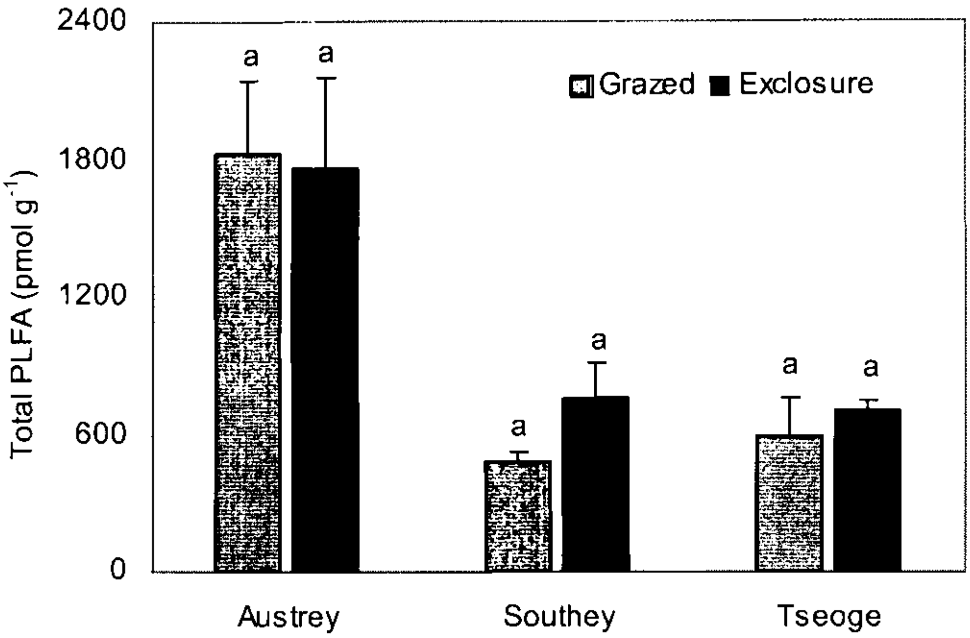

***Figure 3** Total phospholipids fatty acids (Total PLFA) in open-grazed and exclosure plots at the sites. Values are means (n=3) and bars represent standard errors. Means with same lower case letter are not statistically different between the open-grazed and exclosure plots per site P < 0.05*

3.1.3. Species composition and biomass

Sixteen species were identified and recorded (Table 2). High percentage of Increaser II species was observed across all sites and management. The decreaser group was represented by high palatable species (*Digitaria eriantha, Schmidtia pappophoroides* and *Stripagrostis uniplumis*). Increaser II species refers to grass abundant in overgrazed rangelands. Desirable (DE) and highly desirable (HD) species were dominant at the Austrey site (both in the open-grazed and exclosure plots) (Table 2).

Species were unevenly distribution across the sites. Desirable (DE) and highly desirable (HD) species were dominant at the Austrey site (both in the open-grazed and exclosure plots) (Table 2). Species were unevenly distribution across the sites.

Table 2 Species composition, life form, ecological status, frequency (%), and biomass production in the open-grazed and benchmark (exclosure) plots at the study sites

Species composition	LF/P	Austrey		Southey		Tseoge	
		GR	EX	GR	EX	GR	EX
Digitaria eriantha	p/hd	1.1	18.5	-	-	-	3.4
Schmidtia pappophoroides	p/hd	4.5	11.1	1.8	4.7	-	-
Stripagrostis uniplumis	p/de	-	-	8.5	0.7	-	-
Total Decreaser		5.6	29.5	10.3	5.4	-	3.4
Triraphis andropogonoides	p/ld	-	0.8	1.8	6.7	-	-
Eragrostis lehmanniana	p/de	8.3	14.1	5.5	6	-	8.9
Eragrostis trichophora	p/de	21.7	5.9	-	-	-	-
Aristida stipitata	p/ld	18.9	20	26.1	8.7	-	3.3
Melinis repens	p/ld	1.1	-	3	-	-	-
Eragrostis rigidior	p/ld	0.6	5.2	-	-	-	-
Pogonarthria squarrosa	p/ld	-	1.5	33.8	48.6	-	-
Perotis patens	a/ud	1.2	1.5	-	-	-	-
Brachiaria marlothii	a/ud	1.7	-	-	-	20.65	13.3
Eragrostis pallens	p/ld	-	-	*5.5*	*1.3*	-	-
Total Increaser II		53.5	49	75.7	71.3	20.65	25.5
Aristida congesta	a/ud	22.2	12.6	7.9	7.3	-	7.8
Tragus berteronianus	a/ud	12.2	1.5	-	-	-	-
Urochloa brachyura	a/ud	-	-	-	*1.3*	-	-
Total Increaser III		34.4	14.1	7.9	8.6	-	7.8
Bare ground		6.5	7.4	6.1	14.7	79.35	63.3
Biomass (kg ha^{-1})		69.98	1384.6	70.84	179.29	75.75	134.4

LF/P: life form/palatability: "a" = annual, "p" = perennial; hd: highly desirable; de: desirable; ld: less desirable; ud: undesirable; GR: open-grazed plot; EX: benchmark (exclosure) plot.

Across the three sites and treatments, a positive correlation was observed between microbial biomass and soil organic carbon in the exclosure than the open-grazed plot;

it was weaker in the case of the open-grazed plot (r^2=0.21) (Figure 4a). A positive correlation was observed in the exclosure plots between microbial biomass and biomass production (r^2=0.99) (Figure 4b).

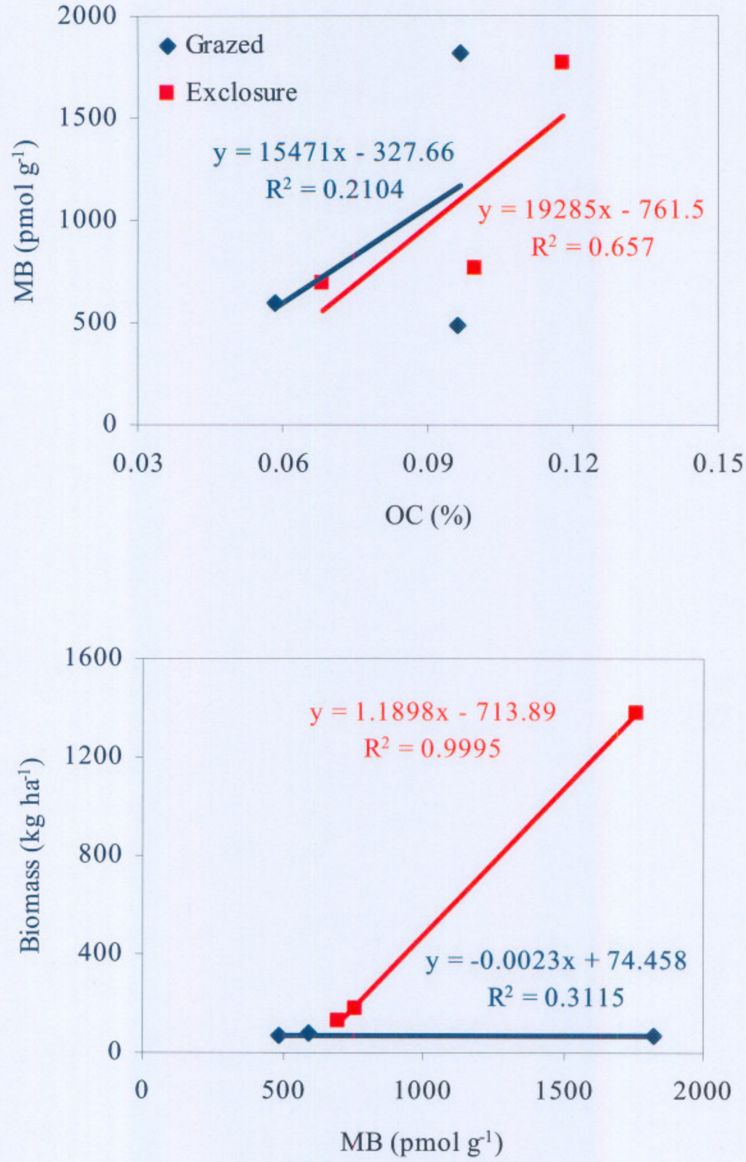

Figure 4 Relationships between microbial biomass and soil organic carbon (a) and between microbial biomass and biomass production (b).

4. DISCUSSION

Soil microbial biomass is a potential source of plant nutrients, and a higher level of soil microbial biomass is considered a good indicator of soil fertility [9]. Soil microbial biomass was higher at Austrey, compared to Southey and Tseoge sites, irrespective of grazing or exclusion condition. These results would suggest thereafter a "relatively" good soil fertility at Austrey, than Southey and Tseoge sites. Relatively with respect to the poor-soil nutrient content (organic carbon and phosphorus) at three sites (Table 1). The quantitative and qualitative differences in substrate supply between grasslands are responsible for the variation in microbial community [3], [5], [6], [33], [21], [22], [63], [52], [13], [7]. In this study, the low soil microbial biomass at Tseoge site could result from the low soil organic carbon content (0.06%), irrespective of grazing and exclusion (Table 1). The low organic carbon might result of limited inputs of organic plant materials added to the soil, which might inhibit the activity of soil microorganisms. Organic carbon depletion in soil is possibly due to reduced quality and quantity of organic matter in soils results in loss in microbial activity [18]. [60] found that low plant cover affects negatively soil microbial activity. [19] recorded in semi-arid Mediterranean that plant cover has a great influence on soil microbiological processes. [70], [40], reported similar results on the negative effects that plant loss had on microbial communities in ecosystems containing infertile soils poor in organic matter. Soil microbial communities rely on materials produced by plants as energy sources for growth and reproduction [39]; it is constrained by plant production and hence soil organic carbon availability [69], [46]. The positive correlation between microbial biomass and organic carbon in the exclosure plot (r^2=0.67) provides some support to these arguments.

According to [1], negative effects of soil microbial depression are likely to occur in nutrient-poor sites. In this study, despite the poor-nutrient content (organic carbon and phosphorus) at the sites, no significant effects of grazing were recorded (Figure 3). The lack of significant effect of grazing on soil microbial biomass has been reported. [31] did not observe any significant differences of soil microbial biomass due to grazing exclusion. In grasslands of Yellowstone National Park (United States), [57] reported that grazing (by elk and bison) exclusion for 35-40 years did not affect soil microbial biomass. On the contrary, [53] showed in artic tundra, that grazing depressed consistently soil microbial biomass. Further, [46] reported greater microbial biomass in soil of fenced grasslands across all levels of soil fertility after grazing exclusion in semi-arid grazing ecosystem. They attributed these effects to the fact that grazers stimulated aboveground plant production in nutrient-rich sites and depressed it in nutrient-poor sites. [44] found no discernable effect of grazing on soil microbial biomass after 17 years of grazing exclusion in semi-arid rangeland.

At two of the three sites (Southey and Tseoge), total PLFA was slightly higher in the exclosure than the grazed plots, whereas at the Austrey site, the inverse was observe, but none of the changes was significant. A reduction of microbial biomass carbon in soils of areas subjected to poor grazing management has been reported [29]. As grazing influences plant growth and composition, this would affect the flow of plant litter to decomposers [57] and consequently the carbon inputs to the belowground microorganisms. Other studies [28], [3] on the contrary reported that, depending on its intensity, grazing might increase the allocation of organic inputs to the soil by rapidly returning plant available nutrients in the form of dung and faeces. Soils of grazed areas tend therefore to have small amounts of dead litter on the soil surface, but do contain large amounts of organic nitrogen and carbon, which provide a favorable environment to stimulate abundant and diverse faunal and microbial community [4]. This might not hold true for the present investigation, as there was little vegetation to start-off; and that it was unclear whether the state of vegetation degradation is due to grazing effect and/or its combination with climatic conditions.

Soil organic carbon did not statistically differ between the open-grazed and exclosure plots at any of the three study sites (Table 1, Fig. 3). Similar results have been documented previously. [35] in a detailed worldwide literature review of grazing effects reported both increases and decreases of soil organic carbon between grazed and ungrazed sites. [31] observed the lack of significant differences between grazed lands and ungrazed for 11 and 16 years. In semi-arid rangelands, [44]) reported also no significant difference in soil organic carbon between grazed and 17 years exclusion of grazing. Our results however do not support the increasing organic carbon reported in grazed rangelands by [47], [45], neither decreases as shown by [58] in carbon storage and accumulation compared to adjacent ungrazed soils. The literature is replete of contrasting results on grazing effects on soil properties [10], probably because of possible differences in environmental characteristics as well as grazing management and treatments tested. In the case of these study sites, the lack of information on grazing history and management has limited the interpretation of these results.

5. CONCLUSION

The aim of this study was to explore patterns of soil microbial biomass in semi-arid rangelands and to investigate possible differences due to the effects of grazing. Feedbacks between soil microbial biomass and aboveground vegetation characteristics (cover, diversity and biomass) were observed. Because of the importance of soil microbial biomass in regulating biogeochemical processes, maintaining a good balance between the above and belowground components is vital in sustaining rangeland ecosystem productivity. Findings from the study provide some support to the non-existing effects of grazing on soil microbial biomass in semi-arid rangelands, as reported previously. More studies however, are needed to better understand the dynamic of soil microbial biomass changes in relation to grazing, as well as how differences in substrates (of grass species) quality and quantity affect soil microbial biomass.

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3.3. A COMPARATIVE ASSAY OF RANGELANDS UNDER DIFFERENT MANAGEMENT SYSTEMS IN SEMI-ARID SOUTH AFRICA: SPECIES COMPOSITION *vs.* SOIL QUALITY INDICATORS

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MANUSCRIPT III: A COMPARATIVE ASSAY OF RANGELANDS UNDER DIFFERENT MANAGEMENT SYSTEMS IN SEMI-ARID SOUTH AFRICA: SPECIES COMPOSITION *vs.* SOIL QUALITY INDICATORS

Abstract

South Africa's arid and semi-arid rangelands are described as degraded, with severe degradation in areas under communal than commercial and/or game management. Species composition have often been used to characterize degradation. In this study, three rangeland management systems (communal, commercial and game) were characterized for species composition and selected indicators of soil quality. The objective was to assess the relevance of each as indicators of degradation. Differences were observed in species composition with the communal management exhibiting higher proportion of increaser species of low grazing value and bare ground. When soil indicators were compared, no clear degradation trend could be determined. The use of sensitive indicators of soil degradation did not show either, a gradient of degradation under communal management. This emphasized the need to consider both soil and vegetation indicators when assessing rangeland health. Comparison between management systems with different characteristics could hide disparities within management system. Whenever possible, a site-specific approach should be recommended and references and/or baselines (not necessarily commercial and/or game management) are required from which degradation could be measured. The portrayed degradation in communal rangelands needs to be re-examined using an integrated approach of soil and vegetation indicators, and assessed against references.

Keywords: rangeland management systems; rangeland degradation; species composition; indicators of soil quality.

1. Introduction

The rangelands of South Africa cover nearly 80% of the land surface area and constitute the single most dominant land use type (Hoffman and Ashwell, 2001). Three main rangeland management systems namely commercial, communal and game ranching, different in management structure, animal diversity, stocking rates, management of grazing resources and products, exist (Palmer et al. 2005; Smet and Ward, 2005). Concerns have been raised over South Africa's rangeland degradation (Hoffman and Ahwell, 2001; Roux, 1983; Snyman, 1998; Hoffman and Todd, 2000). The recent land degradation synthesis (Hoffman and Ashwell, 2001) based on qualitative assessments and expertise of resource conservation technicians' and extension officers, reported high level of degradation in areas under communal than surrounding commercial and game management. Smet and Ward (2005) considered contentious the ways management systems affect rangeland ecosystem, due to inherent differences in management characteristics and the controversy surrounding driving forces in rangeland vegetation dynamics.

Changes of species composition (ecological and palatability status) have often been used to characterize rangeland degradation under different management systems (e.g. Parsons et al. 1997; Todd and Hoffman, 1999; Duma, 2000; Smet and Ward, 2005; Vetter et al. 2006; Anderson and Hoffman, 2007) (e.g. Figure 1). The high proportion of Increaser, less palatable and unpalatable species observed in many communal rangelands has led to the overwhelming perception of degradation in these areas. The sole use of species composition changes as indicators of degradation has been challenged. Tongway et al. (2003) indicated, that while the degradation description based on changes of species may often be a sufficient basis for management action to remedy the situation, in some case it does not; the detection and remedy of degradation is problematic in environments highly variable in space and time. Changes of species composition may relate to other factors than degradation, such as unpredictable and erratic rainfall patterns, mostly in arid and semi-arid regions (Miller, 2000; Vetter, 2005). According to Smet and Ward (2006), vegetation composition is a snapshot of a short-term situation, which does not necessarily reflect the long-term situation.

The importance of soil resource cannot be overestimated because its integrity and associated ecological processes determine rangeland health. Maintaining rangeland in good condition and soil quality is a key, to ensure sustainable utilization (Du Preez and Snyman, 1993; Snyman and Du Preez, 2005). These authors found that organic carbon and nitrogen declined as the condition of rangeland degrades because of overgrazing. The interrelationships between soil and aboveground vegetation community have led to a renewed interest in integrating soil information into rangeland monitoring and assessment (Herrick et al. 2002). In defining rangeland degradation, Abel and Behnke (1996) excluded reversible vegetation changes even if these lead to temporary declines in secondary productivity, as indicator of degradation, but they emphasized irreversible changes in both soil and vegetation as indicators of degradation. It becomes crucial therefore, to monitor indicators of temporal trends in soil and vegetation and to understand the impacts of land use on these trends to assess sustainability (Basher and Lynn, 1996). Rangeland degradation is a contentious issue due to the uncertainty regarding the extent that semi-arid rangelands are regulated by equilibrium or non-equilibrium dynamics (Smet and Ward, 2006). This study investigated species composition and selected soil quality indicators in different rangeland management systems. The objective was to characterize degradation from species composition and soil quality indicators perspectives, and assess the relevance of each, as indicators of rangeland degradation.

2. Materials and methods

2.1. Sites characteristics

The study was conducted in the western Bophirima District in the North-West Province, South Africa. Three communal managed sites (Austrey (26°28'S - 24°14'E), Southey (Eska/Newham - 26°38'S - 23°51'E), and Tseoge (25°57'S - E23°31'E), one commercial site, referred as Lafras (25°48'S - 23°49'E), and one game site, referred as Molopo (25°48'S - 23°49'E) were chosen (Figure 2). The climate in the area is semi-arid. Rainfall is bimodal occurring mainly in summer (80% - October to March) and 20% in winter (April to September) (Mangold et al. 2002). Summer rainfall (350-520 mm) with very dry winters characterizes Austrey site. Summer and autumn rainfall with very dry winters characterize Southey, Tseoge, Lafras and Molopo sites with a mean annual rainfall between 250-400 mm. (Mucina and Rutherford, 2006). An

Aeolian Kalahari sand of tertiary to recent age on flat sandy plains (Mucina and Rutherford, 2006) characterizes Austrey site. The soils are deep (>1.2 m) of the Clovelly and Hutton forms, characterized by an orthic A top soil underlain by a yellow-brown apedal B and a red apedal B horizon, respectively. A Red Aeolian sand of recent age with surface calcrete and secrete characterizes the Tseoge, Southey, Lafras and Molopo sites (Mucina and Rutherford, 2006). The soils at Tseoge and Southey sites are deep (>1.2), and belong to the Mispath form, characterized by an orthic A top soil horizon overlying hard rock (G. Paterson, pers. comm., 2005; Soil Classification Working Group, 1991). The soils are predominantly sandy depositions with calcretes along the riverbed of the fossilised Phepane and the Molopo River at the Molopo and Lafras sites (Anonymous, undated). The vegetation in the area was classified as the savanna biome, dominated by the Kalahari thornveld and shrub bushveld vegetation type (A16) (Low and Rebelo, 1996; Tainton, 1999). It was recently described as the Eastern Kalahari Bushveld (Mucina and Rutherford, 2006). Austrey site falls within the Mafikeng Bushveld (SVk 1) characterized by a well developed tree and shrub layer, dense stands of *Terminalia sericea*, *Acacia luedenritzii* and *Acacia erioloba* in certain areas. Shrubs include *A. karroo*, *A. hebeclada* and *A. mellifera*, *Dichrostachys cinera*, *Grewia flava*, *G. retinervis*, *Rhus tenuinervis* and *Ziziphus mucronata*. The grass layer is also developed. Tseoge, Southey, Lafras and Molopo sites fall within the Molopo Bushveld (SVk 11) characterized by an open woodland to a closed shrubland with the trees *Acacia erioloba* and *Boscia albitrunca* and shrubs *Lycium cinereum*, *L. hirsutum* and *Rhigozum trichotomum*. Grass layer is well developed (Mucina and Rutherford, 2006). Except at the commercial and game managed sites, information on grazing history and management (type of animals, frequency and duration of grazing, stocking rates) at the communal sites was lacking.

2.2. Experimental layout

At each of the five sites, two plots were selected in areas described to be in relative good and poor condition. The plots were established in 1999 at the communal managed sites and in 2003 at the commercial and game managed sites. Criteria such as the composition, cover and density of the aboveground herbaceous layer were used to assess select the plot (Van Herdeen, 2002). The size of the plots was 120 m x 30 m size at the commercial and the Molopo sites and 110 m x 20 m at the communal managed sites.

2.2.1. Species composition and biomass production

The species composition was determined in each plot using the wheel point method (Tidmarsh and Havenga, 1955) along parallel transects running the length in each of the grazed and adjacent exclosure plots. The surveys were carried out at maximum growing season (late April/beginning May). The nearest grass plant in a 45 cm radius of the spoke was visually identified and recorded. When no grass was observed in the 45 cm, it was considered as bare ground. Data were directly entered into a Psion Monitor, which statistically determines the number of points to survey in each plot in order to give a significant reflection of the species composition. The survey was stopped when 98% of the total variation in species composition had been sampled (Coetzee, 2006). Van Oudtshoorn (1999) and Coetzee (2006) classifications were used to group species based on the life forms (annual *vs.* perennial), ecological status (decreaser *vs.* increaser), and palatability (highly desirable, desirable, less desirable and undesirable). Species biomass was determined by the dry weight rank method (t'Mannetje and Haydock, 1963). Within each experimental plot, 30 quadrats were laid alternatively along a 90 m long transect running the length of the plot. The grass material cut for ranking estimate was dried to a constant mass, weighed and production per hectare calculated on a dry mass basis (Coetzee, 2006).

2.3. Soil sampling and analysis

Samples were taken from the soil upper 20 cm within each plot in April 2005. Each plot was divided in three sub-plots, and ten soil samples were collected at a depth of 0-20 cm using a soil auger within each sub-plot; they were mixed thoroughly with coarse organic materials and stones discarded. From the composite sample, a sub-sample was collected for analyses. Thirty samples were collected (6 per site), and analyzed for pH, cation exchange capacity, organic carbon, total phosphorus, dehydrogenase, β-glucosidase, acid phosphatase, and microbial biomass. Soil biological and biochemical properties were selected because they are reported very sensitive to small changes in soil quality and are considered as indicators of soil quality and degradation under different land use and management (Pascual et al. 2000; Trasar-Cepeda et al. 1998;

Ros et al. 2003). Soil pH was determined in 1:2.5 soil-water extract with a calibrated pH at 25°C. Cation exchange capacity (CEC) was determined by the ammonium acetate method as described in Morgenthal and Van Rensburg (2004). Total phosphorus was determined by the method of Bray and Kurtz (1945) and organic carbon (OC) by the Walkley-Black method (Walkley, 1935). Dehydrogenase (DHA) activity was assayed following the method of Von Mersi and Schinner (1991) as described by Alef and Nannipieri (1995). The method was based on the incubation of soil with the substrate iodonitrotetrazolium chloride (INT) at 40°C for 2h followed by colorimetric estimation of the reaction product iodonitrotetrazolium chloride-formazan (INF). β-glucosidase assay was based on the released of p-nitrophenol after the incubation of soil with p-nitrophenyl glucoside solution for 1h at 37°C as described in Alef and Nannipieri (1995). Acid phosphatase (ACP) assay was based on the determination of p-nitrophenol released after the incubation of soil with p-nitrophenyl phosphate for 1h at 37°C. Soil microbial biomass was characterized by analyzing the ester-linked phospholipids fatty acids (PLFA) composition of the soil. Total lipids were extracted from a 5 g lyophilized soil according to a modified method (Bligh and Dyer, 1959) as described by White and Ringelberg (1998). Claaseens (2004) described the full soil enzymatic and microbial biomass characterization method.

2.5. Statistical analysis

One-way ANOVA with management as factor was used to determine differences between management systems. Post-hoc comparisons were conducted using Gabriel test because of differences in sites and soil sample numbers between management. For the site-specific comparison, differences were tested by one-way analysis of variance, and in case of significance, differentiated by Fisher LSD at $p < 0.05$ probability level. All statistics were reported significant at $p < 0.05$ probability level. SPSS 14 2nd edition was used. Descriptive statistic was used for the vegetation characteristics.

3. Results

3.1. Composition and biomass of species

Twenty-one species were identified and recorded under the three management systems. Of the twenty-one species, perennial species accounted for 66.67%, and annual for 33.33%. Less desirable species represented 42.85%, followed by undesirable species (28.57%). The highly desirable and desirable species accounted for 14.3% respectively. Highly desirable species were predominantly *Schmidtia pappophoroides* and *Digitaria eriantha*. Desirable species were represented by *Eragrostis lehmanniana, Eragrostis trichophora,* and *Stipagrostis uniplumis,* while *Aristida stipitata* dominated the group of less desirable species. An unevenly species distribution was observed across the three management systems. Few species such as *Stipagrostis uniplumis, Eragrostis lehmanniana* and *Schmidtia pappophoroides* had a fairly distribution across the three management systems. The ecological status showed high percentage of increaser II species (57.1%), followed by increaser III (23.8%), while increaser I and decreaser species accounted for 4.7% and 14.3% respectively. Figure 3 gives the relative abundance (%) based on the ecological and palatability status. All management systems showed high proportion (± 50%) of Increaser II species. The communal management had higher percentage of Increaser II than the commercial and game management. On the contrary, the percentage of decreaser species was lower under communal management (Figure 3a). In terms of palatability, desirable (DE) species were dominant under commercial, followed by the game and last, the communal management. Higher proportion of less desirable (LD) species was found under communal than the two management systems (Figure 3b). Biomass production was higher at the commercial (1478.4 ± 167.1 kg ha^{-1}) than the game (941.7 ± 304.4 kg ha^{-1}) and communal (653.5 ± 194.5 kg ha^{-1}) management (Figure 3c).

Table 1 gives the life forms, palatability, and ecological status of the species per site. High species diversity was observed at the three communal managed sites (both Austrey and Tseoge had 13 species and Southey had 10 species). The Lafras and Molopo sites had 7 and 8 species respectively. A "relatively" uniform layer characterized the low species diversity, while an inconsistent and patchy layer was observed at Austrey, Southey and Tseoge sites. Perennial species dominated the annual species at all the sites. Austrey, Lafras and Molopo sites showed high proportion of highly desirable (*Schmidtia pappophoroides*) and desirable (*Eragrostis lehmanniana, Eragrostis trichophora,* and *Stipagrostis uniplumis*) species. Less desirable species were predominantly observed at Austrey, Southey and Tseoge sites (31.3%, 68.6%, and 29.5%, respectively), compared to the Lafras and Molopo sites (2.75% and

9.25%, respectively). All sites showed high percentage of Increaser II and Increaser III species (Table 1). The biomass production and percentage contribution of species to the biomass are given in Figure 4. Lafras and Southey sites had the highest biomass production, while Tseoge had the lowest biomass. At Lafras site, *Schmidtia kalahariensis* and *Eragrostis lehmanniana* accounted for almost 74% of the production. *Schmidtia pappophoroides* accounted for 48.75% of the production at the Molopo site. The species contribution to the production was much better distributed between species at the three communal sites.

3.2. Soil quality indicators

Figure 5 gives the means of soil chemical properties under the three management systems. Soil pH ranged from 6.33 to 6.50 and was not significantly different between the three management systems ($F_{2, 27} = 0.136$, $p = 0.87$). Soil organic carbon was higher at the communal management (0.27% ± 0.05) than at the game (0.2% ± 0.01) and the commercial management (0.17% ± 0.01), but this difference was not significant between the three management systems ($F_{2, 27} = 2$, $p = 0.15$). Phosphorus was not significant between management systems ($F_{2, 27} = 0.19$, $p = 0.82$). CEC was significantly different between management systems ($F_{2, 27} = 14.41$, $p = 0.00002$). High CEC value was observed at the game than the commercial and communal management systems; the last two did not show significant difference (Figure 5).

The activity of dehydrogenase was significantly different between management systems ($F_{2, 27} = 6.47$, $p = 0.005$), with higher activity in the soil at the game (41.01 µg INF g^{-1} $2h^{-1}$) than the soils under commercial (33.32 µg INF g^{-1} $2h^{-1}$) and communal (19.95 µg INF g^{-1} $2h^{-1}$) management. The difference was between the game and communal management; no difference was found between the communal and commercial management ($p = 0.10$) nor between the commercial and game ($p = 0.68$). The activity of β-glucosidase was not different ($F_{2, 27} = 1.53$, $p = 0.23$). ACP activity was significantly different between the communal and game management ($F_{2, 27} = 4.02$, $p = 0.02$), but not between the communal and commercial ($p = 0.45$), neither the commercial and game ($p = 0.56$). Total microbial biomass was found higher in the soil under commercial than the communal and game management, but no significant differences were found between any of the management systems ($F_{2, 27} = 0.04$, $p = 0.95$, Figure 6).

Table 2 gives the means (standard error) of the soil chemical properties at each of the five sites. Soil pH ranged from 5.51 (± 0.11) to 7.19 (± 0.11), P ranged from 1.55 (± 0.09) mg kg^{-1} to 3.88 (± 1.23) mg kg^{-1}, OC ranged from 0.17% (± 0.01) to 0.38% (± 0.13) and CEC from 1.86 (± 0.06) coml. kg^{-1} to 4.1 (± 0.10) coml. kg^{-1}. Soil pH ($F = 12.27$, $p = 0.00001$) and CEC ($F = 15.89$, $p = 0.000001$) were significantly different between the sites. Phosphorus ($F = 1.58$, $p = 0.20$) and OC ($F = 1.31$, $p = 0.29$), were not different between sites. There were differences within the communal sites on one hand, and between the communal, commercial, and game sites on another hand (Table 2).

Table 3 gives the mean values (standard error) of soil enzymatic and microbial biomass at the sites. Significant differences between sites were found for the activities of DHA ($F = 4.63$, $p = 0.006$) and ACP ($F = 9.31$, $p = 0.00009$). The activity of β-glucosidase and the total microbial biomass did not show any significant difference between the sites ($F = 0.86$, $p = 0.5$; $F = 0.36$, $p = 0.93$, respectively). The activity of DHA was higher in the soils at the commercial and game sites, compared to the communal sites.

4. Discussion

The objective of the study was to test rangeland degradation condition from a species composition *vs.* selected soil quality indicators perspectives. Species composition was different between the three management systems. No difference of life form (perennial *vs.* annual) was observed. All three management systems however, showed high proportion of Increaser II species. Increaser II are species abundant in overgrazed veld and which, increase due to the disturbing effect of overgrazing, and include mostly pioneer and subclimax species (Van Oudtshoorn, 1999). *Eragrostis lehmanniana*, a perennial grass of average grazing value accounted for 85% and 66% respectively under commercial and game management, while it represented only 11.6% under communal management. The last was characterized by high proportion of *Aristida stipitata* (32.8%), a weak perennial species of low grazing value, and indicator of overgrazing condition. In terms of palatability, the proportions of highly desirable and desirable species were higher under commercial and game management. *Schmidtia pappophoroides*, a perennial highly palatable species accounted for 100% respectively under the commercial and game management. *Eragrostis lehmanniana* represented 36.9%, 89%, and 79%, respectively under communal, commercial and game management. Although the relative abundance of these species could not be compared (in absolute values) to previous studies (e.g. Evans et al. 1997; Duma, 2000; Smet and Ward, 2005; Vetter et al. 2006; Solomon et al. 2006), our results displayed similar trends of increasing less palatable and unpalatable species, as well as increaser II species under communal management. In most of communal areas in semi-arid South Africa, overgrazing and overstocking are considered the determinant of species composition changes through defoliation and removal of species, conversion from palatable to unpalatable species. For this study, it was difficult to draw conclusions of overgrazing effects, in the lack of information on grazing management (stocking rates, frequency and duration of grazing), mainly under communal management. The percentage bare ground was higher under communal (12.53%) than commercial (1.1%) and game (0.4%). Plant cover represents an important soil quality factor (Brockway et al. 1998), as it protects the soil surface from erosion and increasing temperature. In defining function in rangeland using the landscape function analysis (LFA), Palmer et al. (2001) found that low vegetation cover favors nutrients and water movement through the landscape in communal rangeland. In the case of this study, the high bare ground percentage might therefore favor erosion and nutrients loss, and degradation thereof. These arguments could lead to the assumption of higher degradation under communal than commercial and game management.

Looking at site-specific differences (Table 1), there was high species diversity at Austrey, Southey and Tseoge, than Lafras and Molopo sites, although the species were present in low frequency. Species were unevenly distributed across the five sites, with only very few species occurring across all sites. *Digitaria eriantha* a perennial highly desirable and decreaser species was not recorded at Lafras and Molopo sites, but was observed at the three communal sites. Furthermore, *Stripagrostis uniplumis*, a perennial desirable species was observed at Austrey, Southey and Tseoge, but not at Lafras and Molopo sites. On the contrary, *Schmidtia pappophoroides* and *Eragrostis* *lehmanniana* were the single dominant species at Lafras and Molopo, but they did occur in relatively low proportion at Austrey, Southey and Tseoge. The percentage bare ground was high at the Tseoge site only (36.9%). Anderson and Hoffman (2007) found no difference in the number of species recorded between a communal area and privately owned farms for both lowland and upland habitats. They found more species on the communal areas at 10 m^2 sample area than at the commercial farms. It appeared that each of the sites has specific vegetation characteristics, which may relate the prevailing environmental (rainfall variability, soil type, geology, landscape) and management (type of animal, frequency and duration of grazing, stocking rates) condition. Whether they suffer of degradation, remain hypothetical in the absence of previous references. These findings are consistent with Smet and Ward (2006) who characterized vegetation composition as a snapshot at a specific time.

4.2. Soil quality indicator

A low organic carbon and phosphorus characterized all the soils under the three management systems. Soil organic carbon is considered a key indicator of soil quality (Nelson and Sommers, 1996; Murage et al. 2000; Bending et al. 2000). Du Preez and Snyman (1993) found that declining soil organic carbon leads to rangeland condition degradation. Barrios et al., (2006) also stressed the importance of maintaining a high level of organic carbon in rangeland soil. Rangelands with low organic carbon are very often depicted as degraded. In this study, a high soil organic carbon was found under the communal management (0.27 ± 0.05%), but the difference was not significant compared to the commercial (0.17 ± 0.01%) and game (0.20 ± 0.01%) management. It could be hypothesized more soil degradation in the commercial and game than under communal management. Several studies in semi-arid southern Africa have reported similar results. In arid Namibia, Ward et al. (1998) found significantly high organic carbon (1.15 ± 0.10%) in a communal farm than commercial (0.70 ± 0.05%). Mbatha and Ward (2006) showed higher organic carbon in communal management than surrounding commercial farms. Ward et al. (1998) and Mbatha and Ward (2006) attributed high organic carbon levels under communal management to the effects of high stocking rate, which may be conducive to high nutrient deposition, thereby increasing soil quality in communal rangelands.

Phosphorus was not significantly different between communal (2.77 ± 0.4 mg kg^{-1}), commercial (2.79 ± 0.6 mg kg^{-1}) and game (2.23 ± 0.4 mg kg^{-1}). Ward et al. (1998) found in Namibia, similar results of management effect on phosphorus, despite the relatively high phosphorus concentration (approx. 9 mg kg^{-1}). Smet and Ward (2006) also found that soil phosphorus was not affected by management ($F=2.169$; $p=0.119$) in semi-arid savanna of South Africa. In this study, management did not affect soil pH. Smet and Ward (2006) found opposite results with significant difference of pH between management.

Biological and biochemical properties are used as indicators of soil quality and degradation because they are most closely related to nutrient cycles, including soil respiration, and microbial biomass (Trasar-Cepeda et al. 2000). The use of enzymatic and microbial biomass properties was motivated by their sensitivity to change and their ability to detect early temporal changes of soil quality (Dormaar and Willms, 2000). Measurement of enzymatic activity in combination with soil chemical and physical properties provides reliable early indicators of change of soil quality and as applicable for evaluating both short and long-term impacts (Jordan et al. 1995). Studies in arid and semi-arid environment have shown that continuous heavy grazing might affect the enzymatic activity as well as soil microbial biomass. Kieft (1994) did not observe any significant differences of soil microbial biomass due to grazing exclusion. Raeisi and Asadi (2006), after 17 years of grazing exclusion in semi-arid rangeland did not observe any significant effect on microbial biomass. If overgrazing is characteristic of communal management, one could expect to observe lower enzymatic activity and microbial biomass under the communal managed sites in this study. Two of the three enzymes were significantly different between management. Significant difference between management was found for the enzymatic activity of DHA ($F = 4.63$, $p = 0.006$) and ACP ($F = 9.31$, $p = 0.00009$). The higher DHA activity at the game management was associated to a lower activity of ACP, while the opposite was observed under communal management. Little is however known about the effects of rangeland management systems on soil microbial activity in these semi-arid areas. This limitation makes difficult the interpretation of our results, and the assessment of soil degradation using these indicators.

Using site-specific comparisons, not all sites under communal management showed lower soil quality indicators compared to the commercial and game sites. Table 2 and 3 showed that Southey site has higher soil organic carbon and phosphorus that the Lafras and Molopo sites, as well as the activity of DHA and microbial biomass. Soil microbial biomass is a potential source of plant nutrients, and a higher level of soil microbial biomass is considered a good indicator of soil fertility. It is used as early signals of soil degradation or improvement, and as is considered a good indicator of soil quality between different land-uses (Anderson and Domsch 1989; Salinas-Garcia et al. 2002). Soil degradation refers to the loss of soil quality compared to other soil in the same condition, or under similar climatic, substrate and to some extent management condition (Arshad and Martin, 2002). When such conditions are not possible, comparison becomes subjective and of little value.

5. Conclusion

The soils under the three management systems could be considered as poor fertile soils (from a chemical perspective due to their low organic and phosphorus contents). Notwithstanding the limitations of this study (limited sample plots), three conclusions have emerged: a) differences of species composition between management, b) absence of clear degradation trends from a soil quality perspective, and c) difficulty of comparing systems with different environmental and management characteristics. To assess degree and extent of degradation, references or baselines need to be established in the same environment (climate, soil type, grazing management, etc.). The use of commercial and game management as reference might not be appropriate because of these differences. Therefore, caution is needed when assessing degradation in communal rangelands, specifically with commercial and game as references. Soil degradation is a relative concept depending on land use type, management and environmental conditions. The determination of species composition has given a once-off indication regarding species attributes (palatability, desirability and ecological status) with reference to grazing. They do not report sufficiently on ecological processes (such as nutrient cycling, energy flow, water retention and storage) with sustain rangeland health. An integrated monitoring approach (soil and vegetation indicators) should form the core of monitoring and assessment of rangeland health and degradation processes. Monitoring and detection of degradation trends are one aspect of the complex issue of land degradation; understanding the causes of this degradation if degradation is, should form part of any monitoring program.

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Figure 1. Fence-line contrast with commercial (left) and communal management (right) at Tseoge site

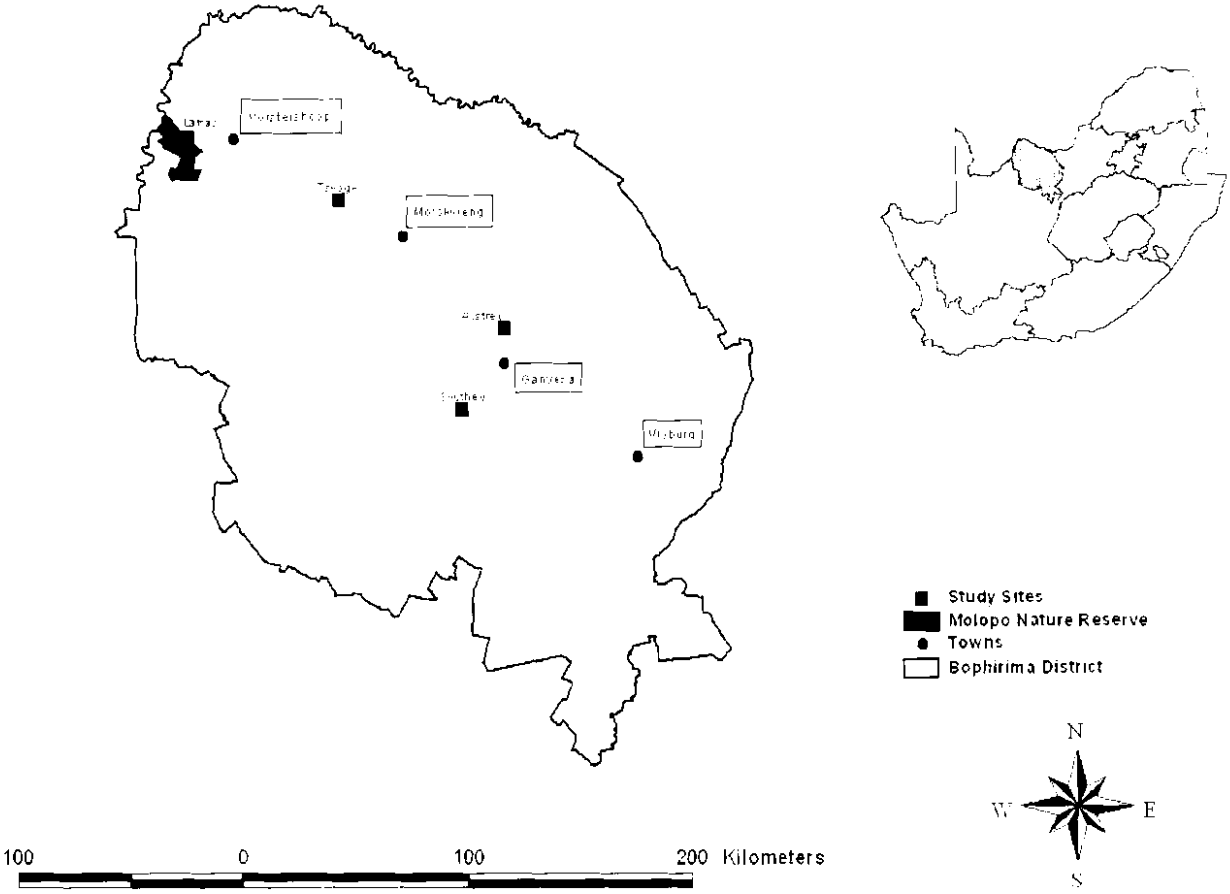

Figure 2. Study sites location in the western Bophirima District, North-West Province

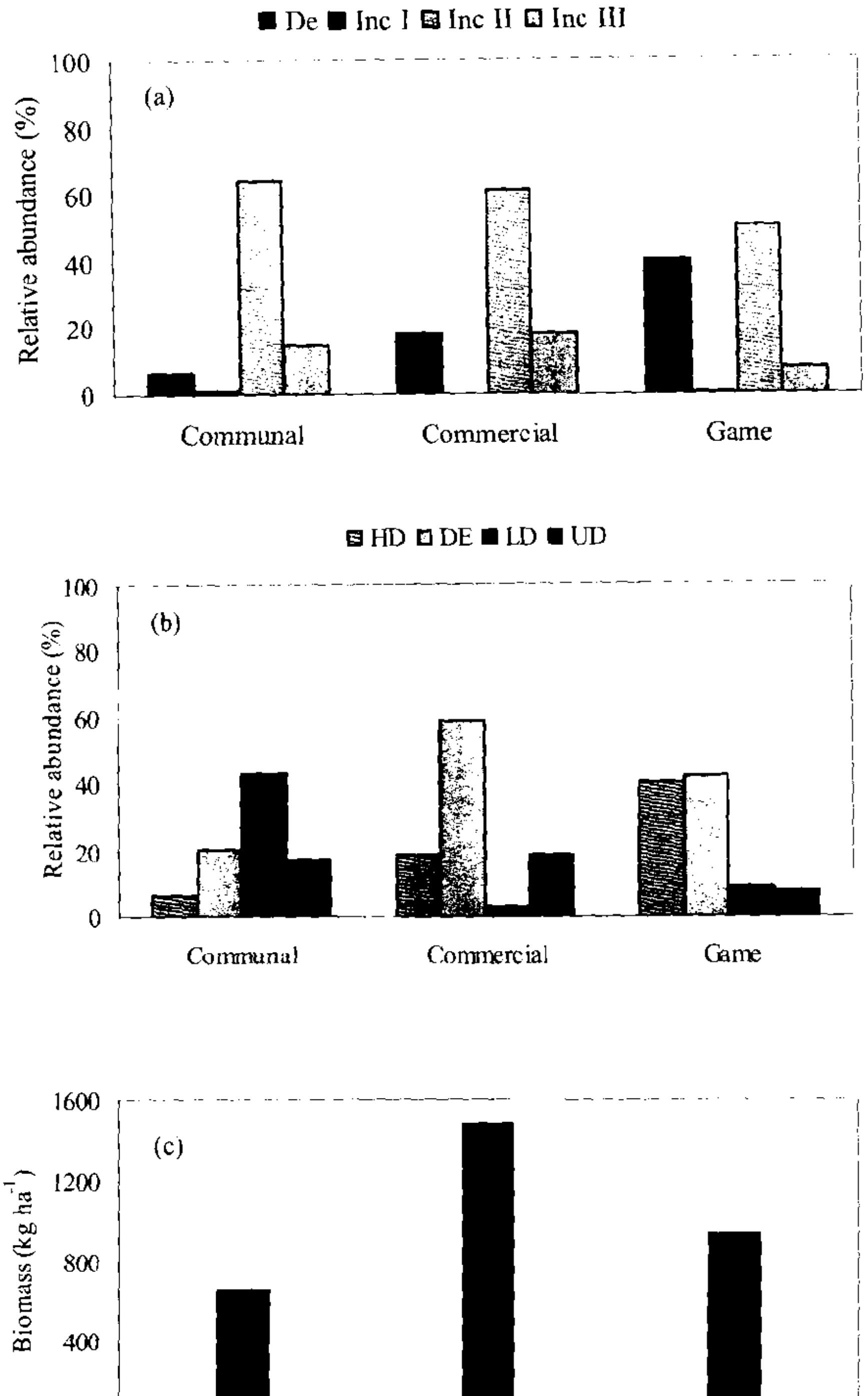

Figure 3. Ecological (a), palatability (b) status of the species based on the percentage frequency of occurrence and biomass production (c) at the three management systems. HD: highly desirable; DE: desirable, LD: less desirable and UD: undesirable species; DE: decreaser, Inc I: increaser 1; Inc II: increaser II, and Inc III: increaser III species

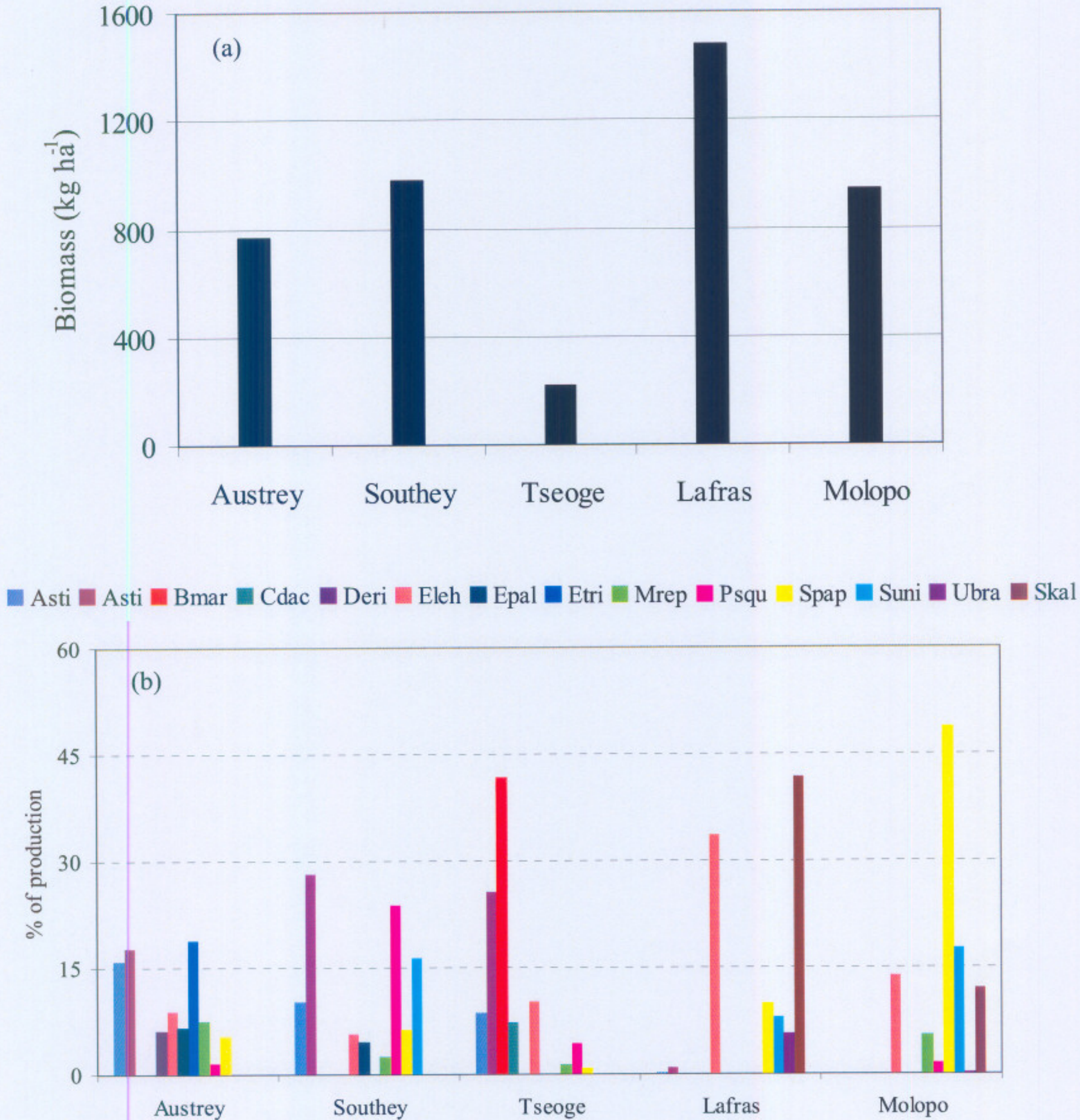

Figure 4. Biomass production (a) and species contribution (%) to the biomass (b) at the study sites.

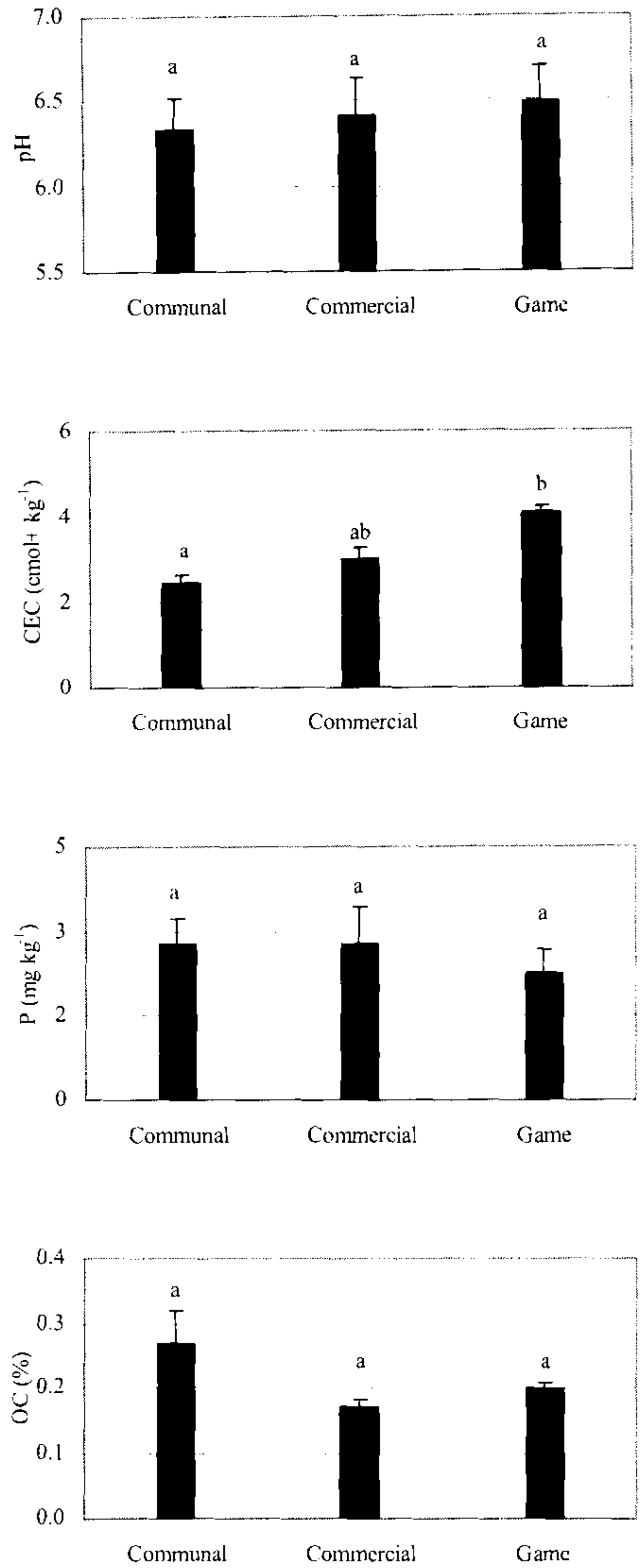

Figure 5. Soil chemical properties at the three rangeland management systems (communal: n=18, commercial: n=6 and game: n=6)

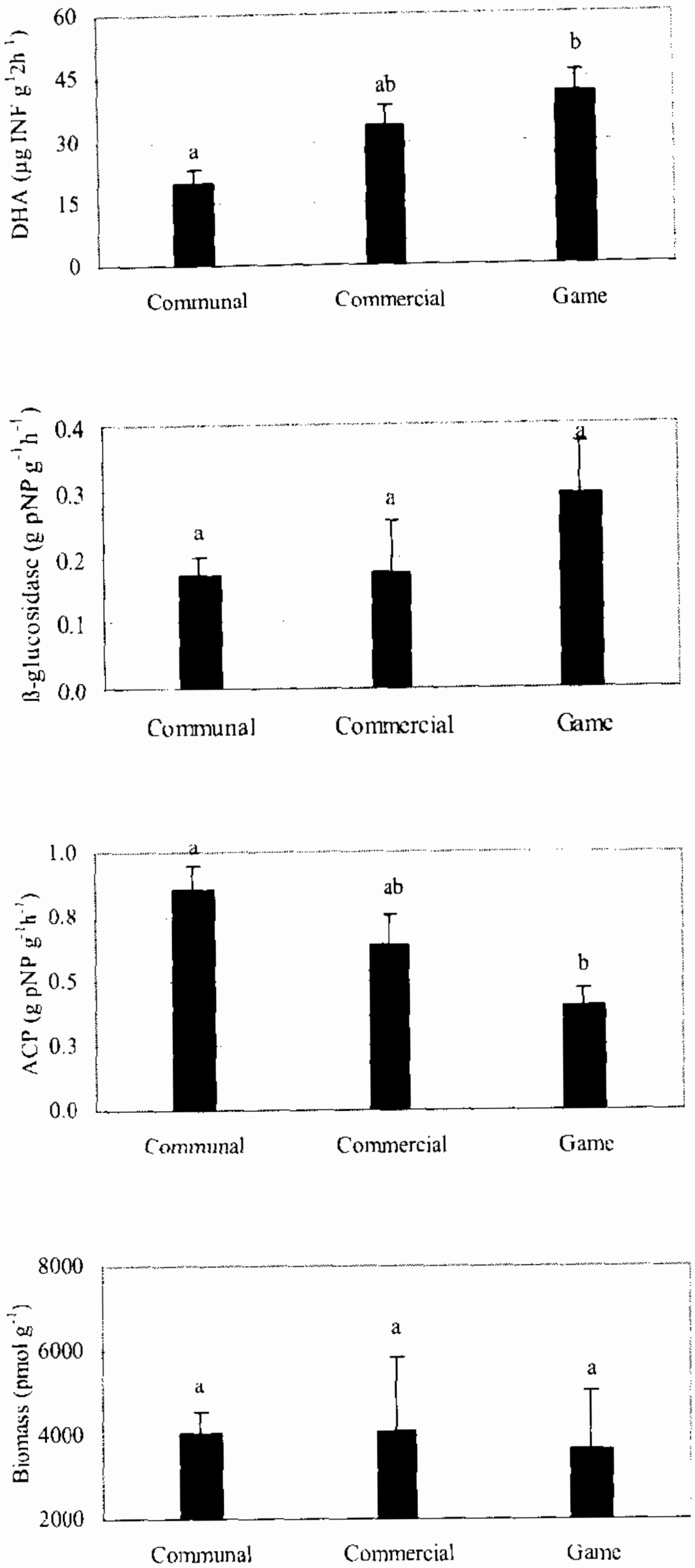

Figure 6. Soil enzymatic activity and microbial biomass at the three rangeland management systems (communal: n=18, commercial: n=6 and game: n=6)

Table 1. Species frequency of occurrence (%), life forms, palatability and ecological status at the study sites

Species	Life form	Palatability	Ecological status	Austrey	Southey	Tseoge	Lafras	Molopo
Digitaria eriantha	P	HD	De	3	1.7	2.25	0	0
Schmidtia pappophoroides	P	HD	De	3.3	5.65	4.15	18.55	40.4
Eragrostis lehmanniana	P	DE	Inc II	13	3.65	5.8	52.95	33.35
Eragrostis trichophora	P	DE	Inc II	0	10.05	0.55	5.9	8.55
Stipagrostis uniplumis	P	DE	Inc II	27.65	0	0	0	0
Aristida stipitata	P	LD	Inc II	19	23.65	21.1	2.2	0
Eragrostis pallens	P	LD	Inc III	2.65	11	0	0	0
Triraphis andropogonoides	P	LD	Inc I	0.65	2.65	0	0	0.8
Pogonartria squarrosa	P	LD	Inc II	3	29.65	5.3	0	3.75
Melinis repens	P	LD	Inc II	5.35	1.65	0.55	0.55	3.75
Cynodon dactylon	P	LD	Inc II	0	0	2.25	0	0
Aristida congesta	A	UD	Inc III	16	9.65	5.3	0.75	0
Perotis patens	A	UD	Inc II	3.7	0	0	0	0
Brachiaria marlothii	A	UD	Inc II	0	0	14.7	0	0
Tragus berteronianus	A	UD	Inc II	2.05	0	0	0	0
Eragrostis bicolor	P	LD	Inc II	0.65	0	0	0	0
Schmidtia kalahariensis	A	UD	Inc III	0	0	0	18	7.95
Urochloa panicoides	A	LD	Inc II	0	0	0	0	0.95
Urochloa brachyuran	A	UD	Inc III	0	0	0.55	0	0
Brachiaria nigropedata	P	HD	De	0	0	0.3	0	0
Aristida meridionalis	P	LD	Inc III	0	0	0.3	0	0
Bare ground	na	na	na	0	0.7	36.9	1.1	0.4

P: perennial, A: annual, HD: highly desirable, DE: desirable, LD: less desirable, UD: undesirable; De: decreaser; Inc I: increaser I; Inc II: increaser II; Inc III: increaser III; na: not applicable

Table 2 Selected soil chemical properties at the study sites

Properties	Austrey	Southey	Tseoge	Lafras	Molopo
pH (H_2O)***	6.27(0.16)^a	5.51(0.11)^b	7.19(0.11)^c	6.4(0.22)^a	6.49(0.20)^a
OC (%)	0.26(0.02)^a	0.38(0.13)^a	0.31(0.07)^a	0.17(0.01)^a	0.20(0.01)^a
P (mg kg-^{1})	1.55(0.09)^a	2.87(0.42)^a	3.88(1.23)^a	2.79(0.65)^a	2.27(0.39)^a
CEC (cmol kg^{-1})***	2.37(0.28)^a	3.12(0.23)^b	1.86(0.06)^a	3.01(0.26)^b	4.1(0.10)^c

OC: Organic carbon, P: phosphorus, CEC: cation exchange capacity. Values are means (n=6) and standard errors in brackets. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. Means followed by same superscript letter are not significantly different ($p < 0.05$).

Table 3 Soil enzymatic activity and microbial biomass at the study sites

Properties	Austrey	Southey	Tscoge	Lafras	Molopo
DHA (μg INF g^{-1} 2 h^{-1})**	15.82(2.7)^{a}	15.11(2.9)^{a}	28.91(8.2)^{ab}	33.24(5.1)^{b}	41.01(5.2)^{b}
(ß-gluco (g pNP g^{-1} h^{-1})	0.17(0.04)^{a}	0.2(0.06)^{a}	0.13(0.02)^{a}	0.17(0.08)^{a}	0.29(0.07)^{a}
ACP (g pNP g^{-1} h^{-1})***	0.54(0.11)^{ab}	1.24(0.13)^{c}	0.76(0.06)^{a}	0.63(0.12)^{ab}	0.4(0.07)^{b}
MB (pmol g^{-1})	3882(913)^{a}	3165(359)^{a}	5120(1106)^{a}	4084(1757)^{a}	3656(1410)^{a}

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. Values are means (n=6) and standard errors in brackets. Means followed by same superscript letter are not significantly different ($p < 0.05$). DHA: dehydrogenase; β-gluco: β-glucosidase; ACP: acid phosphatase; INF: iodonitrotetrazolium chloride-formazan; MB: microbial biomass pNP: p-nitrophenol, pmol: Pico mole.

CHAPTER 4.

SYNTHESIS AND CONCLUSION

This chapter serves as a synthesis of the main outcomes (with reference to the manuscripts) of the study. It is structured following the objectives as stated in Chapter 1. Some limitations of the study and recommendations for future research conclude the chapter.

4.1. BASELINE SOIL CHARACTERIZATION

The soils at the three communal managed rangeland sites were characterized for selected physical, chemical, biochemical, and microbiological properties. Prior to this study, and with the exception of the broad provincial soil description (Mangold *et al.*, 2002), no information exist regarding the soil physical, chemical as well as biochemical and microbiological perspectives.

4.1.1. Physico-chemical properties

From a physical perspective, sandy soils (± 95.1%) were characteristics of all the three communal sites. The clay and silt contents were low, (± 3%, and ± 1.8% respectively). From a chemical point of view, the pH of the soils ranged from 5.51 to 7.11, organic carbon was low, from 0.06% to 0.20% and phosphorus was also low, ranging from 2.27 mg kg^{-1} to 8.66 mg kg^{-1} (Table 4.1.). The low organic carbon and phosphorus contents were reported as general characteristics of the sandy soils in this part of the Kalahari (Thomas and Dougill, 2006; De Beer, 2000; Dougill and Thomas, 2002). Soil organic carbon is a good indicator of soil fertility; the low level of organic carbon at these sites could reflect overall inherent low fertile soils at the three communal sites.

4.1.2. Biochemical and microbiological properties

The enzymatic activities of dehydrogenase, β-glucosidase, and acid phosphatase, and the soil microbial biomass were determined in 2005 at the communal sites and 2006 at the commercial and Molopo sites. The enzymatic activities of dehydrogenase ranged from 18.41 μg INF $g^{-1}2h^{-1}$ to 70.28 μg INF $g^{-1}2h^{-1}$. The Southey site showed the lowest DHA activity. β-glucosidase ranged from 0.09 g *p*NP g^{-1} h^{-1} to 0.29 g *p*NP $g^{-1}h^{-1}$; it was higher at the Molopo site than the other sites. The activity of ACP varied from 0.63 pNP $g^{-1}h^{-1}$ to 2.69 g pNP $g^{-1}h^{-1}$ (Table 4.1.).

Table 4.1. Synthesis of soil properties at the study sites (means and standard error)

Soil properties	Austrey*	Southey*	Tseoge*	Lafras**	Molopo**
Sand (%)	94.3 (0.6)	94 (1.4)	97 (0.01)	nd	nd
Clay (%)	3.4 (0.6)	3.9 (0.01)	1.15 (0.01)	nd	nd
Silt (%)	2.2 (0.02)	2 (1.06)	0.94 (0.006)	nd	nd
pH (H_2O)	5.52 (0.03)	5.55 (0.01)	7.11 (0.01)	6.4 (0.22)	6.49 (0.20)
Organic carbon (%)	0.1 (0.01)	0.1 (0.01)	0.06 (0.001)	0.17 (0.01)	0.20 (0.01)
P Bray 1(mg kg^{-1})	6.3 (0.22)	8.55 (1.2)	8.66 (0.41)	2.79 (0.65)	2.27 (0.39)
DHA (μg INF $g^{-1}2h^{-1}$)	70.28 (2.12)	18.41 (0.26)	35.42 (6.97)	33.24 (5.1)	41.01 (5.2)
β-gluco (g *p*NP $g^{-1}h^{-1}$)	0.18 (0.01)	0.12 (0.07)	0.09 (.02)	0.17 (0.08)	0.29 (0.07)
ACP (g *p*NP $g^{-1}h^{-1}$)	2.69 (0.08)	0.82 (0.03)	1.08 (0.07)	0.63 (0.12)	0.4 (0.07)
MB (pmol g^{-1})	1823 (328)	489.2 (41.5)	593.11 (161.29)	4084 (1757)	3656 (1410)

*β-gluco: β-glucosidase MB: microbial biomass; Nd: not determined; DHA: dehydrogenase, ACP: acid phosphatase; INF: iodonitrotetrazolium chloride-formazan; pNP: p-nitrophenol, pmol: Pico mole * 2005 data; ** 2006 data*

The three communal sites, which constitute the core of this work, differed for the enzymatic activity of DHA and ACP, but not for β-glucosidase (Manuscript I). Soil microbial biomass ranged from 489.2 pmol g^{-1} to 4084 pmol g^{-1} (Table 4.1.). These results showed high variability between the sites in terms of overall microbial activity. High soil microbial activity (enzymes and microbial biomass) is a good indicator of soil quality (Mausbach and Seybold, 1998). It could be speculated a "relatively better soil condition" (quality) at Austrey, than the soils at the Southey and Tseoge sites, because of the overall higher microbial activity. This was only a speculation, as further monitoring using an appropriate framework and taking into consideration the high variability and heterogeneity of the soils at the landscape level. A single minimum data set will probably remain undefined because of the inherent variability among soils, but it may be feasible to identify a suite of physical, chemical, and biological indicators that are useful for evaluating site-specific, temporal trends in soil quality (Campos *et al.*, 2007). The baseline information can nevertheless serve as reference point from which, further evaluation can help determine patterns of soil degradation as indicated by Lal (1998).

Soil properties at the communal managed sites in 2005 and 2006

Soil chemical properties

Soil pH was significantly different between 2005 and 2006, but the direction of change was not consistent across the three sites. Soil organic carbon increased significantly at the Austrey and Southey sites ($p = 0.001$, $p = 0.001$, respectively) but not at the Tseoge site ($p = 0.05$) (Figure 4.1.). It was difficult at this stage of the investigation to determine the exact causes of such increase of soil organic carbon at all the three sites. An increasing aboveground biomass production and litter returned could contribute to build-up of organic carbon. However, this increase could not have contributed to such increase of organic carbon over the two years. Smit and Heuvelink (2007), exploring soil organic matter in grazed and non-grazed Scots pine found that large variability in soil organic matter could be caused either by (a) sampling errors, (b) analytical errors, (c) spatial variability and (d) temporal variability. The variability of soil properties across landscape level was also reported by Nael *et al.*, (2004) who suggested that a mean value of a variable (such as organic matter) across landscape unit and vegetation microsites may not give an accurate indication of how good or otherwise soil quality is at a particular site. In the case of the soil organic carbon, adequate sampling methods as well as a thorough understanding of inputs and outputs of carbon to the soil pool are needed to evaluate stocks and carbon changes in the soil. The understanding of mechanisms that control C storage will allow designing of management systems that optimize the return of C to the soil, and to develop more robust models of soil C turnover and as a result make better predictions of organic matter dynamics (Rees *et al.*, 2005).

There was a significant decrease of the cation exchange capacity ($p = 0.007$, $p = 0.02$, $p = 0.004$ at the Austrey, Southey and Tseoge sites respectively) in 2006. This result was not expected as soil organic carbon and cation exchange capacity are positively correlated. Total phosphorus decreased significantly at the Austrey and Southey sites ($p = 0.0001$, $p = 0.006$, respectively) but not at the Tseoge site (Figure 4.1.).

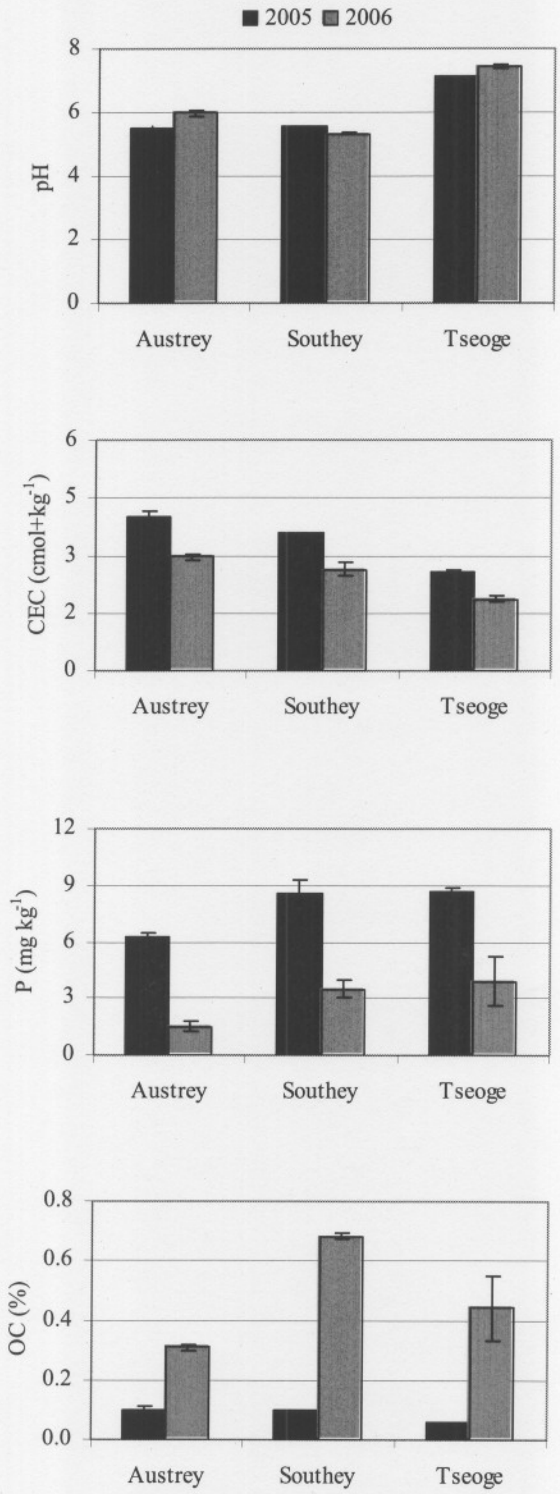

Figure 4.1. Soil chemical properties in 2005 and 2006 at the Austrey, Southey and Tseoge sites (means and bars are standard error, n=3)

Soil biochemical and microbiological properties

Across all the three communal sites, the activity of dehydrogenase decreased significantly at the Austrey and Southey sites ($p = 0.001$, $p = 0.003$ respectively) but not at the Tseoge site ($p = 0.12$). The enzymatic activities of ß-glucosidase and acid phosphatase showed similar patterns, both decreased at the Austrey site but increased at the Southey and Tseoge sites in 2006 (Figure 4.2.). The soil microbial biomass increased overall at all the sites, although it was not significantly ($p = 0.45$, $p = 0.07$, $p = 0.07$ at the Austrey, Southey and Tseoge sites respectively) (Figure 6, Manuscript III). At this early stage of the investigation, it is difficult to speculate on the factors that have led to the observed changes, nor the magnitude of their influence. However, potential interrelationships between aboveground vegetation and microbial activity exist and need further investigation.

Conclusion

All the three communal rangeland sites were characterized by sandy soils with low organic carbon and phosphorus contents, which led them, being described as degraded. Because of the sandy texture, the topsoil horizon is loose resulting in a low water holding capacity and therefore high infiltration rate, and exposition to wind and water erosion due to the lessening of the aboveground plant cover by the continuous grazing system. The high infiltration rate leads to more soil nutrients being infiltrated in the lower soil horizons protecting them of being washed away during erosion processes. In the absence of baseline or references for similar soils for the biochemical and microbiological properties, the evaluation of the soils condition based on these properties was difficult to make. It is cautioned that these are preliminary results, and should not be considered as definitive. Further monitoring using more soil samples is recommended to characterize accurately soil quality, mostly when extrapolations at landscape level are envisaged.

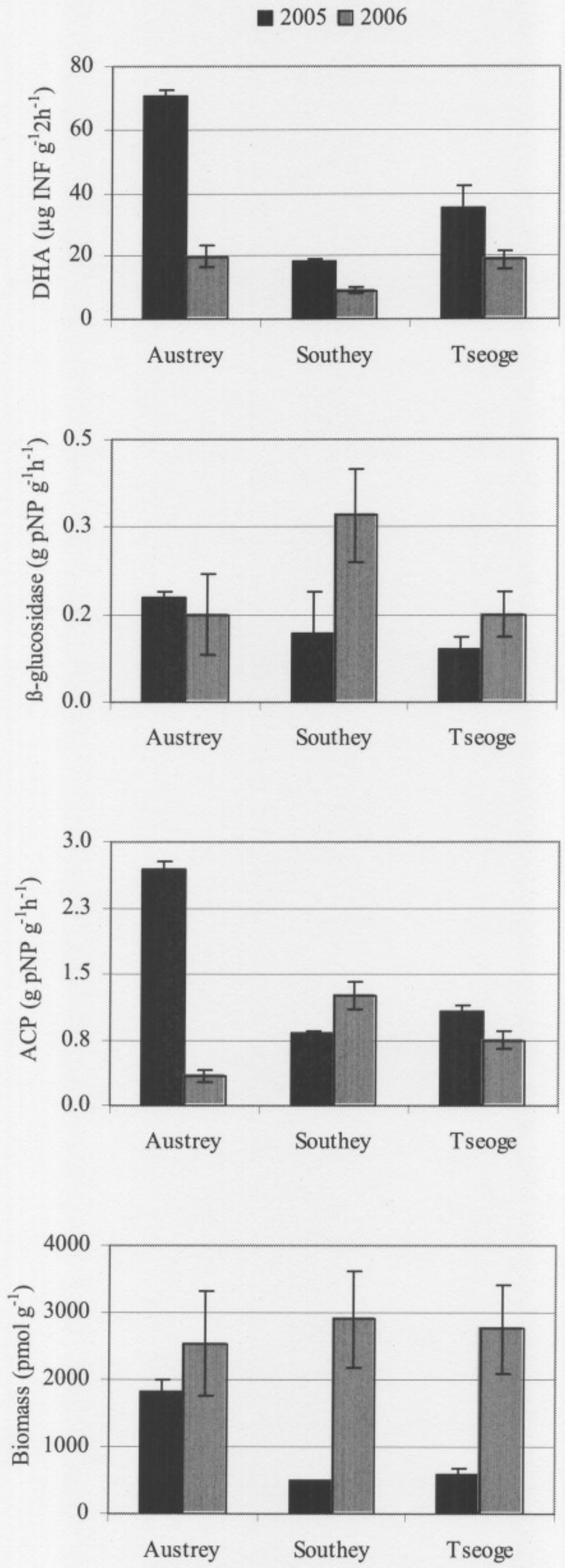

Figure 4.2. Soil enzymatic activity and microbial biomass in 2005 and 2006 at the Austrey, Southey and Tseoge sites (means and bars are standard error, n=3)

4.2. GRAZING AND EXCLUSION MANAGEMENT

The effects of livestock grazing and exclusion management were evaluated at the three communal managed sites. In the absence of background information regarding grazing management (intensity, duration, frequency of grazing, type of animals, and stocking rates), and differences of soil type, geology and environmental variables, a site-specific approach was considered.

The literature on grazing effects on soil nutrients has yielded contrasting results worldwide (Milchunas and Lauenroth, 1993; Lavado *et al.*, 1996). The differences in ecosystem carbon and other nutrients responses to grazing result from different climatic conditions, inherent soil properties, landscape position, plant community composition, ecosystem type and grazing condition such as stocking rate, carrying capacities (Hiernaux *et al.*, 1998). Grazing intensity, frequency and duration are also determinants factors affecting these responses (Bardgett *et al.*, 2001; Reeder and Schuman, 2002; Henderson *et al.*, 2004; Haferkamp and Macneil, 2004).

4.2.1. Soil chemical properties

Soil organic carbon, pH, and phosphorus were assessed in Manuscript I. Soil organic carbon, a major indicator of soil quality (Bending *et al.*, 2004) was not significantly different between the open-grazed and exclosure plots at any of the three communal sites. These results confirm several studies which also reported no significant differences between grazed and exclosure and/or ungrazed treatments (e.g. Berg *et al.*, 1997; Holt *et al.*, 1997; Henderson *et al.*, 2004; Reeder *et al.*, 2004; Cui *et al.*, 2005; Yong-Zhong *et al.*, 2005; Nosetto *et al.*, 2006). These studies however, did not support the increasing organic carbon by grazing as reported by Manley *et al.*, (1995) and Schuman *et al.*, (1999). These authors found higher organic carbon in the grazed treatment compared to the exclosure and they attributed it to litter decomposition as well as inputs of faeces, manure trampling and incorporation in the soil. Soil pH did not differ statistically between the open-grazed and exclosure plots at any of the sites (Figure 2). Phosphorus was statistically different between the open-grazed and exclosure plots at the Tseoge site only ($p = 0.0007$).

4.2.2. Soil biochemical and microbiological properties

Soil chemical properties make a significant contribution to soil quality, but the biochemical and microbiological components are more susceptible to changes (Bending *et al.*, 2004), and can therefore be used as early indicators of ecosystem changes due to disturbances. According to Dick *et al.*, (1996) and Yakovchenko *et al.*, (1996), soil enzymatic activity is a good soil quality indicator, because enzymes are closely related to important soil quality parameters such as organic matter, physical properties, and microbial biomass. Soil microbial biomass reflects the effects of management on soil quality, influences biogeochemical cycles, the turnover processes of organic matter and the fertility and quality of soils (Zelles, 1999). Studies of grazing effects on biochemical and microbiological properties have often been conducted in temperate grasslands; few cases exist in arid and semi-arid rangelands. The differences in climate, soil type and condition, as well as grazing regime or management have led to contrasting results on the effects of grazing on soil biochemical and microbiological properties (Wang *et al.*, 2006).

In Manuscript I, several enzymatic activities (dehydrogenase, β-glucosidase, and acid phosphatase) were characterized. The activity of β-glucosidase was significantly different between the open-grazed and exclosure plots at all the three communal sites, whereas dehydrogenase was significantly different at the Southey site only (Figure 3, Manuscript I). Acid phosphatase did not show any statistically significant difference between the open-grazed and exclosure plots at all three sites. The activity of β-glucosidase was higher in the exclosure than the open-grazed plot. Knight and Dick (2004), Aon and Colaneri (2001), and Gianfreda *et al.*, (2005) found that any change in organic carbon content affects the activity of this enzyme.

In Manuscript II, soil microbial biomass was characterized, as well as the effects of grazing and exclusion management. No significant difference of soil microbial biomass was found between the open-grazed and exclosure plots ($p = 0.84$, $p = 0.07$, and $p = 0.31$ at the Austrey, Southey and Tseoge sites respectively). These results tend to support previous studies by Tracy and Frank (1998) who also reported no difference of soil microbial biomass between the grazed and ungrazed plots.

At the Southey and Tseoge sites, the soil microbial biomass was lower in the open-grazed than the exclosure plots although not significantly, whereas at the Austrey site, it was higher in the grazed plot. Decreasing soil microbial biomass with increasing grazing intensity was reported (Holt, 1997; Northup *et al.*, 1999; Sankaran and Augustine, 2004; Stark and Grellmann, 2002; Grayston *et al.*, 2004; Raiesi and Asadi, 2006). Studying the effects of long-term overgrazing in Iran, Raiesi and Asadi (2006) found that overgrazing might presumably depress microbial activity through either reduced input of fresh plant residue into the soil surface or a lack of roots and exudates, which normally stimulates microbial activity. Soil microbial biomass is well correlated with organic carbon (Sankaran and Augustin, 2004) and plant biomass production. Zak *et al.*, (2003) found that the loss of plant species and production might have the greatest impact on soil microbial communities in ecosystems with infertile soils poor in organic matter. Grazing-induced reduction in microbial biomass is associated with a decline in plant carbon inputs into the soil (Sankaran and Augustin, 2004). The positive effects of grazing on soil microbial biomass have previously been reported (Bardgett *et al.*, 1997; Stark *et al.*, 2002; Wang *et al.*, 2006). Bardgett *et al.*, (1997) found that long-term removal of sheep grazing had a negative effect on soil microbial biomass. Bardgett *et al.*, (2001) found that the effects of changes in plant community structure were responsible for the lower soil microbial biomass values in sites that have been ungrazed for different lengths of time. Wang *et al.*, (2006) found higher microbial biomass in heavily grazed than ungrazed pastures. They attributed this increase to dung and urine deposition, increased root turnover and exudation beneath grazed plants.

Differences in livestock grazing effects on grasslands greatly affect substrate supply to the soils and thus influence the soil microbial activity. Bardgett and Wardle (2003) summarized that positive, negative and neutral effects of grazing on soil biota are possible, depending upon the balance of these effects. They found that positive effects of herbivory on soil biota and soil processes were most common in ecosystems of high fertility and high consumption rates, whereas negative effects were most common in unproductive ecosystems. According to Zak *et al.*, (2003), plant diversity might have an influence on soil microbiological processes because plant species differ in their biochemical composition, and therefore, changes in plant diversity will modify resources availability for microbial communities in the soil, and thus modify their composition and function. In this research, we did not study the chemical composition of the different grass species to verify this hypothesis. Further research in this regard would therefore be very helpful to fill this gap.

Conclusion

Site-specific significant differences were observed between the open-grazed and exclusion plots. Organic carbon and pH were not significantly different between the open-grazed and exclusion plots, but phosphorus was at the Tseoge site. Site-specific significant differences where found for the enzymatic activity of dehydrogenase and β-glucosidase. Overall results showed either an increase or a decrease of soil properties content. These findings support previous studies, which showed both positive and negative effects of grazing on soil properties. The extent of these effects depends on ecosystem resilience and disturbance feedbacks (Franzluebbers and Stuedemann, 2003).

4.3. SOIL PROPERTIES UNDER DIFFERENT MANAGEMENT SYSTEMS

Soil quality indicators as well as species composition were evaluated and compared between three rangeland management systems (communal, commercial, and game) (Manuscript III).

4.3.1. Soil properties

Soil chemical properties

There were no clear patterns of soil degradation that could be concluded from a chemical perspective. Although it was not significantly different between the three management systems, soil organic carbon, a good indicator of soil fertility and quality (Bending *et al.*, 2004) was higher at the communal management than the commercial and game management systems. One could speculate that the soil under this management was of "better" quality than that of the commercial and game management. Many studies reported higher soil organic carbon content under communal managed sites (Ward *et al.*, 1998; Mbatha and Ward, 2006). Smet and Ward (2006) showed higher organic carbon nearby watering point in commercial ranching (because of animal concentration and therefore manure accumulation), but they did not find significant differences over a 75m from the water-point between the commercial and communal management.

Soil biochemical and microbiological properties

In terms of biochemical and microbiological properties, the enzymatic activities of DHA and β-glucosidase were lower under the communal management than the game and commercial systems, whereas ACP and microbial biomass were higher under communal management than the game and commercial systems. The lower dehydrogenase and β-glucosidase under communal managed rangelands were not expected because of the positive correlation between soil organic carbon and the activities of these two enzymes. There were no consistent patterns of either decreasing or increasing of all the soil biochemical and microbiological properties across the three management systems. These results made it difficult to predict which of the soils under the three management systems could be described as being in "better condition". Soil biochemical and microbiological properties perform multiple functions in the soil ecosystem. If these functions of interest are not defined prior to assessment, the significance and interpretation of the values will become a difficult task. These limitations form part of the criticism on the concept of soil quality, in terms of general lack of sufficient quantification and scientific rigor (Sanchez *et al.*, 2003; Letey *et al.*, 2003).

Using a site-specific comparison, some of the communal sites showed similar soils characteristics than the commercial and game sites, despite the apparent degradation condition of the aboveground vegetation at the communal managed sites. The apparent vegetation degradation might result from the influence of continuous grazing on the soil seed bank. This assumption was made in light of studies by Kinloch and Friedel (2005a), Solomon *et al.*, (2006). Soil seed banks are of vital importance in arid systems (Kinloch and Friedel, 2005b; Solomon *et al.*, 2006), being the major source in plant communities regeneration. Regeneration of the soil seed bank is important for the occurrence of valuable grasses and may have a profound effect in maintaining the composition of the grass layer on a degraded rangeland (Solomon *et al.*, 2006). Kinloch and Friedel (2005a) found a decline in the germinable seed bank size and changes in species composition due to heavy grazing over decades. In a study of soil seed bank across different land use systems in Ethiopia, Solomon *et al.*, (2006) showed that differences in grazing pressure was one of the main causes of variation in the soil seed bank. They found that decreasing aboveground species with continuous grazing in communal areas decreases seeds bank in the soil. These findings support the study by Frost and Smith (1991) who showed in revegetation experiments that "poor condition" rangelands were as productive as ever if the undesirable species were removed and desirable ones re-introduced. However, for seed bank to germinate, maintaining good soil condition, as well as controlled grazing management, is crucial. In this study, because we did not study the soil seed bank under these management systems, we could not speculate too much on the effects of grazing on soil seed bank; we would recommend considering this aspect in future monitoring.

4.3.2. Botanical composition

Difference of species composition was noticeable between the three management systems. High species diversity dominated by low palatable species such as *Aristida congesta, Aristida stipitata, Cynodon dactylon, Eragrostis pallens, Perotis patens, and Tragus berteronianus* were recorded under communal management. In contrast, under commercial and game management, a relatively uniform layer of perennial palatable species such as *Eragrostis lehmanniana, Schmidtia pappophoroides* to some extent *Stipagrostis uniplumis* were observed. In the Succulent Karoo, Anderson and Hoffman (2007) found high species diversity per 10m^2 sample area in the communal area than the privately own farm. These findings were consistent with the numerous literature on the effects of management systems on species composition (Parsons *et al.*, 1997; Duma, 2000; O'Connor *et al.*, 2003; Smet and Ward, 2005; Vetter *et al.*, 2006). Studying the effects of land uses on botanical composition in KwaZulu-Natal's grasslands, O'Connor *et al.*, (2003) found that the commercial management was dominated by long-lived mostly perennial grass species whereas the communal management showed short-lived perennial, more of annual grass species many of poor forage quality. These changes in botanical composition reflect differences of management such as stocking rate, patterns of animal movement, and therefore the temporal pattern of grazing, season of grazing, type of livestock and fire management.

Conclusion

The evaluation of range condition based on the species composition showed clear differences between the three management systems. However, the same evaluation using soil properties did not show a clear gradient of degradation under communal management, compared to the commercial and game management. These results show the relevance of integrating soil indicators in rangeland monitoring and evaluation. Lal (1998) considered soil degradation as a relative concept, depending on the land uses, management and environmental conditions. It is always relative to a reference soil. These arguments point the need to locally consider degradation and the importance of baseline data.

4.4. AWARENESS AND CAPACITY BUILDING

Monitoring changes is essential for management implications, but the data will only be useful if used in management decisions to first preserve the current condition of the soil and afterward, to improve the quality of the soil. Monitoring is intended to (i) serve decision-making through providing information required for amending management actions in order to improve production goals or other management objectives; (ii) serve decision-making of regulatory bodies and policy-makers; and (iii) serve scientific purposes, in which case, it has traditionally been most widely practiced on conservation properties (O'Connor, 2007). For monitoring to be locally and globally useful, it must provide information to local users in a timely and usable format and simultaneously provide data on which deleterious environmental impact can be assessed independently of the users (Western, 2004). The highest priority for integrated monitoring lies in creating user awareness of monitoring and demand for information, and applying the results to improve livelihoods and the state of the environment (Western, 2004). Awareness and capacity building are keys components to empower and enhance decisions making of local stakeholders in natural resources management. Stakeholders at community level are the beneficiaries and end-users of rangeland resources. To share and discuss the information from the study, workshops were held at all the communal managed sites (Figure 4.3.). The workshops were organized with the collaboration of the North-West Department of Environment, Conservation and Tourism (NWDACET), and other DMP projects[7] involved in the area.

Figure 4.3. Awareness, capacity building and demonstrations during workshops

From this study's perspective, the aim was to create awareness on the importance of integrating soil indicators into rangeland monitoring and assessment methods. At a broader scale, the workshops aimed to stimulate community participation and contribute to the up-and out-scaling of the DMP activities, which will ensure that farmers and other resource users adopt good and sustainable natural resource management practices in the long-term. Presentations of preliminary results, demonstrations followed by discussions, were carried out to raise awareness, inform, and capacitate local land users on various aspects of rangeland ecology and management, and biodiversity conservation. Approximately 500 farmers including women, youth, and other community members attended these workshops. A pamphlet on soil quality management for rangeland sustainability (appendix 3) was presented and distributed to land users and community members.

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[7] Project 5: Biodiversity: Importance for sustainable utilization of desert margins areas and use of birds as indicators of degradation – Project 6a: Best Land-use strategies toward sustainable biodiversity and land degradation management in semi-arid Western rangelands in South Africa with special reference to ants as bio-indicators – Project 6b: The evaluation and promotion of best practices for best practices for biodiversity restoration in selected arid and semi-arid regions of Southern Africa.

4.5. CONCLUDING REMARKS

The maintenance of the productive potential of land (soil) depends on management practices that sustain and improve the quality of the soil resource base. It is of critical importance for land-users, as well as policy makers, to have a good knowledge of the condition of the soil resources, as well as the capacity to monitor changes resulting from management practices and/or environmental factors. The information will help to screen appropriate management-decisions to sustain resources productivity.

Valuable information on soil fertility and quality was gained, and it is expected that this information will serve to monitor degradation in these communal areas. The limitations of the study were acknowledged (section below), which makes extrapolation and generalization at larger scales difficult. All the three sites were dominated by poor fertile sandy soils with low nutrients status (organic carbon and phosphorus). In the absence of historical or reference data, the status of the biochemical and microbiological properties could not be assessed. Furthermore, evaluating whether the soils under communal management system are degrading or improving was difficult to prove over such a short study period. The baseline data however, can serve as a reference point for any monitoring program aiming at assessing the impact of grazing management in the long-term. In terms of grazing and exclusion management, no generalization could be made, as soil properties either increased of decreased because of grazing effects. The comparison of soil properties under different management systems showed that the soils under communal management were not so severely degraded as described. Similarities of soil properties exist with those at the commercial and game managed sites. However, in terms of the species composition, differences were found. Abel and Behnke (1996) excluded reversible vegetation changes as degradation, but included effectively reversible changes in both soils and vegetation. Our results are in line with this argument, as they showed that the degradation of the vegetation was not necessarily correlated to soil degradation. This emphasizes the importance for an integrated approach combining both soil and vegetation parameters in future monitoring and assessment of rangeland health.

At this stage of the investigation, it was precarious to recommend a set of indicators to be used for monitoring purposes. As pointed by Campos *et al.*, (2007), a single minimum data set will probably remain undefined because of the inherent variability among soils, but it may be feasible to identify a suite of physical, chemical, and biological indicators that are useful for evaluating site-specific, temporal trends in soil quality. The process of selecting appropriate indicators to assess rangeland health is based on a long-term investigation, and the development of an appropriate framework. A two years period is definitely not enough to recommend indicators in these highly variable environments (soil, geology, climate, management regimes). However, these results could be used as a first step towards designing an appropriate framework through integrated approaches (participatory community-based indicators) that will allow the identification and screening of indicators to monitor changes of ecosystem services in order to ensure sustainable resources use. The results of this study fit well within the framework proposed by Tugel *et al.*, (2005) (Table 1.1.) to assess soil health. This thesis has addressed some of these questions, such (a) What is the condition of the soil or level of function? (b) Is it degrading, improving, or steady? (c), What should soil condition be for the intended or sustained use? and (d) What can be used to detect soil degradation before it occurs? However, further monitoring is needed to gain better insights and draw conclusive answers. Another question that could not be answered was: Are these rangelands healthy? Referring to the definition of rangeland health and the classification of rangeland (healthy - at risk - unhealthy), this two years investigation cannot appropriately answer this question. The evaluation of rangeland health requires the functioning of fundamental ecological processes such as water cycle (caption, storage and release), energy flow (photosynthesis process, then animal matter) soil development and nutrient cycling (flow of nutrient such as carbon, nitrogen), structure and dynamics of plant and animal communities. Assessing these processes and evaluating if they function well and properly over time is difficult over such a short period, because of the complexity and interrelationships between many of these processes (Pellant, undated). Therefore, it appears inappropriate to attempt any classification on the present status of these rangelands.

Rangelands are the principal resource base for livestock production in these communal areas. They support livelihood of through domestic livestock production. In such circumstances, the ability of land-users to detect degradation condition is crucial in achieving these goals. Therefore, their perception on the condition of rangeland resources is important because it affects livestock production. Over the past decades, the top-down approach used in rangeland monitoring has proven its limits. Local land users barely considered indicators derived from science-experts knowledge and monitoring, because they were not involved as partners in the monitoring, and scientists chose these indicators (Reed, 2005). In order for local land-users to benefit from this monitoring and feel the sense of responsibility into managing rangelands, their participation is a key to achieve sustainable resources uses objectives. This participation should not be passive, but also take into consideration the indigenous knowledge in the process. Reed and Dougill (2002; 2003) in a study of rangeland indicators selection in the Kalahari, emphasized the importance of an effective participation of local stakeholders in the process of developing indicator-based management tools that can facilitate sustainable resource management. Fraser et al., (2006), also reported the development of indicators by means of participatory research. According to these authors, the conventional expert-led indicators of degradation over-simplify degradation assessment, but efforts should rather strive to integrate local knowledge and scientific research and policy using a bottom-up approach. In Namibia for example, farmers through the Forum for Integrated Resource Management (FIRM) have developed simple, easy-to-follow and repeatable steps on how to monitor rangeland condition for improved decision-making. This process, known as Local Level Monitoring (LLM)[8] enables stakeholders at local level to collect information on important indicators and monitor changes over time and to use this information to make informed management decisions. As the Desert Margins program also operates in Namibia, cross-country interactions will facilitate learning processes of this successful experience, as well as the replication of the model in the Bophirima District where this study was carried out.

Limitations of the study

Limitations were encountered throughout the period of this study. They include:

- The lack of background information on the past and present historical management at the communal managed sites. As indicated in the materials and methods chapter, these sites were established for demonstrations purposes through the provincial LandCare program and consequently, there were no

[8] NAPCOD, 2003. Local Level Monitoring for enhanced decision making: A tool for improved decision-making by farmers in Namibia.

records, nor a thorough documentation and baseline data on the condition of the sites (plots). The limited number of plots (because of demonstrations purposes) makes any generalization of the results at landscape level very speculative, because of the high variability re were a limited number of plots and there were no true replicates for statistical purposes. This makes generalization of the grazing effects difficult at wider scales (landscapes with different soil types, geology, and rainfall patterns) despite the fairly "understanding" of grazing effects on these few plots.

- Research on land degradation requires long-term monitoring; therefore the two-year period of this study couldn't allow the detection of significant changes in rangeland condition and draw conclusive evidence about soil degradation and its extent, as well as to develop grazing practices for sustainable soil management under the conditions of the communally managed rangelands. However, the use of sensitive soil indicators could help to shorten monitoring programs.
- There is a need to integrate both soil and vegetation parameters in future monitoring.

Recommendations

In view of the limitations mentioned above, a number of refinements could be made to improve the monitoring of rangeland degradation in future research agendas. These include:

- Further monitoring (using adequate design i.e. number of plots, replicates, soil types, landscape position) is needed to gain realistic information into soil dynamics (degradation patterns) and understand of the underlying factors causative of the changes in soil quality.
- Recognizing the feedbacks between soil and vegetation properties, there is a need to integrate more information regarding vegetation dynamics and properties (compositional change, seed bank, biochemical composition of dominant grass species, basal cover) in future monitoring.
- There is a need to integrate both scientific and local knowledge (identification of local indicators of degradation) in order to empower land users to combat degradation. Research should strive to develop a series of local assessment

indicators through participatory monitoring. The methodological framework developed by Reed (2005) and Fraser *et al.*, (2006) in communal rangelands in Botswana could serve an entry point.

- The integration of ground-based information (soil and vegetation indicators) with remote sensing will provide better coverage and significantly contribute to enhance the monitoring and assessment of degradation steps at larger scales.
- *Very important is that extrapolation of these results beyond the characteristics (biophysical. management, history, socio-economic) of these sites is cautioned.*

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Conferences contributions

Since the onset of this study, various results have been presented in both poster and oral formats at national and international forums. The titles and abstracts of the presentations as well as two posters are given below.

National conferences

1) "Grazing effects on soil properties under communal semi-arid rangelands in the North-West Province". Oral presentation - Arid Zone Ecology Forum (AZEF), Victoria West, Northern Cape Aug 30th - Sep 2nd 2004

Abstract

Rangeland degradation has become a major threat to sustainable livestock production in South Africa, as an estimated 66% has undergone moderate to serious degradation processes. It is perceived to be more of a problem in the communal areas than commercial areas, although considerable variations exist. Little empirical data concerning the functioning of communal lands to support of refute the notion that these systems are on the brink of imminent collapse exists. In the North-West province, soil degradation is considered a major problem with a degradation index of 272, making it the fourth most degraded province. Most studies on rangeland condition have been focused on vegetation composition and herbaceous production, to a little extent, changes of soil properties. However, vegetation changes cannot alone be used as indicators of land degradation, neither for soil chemical and physical properties alone such as organic matter, nutrients status as they are slow to monitor and cannot reveal some biological aspects of soil. As rangelands sustainability depends on the integrity of soils and ecological processes, assessing soil quality/health is needed to identify and monitor changes in soil properties for sustainable use of rangelands. We investigated soil physico-chemical and biological properties and their relationships in communal managed rangelands, as they are regarded as reliable early indicators of changes in soil quality, and as applicable for evaluating both short and long-term impacts on soil management. Soils samples were collected at 20 cm depth in April 2004 and analyzed for texture, organic carbon, pH, available phosphorus, ammonium, nitrate, cation exchange capacity, base saturation, electronic conductivity and for selected enzymes activities such as dehydrogenase, (-glucosidase, alkaline and acid phosphatase, and urease. All sites showed poor soil chemical properties; they are sandy (± 95%) moderately acidic (4.4) organic content (0.16%), CEC (2.65 cmol kg-1), EC (0.03 mS cm-1). Sites differed significantly for NO3-, NH4+, pH, EC, OC and ACP. No differences were found between the grazed and exclosure treatments. There were no differences with regard to the vegetation condition. In general, pH showed positive correlation with BS, sand, DHA, AKP and urease, whereas negative correlations were found with OC and ACP. There was a strong correlation between AKP and urease and to some extent with (-glucosidase. Correlations between soil properties displayed similar trends when comparing the grazed and exclosure treatments. These results are preliminary findings of a two-year project under the Desert Margins Program (DMP) in the North-West Province. Research is on-going to accurately assess grazing impacts and draw conclusive evidence of their effects on communal semi-arid rangelands.

2) "Impact of communal grazing on soil and vegetation properties and their relations in a semi-arid rangelands in the North-West Province, South Africa". Oral presentation - LandCare/DMP Symposium (North-West Department of Agriculture, Conservation, Environment and Tourism, Potchefstroom Jun 22 2005).

3) "Livestock grazing and rangeland degradation in semi-arid communal areas: effects on selected soil quality indicators". Oral presentation - 40th Congress of the Grassland Society of Southern Africa (GSSA), Port Shepstone Jul 19th 2005.

Abstract
Approximately 66% of the total rangeland surface has become degraded in South Africa, with overgrazing being one of the most important causes, especially in communally managed lands. The effects of overgrazing on vegetation are well documented. Less is known, however on the associated changes of soil condition on communally managed rangelands, mostly in terms of suitable indicators of soil quality. Given the importance of soil-vegetation relationships in rangeland health, interest has emerged in integrating soil condition information in rangeland monitoring, and this needs to be quantified in order to develop suitable grazing practices. In this study, we assessed the effects of continuous livestock grazing on soil organic carbon, phosphorus and selected enzymes activities (dehydrogenase and (-glucosidase). Soils were sampled at a depth of 20 cm in April 2005 in grazed and un-grazed plots. Soil responses varied across sites. Only the activity of dehydrogenase was significantly different between grazed and un-grazed plot at the Southey ($p = 0.01$) and Tseoge ($p = 0.03$). (-glucosidase and organic carbon decreased at all sites but not significantly, whereas phosphorus increased at the Southey and Tseoge with continuous grazing. Results although preliminary showed that grazing induced rangeland degradation should not be generalized; it is site-specific, with variable response sin terms of the soil properties studied. Therefore, management should be planned accordingly.

International conferences

4) "Patterns of soil organic carbon and nitrogen in grazed and ungrazed exclosure of semi-arid rangelands in South Africa". Poster - First International Symposium on Management of Tropical Sandy Soils for Sustainable Agriculture (Khon Kaen, Thailand Nov 28th - Dec 2nd 2005).

Abstract
Approximately 66% of the total rangeland surface has become degraded in South Africa. Overall synthesis derived from participatory research has shown that communal rangeland management characterized by overgrazing and overstocking was unsustainable and will lead to irreversible rangeland degradation. However, there is scant quantitative information on the influence of soil factors on rangeland degradation in some of these areas. In this study, we examined the effects of livestock grazing and exclusion on soil organic carbon and nitrogen (nitrate and ammonium) at three communal sites (Austrey, Southey and Tseoge). Soil samples were collected at 20 cm depth in April 2004 from open grazed plots and 5 year exclosures. Anova and Tukey HSD ($p<0.05$) were used to test significant differences. Only organic carbon was significantly different across sites ($p=0.049$), averaging 0.18 mg kg-1. Overall no significant difference was recorded at the sites for organic carbon ($p=0.37$), NO_3^- ($p=0.66$), and NH_4^+ ($p=0.90$) between grazed and un-grazed plots. Patterns of soil variables differed across sites. At the Southey and Tseoge sites, organic carbon increased with grazing, while it decreased at the Austrey. Nitrate increased at the Austrey and Tseoge whereas it decreased at the Southey. Results from this study showed that grazing-induced rangeland degradation is site-specific and might be related to some other factors.

5) "Soil indicators of rangeland degradation in a semi-arid communal district in South Africa". Oral and poster presentations - International Scientific Conference "Future of Drylands" (Tunis Tunisia, 19-21st June 2006). The manuscript of this presentation has been accepted in the proceedings of the conference.

Abstract
Rangeland degradation is a major threat to sustainable livestock production in South Africa. The changes of the aboveground vegetation have mainly been used to describe rangeland

degradation, whereas little research has been carried to assess the extent of soil degradation, particularly in communal managed grazing lands. The objective of this study was to provide some baseline reference indicators of soil quality and changes at three communal managed grazing sites (Austrey, Southey and Tseoge) in the Bophirima District in the North-West Province. This on-going study forms part of the Desert Margins Program (DMP) in South Africa. Soils from benchmark plots (grazed and adjacent ungrazed exclosure) were monitored for indicators such as pH, organic carbon and phosphorus, dehydrogenase, β-glucosidase and acid phosphatase in 2005 and 2006. The soils are predominantly sandy (± 95%) with low fertility (organic carbon ranging between 0.06 to 0.10%, and phosphorus from 6.3 to 8.66 mg kg^{-1} irrespective of grazing or exclusion. At all sites, there were few significant differences between the grazed and ungrazed plots for soil chemical properties, as well as for enzymes activities, but the sites did differ between them. The results were presented and discussed with communities' members during workshops to raise awareness on soil degradation. At this early stage, it was difficult to detect significant trends of soil properties resulting from grazing management. Long-term monitoring and further indicators are required for a thorough assessment of soil properties responses. Furthermore, as land (soil) degradation is not only about the land, but also about people, a multi/interdisciplinary approach should be followed in analyzing soil degradation issues on these areas.

PATTERNS OF SOIL ORGANIC CARBON AND NITROGEN IN GRAZED AND UNGRAZED EXCLOSURES OF SEMI-ARID RANGELANDS IN SOUTH AFRICA

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INTRODUCTION

In South Africa approx. 82% of the land area consists of rangelands of which 66% has suffered moderate to serious degradation over the past decades. The National review of land degradation indicated that this degradation is more of a problem in communal districts rather than in commercial farming areas (Hoffman & Ashwell, 2001).

In communal districts, livestock is important in supporting the livelihoods of the poor; it contributes asa source of income, insurance, as well as important farm inputs such as manure and draught power. Rangeland monitoring has put more emphasis on grazing management effects on forage production, but little attention has been given on grazing impacts on soil quality (Snyman and du Preez, 2005).Improving rangeland management that ensures better resources use requires an holistic monitoring approach of soil and vegetation resources and determining how human management activities (such as grazing) impact on the system.

The objective of this study was to assess patterns of soil organic carbon and nitrogen in relation to grazing and exclusion at three communal managed rangelands sites in the North-West Province. The study forms part of the Desert Margins Program (DMP) activities in South Africa. The DMP aims to address issues of global environmental importance in particular the loss of biological diversity, reduced carbon sequestration associated with land degradation in sub Saharan Africa.

MATERIALS AND METHODS

Study area and sites

The study area was located in the Bophirima District in the North-West Province. Three communally managed sites (Austrey, Eska-Neuham and Tseoge) were chosen. The climate is semi-arid, with rainfall averaging between 200-400mm. Land users and stakeholders depicted rangelands in these areas as overgrazed and overstocked, leading to soil degradation. Some characteristics of the sites are given in Table 1.

Treatments:

Grazed (GR) vs. Ungrazed exclosures (UNGR) (5 years)
2 replicates
Plots size: 110 m x 20 m

Soil sampling and analysis

Soil samples were collected at each of the three sites in the plots along two parallels transects (100 m and 5 m apart) at 10m regular intervals, and 25cm depth.

Soil organic carbon (OC) was analyzed by the Walkley-Black method (Walkley, 1935). Soil nitrate (NO_3^-) was determined using an Ion Chromatograph (Metrohm 761, Switzerland), and soil ammonium (NH_4^+) was analyzed with the ammonium selective electrode method as described by Bankwart et al., (1972). Data were analyzed with Statistica 7 and separation of means done at 0.05 probability level.

Sites location

Sites	Austrey 1	Eska-Neuhan	Tseoge
Sand	94.3	94	97.2
pH (H_2O)	6.3	6.3	6.9
CEC	2.4	2.9	2.7
OC	0.2	0.2	0.1
P-Bray 1	6.4	6.3	6.9

Table 1 Soil properties at the sites

Soil sampling

RESULTS AND DISCUSSION

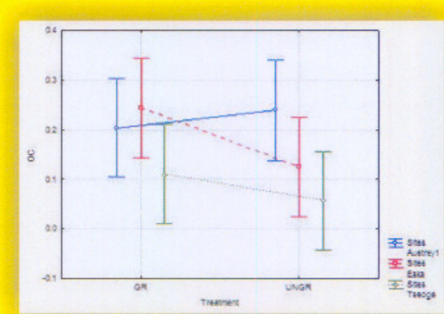

Fig 1. Soil organic carbon in grazed and ungrazed treatments

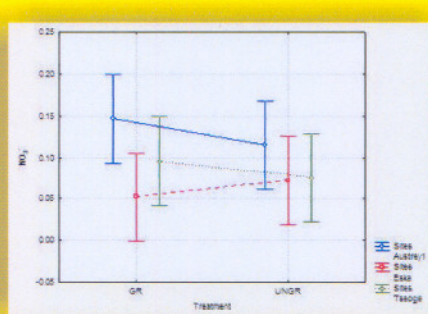

Fig 2. Soil nitrate in grazed and ungrazed treatments

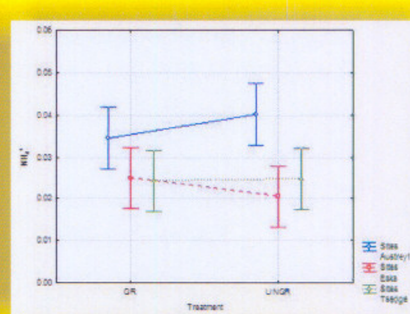

Fig 3. Soil ammonium in grazed and ungrazed treatments

These preliminary results from the study showed different patterns of soil properties in relation to grazing and exclusion. Soil organic carbon (OC) in the top soil (25 cm) was higher in all grazed plots, compared to that of the ungrazed excloures (Fig 1) at Eska-Neuham and Tseoge, whereas at Austrey, an opposite trend was recorded. The effect was however not significant at any of the sites. Soil nitrate (NO_3^-) (Fig 2) was higher in grazed plots at Austrey and Tseoge, but lower at Eska-Neuham site. The ammonium (NH_4^+) (Fig 3) tends to be higher in grazed plots at Eska-Neuham and Tseoge, but lower at the Austrey site.

The data did not indicate any single or consistent response of soil organic carbon and nitrogen to grazing, suggesting that grazing and its exclusion effects were dependent on several factors. Some authors found that soils with inherently low OC are more prone to change in response to grazing management (history, intensity, type of animal, duration, etc) (Manley et al., 1999; Schuman et al., 2002). The latter could explain these results, as adequate and reliable information on grazing management is lacking at the sites, making therefore any interpretation speculative at the moment.

Rangeland ecosystems are very complex, both in terms of vegetative community and soils, making it difficult to adequately characterize soil carbon and nitrogen dynamic. Long-term monitoring is therefore needed to assess changes due to management activities and/or environmental factors.

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- First International Symposium "Management of Tropical Sandy Soils for Sustainable Agriculture" 27th Nov - 2nd Dec 2005, Khon Kaen, Thailand -

SOIL INDICATORS OF RANGELAND DEGRADATION IN A SEMI-ARID COMMUNAL DISTRICT IN SOUTH AFRICA

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Figure 1 The distribution of communal areas in South Africa showing the percentage of magisterial district under a communal land tenure system (Hoffman et al., 1999)

Figure 2 Soil, rangeland and combined land degradation in South Africa (Hoffman and Ashwell, 2001)

INTRODUCTION

South Africa, land surface: 1,219,080 km^2. 91% consists of fragile drylands areas that are affected by desertification and land degradation. Roughly 80% of the land is used for agriculture but only 13.5% is considered arable. Two main land tenures exist: commercial and communal, 70% and 14% of the land surface, respectively.

Desertification, which is a serious form of land degradation affects all land use types and results in reduced land productivity, loss of biodiversity and increased poverty. The first national audit of land degradation (1999) drew on the expertise of agricultural technicians, extension officers and land users indicated that communal districts have significantly higher soil, rangeland and combined soil/rangeland degradation indices than in commercial districts (Hoffman et al., 1999; Hoffman and Ashwell, 2001).

Communal rangelands, which occupy approximately 14% of the land surface in South Africa have been viewed as degraded because of continuous grazing at high stocking rates. However, there is still debate around appropriate definition of degradation and overgrazing in communal rangelands (Vetter et al., 2006). Degradation is mainly described by shifts from palatable to unpalatable species, bush encroachment and invasion of alien plants. Very little research has been carried out on the impact of degradation on soil properties, particularly in communal districts. Soil health/quality is a integral part of sustainable agriculture and indicators are needed to help land managers identify degraded areas and make management decisions for sustainable land use.

OBJECTIVE OF THE STUDY

Long-term monitoring is essential to provide reliable information to land users on the status of land degradation (especially with regard to soil quality) that could serve as a guide for the prevention and/or reduction of degradation. The objective of this study was to establish some baseline indicators of soil condition in rangelands and understand the changes resulting from management in a communal managed district in the North-West Province, South Africa. The study forms part of the Desert Margins Program (DMP), which overall objective is to arrest land degradation in Africa's desert margins through demonstrations and capacity building.

STUDY SITES AND METHODS

The study was conducted in the Western Bophirima District in the North-West Province. The climate is semi-arid with a low annual rainfall (200-400mm/annum). Most rangelands in the area are regarded as degraded due mainly to overgrazing resulting in soil degradation. Three communal grazing sites, namely Austrey, Southey and Tseoge (Figure 3) were selected.

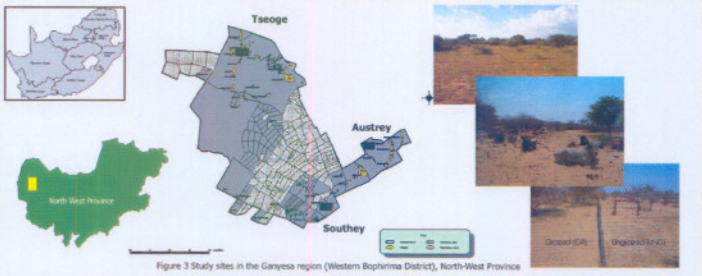


Figure 3 Study sites in the Ganyesa region (Western Bophirima District), North-West Province

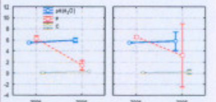
At each of the three sites, benchmarks were erected in 2001 at Austrey and 2003 at Southey and Tseoge. Grazed and ungrazed plots (100 x 20 m^2) were monitored. Soil samples were collected (0-20 cm) in 2005 and 2006 and analyzed for pH (H_2O), P-Bray1, OC and the activity of beta-glucosidase, dehydrogenase and acid phosphatase.

RESULTS

Chemical properties

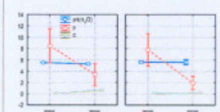
AUSTREY SITE

pH: 5.52
OC: 0.10%
P-Bray 1: 6.3 mg kg^{-1}
There were no statistically significant differences of soil pH, phosphorus and organic carbon between GR and UNG respectively in 2005 and in 2006. Phosphorus was significantly lower in 2006 in GR, as well as in UNG. Soil organic carbon was significantly higher in 2006 compared to 2005 in the grazed plot.



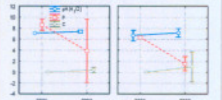
SOUTHEY SITE

pH: 5.55
OC: 0.10%
P-Bray 1: 8.55 mg kg^{-1}
Soil phosphorus was not statistically different between GR and UNG both in 2005 and in 2006. Soil organic carbon was not statistically different between GR and UNG plots in 2005, but it was in 2006. It was significantly higher in 2006 in the grazed plot only, compared to 2005.



TSEOGE SITE

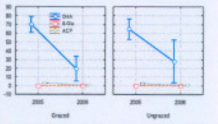
pH: 7.11
OC: 0.06%
P-Bray 1: 8.66 mg kg^{-1}
Soil phosphorus was statistically different between GR and UNG in 2005, but not in 2006. In the GR plot, P-Bray 1 was not significantly different between 2005 and 2006, although lower in 2006. Soil organic carbon was not different between GR and UNG both in 2005 and in 2006. There was no difference between 2005 and 2006 in GR and UNG



Enzymes activities

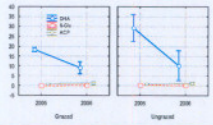
Austrey site

DHA: no significant difference between GR and UNG both 2005 and 2006. DHA was significantly lower in GR and UNG in 2006.
Beta-glucosidase: not statistically different between GR and UNG in 2005, but was in 2006. No difference over two years in GR, but significantly different in UNG.
ACP: significant difference between GR and UNG in 2005, but not in 2006. The activity of ACP was significantly lower in 2006,



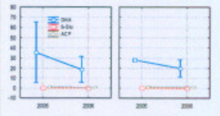
Southey site

DHA: significantly different between GR and UNG in 2005, not in 2006. It was significantly lower in 2006 in both GR and UNG.
Beta-glucosidase: no significant difference between GR and UNG both years and within a plot between years.
ACP: was not different between GR and UNG in both 2005 and in 2006, but it was significant over the two years at the grazed plot.



Tseoge site

DHA: no significant difference of activity between GR and UNG in 2005 and 2006, but it was significant between 2005 and 2006 in the grazed plots only.
Beta-glucosidase: was not significantly affected by GR neither UNG in 2005, but in 2006. There was no difference between GR in 2005 and 2006.
ACP: significantly affected by grazing exclusion in 2005, but not in 2006. No significant differences between GR plots and UNG plots in both years



CONCLUSIONS

The major feature of the soils was their general low fertility (low organic carbon and P-Bray 1), irrespective of grazing or exclusion. There were no clear trends across the three sites of soil properties degradation. At this early stage, it is difficult to draw conclusive evidence if the soils in these communal managed grazing sites are degraded. But the information from this study can however be used as valuable reference (baseline) data for long-term monitoring and will help in the decision-making of land use and management in the future. Monitoring and assessing soil indicators provided relevant information, but it form only one aspect of a complex and multidimensional problem of land degradation. Since land degradation is often not only a biophysical problem, but also deeply rooted in the socioeconomic and policy issues, an multi/interdisciplinary approach in addressing soil degradation, particularly in poor and former disadvantaged communities should be followed.

SCALING OUT

(Demonstrations and capacity building)

Land users have access to information on the condition of their land and on appropriate management practices for sustainable land use.	User-friendly information materials (flyers) are developed and disseminated to land users.	Strengthen local knowledge on the causes and consequences of soil degradation. Sensitize land users on the relationships between soil quality, rangeland health and productivity. Youth environmental education	Indicators for the monitoring and assessment of desertification and land degradation for policy recommendations (e.g. State of the Environment Report of the North-West Province), as well as the National Action Programme (NAP) of the United Nations Convention to Combat Desertification (UNCCD).

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