

Investigating Livestock Dynamics in Relation to Livestock Water Productivity in Smallholder Mixed Crop-Livestock Systems: A Case Study of Ntshiqo in the Eastern Cape

By
Lynton Jason Dedekind
210513909

University of KwaZulu-Natal
Pietermaritzburg

**Submitted in fulfilment of the academic requirements for the degree of Master of Science, in
the School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal,
Pietermaritzburg.**

March 2016

Abstract

Livestock provide net benefits such as food production (milk, meat), raw materials (wool), draught, manure, cultural practices, income and investment, and can improve the resilience of smallholder mixed crop-livestock farmers in developing countries, against external vulnerabilities such as water scarcity and climate change. A Livestock Water Productivity (LWP) framework represents ways to increase livestock production and benefits derived from animals without depleting water resources or causing environmental degradation for smallholder mixed crop-livestock systems. It is comprised of technical interventions (feed, water and animal management), supportive institutions and enabling policies. The research focuses on the technical feed management component of the LWP framework, in relation to livestock production in Ntshiqo, Eastern Cape. Sourveld regions in South Africa generally experience forage quantity and quality deficiencies during winter. The impact of a 17 month rest (exclosures versus grazed areas), a short (Oct 2014 - January 2015) and a full (Oct 2014 - June 2015) summer rotational resting experiment, on forage quantity and quality (Acid Detergent Fibre (ADF), Neutral Detergent Fibre (NDF), Crude Protein (CP) and Phosphorus (P)) were tested. Additionally, the influence of a protein lick on the body condition of sheep during the winter months (June - September) was tested. A significant difference ($p < 0.05$) in forage quantity was found between the exclosures and grazed areas, and the short and full summer rest. No significant difference ($p > 0.05$) was evident in the forage quality between the exclosures and grazed areas. There was a significant difference between the ADF values of a full and short summer rest, whilst no significant difference was evident between the other feed quality variables. The protein lick had a significant ($p < 0.05$) positive effect on the body condition of sheep over winter. Fodder crops (vetch and oats), were a viable additional form of supplementary feed to improve forage quality and intake. Smallholder farmer perspectives were obtained from Focus Group Discussions (FGDs), which informed and supplemented the results of the technical feed management interventions. Additional alternative management interventions (burning, re-seeding) are proposed. Technical interventions have positive influences on LWP in smallholder farming systems in developing countries. A collaborative or integrative management approach is recommended for long term crop, livestock, land and water management, which are crucial in improving LWP in smallholder mixed crop-livestock farming systems.

Key Words

Smallholder farmers, LWP, feed management, forage quantity and quality, vulnerability, resilience

Declaration

This study was undertaken for the fulfilment of Masters of Science degree in Geography and Environmental Science, which represents work originally done by the author. Acknowledgements of other authors or organisations have been made within text and in the references chapter.

Lynton Jason Dedekind

Ms. Dayle Trotter

Acknowledgments

To Ms Dayle Trotter, thank you for your continuous advice and assistance during my Masters project. Your time and effort are much appreciated and have greatly aided in the completion of my research. Thank you for all the opportunities you have provided me in terms of contacts and work experience, which will stand me in good stead for my future.

This research originated from a project initiated, managed and funded by the Water Research Commission (WRC project No. K5/2177//4: Up-scaling of rainwater harvesting and conservation on communal crop, and rangeland through integrated crop and livestock production for increased water use productivity). The researcher would like to thank the WRC for sponsoring the project.

To Mr. Jon McCosh, thank you for your contribution especially in the fieldwork components of my research. Your time, advice and encouragement throughout my research are greatly appreciated. I am grateful to have conducted my postgraduate research in collaboration with the Institute of Natural Resources.

To Dr. Terry Everson and Mr. Craig Morris, thank you for your continuous input and advice regarding the statistical and structural components of my research. Your expertise within rangeland management helped me focus my research approach. Furthermore, thank you for proving valuable sources of information and clarity to aspects pertaining to my research.

I would like to thank Mr. Mawethu Tshabu for his continuous monthly assistance in the fieldwork components of my research. Your input has greatly assisted in gathering accurate results.

To Perushan Rajah, thank you for your time in editing some of my GIS map outputs.

List of Acronyms

ADF - Acid Detergent Fibre

ATNESA - Animal Traction Network for Eastern and Southern Africa.

AU - Animal Unit

AUE - Animal Unit Equivalent

BCS - Body Condition Scoring

BRG - Bioresource Group

BRU - Bioresource Unit

CP - Crude Protein

CSG - Controlled Selective Grazing

DAEA - Department of Agriculture and Environmental Affairs

DAFF - Department of Agriculture, Forestry and Fisheries

DEAT - Department of Environmental Affairs and Tourism

DEFRA - Department for Environment, Food and Rural Affairs

DoA - Department of Agriculture

DPM - Disc Pasture Meter

ECDRDAR - Eastern Cape Department of Rural Development and Agrarian Reform

EDTEA - Department of Economic Development, Tourism and Environmental Affairs

FGDs - Focus Group Discussions

GCMs - General Circulation Models

GIS - Geographic Information System

GPS - Global Position System

INR - Institute of Natural Resources

IAEA - International Atomic Energy Agency

IPCC - Intergovernmental Panel on Climate Change

KZN - KwaZulu-Natal

LUDC - Land Use Development Committee

LWG - Livestock Working Group

LWP - Livestock Water Productivity

MSA - Municipal Systems Act

NDF - Neutral Detergent Fibre

NPOs - Non-Profit Originations

NRC - National Research Council

NSG - Non-Selective Grazing

P - Phosphorus

RWH&C - Rainwater Harvesting and Conservation

SDG - Short Duration Grazing

WOCAT - World Overview of Conservation Approaches and Technologies

WRC - Water Research Commission

Table of Contents

Abstract.....	i
Declaration.....	ii
Acknowledgments.....	iii
List of Acronyms	iv
1 Chapter One Introduction	1
1.1 Research Statement.....	3
1.2 Research Questions.....	4
1.3 Aim and objectives	5
1.4 Rationale for the Research	5
1.5 Structure of the dissertation	5
2 Chapter Two Literature Review.....	7
2.1 Introduction.....	7
2.2 Smallholder farming systems.....	8
2.3 Dependencies on Livestock in smallholder farming systems	8
2.3.1 Food production.....	9
2.3.2 Raw materials	10
2.3.3 Production of manure.....	11
2.3.4 Provision of labour.....	11
2.3.5 Resilience against external shocks, source of security, cash, investment and insurance	12
2.3.6 Cultural and social factors	13
2.3.7 Consequences of population growth and urbanisation	13
2.4 Mixed crop-livestock systems.....	14
2.5 Communal lands and Traditional Authorities	15
2.6 Water Scarcity, Demand and Availability	16
2.6.1 Increasing demand	17
2.6.2 Climate change and rainfall variability.....	17
2.6.3 Impacts on the agricultural sector and smallholder farmers	19
2.7 Livestock Water Productivity (LWP)	21
2.7.1 Livestock-water interactions.....	24
2.8 Interventions for LWP improvement	26
2.8.1 Technical Components	28
2.8.2 Supportive Institutions	38
2.8.3 Enabling Policies	39
2.9 Rangeland Systems and management	41
2.9.1 Burning	41

2.9.2 Grazing Management.....	43
2.10 Conclusion	48
3 Chapter Three Methods	49
3.1 Introduction and Research Design	49
3.2 Research Setting - Case study community of Ntshiqo, Eastern Cape.....	49
3.2.1 Geographical Context	52
3.2.2 Biophysical characteristics and current farming practices.....	52
3.2.3 Institutional Arrangements	53
3.3 Sampling and Data Collection	56
3.3.1 Fieldwork.....	56
3.3.2 Focus Group Discussions.....	67
3.4 Data Analysis	69
3.4.1 Field measurements	69
3.4.2 Image processing	70
3.4.3 Focus Group Discussions.....	71
3.4.4 Documentary analysis.....	71
3.4.5 Statistical analysis.....	71
3.5 Methodological Reflections	72
3.5.1 Language Barrier	72
3.5.2 Livestock Working Group	72
3.5.3 Supplemental feeding	72
3.5.4 Rotational Resting.....	73
3.5.5 Exclosures and Grazed Areas	73
3.5.6 Broader Research.....	73
3.6 Conclusion	73
4 Chapter Four Results	74
4.1 Rangeland Condition	74
4.1.1 Species Composition.....	74
4.1.2 Grazing Capacity, Veld Condition and Stocking Density	77
4.2 Forage Quantity and Quality.....	79
4.2.1 Exclosures and grazed areas	79
4.2.2 Rotational Resting.....	91
4.3 Protein lick.....	95
4.4 Fodder Crops (Vetch and Oats)	96
4.5 Conclusion	97
5 Chapter Five Discussion	98

5.1	Rangeland Condition, Grazing Capacities and Stocking Density	98
5.2	Forage Quantity	99
5.2.1	Exclosures and Grazed Areas	99
5.2.2	Rotational Resting.....	102
5.3	Forage Quality	103
5.3.1	Exclosures and Grazed Areas	103
5.3.2	Rotational Resting.....	105
5.4	Protein Lick.....	105
5.5	Recommended Management Interventions.....	106
5.5.1	Role of Fire	107
5.5.2	Grazing and Resting.....	108
5.5.3	Re-seeding	109
5.5.4	Protein supplementation	110
5.5.5	Fodder Crops (Vetch and Oats)	110
5.6	Collective management for improved LWP	111
6	Conclusion	115
	References	119
	Appendices	153
	Appendix 1: Plates	153
	Appendix 2: Full Feed Analysis	167

List of Tables

Table 3.1: Dates of grass clippings used in full feed analyses (Sites 1 -3)	62
Table 3.2: ANOVA results for the regression between Disc Metre Height (cm) and Mean Biomass (t ha ⁻¹)	63
Table 4.1: Species composition and veld condition scores of Sites 1, 2, and 3 in Ntshiqo	76
Table 4.2: The Percentage of the Ecological Status of Grasses, for Sites 1-3	77
Table 4.3: Comparison of the Veld Condition Scores, Potential Grazing Capacities and Current Grazing Capacities for Sites 1-3	78
Table 4.4: Mean biomass (t ha ⁻¹) produced at the peak (May) and end of the growing season (August), in the exclosures and grazed areas for Sites 1-3	82
Table 4.5: Summary table comparing the mean ADF (%) values produced in summer (February), winter (June) and spring (October) in the exclosures and grazed areas for Sites 1-3	83
Table 4.6: Summary table comparing the mean NDF (%) values produced in summer (February), winter (June) and spring (October) in the exclosures and grazed areas for Sites 1-3	85
Table 4.7: Mean CP (%) values produced in summer (February), winter (June) and spring (October) in the exclosures and grazed areas for Sites 1-3	87
Table 4.8: The mean P (%) values produced in summer (February), winter (June) and spring (October) in the exclosures and grazed areas for Sites 1-3	89
Table 4.9: Biomass (t ha ⁻¹) produced in a short and full summer rotational resting experiment	92
Table 4.10: The mean ADF, NDF, CP and P (%) values in a short and full summer rotational resting experiment	93
Table 4.11: Mean body condition scores of sheep in a control (n=50) and treatment (protein lick, n=54) over four months (June - September).....	96
Table 4.12: ADF, NDF, Crude Protein and Phosphorus values for vetch and oats	97

List of Figures

Figure 2.1: The LWP framework for mixed crop-livestock systems (Descheemaeker <i>et al.</i> 2010a).....	23
Figure 2.2: The integration of biophysical and socioeconomic interventions to improve LWP (Descheemaeker <i>et al.</i> 2009).....	27
Figure 2.3: Components of an innovation system for improved LWP (Amede <i>et al.</i> 2009).....	28
Figure 3.1: Locality of the Ntshiqo case study community in South Africa	51
Figure 3.2: Depiction of the exclosures and grazed areas for Sites 1-3 in Ntshiqo.....	59
Figure 3.3: Depiction of Area 1 and 2 of the Rotational Resting Experiment in Ntshiqo.....	61
Figure 3.4: Combined calibration graph (n=162) illustrating Disc Metre Height (cm) and Mean Biomass (t ha ⁻¹)	63
Figure 3.5: Body Condition Score 1 (Emaciated).	66
Figure 3.6: Body Condition Score 2 (Thin).....	66
Figure 3.7: Body Condition Score 3 (Average).....	66

Figure 3.8: Body Condition Score 4 (Fat).....	66
Figure 3.9: Body Condition Score 5 (Obese)	66
Figure 4.1: Site 1: Mean (\pm se) biomass for exclosures and grazed areas over time.....	80
Figure 4.2: Site 2, mean (\pm se) biomass for exclosures and grazed areas over time	80
Figure 4.3: Site 3, mean (\pm se) biomass for exclosures and grazed areas over time	81
Figure 4.4: Mean biomass comparisons between 9 replicates of paired samples of exclosures and grazed areas in (a) – peak of growing season (May), and (b) – end of growing season (August) (1 = Site 1, 2 = Site 2, 3= Site 3)	82
Figure 4.5: Comparison between the mean ADF values in 9 paired samples of exclosures and grazed areas in (a) summer (February), (b) winter (June) and (c) spring (October).....	84
Figure 4.6: Comparison between the mean NDF values in 9 paired samples of exclosures and grazed areas in (a) summer (February), (b) winter (June) and (c) spring (October).....	86
Figure 4.7: Comparison between the mean CP values in 9 paired samples of exclosures and grazed areas in (a) summer (February), (b) winter (June) and (c) spring (October).....	88
Figure 4.8: Comparison between the mean P values in 9 paired samples of exclosures and grazed areas in (a) summer (February), (b) winter (June) and (c) spring (October)	90
Figure 4.9: Mean (\pm se) biomass in the rotational resting treatment for a short and full summer rest.....	91
Figure 4.10: Mean biomass (t ha^{-1}) values for a short and full summer rotational resting experiment.....	92
Figure 4.11: Figure 4.11. Mean (a) ADF, (b) NDF, (c) CP and (d) P (%) values for a half and full summer rotational resting experiment	94
Figure 4.12: Mean (\pm se) body condition scores for sheep in a control and treatment over time (June - September)	96

List of Boxes

Box 3.1: Veld Condition and Current Grazing Capacity calculations for Site 1	77
--	----

List of Plates

Plate 3.1: Livestock Working Group	153
Plate 3.2: Levy Bridge	153
Plate 3.3: Site 1, Exclosure 1	154
Plate 3.4: Site 1, Grazed 1.....	154
Plate 3.5: Site 1, Exclosure 2	155
Plate 3.6: Site 1, Grazed 2.....	155
Plate 3.7: Site 1, Exclosure 3	156
Plate 3.8: Site 1, Grazed 3.....	156
Plate 3.9: Site 2, Exclosure 1	157
Plate 3.10: Site 2, Grazed 1.....	157

Plate 3.11: Site 2, Exclosure 2	158
Plate 3.12: Site 2, Grazed 2.....	158
Plate 3.13: Site 2, Exclosure 3	159
Plate 3.14: Site 2, Grazed 3.....	159
Plate 3.15: Site 3, Exclosure 1	160
Plate 3.16: Site 3, Grazed 1.....	160
Plate 3.17: Site 3, Exclosure 2	161
Plate 3.18: Site 3, Grazed 2.....	161
Plate 3.19: Site 3, Exclosure 3	162
Plate 3.20: Site 3, Grazed 3.....	162
Plate 3.21: GPS data collection (Trimble GeoExplorer 6000 Series).....	163
Plate 3.22: Disc Pasture Meter	163
Plate 3.23: Disc Pasture Meter Ring	164
Plate 3.24: Conducting grass clippings	164
Plate 3.25: Body Condition Scoring of Sheep	165
Plate 3.26: Protein lick (Multi Block 28).....	165
Plate 3.27: Sheep eating the Protein lick.....	166
Plate 3.28: Vetch and Oats (winter fodder crop)	166

1 Chapter One Introduction

Livestock production has a direct influence on food supply and nutrition security worldwide (Smith *et al.* 2013). Apart from food production, livestock offer value in terms of transport, draught, support of cultural values and to increase smallholder farmers' resilience against external shocks and stresses such as drought, water scarcity and climate change, and crop failure (Descheemaeker *et al.* 2009; Molden *et al.* 2010; Thornton and Herrero, 2015). Livestock are considered essential assets and create important livelihood strategies for people living in smallholder farming systems in developing countries (Descheemaeker *et al.* 2010a; Notenbart *et al.* 2013). The livestock sector is the most rapidly growing agricultural sub-sector and contributes to 40% of the gross value of agricultural production throughout the world (Parthasarathy Rao *et al.* 2005).

Within sub-Saharan Africa, livestock productivity is low due to numerous reasons such as poor quality feed, low-yielding breeds, lack of water resources for drinking, disease occurrence, livestock mortality, lack of technology, and additionally a lack of land and credit (Anteneh *et al.* 1988; Descheemaeker *et al.* 2010a). A lack of credit (financial access) constrains these smallholder farmers to take out required loans, to help fund farming operations such as buying fertilizer and machinery. Dovie *et al.* (2006) state that low returns of livestock production are due to a lack of empirical case studies. Studies within developing countries (Barrett *et al.* 2002, Tittone *et al.* 2009) indicate that smallholder farming systems are inefficient and resource poor, and are vulnerable to changes in external variables in the market, biophysical and institutional environments. However, farmers within mixed crop-livestock systems produce about half of the world's food, hence making these systems vital for livelihood purposes (Wright *et al.* 2012). Within developing countries, these systems support almost two billion people, half of which are poor and the majority being smallholder farmers (Wright *et al.* 2012).

In the smallholder farmers' context, mixed crop-livestock systems contribute significantly to peoples' livelihoods (Descheemaeker *et al.* 2011). According to Herrero *et al.* (2009), mixed crop-livestock systems are responsible for producing 65% of beef, 75% milk and 55% of the lamb produced in developing countries. Over two thirds of the human population live in mixed farming systems¹ (Descheemaeker *et al.* 2011). Within some small-scale mixed farming systems, the output of animal products are higher per unit input compared to

¹ Mixed farming systems refer to mixed smallholder crop-livestock systems

grassland-based or industrial-based systems (Sere and Steinfeld, 1996). This highlights the importance of livestock within the smallholder farming systems (Waters-Bayer and Bayer, 1992; Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a; Descheemaeker *et al.* 2011).

Water scarcity is an ever-growing concern worldwide, increasing livelihood vulnerabilities especially within the dryland smallholder farmer context (Descheemaeker *et al.* 2010b). It is estimated that two-thirds of the worlds' population will live in water stressed environments by 2025 (Maurya *et al.* 2014). The interaction between water and livestock is crucial as livestock production requires much water for feed production and drinking purposes (Descheemaeker *et al.* 2010b). Livestock systems contribute strongly to the livelihoods of people within developing countries, however, due to increasing water scarcity and water competition by numerous users, meeting increasing food demands for an expanding population remains a serious challenge (Descheemaeker *et al.* 2011). In the face of water scarcity and climate change, it is important to meet food requirements of growing populations without further depleting already scarce water supplies (Descheemaeker *et al.* 2010b). Therefore there is a need or opportunity to improve water productivity in livestock production systems which can benefit the environment and the livelihoods of people (Bossio, 2009; Cook *et al.* 2009).

Livestock water productivity (LWP) is defined as the ratio of the sum of the net benefits derived from livestock compared to the volume of water depleted used to produce these benefits (Peden *et al.* 2008; Peden *et al.* 2011). The concept of LWP was introduced by Peden *et al.* (2007) to investigate and find ways to increase livestock production, but simultaneously reduce the water utilised per unit output (Amede *et al.* 2009). Much water is depleted worldwide for livestock production which cannot be used again (Peden *et al.* 2011). A framework is proposed by Descheemaeker *et al.* (2010a) for smallholder mixed crop-livestock systems which investigate interventions that can improve LWP. These are classified into technical strategies, supportive institutions, and enabling policies (Amede *et al.* 2009). The technical interventions can be classified into three categories namely feed, water and animal management (Peden *et al.* 2007; Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a). Supportive institutions are rules which govern society and inform decision making (Arellano *et al.* 2011). They can be classified as rules which monitor the technical interventions. The policy environment is there to support technical interventions and institutional structures which are important for the success of LWP (Amede *et al.* 2009). It is of no use to implement various management strategies (water, soil, vegetation) without creating supporting institutional or policy changes which manage and promote the success

these interventions (Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2011). It is thus important to adopt a holistic approach which integrates the various interventions to efficiently promote LWP (Descheemaeker *et al.* 2009; Amede *et al.* 2009; Descheemaeker *et al.* 2011, Peden *et al.* 2011).

1.1 Research Statement

Theoretical strategies have been proposed for improving LWP, however, there is a need for real-world assessment on the effectiveness of such interventions (Descheemaeker *et al.* 2010b). A knowledge gap exists in the amount and feed quality of forage required for livestock in different seasons and regions, in smallholder mixed crop-livestock systems in developing countries (Descheemaeker *et al.* 2009). Furthermore, there is limited research on resting in communal rangelands (Shackleton, 1993). There is a lack of knowledge on the conversion efficiency of various feed types, by different species of livestock (Descheemaeker *et al.* 2009). To improve LWP, a better understanding of livestock-water interactions is required (Peden *et al.* 2009). Additionally numerous management decisions fail due to a lack of information on the availability of water resources, frequency of watering, management, the control over access and its impact on LWP (Duguma *et al.* 2011). Therefore increased knowledge is required on the impact of vegetation, land and grazing management on runoff production. Research needs to identify incentive mechanisms for communities to enhance the adoption and invest in land and water management strategies which improve LWP (Peden *et al.* 2009). It should also be acknowledged that while there is a need for additional research on feed quantity and quality aspects in the rangelands of smallholder mixed crop-livestock systems, institutional and policy components also require further investigation and integration (Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2011). Furthermore, there is a lack of concrete information on the potential effects of the integration of various technical, institutional and policy interventions on LWP in developing countries (Descheemaeker *et al.* 2011).

The current research focuses on the feed management component of the LWP in the case study community of Ntshiqo, which can be sub-divided into feed type selection, feed quality, feed water productivity and grazing management. Feed type selection, assesses the suitability of different feed types in terms of their water productivity (Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a), and feed quality emphasises the importance of forage quality in livestock production (Descheemaeker *et al.* 2010a). The rangeland in the smallholder mixed farming system of Ntshiqo, is classified as sourveld, which is veld in which forage plants

become unacceptable and less nutritious after maturity, making the grass only grazeable for certain periods of the year (Trollope *et al.* 1990). Supplementary feeding can be seen to improve forage quality and hence livestock production and LWP in smallholder farming systems (O'Reagain and Mentis, 1988; Van Niekerk and Jacobs, 1985; Assefa and Ledin, 2001; Sprinkle, 2001). Feed water productivity reviews ways to improve feed water productivity namely through crop, soil and water management (Peden *et al.* 2007). Grazing management promotes interventions such as resting and reduced animal numbers to improve vegetative ground cover, vigour of plants and species composition of plants (Kirkman and Moore, 1995; Tainton and Danckwerts, 1999; Navarro *et al.* 2006). Specifically, the research focuses on the feed quality and grazing management components in relation to feed management of the LWP framework, in the smallholder mixed crop-livestock system of Ntshiqo, hence filling an important research gap. Feed type selection and feed water productivity are mentioned but are not the focus. These technical interventions can aid in the management of livestock, land and water management, which are important in the livelihoods of smallholder farmers, and are crucial in improving LWP in smallholder farming systems in developing countries (Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a, Descheemaeker *et al.* 2011).

1.2 Research Questions

This dissertation raises several questions, namely:

- i. What is the mean difference in forage quantity (t ha^{-1}) across 9 replicates of paired samples of exclosures and grazed areas in the peak of growing season (May) and the end of growing season (August)?
- ii. What is the mean difference in forage quality (ADF, NDF, CP, P %) across 9 replicates of paired samples of exclosures and grazed areas in summer (February), winter (June) and spring (October)?
- iii. What is the mean difference in forage quantity (t ha^{-1}) between a short (October 2014 - January 2015) and full (October 2014 - June 2015) summer rotational resting experiment?
- iv. What is the mean difference in forage quality (ADF, NDF, CP, P %) between a short and full summer rotational resting experiment?
- v. Does a protein lick have a significant effect on the body condition of sheep during winter months (June – September 2015)?

1.3 Aim and objectives

The aim is to understand the effect of specific technical interventions on LWP in smallholder mixed crop-livestock systems in South Africa through a case study analysis of Ntshiqo.

The specific objectives of this research are to:

- i. Develop an understanding of the livestock water productivity (LWP) concept and framework against the backdrop of climate change and water scarcity, and critically review documented interventions for improving LWP in smallholder mixed crop-livestock systems in developing countries;
- ii. Analyse the feed management component of the LWP framework by investigating the effect of resting on the quantity and quality of fodder produced from rangelands at the case study site;
- iii. Analyse the effect of protein supplementation on the body condition score of sheep at the case study site and;
- iv. Determine the influence of these specific management interventions on LWP, and the implications for the environment and livelihood dependencies of smallholder farmers.

1.4 Rationale for the Research

LWP is a relatively new concept, hence a gap exists in the published literature due to only limited research having been conducted globally, with an emphasis on sub-Saharan Africa but limited work in South Africa (Amede *et al.* 2009; Hailelassie *et al.* 2009). The current research, aims to find appropriate technical interventions that positively contribute to LWP in mixed smallholder crop-livestock systems in South Africa and thus contribute to filling this gap. It was conducted in collaboration with the Institute of Natural Resources (INR), and funded by the Water Research Commission (WRC), Project K5/2177//4. It is intended that these findings will aid future decision-makers their understanding of LWP, potentially improve production (rangeland and livestock), and ultimately the livelihoods of people and resilience to water scarcity and climate change. As noted, literature and case studies to support the current research are limited in South Africa.

1.5 Structure of the dissertation

The following presents the overall outline and structure of the composed dissertation

Chapter One: Introduction

This chapter provides an overview of current research related to LWP. Additionally, the key themes are outlined here, which are expanded on within the body of the dissertation. The aim and objectives are presented.

Chapter Two: Literature Review

The chapter specifically reviews a plethora of published literature, that explores the role of livestock in smallholder mixed crop-livestock farming systems; water scarcity and the impact of climate change on smallholder farming systems; the LWP concept and framework; followed lastly by interventions for LWP improvement. Different case studies and examples are provided from the smallholder farming context throughout the dissertation in developing countries with a specific focus on South Africa.

Chapter Three: Methods

This chapter provides background information on the locality and settings of the study site. The various biophysical conditions and agricultural potential are described. The methodology chapter describes the research design, with background on the chosen research methods. The techniques utilised in the fieldwork are described. Finally, methodological reflections are presented, which show the limitations of the study and what components of the study were successful.

Chapter Four: Results

This chapter provides the results obtained from implementing the various technical interventions (resting, protein supplementation and fodder crops) of the feed management component of the LWP framework, as informed by and in relation to smallholder farmer perspectives on the implementation of such technical interventions.

Chapter Five: Discussion

The discussion chapter discusses the applicability of these technical interventions in improving LWP. Additionally management interventions are proposed which can aid LWP in the Ntshiqo community and contribute to community resilience to external shocks such as water scarcity and climate change.

Chapter Six: Conclusion

The thesis culminates with conclusions that link back to the aim and objectives. Additionally, the main findings are presented and avenues of future research are outlined.

2 Chapter Two Literature Review

2.1 Introduction

This chapter explores the links between the different components of the LWP framework (Descheemaeker *et al.* 2010a), with a specific focus on feed management interventions (Amede *et al.* 2009). The nature of this research requires an understanding of the technical interventions such as feed, water and animal components affecting LWP, while simultaneously acknowledging the importance of socio-political-economic factors which include supportive institutions and enabling policies.

Due to the interrelated nature of this research this chapter is divided into eight sections and includes case studies from developing countries, but focuses primarily on the South African smallholder farming systems and communal tenure lands. The first section defines smallholder farming systems and the importance thereof in South Africa and developing countries. The second section explores the importance of livestock within the smallholder agricultural context. Around 70% of the sub-Saharan African population are dependent on livestock for their livelihoods, and are considered important strategic assets of poor populations (Stroebe *et al.* 2011). Livestock are thus very important in rural communities and provide numerous benefits which are discussed in greater detail (Waters-Bayer and Bayer, 1992). The third and fourth section focuses on mixed crop-livestock systems in smallholder farming systems. The challenges and opportunities of these systems are critically reviewed and the roles of traditional authorities which manage these communal land systems are highlighted. The fifth section investigates the water sector particularly in terms of demand, scarcity and availability. This section also assesses the impacts of climate change on agriculture. The sixth section defines and explains the LWP concept and framework in depth. The focus of LWP is to improve livestock productivity without contributing further to water scarcity and environmental degradation. The importance of livestock-water interactions is analysed. The seventh section, based on the LWP framework, details the three main interventions that positively affect LWP namely technical factors (animal, feed and water management), institutional dynamics, and the policy environment. This section sets out to synthesize a plethora literature to realise the benefits of improving LWP within the smallholder agricultural context. Better management of natural resources through biophysical strategies, supportive institutions and enabling policies, are key areas which contribute to overall LWP. The final section details the rangeland systems and management elements of the feed component, comprising the technical interventions of the LWP framework.

2.2 Smallholder farming systems

The definition of smallholder farming systems varies between countries and agro-ecological zones (Pienaar, 2013). Numerous terms are associated with the smallholder concept namely: "small-scale", "subsistence", resource-poor", "low-income", "low-input" and "small" (Powell *et al.* 2004; Pienaar, 2013). Machingura (2007) defines smallholder farmers as farm households which have access to land in which family are the primary source of labour to ensure agricultural production for subsistence or market sale. Additionally, smallholder farming systems can be defined on the basis of land and livestock holdings, where cropping generally takes place on less than 2 hectares and only own a few head of livestock (World Bank, 2003; cited in Pienaar, 2013; Salami *et al.* 2010). They can also be defined as households operating on small tracts of land with limited labour (Havemann and Muccione, 2011). Production from these systems tends to be on a subsistence scale for household consumption produced from homestead gardens, demarcated fields or communal rangelands (Aliber and Hart, 2009).

In South Africa, many smallholder farming systems are characterised by dryland agriculture due to the arid and semi-arid nature of the country (Vetter, 2009). Dryland agriculture is defined as agriculture in regions where a lack of moisture limits crop and rangeland production (Stewart *et al.* 2006). In essence, the smallholder farming systems in these water-stressed environments are reliant on rainfed agriculture, making them vulnerable to climatic variables (Stewart *et al.* 2006; Van Averbeke and Khosa, 2007; Thornton and Herrero, 2015).

Smallholder systems in developing countries are important to employment, livelihoods and political stability, and should not be treated as a small, insignificant adjusting sector of a market economy (Delgado, 1999; Russelle *et al.* 2007). Smallholder agriculture is the backbone of rural livelihoods and contributes to economies in many regions (Louw *et al.* 2008). However, numerous challenges need to be overcome and there still exists a need to promote the growth of smallholder farming systems within developing countries (Delgado, 1999). Livestock are important components in the livelihoods of people living in these smallholder farming systems.

2.3 Dependencies on Livestock in smallholder farming systems

Livestock play an important role in the livelihoods of millions of people in smallholder farming systems in developing countries (Marshall *et al.* 2011). Livestock do not serve a single purpose, but rather are an integral part of a smallholder farming systems (Dovie *et al.*

2006). In many developing countries livestock keeping is the main livelihood strategy (McDermott and Arimi, 2002). The livestock sector in South Africa contributes up to 49% of the countries agricultural output (Munyai, 2012). Respectively cattle, sheep and goat production are the most important livestock sub-sectors in South Africa (Ogunkoya, 2014). Global population numbers are expected to increase from 6.5 billion today to 8.2 billion in 2050, of which 1 billion is expected in Africa (Herrero *et al.* 2009). The development of livestock production is essential in the context of sustaining the livelihoods of smallholder families (Waters-Bayer and Bayer, 1992). This section reviews the importance of keeping livestock in smallholder farming systems and the dependence of smallholder farmers. Keeping livestock within the rural context serves as a means to achieve various aims, namely food production, raw materials, production of manure, provision of labour, cultural and social factors. Furthermore, the consequences of the increasing demand of livestock products, through population growth and urbanisation are reviewed.

2.3.1 Food production

Livestock contribute significantly to global food supply by converting low-quality forage into milk, meat and eggs for human consumption (Pratt, 1984; Waters-Bayer and Bayer, 1992; Smith *et al.* 2013; Okungoya, 2014). Animal source foods are nutritionally dense sources of energy, amino acids protein and essential micronutrients which are vital for normal human development, growth and health, and preventing under-nutrition and nutrient deficiencies (Smith *et al.* 2013).

Milk is a vital dietary component for people living in smallholder farming systems as it is rich in fat, protein and energy (Grandin *et al.* 1991). Milk production varies amongst different households and is influenced by factors such as stress factors, parasitic infections and disease challenges (Barrett, 1992). Utilising animals for draught power and transportation does decrease the frequency of lactation (Barrett, 1992). Therefore it is important to establish trade-offs to determine which resources are most valuable in such multipurpose livelihood systems. If milk production is highly valued, then specific livestock should not be utilised extensively for draught power and diets should be improved to more palatable feed with supplements which decrease nutrient deficiencies (Urassa and Raphael, 2004).

Further, livestock are utilised for meat and egg production, which are major sources of protein vital for human diets (Kotula, 1991). In areas where poultry production and consumption is prevalent, protein malnutrition is alleviated especially in vulnerable groups such as pregnant women and children (Pathak and Nath, 2013). Animal-source foods

contribute greatly to dietary and nutrient requirements within the smallholder farming systems.

As with most developing countries, livestock production contributes significantly to food security in South Africa (Meissner *et al.* 2013; Ogunkoya, 2014). There are about 38 500 commercial farmers and 2 million smallholder farmers in the country (Meissner *et al.* 2013). These traditional smallholder farmers are in the majority and comprise only 17% of the total available farming area, while the commercial farmers comprise the other 83% (Munyai, 2012). The lack of finance to obtain supplementary feed in dry years and the loss of sustainable grazing systems due to overgrazing and climate variability, threaten food productivity in smallholder farming systems (Mapako, 2011; Munyai, 2012).

2.3.2 Raw materials

Livestock are not only useful for providing foodstuffs but provide raw materials which are important within the smallholder agricultural context. These materials include wool, hides and feathers which can be utilized for producing clothing, furnishings and implements for private or selling purposes (Waters-Bayer and Bayer, 1992; Sani, 2009). Hides and skins are important for traditional clothing purposes. The added value of processing the raw materials is a further source of income which aids in financial security for many smallholder farmers worldwide (Waters-Bayer and Bayer, 1992; Stroebel, 2011).

Wool production plays a key role within smallholder farming systems. Wool can be utilized for purposes such as clothing and carpets (Pratt, 1984). Wool can also be sold and provide much needed revenue. In South Africa, smallholder wool farmers currently supply 12% of the national wool clip mainly supplied from the Eastern Cape and KwaZulu-Natal (De Beer, 2012). Due to this percentage being low, the National Wool Growers Association has implemented a program since 1997 to improve the quantity and quality of wool produced in communal land areas. The project aims at upgrading existing and constructing new shearing sheds, equipment and dipping facilities; marketing support; genetic improvement of communal sheep and providing a higher degree of training (De Beer, 2012). Improving the genetic make-up of sheep is one of the most important aspects of the project. Rams of inferior genetic make-up are removed and replaced by quality rams (about 3000 rams per annum) from two commercial breeding types (De Beer, 2012). By improving the genetic make-up of sheep, the quality of wool can be improved thereby generating higher revenue for smallholder sheep farmers. This initiative has yielded positive results allowing smallholder farmers to participate in the export market with commercial farmers and earning foreign currency (De

Beer, 2012). This has huge potential for smallholder farmers, however, needs to be expanded nationwide to upscale the benefits. Progress has been made for wool growers in communal areas. In the 1997/8 season the Eastern Cape's communal wool farmers sent 222 610kg of wool to the formal market and earned R1.5 million. In 2013/4 they sent 3.8 million kilograms and earned R138 million. Additionally, these farmers are producing much finer wool with an average of 19 microns. This has improved the quality of the wool and these communal farmers are hence achieving market prices. These are positive signs for communal wool growers in South Africa (Dugmore, 2015).

2.3.3 Production of manure

The production of livestock manure is important for cropping purposes in mixed-crop livestock systems. Livestock manure, which is a mixture of faeces, urine and feed refusals is beneficial to crop growth and improves soil fertility, due to their nutrient rich content (Tanner *et al.* 2001; Ndlovu and Mugabe, 2002). Manure is a freely available resource, which is important to smallholder farmers for fertilising their crops and lands (Sani, 2009; Thornton and Herrero, 2015). According to Somda *et al.* (1995; cited in Tanner *et al.* 2001), manure contains nutrients, namely phosphorus, potassium and nitrogen, which are more readily available to plants than would be if plant biomass was directly recycled to the soil. Furthermore, it increases the soil organic matter content which enhances productivity (Ndlovu and Mugabe, 2002). Manure is key in ensuring nutrient levels especially in areas where rotational cropping is not possible (Waters-Bayer and Bayer, 1992; Castellanos-Navarrete, 2014). However the use of manure is recommended with inorganic fertilizers to account for any nutrient deficiencies.

In South Africa, dryland smallholder farmers mainly utilise animal manure to maintain fertility in their croplands (Okorogbona and Adebisi, 2012). According to Mkhabela (2006), 69% of farmers who used animal manure to manage soil fertility indicated improved soil conditions, crop growth and yields. The use of manure offers those dryland smallholder farmers who are unable to finance commercial fertilizers an avenue to improve soil fertility.

2.3.4 Provision of labour

Farmers in these smallholder systems rely on livestock for the provision of labour (Tarawali *et al.* 2011). Draught animals are utilized approximately for 80% of power used in smallholder farming in developing countries (Chawatama *et al.* 2003). These animals are used for a number of purposes such as ploughing, weeding, pulling loads and transport (Waters-Bayer and Bayer, 1992; Dovie *et al.* 2006; Tarawali *et al.* 2011). These animals

serve an important role in the rural context where mechanisation is not readily available (Thornton and Herrero, 2015). Cows and oxen are seen as the most valued draught animals, however, other important livestock species include horses, donkeys, sheep and goats (Pearson, 1993; Wilson, 2003).

Animal traction is favoured in many developing countries (Tanzania, Kenya, South Africa) due to high costs of mechanisation, related machinery, spare parts and fossil fuels (Preston and Leng, 1987, Wilson, 2003). In South Africa, animal traction is still used today especially in smallholder farming systems (Simalenga and Joubert, 1997). The South African Government has promoted the use of mechanisation in crop production through tractor hire schemes. These schemes have not yielded positive results due to smallholder farmers not being able to afford those (Simalenga *et al.* 2000). Approximately 40-80% of smallholder farmers still utilise animal traction for farming activities (Fowler, 1999).

2.3.5 Resilience against external shocks, source of security, cash, investment and insurance

Rural households in developing countries are at risk from drought, poverty, income shocks and crop failure (Paraiwa, 1992; Kazianga and Udry, 2006). Livestock can be utilized to shield households from such risks by improving resilience against external shocks and acting as a source of security and insurance (Kazianga and Udry, 2006; Vrieling *et al.* 2014). Livestock are utilised to ensure survival of households when various other livelihood strategies fail (Waters-Bayer and Bayer, 1992).

Often smallholder farmers do not have access to financial markets and banks (Stroebe *et al.* 2011), hence livestock serve an important function as a living savings account, producing offspring as interest (Waters-Bayer and Bayer, 1992; pg 7). This savings account can be sold or converted into cash as required (Stroebe *et al.* 2011) and can act as insurance for emergency expenditure (Tarawali *et al.* 2011). Cash income can be generated through the sales of animals, their products (milk, eggs, meat) and their services. This cash can be used to buy staple foods and basic household products, fertilizer, cover medical costs or house repairs (Water-Bayer and Bayer, 1992; Smith *et al.* 2013). Income from livestock sales is an integral part of livelihoods in smallholder farming systems, which contributes over 25% of total incomes in all the food security categories in southern Africa (Munyai, 2012).

A study conducted in Lesotho by Swallow and Brokken (1987; cited in Waters-Bayer and Bayer, 1992) indicated that investing in cattle (income produced from crops) earned an equivalent of a 10% interest rate, whereas a bank account lost 10% due to inflation. A huge

advantage of livestock is that they can be sold at any time of the year compared to crops which are highly seasonal (Stroebe *et al.* 2011). Therefore it is evident that smallholder farmers rely heavily on livestock as a source of security, cash, insurance and investment against external shocks.

2.3.6 Cultural and social factors

Cattle also play an important cultural and spiritual role within rural communities (Barrett, 1992). Cattle numbers are highly important when the traditional practice of bride payment known as Lobola takes place (Kunene, 1992). Lobola is custom practised by numerous Southern African countries (South Africa, Botswana, Zimbabwe, Swaziland) used to seal a relationship between two people who plan on getting married and their families or clans (Heeren *et al.* 2011). Cattle or livestock are also utilised as gifts to people either for a ceremony, during illness, while visiting or due to friendship (Grandin *et al.* 1991). Therefore it is evident that livestock play an integral part in social and cultural aspects of various developing countries. Growing populations have increased the pressure on livestock production on a global scale (Thornton and Herrero, 2010).

2.3.7 Consequences of population growth and urbanisation

Despite the importance of livestock in developing countries, livestock productivity has remained stagnated over the last 40 years. Numerous structural (poor infrastructure), technological (low availability and use of modern technology such as IT) and institutional weaknesses (weak markets, credit, insurance) and high poverty rates are reasons for low livestock productivity (Hassan, 2010). This is a worrying statistic as population growth and demand for livestock products continue to rise in developing countries (Thornton and Herrero, 2010). Research has primarily focused on livestock in developing countries, therefore major improvements in livestock productivity are possible which could contribute to economic growth and satisfy the need of growing populations (Nin, 2007).

It is evident that the livestock sector needs to grow to satisfy human consumption, however, trade-offs in the natural resources are also expected (Herrero *et al.* 2009). Rapid population growth could hamper improvements in food security in developing countries (Thornton and Herrero, 2010). Increased demand of livestock products requires a greater input of water and land resources (Ndoro *et al.* 2014). The viability of cattle-based livelihoods are threatened by the competition of natural resources such as land and water (Ndoro *et al.* 2014). If these resources are not managed in a sustainable manner, they will not be able to satisfy future

population needs. Therefore both livestock and the resources upon which they depend require careful management to ensure sustainable production (Lemaire *et al.* 2014).

Livestock production is important and upon which many livelihoods depend, especially in developing countries (Ndoro *et al.* 2014). However, livestock production often forms part of a bigger mixed-crop livestock system within smallholder farming systems, particularly in developing countries, including South Africa's communal lands.

2.4 Mixed crop-livestock systems

Mixed crop-livestock systems integrate both crop and livestock components into farming operations (Hailelassie *et al.* 2009; Thornton and Herrero, 2015). Historically, crop and livestock have been operationally separated but functionally linked in smallholder farming systems in developing countries (Powell and Williams, 1994). Farmers in mixed crop-livestock systems produce about half of the world's food supply (Wright *et al.* 2012). In developing countries, mixed crop-livestock systems contribute to the livelihoods of two-thirds of the population, producing a large percentage of the staple food and animal products consumed by people (Valbuena *et al.* 2012). These systems are seen as complementary and competitive at the same time (Parthasarathy Rao *et al.* 2005; cited in Descheemaeker *et al.* 2010a). They are complementary in the sense that crops provide up to 30% of livestock feed and livestock are a sources of draught and fertilizer (Hailelassie *et al.* 2009). Crop residues are an important feed source for livestock in developing countries, where 75% milk and 60% of meat are produced in these mixed systems (Baudron *et al.* 2014). Further, crop residues are important as surface mulch which reduces evaporation, soil water loss and runoff which contribute to conservation agriculture (Baudron *et al.* 2014). However, they compete for land, water and resources (Hailelassie *et al.* 2009). Additionally crop residues are not only utilised for feed purposes but also for mulch, fuel and construction (Valbuena *et al.* 2012). The project adopted by the researcher is centred in mixed crop-livestock in the smallholder farming context, but focuses on the livestock component.

Mixed crop-livestock systems provide opportunities for resource-poor farmers to diversify livelihood strategies and reduce risks (Shackleton *et al.* 2001; Wright *et al.* 2012). For example, if a crop failure occurs, livestock and livestock products can be sold to generate additional revenue. For instance Tichit *et al.* (2011), show that a herd including goats with a diversity of milk production and feeding regimes offers a win-win situation between production and efficiency. Allred *et al.* (2014) state, that if livestock heterogeneity (different breeds of cattle, sheep and goats) is present, livestock production can be stabilised against

perturbations. Especially in the face of climate change diversified mixed crop-livestock systems appear to be a path forward for agricultural development (Lemaire *et al.* 2014). According to Ryschawy *et al.* (2012), these systems are considered to be a good way to achieve sustainable intensification of agricultural systems. Hence these mixed crop-livestock systems characterise most smallholder farming systems in South Africa, including the current case study area, Ntshiqo (Valbuena *et al.* 2012; Thornton and Herrero, 2015).

Smallholder farming systems within developing countries occur within environments of diverse biophysical and socio-economic conditions (Van Wijk *et al.* 2009; Pienaar, 2013). These rural livelihoods can be characterised by diverse economic and social activities which could be either farm or non-farm related (Pienaar, 2013). In South Africa, most rural areas are characterized by smallholder communal land ownership (Neves and Du Toit, 2013).

2.5 Communal lands and Traditional Authorities

Communal lands are characterised by resources (rangelands, water) which are communally owned as opposed to private ownership (Everson and Hatch, 1999). These lands support the majority of the rural population in South Africa (Tau, 2005). Traditional authorities are responsible for the effective management of communal natural resources (Tau, 2005).

Traditional leaders are people which occupy communal leadership positions influenced by strong historical cultural values, who direct the affairs of specific communities (Keulder, 2000). Suitable candidates with proven track records are appointed and installed in line with their native laws to act as custodian of their people's norms, cultures, traditions and practices (Peter, 2014). The basis or legitimacy of traditional authority is tradition which includes inherited culture and way of life, people's history, social and moral values and traditional institutions² (Keulder, 2000). Historically, the African people practiced no other form of governance than traditional leadership (Peter, 2014). Today, traditional authorities are important institutions and play important roles in the day-to-day administration of areas in which smallholder agriculturalists reside (Tlhoale, 2012). Traditional leaders have the final say in terms of not only who has access to land, but also in terms of quantity and the authority of dismissing people from land (Khan and Lootvoet, 2001). Traditional leadership is a facilitatory democracy more focused on issues than rigidified processes (Sithole and Mbele, 2008). Any issues experienced in a community typically within homesteads (where families

² Institutions are the rules of the game and if designed correctly, people will follow them and change their behaviour accordingly. They govern society and inform decision making (Arellano *et al.* 2011).

live), the cropping fields and common property (livestock grazing) can be forwarded to traditional authorities i.e. breaking of local laws (intentional fire, stock theft), allocation of new land, compilation and implementation of new laws. For centuries smallholder farmers have invented locally adapted and diverse agricultural systems, managing them with ingenious practices that promote both food security and conservation of agrobiodiversity under traditional authority (Altieri, 2004). In South Africa, large population percentages reside in areas still governed by traditional authority (Meer and Campbell, 2007). Traditional authorities need to transform and evolve with time to reduce negative aspects and increase positive aspects to promote solid input into the lives of smallholder farmers. Smallholder farmers rely on effective governance of traditional authority due to the lack of support from agricultural departments and extension support (Williams *et al.* 2008, Ogunkoya, 2014).

Despite the importance of traditional authorities in smallholder agricultural communities, there are numerous negative aspects. Firstly, these systems do not provide everyone an equal right to be elected, with no apparent avenues to rule against unfair exercise of power (Sithole and Mbele, 2008). Secondly, traditional leadership can be seen as detrimental to women's rights to equality in rural areas. According to Sithole and Mbele (2008), these systems favour men via systems of inheritance. In traditional courts, women are not allowed to preside over or participate in the proceedings except as litigants assisted by men. Hence the creation of a democratic environment can be compromised. Thirdly, traditional authorities can be seen as "self-centred", making decisions to promote self-gain i.e. creating advantageous relationships with the elites (Sithole and Mbele, 2008). Lastly, due to indigenous knowledge and the inheritance of traditional farming practices, these authorities may not encourage the implementation of new farming techniques which could improve productivity.

Smallholder mixed-crop livestock systems under traditional authority are ultimately reliant on rainfed agriculture. This has its challenges as crop and livestock production is dependent on climatic variables. The following section reviews smallholder farming systems in the face of water scarcity and changing climates.

2.6 Water Scarcity, Demand and Availability

Water scarcity is a real threat to food production for millions of people in arid and semiarid areas of developing countries (Tulu, 2006; Helmreich and Horn, 2009). Water scarcity means limited access to water, where the demand for water is higher than the ability of water supply (Milda, 2009). Water is a critical natural resource and without it, human and natural resources cannot be sustained (Rajabu, 2005). Approximately two billion people are currently living in

highly water stressed environments and the situation is likely to worsen in the future as regions are subject to more extreme climatic conditions and a higher water demand (Hejazi *et al.* 2014). In many developing countries, inhabitants rely on rain-fed agriculture to sustain their livelihoods, emphasizing the importance of water (Kahinda *et al.* 2007). It is often not the total amount of rainfall that affects the success of crop and livestock production, but rather the variability of rainfall events (Biazin *et al.* 2012). A region can receive a substantial rainfall event, however, if followed by several months of no rain, this area would experience water scarcity. This is a major problem which many poor countries in semi-arid regions are faced with, where rainfall is their only source of water, to sustain their livelihoods. This section reviews the increasing demand of water globally; climate change and rainfall variability. The impacts of climate change on smallholder farming systems and related adaptive measures are reviewed in developing countries and with emphasis on the South African context.

2.6.1 Increasing demand

Water is emerging as the most critical issue facing humanity, as no human, plant or animal can live without it (Hinrichsen and Tacio, 2002). The supply of freshwater is limited, with both the world's population and demand for the resource continuously increasing (Hinrichsen and Tacio, 2002). Abramovitz (1996) states, that humans are withdrawing water far faster than it can be recharged, hence unsustainably 'mining' a resource which was once a renewable resource. During this century, water usage through depletion and pollution (sewage, toxic chemicals, oils and industry effluent) has increased sixfold, twice the rate of population growth (Milda, 2009). Rising standards of living, which bring amenities such as running water to homes drastically increase water use globally (Hinrichsen and Tacio, 2002). The agricultural sector is the leading consumer of water, contributing 70% of global water consumption (Bonsch *et al.* 2015). If the growth in demand is not curbed, it is estimated that two thirds of the world's population could be living in countries with enormous scarcity of freshwater by the year 2025 (McKenzie and Bhagwan, 1999; Milda, 2009). A sufficient water supply is essential for meeting basic human needs, for the functioning of various sectors of the economy and for agricultural production in smallholder farming systems (Savenije and van der Zaag, 2002; Hejazi *et al.* 2014).

2.6.2 Climate change and rainfall variability

Rainfall variability has often been related to the process of climate change. Climate change is the alteration or change of regular or standard weather conditions (Thornton and Herrero,

2015). The effects of climate change have become noticeable, through increased temperatures and erratic rainfall, experienced over the last three decades, worldwide (Youn *et al.* 2012). It has the potential to increase the natural extreme weather events, such as extended drought periods, hurricanes, floods and severe thunderstorms. Additionally, it can increase evaporation and evapotranspiration, hence possibly increasing agricultural vulnerability in various regions (Youn *et al.* 2012). Climate change can be explained or thought to be caused by natural or anthropogenic causes (IPCC, 2001; Ogunkoya, 2014, IPCC, 2014).

There has been an on-going debate whether climatic changes have been caused by anthropogenic causes or purely due to natural climate variability (Corti *et al.* 1999; Desler *et al.* 2012). Data in the Northern hemisphere has been found depicting that recent climate change has been due to natural atmospheric circulation variability (Desler *et al.* 2012). Natural factors or processes such as volcanic eruptions and changes in solar irradiance have been found to influence climatic variability (IPCC, 2001; IPCC, 2014). According to the IPCC (2007b), climate changes of at least seven centuries before 1950 were unlikely to be caused by natural variability in the climate systems alone. Anthropogenic climate change is due to human-induced influences, such as fossil fuel burning, aerosol use and an increase in greenhouse gas concentration, within the atmosphere (Rosenzweig *et al.* 2008; IPCC, 2014). It is very unlikely that global climate change has been caused only by natural causes alone (IPCC, 2007b; IPCC, 2014). It is likely that anthropogenic factors have contributed to the early 20th century warming (IPCC, 2007b). Therefore climate change can be caused by human or unnatural processes (IPCC, 2001). However, quantifying and predicting climatic change remains a difficult process (Allen, 2000).

A study was conducted in South Africa which made use of four General Circulation Models (GCMs) predicting the impacts of climate change that would be experienced in the year 2050 (Turpie *et al.* 2002; Rumsey and King, 2009). All four predicted that temperatures are going to rise between 2-6 °C (Rumsey and King, 2009), with the biggest increase experienced in the north-central parts of South Africa (Turpie *et al.* 2002). Rainfall patterns were also predicted to vary 5-10% from current rainfall (Rumsey and King, 2009), impacting on the hydrological functions within South Africa. Increasing temperatures and altering rainfall patterns promote the spread of arid areas, increasing the risk linked to rain-fed agriculture in smallholder farming systems (Turpie *et al.* 2002; Stringer, 2009).

2.6.3 Impacts on the agricultural sector and smallholder farmers

One major challenge of the current century lies in the increase and security of food and agricultural production in the context of climate change (Bär *et al.* 2015; Martin and Magne, 2015). Most agricultural activities worldwide are ultimately reliant on rainfall in an attempt to sustain their crop production (Biazin *et al.* 2012). Water resources are important in crop and livestock production as they require much water to grow (Bär, 2015). As noted, in many developing countries, communities often practice smallholder rainfed agriculture as a means to sustain their livelihoods within communal land (Motsi *et al.* 2004). These farmers are often additionally located on marginal land and are limited by various socioeconomic and demographic factors, hindering their ability to adapt to climate change and rainfall variability (Morton, 2007). Many families within developing countries, rely solely on their crop production within a particular season for food or income (Lybbert and Sumner, 2012). If a certain crop is subjected to natural disasters, such as extended drought periods or a hailstorm, these families or communities are subject to great vulnerability (malnutrition, poverty). Climate change poses a threat, which constrains smallholder farming systems in developing countries because of extreme weather events, water scarcity and climate variability (Stringer, 2009; Turpie and Visser, 2012).

Solar radiance, temperature and precipitation are the main drivers or factors that affect crop growth and hence production (Rosenzweig *et al.* 2001). Through fluctuations of these factors, crop production in smallholder farming systems may not produce sufficient outputs. Through the effect of climate change and warming temperatures (IPCC, 2014; Thornton and Herrero, 2015), certain weed species, diseases and pests are expected to move to higher altitudes and affect a greater proportion of crops worldwide (Sutherst and Maywald, 1990; Dahlstein and Garcia, 1989; cited in Rosenzweig *et al.* 2001). Globally, diseases account for 9-16% of agricultural losses in various crops such as maize, rice, soya, potato, wheat and barley (Chakraborty *et al.* 2000). South Africa is already a high risk cropping environment due to frequent droughts and erratic rainfall patterns, making the country more susceptible to climate change damages (Deressa *et al.* 2005; Gbetibouo and Hassan, 2005; Turpie and Visser, 2012). Maize production which contributes about 70% of the total grain production is estimated to fall by up to 20% in the next 50 years (Rumsey and King, 2009). Maize is an important feed source for livestock, hence negatively affecting livestock production (Ogunkoya, 2014). Pests and diseases which threaten maize production are estimated to increase due to warmer temperatures (Rumsey and King, 2009). Significant correlations have

been found between higher historical temperatures and reduced dry-land staple production, with a predicted fall in net-crop revenues by as much as 90% by 2100 (Enete and Amusa, 2010). Rangelands in South Africa are expected to decline in productivity due to changing rainfall patterns and temperatures. Additionally, diseases will spread which has a negative impact on cattle production in South Africa (Rumsey and King, 2009). Smallholder farmers in South Africa are expected to be most vulnerable, as they have limited resources to mitigate risks of climate change (Turpie and Visser, 2012). Rangelands comprise an important component of this research.

On the contrary, some positive impacts through climate change have been observed. Due to increasing temperatures, sowing may be completed earlier, the risk of freezing decreases and plant productivity can be enhanced (Bär *et al.* 2015). According to Johnston (2014), maize production is likely to increase in South Africa (Johnston, 2014). There has been limited research conducted on the effect of climate change on agricultural production in South Africa and also globally, hence there is a need for more research (Deressa *et al.* 2005; Gbetibouo and Hassan, 2005).

There is evidence suggesting, that the negative effects of climate change on agricultural production are more common than positive impacts (Rumsey and King, 2009; Moyle *et al.* 2013; IPCC, 2014). Therefore it is vital to gain an understanding of these changes associated adaptation, in an attempt to reduce vulnerabilities within developing countries. The impact of water scarcity can be reduced by conservation, optimum utilization and efficient management of the scarce resource (Duguma *et al.* 2011). Crop growth models based on data retrieved from controlled agronomic experiments have been utilised to determine the response of crops to different climatic conditions (Hassan, 2010). Furthermore, vulnerabilities caused by climate change can be reduced by sufficient water governance institutions (Lynch, 2012).

In South Africa, climate change impacts will not be uniform across the vastly different agro-ecological regions of the country, hence highlighting the importance of formulating adaptation strategies (Gbetibouo and Hassan, 2005; Rumsey and King, 2009). The national strategy proposes that intensive modelling studies and scenario analyses should be conducted to determine areas of specific vulnerability to climate change, and hence develop adaptive measures accordingly (Rumsey and King, 2009). Unfortunately, limited concrete action plans have been initiated or implemented (Rumsey and King, 2009). According to results obtained from Gbetibouo and Hassan (2005) where climate change scenarios were modelled, adaptive measures would include distinct alterations in farming practices such as shifts in crop

calendars and growing seasons, alternating between crops or removing field crops from various areas. Planting different crop varieties; changing the dates of planting and harvesting; the use of irrigation; and water and soil conservation techniques are additional adaptive measures (Turpie and Visser, 2012). Introducing new drought tolerant crop varieties could improve agricultural production in changing climates (Turpie and Visser, 2012). Additionally, the use of mulching will reduce soil temperature and ensure less water is lost through evaporation, reducing the need for irrigation (Johnston, 2014). Adaptation techniques in livestock systems can include the provision of shade, altering of feeding schedules, and introducing new breeds which perform better in changing climates (Ogunkoya, 2014). Successful implementation of adaptation strategies can reduce production risk and the negative effects of climate change and secure food security especially in smallholder farming systems (Turpie and Visser, 2012; Johnston, 2014). The researcher aims to promote the adoption of suitable technical interventions that will improve livestock water productivity (LWP) and hence reduce vulnerabilities of smallholder farmers to changing climates in Ntshiqo.

2.7 Livestock Water Productivity (LWP)

Improving water productivity is a critical response to growing water scarcity, especially for smallholder livestock production systems. Water is considered ‘depleted’ when it flows to an area where it cannot be readily reused, becomes evaporated, heavily polluted or used within a product (Seckler, 1996; Molden *et al.* 2010). Water productivity (WP) is defined as the net return for a unit of water which is utilized (Molden *et al.* 2010). To measure the productivity of any input used in production, one calculates the value of total output per a unit of input used in that specific production process (Tulu, 2006). Water productivity can be used as an indicator for sustainable agricultural intensification which can be expressed in physical or economic terms (Erkossa *et al.* 2014). It enables the assessment of interactions between different components (livestock and crop) and creates an enabling environment for a better understanding of system efficiency (Peden *et al.* 2009). The following formula can be utilised to calculate water productivity.

$$\text{WP} = \frac{\text{the sum of values of all outputs produced using water as input}}{\text{quantity of water depleted in the production}}$$

Improving water productivity is important in agricultural terms, especially in developing or subsistence dryland agriculture where drought or climate variability as previously asserted,

has major effects on production. There are a number of reasons which support this, namely to meet growing food demands of expanding populations and to contribute to poverty reduction as well as economic growth (Molden *et al.* 2010). Further, more productive uses of water can mean better nutrition for families and more income, in smallholder farming systems (Molden *et al.* 2010). In mixed-crop livestock systems the interactions between livestock and water are also important as livestock production depletes large quantities of water for feed production and is partly responsible for environmental degradation through overgrazing (Descheemaeker *et al.* 2011). Increasing the water efficiency by crops and livestock continue to be topics of concern for developing countries because of the increasing demand for water (Hatfield *et al.* 2001).

Livestock water productivity (LWP) as a concept, is defined as the ratio of livestock outputs, including milk, meat, manure, draught power and transport, over the volume of water used to produce them (Peden *et al.* 2008; Hailelassie *et al.* 2009; Mekonnen *et al.* 2011). It is the net livestock-related benefits which are obtained from the amount water utilized in producing these, which is summarised in the LWP equation (Descheemaeker *et al.* 2010a).

$$\text{LWP} = \frac{\sum \text{Net livestock products \& services}}{\sum \text{Water depleted \& degraded}}$$

The LWP concept was introduced by Peden *et al.* (2007). Therefore it is still a new concept without many criticisms (Amede *et al.* 2009; Hailelassie *et al.* 2009). Therefore there is a gap in the literature due to the limited work that has been conducted on LWP in different regions globally.

From this concept, Descheemaeker *et al.* (2010a) developed a LWP framework. This framework accounts for the multiple benefits received from livestock, as highlighted in section 2.3, the different water flows (inflows and depletion) and other factors influencing LWP (technical and socio-political-economic) (Descheemaeker *et al.* 2010a) (Figure 2.1). It is a framework designed to analyze livestock-water interactions within mixed farming systems. Furthermore, it can be used to account for water use in agricultural systems and illustrate the importance of water productivity concepts for improving effective water use (Sonder *et al.* 2003). The conceptual framework of LWP represents ways to increase livestock production and benefits derived from animals without depleting water resources or causing environmental degradation (Peden, Undated; Peden *et al.* 2009; Descheemaeker *et al.* 2011).

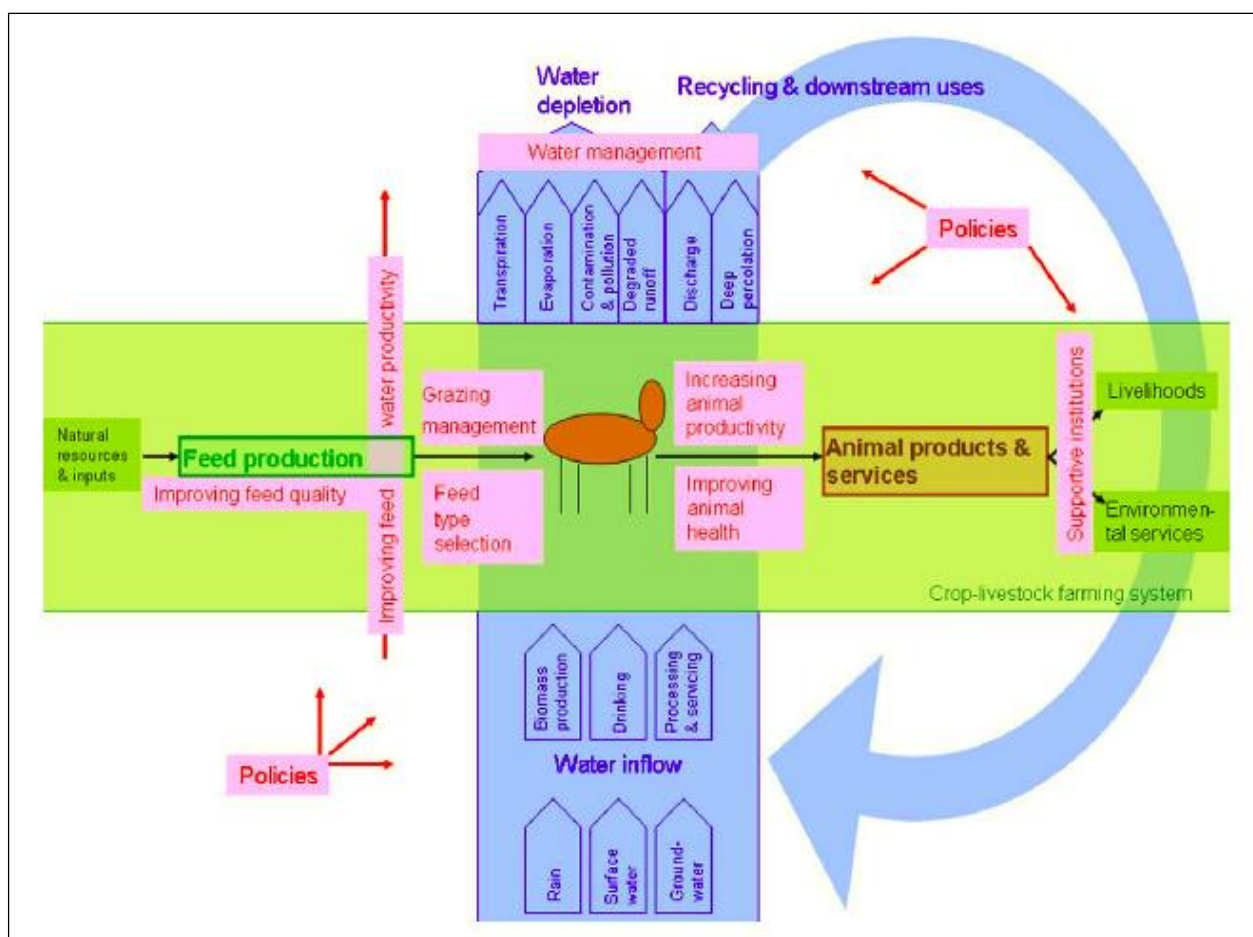


Figure 2.1: The LWP framework for mixed crop-livestock systems (Descheemaeker *et al.* 2010a).

(The green area focuses on the livestock component of the mixed farming systems (feed and animal outputs). The blue areas represent water inflows and outflows. The pink areas are methods to improve overall LWP within the crop-livestock systems, which include supportive institutions and enabling policies).

This framework depicts interventions which promote the reduction of water needed per unit of output generated (Amede *et al.* 2009). There are a number of interrelated factors that influence LWP, including technical components such as feed, water and animal management; and socio-political-economic factors including supportive institutions and enabling policies (Descheemaeker *et al.* 2010a). For any interventions to be successfully adopted, these factors need to be taken into account collectively, to effectively increase or improve LWP (Descheemaeker *et al.* 2010a). It is a systems concept and LWP success can only be achieved if it is understood as a system-wide change (Amede *et al.* 2009).

However, a lack of research impedes targeted decision making on best strategies and interventions to improve LWP in different areas (Descheemaeker *et al.* 2011). Further, it is unknown what it takes for smallholder livestock keepers to adopt such interventions (Amede

et al. 2009). Descheemaeker *et al.* (2009) state that more LWP interventions have focused on the technical aspects compared to other dimensions.

Numerous other frameworks have been developed (Amede *et al.* 2009; Descheemaeker *et al.* 2009; Peden *et al.* 2009; Descheemaeker *et al.* 2010a; Descheemaker *et al.* 2011; Peden *et al.* 2012; Hailelassie *et al.* 2013) or updated from the earlier work conducted by Peden *et al.* (2007). The researcher has chosen the Descheemaeker *et al.* (2010a) framework updated from Peden *et al.* (2007) to frame the present research. For this level of research, it is not feasible to quantify or assess each individual component of the LWP framework (Fig 2.1). Therefore the researcher has selected various components of the framework to focus on. For the technical aspects of the framework, feed management is focused on. Furthermore, to a lesser extent, the influence of supportive institutions and enabling policies in managing these technical factors is investigated. These selected components will contribute to required research in understanding the LWP framework.

Increasing water scarcity and demand between different users hamper meeting increasing food demands in smallholder agricultural systems (Descheemaeker *et al.* 2011). Integrating livestock and water management and development through the LWP framework, has the potential to reduce poverty, increase food production and reduce pressure on environments which are water stressed (Peden *et al.* 2009). The LWP concept and framework acknowledges the importance of competing uses of water, but focuses on livestock-water interactions. Therefore there is a need to understand livestock-water interactions (Hailelassie *et al.* 2013). This falls outside the scope of the research, however it should inform further research.

2.7.1 Livestock-water interactions

Despite the fact that livestock can receive between 70 to 90% of their water requirements from vegetation, clean drinking water supply is still essential especially on warm sunny days (Undersander *et al.* 1993). Water acts as a biological solvent in which various biochemical reactions and inter-conversions occur. It serves as a medium for the dilution of cell contents and body fluids, for digestion, absorption, cellular reactions, waste excretion and transportation of nutrients, wastes, hormones, gases and other materials (Duguma *et al.* 2011). Water is used by animals as a medium for physical and chemical energy transfer, and is vital for intermediary metabolism (Taddese, 2005). Animals can lose almost their entire fat and half of their protein and survive, however a 10% water loss can be fatal (Duguma *et al.* 2011). This highlights the importance of water especially in water scarce areas.

The drinking frequency of livestock is a function of water-use efficiency and other factors such as degree of dehydration, nutritional status, vegetation type, paddock size, distance to water and water quality (Squires, 1981). As designated grazing areas become larger, the distance travelled by livestock may increase whilst drinking frequency may decline (Squires, 1981). For example, sheep that drink once daily can probably be found in an area up to a 10 kilometre radius compared to sheep which drink twice daily range over land within a 2 to 3 kilometre radius (Squires, 1981). Livestock can spend much time and energy moving to water sources which may result in a loss of body condition and a reduction of productivity (Duguma *et al.* 2011).

Livestock can affect WP in two main areas namely through the feed that they consume and damage to landscapes hydrology (Amede *et al.* 2009). Roughly 450m³ of water is required annually to produce the forage needed to maintain one Tropical Livestock Unit (250kg liveweight) (Amede *et al.* 2009). When animals are growing, working or lactating, this amount increases. Water used to produce feed is estimated at 500 billion m³ or more year annually for maintenance (Amede *et al.* 2009). Feeds have highly variable water productivity which range from 0.5 kg above-ground dry matter per m³ water to 8 kg per m³ (Peden *et al.* 2007). The volume of water depleted in rangeland livestock production systems (mixed-rain fed) is especially concerning in dryland areas (Haileslassie *et al.* 2013).

As highlighted, changing climates, water availability and accessibility may pose as constraints to livestock productivity in South African smallholder livestock production (IPCC, 2001). Predicted increasing temperatures will increase evaporation which affects water availability and is an important requirement for livestock production (Ogunkoya, 2014). Compounding effects may be experienced by dryland agricultural livelihood systems with recurring drought occurrences due to their inability to deal with external shocks and stresses (Mati *et al.* 2005). Additionally, South African veld has been in bad condition dominated by unpalatable vegetation. This is attributed by environmental conditions, overutilization of the veld due to high stocking densities and generally a lack of knowledge (Ogunkoya, 2014). Snyman (2006) states that it is vital to keep rangelands in good condition to efficiently manage and utilise limited soil-water for sustainable plant and hence animal production. Degraded veld results in decreased plant available water in the soil profile due to high runoff and evaporation (Snyman, 2006). Good rangeland management is required to prevent or reduce water losses, to ensure optimal livestock-water interactions. This is reinforced by the researcher focusing primarily on the feed management variables of the

LWP framework. Livestock-water interactions are complex, not well understood and often ignored in agricultural water development and research (Peden *et al.* 2008). As a consequence, there is limited information on the water requirements of different livestock systems (Wright, 2013). Data from one system is not necessarily applicable to another. For example the amount of water required to produce 1kg of beef in a North American feedlot does not mean the same amount will be required in a smallholder mixed crop-livestock South African context (Wright, 2013).

There is thus a need to better understand livestock-water interactions and designs for comprehensive points to improve LWP in smallholder farming systems in South Africa (Thornton and Herrero, 2010; Haileslassie *et al.* 2013). To improve overall LWP within these smallholder systems, numerous interventions are required.

2.8 Interventions for LWP improvement

Descheemaeker *et al.* (2009), suggest two entry points to improve LWP namely biophysical and socio-political-economic aspects (Fig 2.2). These are represented as spheres of influence. Therefore, interventions to increase LWP should be sought after within both spheres of influence in an integrated manner (Descheemaeker *et al.* 2009). This depicts a broad approach in improving components of the Descheemaeker *et al* (2010a) LWP framework.

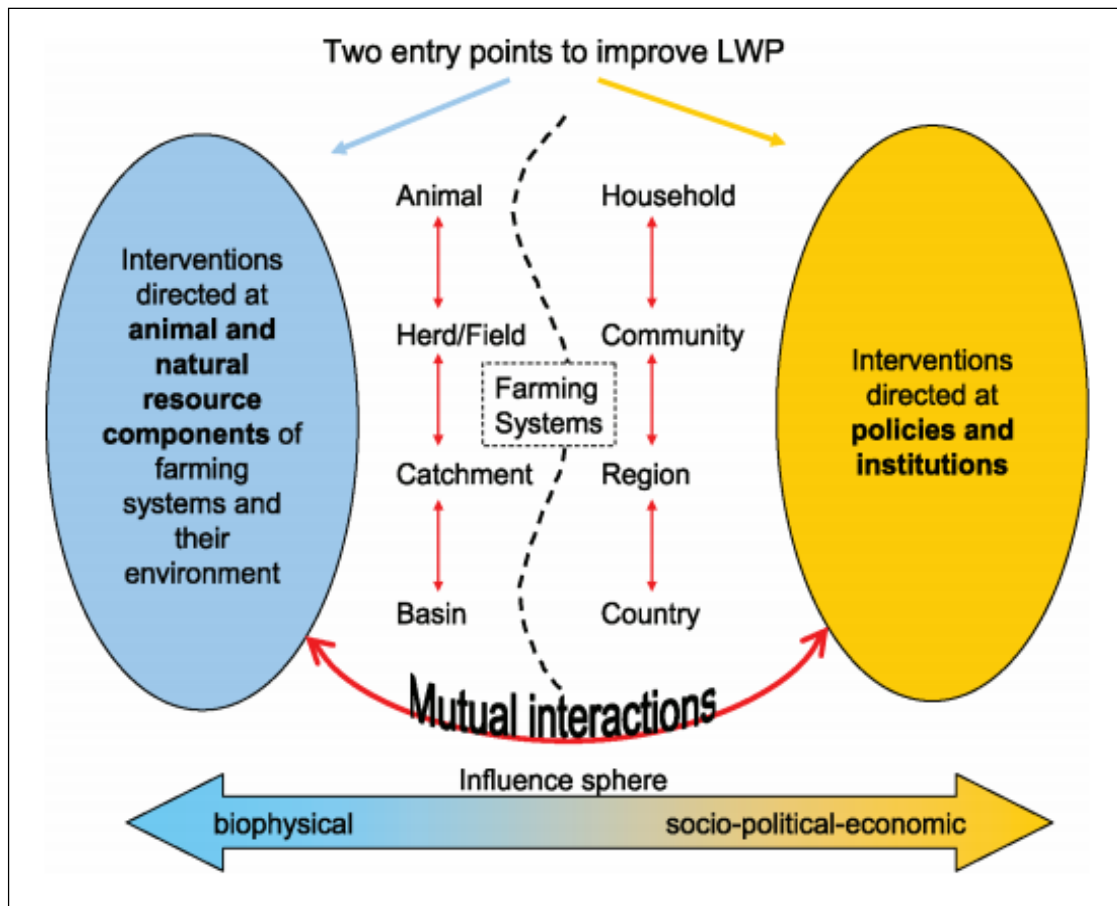


Figure 2.2: The integration of biophysical and socioeconomic interventions to improve LWP (Descheemaeker *et al.* 2009).

Innovations are ways of doing things better or differently, often by quantum leaps rather than incremental gains (Amede *et al.* 2009). They reflect the dynamics of creating and applying new knowledge (Waters-Bayer and Bayer, 2009). This includes modifying or adapting existing knowledge, which can either be endogenous or externally conceived (Waters-Bayer and Bayer, 2009). The researcher chose to adopt figure 2.3 (Amede *et al.* 2009) for analysis purposes, and it is this system which ultimately frames the research, in relation to the Descheemaeker *et al.* (2010a) LWP framework. Through the innovative system (Fig 2.3), there are three main interventions to positively affect LWP namely technical, institutional and the policy environment (Amede *et al.* 2009). An intervention is termed an act of intervening with the intent of modifying an outcome (Wensing *et al.* 1998). The technical interventions are grouped into three categories namely feed, water and animal management (Descheemaeker *et al.* 2010a). Institutional aspects are rules which govern society and inform decision making (Arellano *et al.* 2011). They can be classified as rules which monitor the technical interventions. The policy environment is there to support positive technical interventions and institutional aspects which are important for the success of LWP. Therefore

it is vital to integrate technical interventions with institutional and policy measures to ensure adoption (Amede *et al.* 2009).

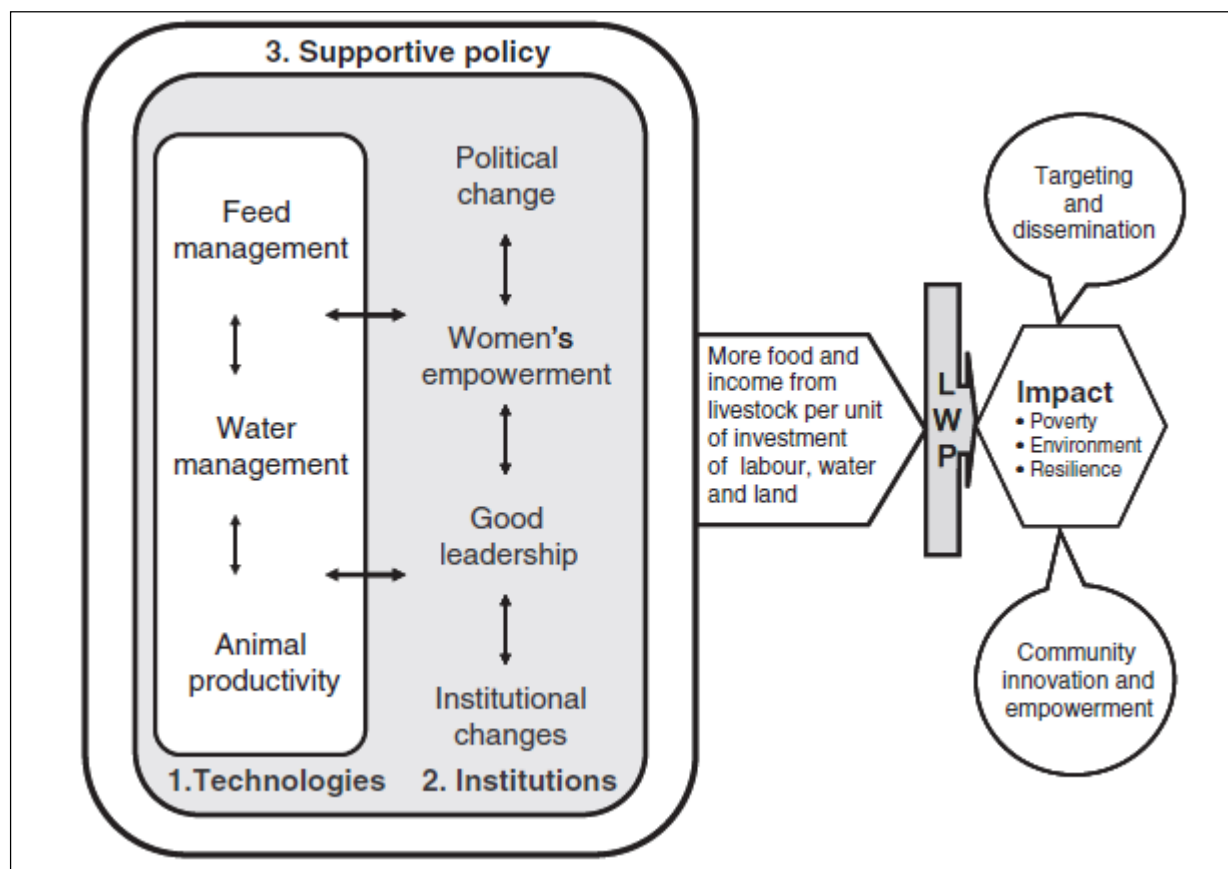


Figure 2.3. Components of an innovation system for improved LWP (Amede *et al.* 2009).

2.8.1 Technical Components

In relation to the Descheemaeker *et al.* (2010a) LWP framework, there are three technical categories to increase LWP. These are feed, water and animal management, in which nine specific strategies have been created (Figure 2.1 and 2.2). Feed management targets feed type selection, feed quality, feed water productivity and grazing management (Descheemaeker *et al.* 2010a). The production of quality fodder is emphasised without using excessive or interfering with other water components (Amede *et al.* 2009). This forms the focus of the current research and is addressed in detail in section 2.8.1.1.

Water management

The aim of water management strategies are to increase the productive water losses (rain, surface water, ground-water) and decrease the unproductive water losses (transpiration, evaporation, contamination and pollution, discharge, deep percolation), to increase the water use efficiency of the system components (Fig 2.1) (Descheemaeker *et al.* 2010a). Soil and water conservation measures comprise physical structures and vegetation management.

Vegetation has both direct and indirect impact on infiltration and runoff (Descheemaeker *et al.* 2006). Changes in vegetation cover can have various complex impacts such as changes in soil temperature, evaporation and transpiration. However, in terms of water management, increased vegetation cover generally indicates higher biomass and a higher ratio of productive over unproductive water losses (Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a). The productive water flowing into a system is used for biomass production, drinking, production of animal outputs through consuming different feeds and other natural resources (Descheemaeker *et al.* 2009). This interaction is seen as positive (productive), however, can become negative (unproductive) if poorly managed. In areas of limited financial and human resources, efforts should be focused on the prevention and mitigation of negative impacts on soil, water and vegetation resources (WOCAT, 2007). Correct water management initiatives go hand in hand with soil and vegetation strategies which aid in overall LWP. The correct management of these natural resources has the potential to decrease land degradation, water scarcity in a time of changing climates and biodiversity conservation (WOCAT, 2007).

Inappropriate livestock management strategies use excessive water and causes water and land degradation (Peden *et al.* 2008). In areas of scarce water supplies, correct management strategies are of utmost importance. Livestock consume a small amount of water compared to crops and feed. However, this small fraction is vital as it enables animals to access feed and convert it into animal products which improve LWP (Descheemaeker *et al.* 2009). The placement and monitoring of animal numbers around watering points is a key challenge for improving LWP (Holecheck, 1992; Farmer, 2010; Rigge *et al.* 2013). Firstly, to reduce the distance travelled by livestock. Limiting animal movement can result in lower energy required; leading to higher LWP values (Haileslassie *et al.* 2013). About 12% of the metabolizable energy in animals is spent walking to feed and water (Haileslassie *et al.* 2013). Secondly it is important to avoid high concentrations of animals around watering points to prevent soil and vegetation degradation, depletion of vegetative cover, desertification and water contamination (Rowntree *et al.* 2004; Peden *et al.* 2007). These matters are important because population numbers are increasing, hence demand for livestock products is greater and pressure on water and feed resources is ever increasing (Amede *et al.* 2009). Livestock and crop production are dependent on water resources, hence sound water management is required to ensure sustainable food production which simultaneously contributes to LWP (Amede *et al.* 2009; Thornton and Herrero, 2010; Kahinda and Taigbenu, 2011).

Animal management

Although not the focus of the current research, as with water management, it is important to understand the context of animal management in relation to LWP. Animal management deals with increasing animal productivity and health, and decreasing animal morbidity and mortality (Descheemaeker *et al.* 2010a). Animal productivity in developing countries in terms of milk and meat production, growth rate and calving rates are generally low due to genetic structures geared to survival rather than productivity (Anteneh *et al.* 1988). These lower quality breeds are able to endure harsher environmental conditions. A study conducted in Msinga, KwaZulu-Natal, South Africa, indicates that most of these cattle are not purebred and are adapted for survival in a drought prone area, capable of coping with low-quality feed, tick tolerant and efficient for draught purposes (Bayer *et al.* 2004). Genetic selection in livestock can have an impact on the productivity. By introducing better quality breeds in the gene pool, livestock can become more productive and more resistant to disease (Descheemaeker *et al.* 2009). The selective crossing of local breeds and within breed selection are practices that should be encouraged to improve productivity (Haileslassie *et al.* 2013). However, one must not only look at productivity alone, but also how specific breeds and species adapt to localised environments (Descheemaeker *et al.* 2009). Therefore animal management needs to be adapted for specific areas to aid in higher LWP.

Animal health is another factor which affects animal productivity within smallholder agriculture systems (Figure 2.3) (Homewood *et al.* 2006). Due to a lack of funds, research and manpower, veterinary services are limited in most smallholder farming systems in South Africa (Marufu, 2008; Tschopp *et al.* 2009). Hence livestock diseases, parasitism and deaths are major threats to smallholder cattle production systems (Marufu, 2008; Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a). Diseased or ‘over-worked’ animals lead to lower livestock productivity as they consume feed and water but do not convert these resources into services or animal products (Descheemaeker *et al.* 2010a). Amede *et al.* (2011), illustrate that improving animal health and therefore reducing mortality led to greater animal outputs from the same water and feed resources. A study conducted in Ethiopia by Descheemaeker *et al.* (2011) indicated that improved animal health reduced mortality from 10% to 5%. Providing livestock with sufficient health care and veterinary services can contribute greatly to increasing LWP in smallholder farming systems (Molden *et al.* 2010).

Therefore the improvement of LWP may depend on the integration of several interventions across spatial and temporal scales, rather than single interventions (Amede *et al.* 2011).

Numerous technical interventions have commonly failed to be adopted by end-users, as they have been developed without considering the context of target communities and their institutions (Amede *et al.* 2009). This research focuses primarily on the feed management component of the LWP framework, with reduced emphasis on the interventions directed at policies and institutions which manage these technical components. Water and hydrological aspects are not focused on, however, anecdotal evidence is utilised to assess the positive influence of selected interventions on these aspects and overall LWP.

2.8.1.1 Feed Management

Feed is an integral component of the LWP framework as livestock depend on it for production, and it utilises water for growth (Descheemaeker *et al.* 2009). Strategies that affect feed management (Figure 2.1) are critically reviewed, such as interventions that affect feed type selection, feed quality, feed water productivity, and rangeland systems and grazing management.

Feed type selection

Water is used and depleted depending on the type of feed utilized, utilisation of irrigation, climate and the field management implemented (Blümmel *et al.* 2009). Therefore certain trade-offs need to be considered because strategic choice of feeds can improve LWP (Peden *et al.* 2007).

The utilisation of crop residues as feed in smallholder farming systems in developing countries has been an area of intensive research since the mid 1970's (Owen and Jayasuriya, 1989). Crop residues are very important sources of feed for livestock especially in the dry season when grazing is often limited (Keftasa, 1988). Globally, grazing lands have decreased due to agricultural expansion, hence crop residues have become a major feed source for livestock (Bogale *et al.* 2008). Crop residues are important sources of feed and because they do not have any additional water requirements, they allow for increased feed water productivity and LWP (Descheemaeker *et al.* 2010a). What is so attractive about these dual purpose food-feed crops is that they can be used for human and livestock consumption (Descheemaeker *et al.* 2009). Therefore no additional land and water is required or utilised which increases the productivity of the system. A disadvantage of using crop residues is that a portion of crop residues are required for soil fertility (Descheemaeker *et al.* 2010a). Furthermore, crop residues when used as the sole feed source can be low in nutritional quality and digestibility, deficient in metabolizable energy, low protein content, poor digestibility and rough texture (Keftasa, 1988). Nonetheless crop residues are important feed sources in

mixed crop-livestock smallholder farming systems in developing countries (Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a).

Rangelands or pastures are components which promote livestock production. They are normally situated on marginal land not suitable for crop production and make use of naturally occurring resources (Descheemaeker *et al.* 2009). This can be seen as increasing the productivity of the livestock system. As a result of being located on marginal landscapes, rangelands can be subject to severe degradation due to overgrazing and incorrect management interventions (Descheemaeker *et al.* 2009). Surface area of grazing lands can become reduced through excessive erosion and gully formation. These systems are then subject to much water loss and runoff thereby lowering overall LWP. Often these consequences are experienced most severely in communal grazing lands, due to continuous grazing and utilisation without rest or appropriate management techniques, as is the case in South Africa (Kiage, 2013). It is vital to implement correct management practices to prevent unproductive water losses.

Fodder crops are key components which influence feed management and livestock productivity. Not much is known about their water productivity, nevertheless these nutritious crops, when added to animals' diets, improve animal productivity (Descheemaeker *et al.* 2010a). Fodder crops include legumes such as cowpea, lucerne, alfalfa, vetch and oats, which improve animal productivity, contribute to soil fertility through fixation of atmospheric Nitrogen and are good source of food (Descheemaeker *et al.* 2009; Dube, 2012). They have shown to increase both the intake and digestibility of fodder crops (Keftasa, 1988). Legumes can be used in livestock nutrition for their high digestible protein content and digestible nutrients which can reduce additional expenditure normally spent on other protein supplementation (Eskandari *et al.* 2009). Napier grass is a fast growing fodder crop which provides much biomass for fodder and has the ability to stabilize soil erosion thereby enhancing water conservation. However, it is also water intensive which may decrease overall LWP (Descheemaeker *et al.* 2009). The cultivation of fodder crops has the potential to reduce, feed scarcity especially in smallholder farming systems with limited inputs (Yami *et al.* 2013).

It is clear that different types of feed have different water usage properties which affect LWP (Descheemaeker *et al.* 2009). Therefore trade-offs between water and feed need to be made. In a climate where water scarcity is becoming more common, water costs and usage have to be taken into account in deciding what fodder feed is cultivated. Feed which is highly nutritious

but at the same time promotes water conservation to improve overall LWP is recommended (Blümmel *et al.* 2009). Therefore it is vital to understand factors which affect the quality of forage so that appropriate interventions can be implemented if forage quality is of a poor standard, to ensure optimal animal production (Eskandari *et al.* 2009).

Feed quality

Livestock water productivity is not only influenced by the quantity and availability of feed, but also largely by the quality and nutritive value of feed (Blümmel *et al.* 2009; Descheemaeker *et al.* 2009). If animals are subject to crop residue diets, quality can be improved by introducing higher quality leguminous crops (Descheemaeker *et al.* 2010a), or through supplementation of urea-molasses based products (Akbar *et al.* 2006). Therefore it is important to implement strategies which ensure feed quality is of the highest standard to promote livestock productivity.

Forage quality is “defined as the extent to which forage has the potential to produce a desired animal response” (Ball *et al.* 2001; pg 2). Tissue age, tissue type, plant groups, anti-quality agents (lignin, cellulose, secondary compounds) are characteristics and factors which affect quality (Briske *et al.* 2008). Tissues with the highest soluble to structural ratio are more palatable and preferred by animals (Briske *et al.* 2008). The performance of livestock is largely determined by the properties of feed consumed (Bransby, 1981; Hatch, 1991). The nutritive value, digestibility, palatability and feed intake are the main factors which comprise forage quality and that determine animal production (Meissner *et al.* 1999; De Bruyn and Koster, 2000; Newman *et al.* 2006; Mapako, 2011; Munyai, 2012). Nutritive value is defined as the animal production response per unit of feed consumed or the concentration of nutrients in the feed (Meissner *et al.* 1999; Bransby, 1981; Descheemaeker *et al.* 2009). Digestibility is termed the difference between the amount of feed ingested and the amount excreted (Meissner *et al.* 1999). Digestibility is normally positively correlated to concentrations of nutrients in the feed and to its intake (Meissner *et al.* 1999). Immature, leafy plant tissues may be 80 to 90% digested compared to mature, stemmy material of which only 50% is digested (Ball *et al.* 2001). Palatability determines if an animal will eat a specific forage or not, the attractiveness of the feed to animals and may be influenced by texture, compounds, fibre content, leafiness and moisture content (Van Dyne *et al.* 1990; Bransby, 1981; Hatch, 1991; Ball *et al.* 2001). Fibre content has an important role in determining palatability.

Two important components when determining forage quality are Acid Detergent Fibre (ADF) and Neutral Detergent Fibre (NDF). ADF is the percentage of highly indigestible plant

material in feed or forage and measures a portion of the cell wall, namely lignin and cellulose (Beauchemin, 1996; Robinson *et al.* 1998; Mapako, 2011). ADF is used as a predictor for forage digestibility (Newman *et al.* 2006). Therefore the lower the ADF percentage, the easier an animal can digest feed. NDF measures the total plant cell wall material and contains mainly hemicellulose, lignin and cellulose (Beauchemin, 1996; Robinson *et al.* 1998; Ball *et al.* 2001; Mapako, 2011). The hemicellulose and cellulose are slowly digested by ruminants, whereas lignin is indigestible (Beauchemin, 1996). For forage, the digestibility of plant cell walls is important as cell wall contents are completely digestible, thereby making cell wall concentrations a key determining factor in the digestibility of forage (Kramer *et al.* 2012). The NDF values determine forage intake of an animal (Newman *et al.* 2006). Feed intake is the amount of forage consumed by an animal and is termed twice as important as digestibility in determining animal performance (Meissner *et al.* 1999). Both ADF and NDF values are good indicators for the amount of fibre within forage and are closely related to the digestibility of forage and forage intake respectively. The higher the percentage of ADF and NDF values the higher the fibre content, the lower the energy value and generally the lower the digestibility, palatability, intake and forage quality (Ball *et al.* 2001). Therefore animals will if possible select leaf material in preference to stem and young material instead of stem material or high fibre content forage (Hatch, 1991).

Other factors which influence palatability are chemical compositions of forage such as minerals, structural constituents, vitamins and anti-quality and toxic substances (Meissner *et al.* 1999). Crude protein (CP) and phosphorus (P) are two additional nutrients that can pose as limiting factors in rangelands (Van Niekerk and Jacobs, 1985; Ruyle, 1993). CP is the primary limiting nutrient in the diet of livestock. CP is important as rumen microbes can convert non-protein nitrogen to microbial protein, which can be utilised by livestock (Ball *et al.* 2001). However, if insufficient, rumen microbes will be unable to degrade fodder especially that of poor quality, hence a decrease in forage intake (Newman *et al.* 2006). This can result in weight loss as livestock must break down tissue to supply the required protein (Sprinkle, 2001). Sufficient CP is required to ensure lactation as this is the most stressful activity for an animal (Lalman, Undated). Additionally it is required for increasing body condition, mass and health of livestock (Lalman, undated; Mvinjelwa *et al.* 2014). Phosphorus is the second most important and limiting plant nutrient in forage (Van Niekerk and Jacobs, 1985; Miller and Gardiner, 1998). De Brouwer *et al.* (2000) state, that P content in rangelands in many areas of South Africa is insufficient to support productive livestock. Sufficient P levels are required to ensure the functioning of energy metabolism in animals,

good conception rates and milk production (De Brouwer *et al.* 2000; De Bruyn and Koster, 2000).

Range forage is sometimes the only type of feed that dryland agricultural farmers have to offer their livestock. During winter nutrient values decrease significantly and pose threats to managers due to potential insufficient forage availability (Ruyle, 1993). Different types of veld respond to seasons differently, and hence require differing management techniques. Sweetveld is defined as veld in which forage plants retain their acceptability and nutrient value after maturity, allowing livestock to graze plants year round (Trollope *et al.* 1990). Sourveld is veld in which forage plants become unacceptable and less nutritious after maturity, making the grass only grazeable for certain periods of the year (Trollope *et al.* 1990). The case study site falls within a sourveld region. Winter poses a huge problem for farmers especially in Highveld and Sourveld regions of South Africa (De Bruyn and Koster, 2000). The levels of protein are lower than required which has a negative influence on intake and digestibility of the forage (Mapako, 2011). Further, grasses increase in fibre content, lowering digestibility and intake thereby negatively affecting animal production, reproduction and body condition of livestock (Ruyle, 1993; De Bruyn and Koster, 2000). Therefore supplementation is a vital management strategy in improving forage quality and livestock productivity in smallholder farming systems in developing countries (Louw, 1979; Van Niekerk and Jacobs, 1985, Brundyn *et al.* 2005).

The combined effect of deficiencies can result in a loss of condition in gestating cows and reduce reconception in subsequent years (De Bruyn and Koster, 2000). Strategies are required to improve the acceptability and digestibility of forage and simultaneously accounting for nutrient deficiencies. Analysing the nutrient content of forages can be used to determine whether forage quality is sufficient and to guide proper ration supplementation (Ball *et al.* 2001). Supplemental feeding such as protein licks, urea-molasses licks and fodder crops are techniques which can improve the acceptability, digestibility and intake of forage materials and account for nutrient deficiencies.

A study conducted by Brundyn *et al.* (2005) in the winter rainfall region of South Africa, indicates positive effects of supplying a protein lick to ewes. The ewes increased in body mass and overall animal performance (Brundyn *et al.* 2005). Additionally the lambing and weaning percentages were improved through protein supplementation (Brundyn *et al.* 2005). Protein licks are low-cost and easy to adopt technologies which have great potential to enhance nutrition of livestock in smallholder farming systems in developing countries (Akbar

et al. 2006). Furthermore, the introduction of urea-molasses licks in South Africa has ensured farmers obtain maximum production from poor and inferior rangeland (Louw, 1979). Molasses is a good form of energy as it contains high levels of sugars, however, it is deficient in protein. Molasses is universally liked by livestock such as cattle, pigs and sheep and therefore enables these animals to eat unpalatable feed such as mealie cobs, damaged hay or pastures, chaff and stover (Cleasby, 1963). Urea is an inorganic fertilizer which acts as a supplementary protein for livestock because of their ability to convert urea to essential amino acids (Manta *et al.* 2013). A study conducted by Louw (1979), indicated that by using urea-molasses licks, the acceptability and digestibility of forage increased, livestock gained weight and improved overall performance. In times of drought this can be the difference between losing and saving animals (Cleasby, 1963). Licks should never substitute feed but rather purely be supplementary, to account for specific nutrient deficiencies and ensure optimal utilization of feed and hence improve productivity (health, milk and meat production and work potential). Therefore maintaining sufficient protein in animal diets is critical for livestock productivity, hence supplementation can be implemented to account for deficiencies.

A study was conducted by Fair (2013) to show the value of feeding vetch as a supplement compared to low quality *Eragrostis* veld to cattle during winter, in the Free State, South Africa. A gestating cow requires 0.36 kg of digestible protein a day. The veld tested in the study area had 1.35% digestible protein. The cow would have to consume 27kg of poor quality veld a day, which is impossible. A vetch pasture has a digestible protein of 22%, hence a cow would only need to ingest 1.6kg to supply its protein requirements (Fair, 2013). Fodder crops can be a viable alternate source of supplementary feed in smallholder farming systems (Keftasa, 1988; Assefa and Ledin, 2001; Descheemaeker *et al.* 2010a).

Good quality forage is key for any livestock production and it is the foundation of most rations in forage-based diets (Newman *et al.* 2006). Foraging behaviour of animals is central to understanding plant-herbivore interactions, efficient management of grazing systems and eventually profitable livestock production (Mkhize, 2008). Producing quality forage for animals requires knowing the factors which influence forage quality and then exercising management practices accordingly (Ball *et al.* 2001). Understanding and ensuring forage quality has direct impacts on animal performance, forage value and ultimately profits, which can improve LWP (Ball *et al.* 2001).

Therefore the management of sourveld for sustained animal production cannot be considered independently of supplementary feeding, especially during winter (O'Reagain and Mentis, 1988; Danckwerts, 1989; De Bruyn and Koster, 2000; Kirkman and De Faccio Carvalho, 2003). Overall, supplemental feeding can play an important role in maintaining animal productivity (Ball *et al.* 2001). Its importance is highlighted in times when grazing is limited especially in areas where communal grazing is the only feed type. Making unpalatable feed acceptable and digestible can be the difference between life and death for livestock.

Feed water productivity

In mixed crop-livestock systems, feed production is the largest water consumer for the production of livestock (Peden *et al.* 2007). Ways to improve feed water productivity can be grouped into three classes namely crop, soil and water management.

The type of cropping system implemented can substantially impact water productivity as it influences the quantity and quality of forages and crop residues and fallow land. Agroforestry and intercropping are seen as efficient dual purpose cropping systems where for example trees are intercropped with fodder crops (Nair, 1998). This has the potential to produce high quality fodder crops and simultaneously reduce runoff through better soil cover and soil physical properties. Additionally these systems create suitable microclimate conditions which reduce the vapour pressure deficiency at the plant level (Descheemaeker *et al.* 2009). With these noted impacts, the cropping patterns, cropping systems and the specific crop choice can prevent unproductive water losses. According to Ramesh (2010), intercropping where water is scarce ensures the best use of soil and inter-row moisture harvesting. In semi-arid regions of South Africa, intercropping with maize and beans improved water use efficiency (Ramesh, 2010).

Soil comprised of physical, chemical and biological characteristics is one of the most important factors influencing feed production. Mulching or leaving crop residues on the field increases soil organic content which aids in soil structure and water holding capacity and infiltration. It protects soil from erosion and improves the soils physical and chemical properties. Mulching is important in improving water productivity. A study conducted in the Free State, South Africa, indicated that mulching in dryland agriculture reduced runoff, reduced evaporation and improved the water holding capacity of soil (Bennie and Hensley, 2001). However, trade-offs need to be made especially in smallholder agricultural systems on what percentage of crop residues should be used for animal feed and soil conservation

respectively. Furthermore, fertilizer, inorganic or organic (manure) can be used to improve the fertility of soil which aids in water productivity (Descheemaeker *et al.* 2009).

Water management needs to look at strategies to reduce water losses at both the field and rangeland scale. Water stress can be eliminated through irrigation and greater water use efficiency. Reducing water stress will promote better LWP (Descheemaeker *et al.* 2009). Effective grazing management is an avenue to improve LWP in smallholder farming systems in South Africa.

Grazing Management

Efficient grazing management is important for pasture and rangeland productivity (Navarro *et al.* 2006). Better rangeland productivity can relate into improved livestock production and overall LWP in smallholder farming systems in developing countries (Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a; Descheemaeker *et al.* 2011). Grazing management will be discussed in greater detail in section 2.9. Institutions play an important role in determining the success of technical interventions (Douthwaite, 2002; Amede *et al.* 2009).

2.8.2 Supportive Institutions

Institutions are the structures which matter the most in the social realm, comprised of law, customs, language, formal and informal organizations (Cleaver, 2000; Hodgson, 2006). "Institutions are the rules of the game and organizations are the players" (North, 1993, p. 15). They are the rules which govern society and inform decision making (Denzau and North, 1994). Institutions can be either formal or informal. Formal institutions are the written rules such as the constitution, laws and property rights. Informal institutions are rules informed by behavioural norms in society, families or communities and include traditions, sanctions and code of conduct (Descheemaeker *et al.* 2009). Both of these institutional forms are important aspects which govern communities, influence the livelihoods of smallholder farmers and aid in the adoption of LWP interventions.

In South Africa, there is ambiguity around land access and the general failure of natural resource governance that characterises smallholder farming systems (Bennett, 2013). There is an absence of a definitive land tenure framework for communal areas which encourages the existence of different traditional, civil society (local farmers' associations) and local government institutions (ward councillors) (Bennett, 2013; Bennet *et al.* 2013). This has led to conflict between institutions, which hinder effective management of resources such as communal rangelands (Ntshona and Lahiff, 2003; Bennet, 2013). In Rockcliff village,

Eastern Cape, the Land Use Development Committee (LUDC) incorporates both civil society and the ward councillor into structures of land allocation and development which is chaired by the traditional authorities of the village (Bennett *et al.* 2013). Through this formulated collaborative structure, a grazing committee is elected to implement a rotational grazing regime (Bennett *et al.* 2013). The committee decides which camps are rested after a community meeting. To aid this collective grazing management strategy, fines are imposed for transgressing the grazing rules (R5 for each animal found in the rested area). This has aided in higher biomass production, better forage quality and hence animal production thereby contributing positively to LWP (Bennett *et al.* 2013). The poor quality of the fencing is an issue in controlling livestock movement. This is an example of how collective management can improve institutional arrangements and improve management systems and LWP.

Institutions play important roles in determining the success of LWP (Figure 2.3). The rules which are formulated within smallholder farming systems are significant and reflect the way in which resources should be managed (Pejovich, 1999). Institutions should not be rigid, but rather flexible which can fluctuate through time as conditions change and new opportunities arise (Cleaver, 2000). Natural resource management is an area which requires careful implementation of rules as the management of one resource complements the other (Fig 2.2). For example, correct vegetation management (adhering to stocking rates and carrying capacities) will promote good vegetative cover and biomass production. This in turn ensures soil management by reducing runoff and erosion, hence additionally promoting water management (Fig 2.1). Generally, technical innovations will not occur without a degree of corresponding institutional change (Amede *et al.* 2009) (Figs 2.1; 2.2; 2.3). However, the institutions and rules constructed will only be as effective as the enforcement. The establishment of permits, penalties or fine violations are ways to improve the enforcement of regulations (water quality, groundwater depletion) (Descheemaeker *et al.* 2009). The success of institutions largely depends on efficient and sound policy making.

2.8.3 Enabling Policies

Policies in the smallholder agricultural context need to encourage or create an environment to ensure successful innovation and institutional change, which can promote LWP (Fig 2.3) (Amede *et al.* 2009). The policy process can be seen as a series of responses to specific problems (Adams *et al.* 2002). They are decisions and guidelines that direct human behaviour towards achieving specific goals.

Common pool resources (grazing/pasture land) contribute significantly to the livelihoods of dryland smallholder farmers (Tegegne, 2012). Common pool resources are defined as a community's natural resources where every member has access (Mahanta and Das, 2012). "Appropriate policy formulation with respect to common pool resources requires an empirical understanding of drivers and processes determining the diverse roles that they play" (Chopra and Dasgupta, 2002; pp 54). Understanding dynamics of peoples livelihoods and the impact of potential policies, help inform policy making decisions. The roles of policies are to address issues such as poverty alleviation, empowerment of women, political change, institutional change and good leadership (Fig 2.3) (Chopra and Dasgupta, 2002).

At a national South African agricultural context, range management and monitoring policies for stable and economically viable livestock production are based on commercial parameters (carrying capacity, conservative stocking rates, fencing and rotational grazing); with no discussion how these can be implemented in smallholder farming systems (Vetter, 2013). Policy interventions in South Africa have largely failed due to them being implemented in a top-down approach with insufficient participation from smallholder farmers in setting their own priorities, and are often strongly driven by interests other than those of communal farmers (Greenberg, 2010). If there is no support, genuine participation and involvement from the intended target group (smallholder farmers), policy interventions will not work. Communal rangelands comprise approximately 13% of the total agricultural land in South Africa, hence the livelihoods of a large percentage of the population depend on these resources (Vetter, 2013). A common misconception of policy makers is to promote commercial farming as a model for livestock production in communal rangeland systems. Policies should support livelihoods of people in smallholder farming systems to enhance resilience and reduce risk (climate change, crop failure, disease), provide training in range management, strengthen common property management and promote livestock development (Vetter, 2013). A possible way forward is to create and fund platforms that can facilitate collaboration between smallholder farmers, Non-Governmental Organisations (NGOs), researchers, the private sector and local government which can provide solutions to current problems (Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2011). A collaborative approach is advised compared to a traditional top-down approach, which should strongly contribute to defining policies in the future which contribute to LWP. The correct management in rangelands is vital for long term range and animal production, hence has the potential for improving LWP (Tainton and Danckwerts, 1999; Tainton *et al.* 1999; Descheemaeker *et al.* 2010a)

2.9 Rangeland Systems and management

There are two main rangeland systems found in South Africa namely commercial and communal livestock ranching (Kotze *et al.* 2013). A commercial system is well developed, capital intensive, largely export orientated and additionally aims to achieve faster growth, less mortality and higher turnovers (Kotze *et al.* 2013). This system focuses on pattern of movement (O'Connor *et al.* 2010), which entails farms being divided into camps with the livestock distributed accordingly to prevent overgrazing and land degradation. The communal rangelands differ significantly from the commercial ones, in terms of their production systems, objectives and property rights (Kotze *et al.* 2013). Communal production is characterized by a grazing area shared amongst a community, with unclear boundaries and open access rights to grazing year round. Furthermore, communal systems keep livestock for various purposes such as milk, meat, ceremonial slaughter, draught power, dung, cash income, capital storage and other socio-cultural purposes (Waters-Bayer and Bayer, 1992; Duvel and Afful, 1994; cited in Masika *et al.* 1998; Kotze *et al.* 2013). Therefore livestock are kept in these two systems for different reasons and purposes. The correct management of rangeland systems is important in improving LWP in smallholder farming systems, hence making it an integral component of the research.

The management techniques adopted in these two rangeland systems vary significantly. Various rangeland management techniques affect grass species differently. The most common management techniques are comprised of burning and grazing (Tainton, 1981). Each method, with its characteristics, is reviewed separately.

2.9.1 Burning

“Fire can be seen as a bad master but a good servant” (Trollope, 1989; pg 67). This means that the application of fire can have positive and negative impacts depending how it is managed. The role of fire in rangeland management has been misunderstood by the public in general, hence the diminishing use (Mapiye *et al.* 2008). Many factors contribute to this reduction such as the elimination of potentially available forage, threat of fire escaping the boundaries of a prescribed burn and the destructive effects of runaway fires (Mapiye *et al.* 2008). In the communal rangelands of smallholder farming systems in South Africa, fire is generally associated as a negative component as it reduces forage availability (Trollope, 1989; Mapiye *et al.* 2008). It is often difficult to replace old paradigms formulated by traditional authorities based on simplification and subsistence (Lemaire *et al.* 2014). Therefore the adoption of new, efficient rangeland management techniques, remain a

challenge in smallholder farming systems. It is understandable as a limited grazing area and fodder is shared amongst a community. The rangeland is the primary form of nutrition for the livestock, hence burning this resource is not encouraged. Fire compared to other defoliation techniques such as mowing is more destructive as it causes more damage to the aerial growth points of the plants and leaves the soil exposed to the elements (Tainton, 1981). Through the incorrect use of fire, much deterioration of productivity and condition of the rangeland can occur with potential widespread erosion (Trollope, 1989). Caution is required so as to avoid excessive burning, burning followed by overgrazing, infrequent burning and underutilization, burning followed by extended dry periods and burning actively growing material which are harmful to veld (Camp, 1997a).

Conversely fire has shown to be an important management tool for grazing systems, as it can be utilized to overcome a number of issues such as grazing selectivity, aid in the control of invasive species and control the abundance of palatable and unpalatable grass species (Trollope, 1989; Martindale, 2007). It plays a vital role in the maintenance of sourveld (Kirkman and Moore, 1995). Fire can be used to remove surplus or unacceptable vegetation which then promotes new growth (Mapiye *et al.* 2008). Without correct fire regimes or regular defoliation, excessive biomass shading can occur, where the centre of the grass tuft often dies out since mature tillers cannot be replaced by new populations of lateral tillers (Tainton, 1981; Menke, 1992). Removing moribund grass material after winter ensures uniform utilisation of the veld in subsequent seasons and promotes the growth of higher quality range which aids LWP (Engelbrecht *et al.* 2004). Burning can maintain grass sward vigour and removes or suppresses woody vegetation growth or bush encroachment (Adie *et al.* 2011). Additionally early dry-season prescribed burning reduces fuel loads and can prevent late, high intensity fires which have the potential to eliminate or destroy large grazing lands (Sow *et al.* 2013). Understanding the response of vegetation to fire in terms of timing and type and intensity of fire is a fundamental component of rangeland management (Adie *et al.* 2011). Fire can destroy or aid in reducing populations of parasites such as ticks (I'Ons, 1960). Hence the effects of burning practices have long remained a topic of great controversy for various discussed reasons throughout history (I'Ons, 1960).

The veld grasses of South Africa are generally well adapted to survive burning. For example, a long-term trial at Ukulinga research farm in Pietermaritzburg (KZN) subject to annual winter or early spring burning has not reduced the overall cover or diversity of the grassland (Tainton, 1981). Fire, if understood and applied correctly, can improve range conditions and

functioning of ecosystems, and therefore lead to increased vigour, higher vegetation production and quality, which can lead to higher animal productivity and aid overall LWP (Snyman, 2006). Implementing correct grazing management techniques are key in terms of LWP.

2.9.2 Grazing Management

Grazing management involves the management of livestock and vegetation resources (O'Connor *et al.* 2010). Grazing management strategies are intended to maintain a sufficient vegetative cover and to ensure healthy, productive rangelands. Correct management ensures sufficient biomass production and aids in environmental functions such as biodiversity conservation (Descheemaeker *et al.* 2009; Mapiye *et al.* 2009). A lack of defined goals or inefficient rangeland management strategies can lead to veld deterioration through overgrazing. Overgrazing is defined as excessive defoliation of the grass sward by livestock which negatively affects the veld or range condition (Trollope *et al.* 1990). Hence, grazing management strategies need to be carefully planned and implemented for the benefit of LWP and the surrounding ecosystems.

The choice of grazing system is one of the most important decisions a farmer makes as it has impacts on the condition and biodiversity of the grassland (O'Connor *et al.* 2010). Rangeland monitoring is an integral part of effective management (Reed and Dougill, 2010). All rangeland management strategies are concerned with livestock type, number and seasonal pattern of movement (O'Connor *et al.* 2010). Foran *et al.* (1978) developed the first formal range condition assessment which is a technique that grouped grass species according to their ecological status, namely into i) desirable “decreaser” species that decrease in abundance in overgrazed veld, “increasers” that increase in abundance with under grazing (increaser I), overgrazing (increaser II) and selective overgrazing (increaser III) (Reed and Dougill, 2010). The degree to which grass species respond to defoliation categorizes them into increaser or decreaser species (Mapako, 2011). At the research site, there is a high level of utilisation in this unit leading to degradation and transformation of the vegetation (Mucina *et al.* 2006). Poor grazing management has led to the dominance of unpalatable Increaser II grass species (*Eragrostis plana* and *Sporobolus africanus*) and invasion of alien forb species (Mucina *et al.* 2006). Rangeland evaluation is an essential tool for quantifying change in range condition with the intention to monitor management effectiveness and indication of the necessary management inputs. Rangeland assessment measures the deterioration and improvement of range condition in terms of productivity, on short and long term basis (Solomon *et al.* 2007).

"Rangeland condition refers to the health status of the range based on its ability to produce forage in a sustainable manner" (Mapako, 2011, p. 30). Evaluating rangeland condition can inform decision making on what rangeland management practices are most suitable for specific areas.

There are different forms of grazing systems such as continuous grazing, rotational resting and rotational grazing (Smith, 1997). Continuous grazing is where an area or camp is allocated to livestock and grazed from the start to the end of the growing season with no rest (Barnes, 1989a; Smith, 1997). No portion of the veld is given a rest for any period of time. Rotational grazing is defined as the type of management which requires that the grazing allotted to certain animals for the entire grazing period, be subdivided into at least one or more camp than groups of animals (Barnes, 1989a). Only a portion of pasture is grazed while the remainder is rested (Undersander *et al.* 2002). It can be seen as successive grazing in a rotation, which ensures that not all the veld is grazed simultaneously. This system is comprised of altering periods of occupation which regulates grazing intensities for specific rangeland management purposes. There are a number of commonly used rotational grazing systems for different objectives such as non-selective grazing (NSG), controlled selective grazing (CSG) and short duration grazing (SDG) (Smith, 1997; Engelbrecht *et al.* 2004). NSG is referred to as high utilisation grazing and herbage utilisation is maximised. High stocking densities and grazing intensities are required to ensure that even unpalatable species are grazed (Smith, 1997; Briske *et al.* 2008). This system aims at reducing selectivity and grazing the more unpalatable species at a stage when they have not become mature and unacceptable to stock (Tainton *et al.* 1999). CSG is known as high production grazing and the stocking rates and grazing intensities are based on palatable species composition (Smith, 1997). Livestock are not forced to graze unpalatable species. SDG emphasizes the need for a short period of stay and prevents grass plants from being grazed more than once or excessively during a period of stay (Smith, 1997; Tainton *et al.* 1999). This allows grasses to recover before being grazed again. Rotational resting is similar to rotational grazing, however, emphasises a longer period of rest. The general rule of thumb is that veld should receive a full season's rest once every four years (Smith, 1997). A quarter of the veld is rested with the remainder being available for grazing. This ensures that a portion of the veld is rested every year, allowing vegetation to recover and provide better grazing. The research included a rotational resting experiment, to observe the effects of rest on forage quantity and quality and hence LWP in Ntshiqo.

There has been an ongoing debate whether rotational grazing and resting or continuous grazing is the most suitable grazing management regime. Ecological variation such as rainfall regimes (amount, seasonality and variability), vegetation structure, previous land use and livestock characteristics (breeds, management) contribute and influence the complexity of choosing the most suited management regime (Briske *et al.* 2008). This ecological variability is compounded by the variability of the goals (production versus conservation) and opportunities (land ownership, alternate revenue sources) (Briske *et al.* 2008). Each management regime has pros and cons. The rangeland at the research site is characterised by long term continuous grazing.

High intensity continuous grazing has the ability to remove dead stem bases, litter and the moribund build-up of plant material (Menke, 1992). Immediate advantages of continuous grazing include no fencing requirements; less labour is needed to move animals and management decisions are reduced (Vendramini and Sollenberger, 2007). These systems require the least amount of money invested and management due to its simplicity. Some authors such as Briske *et al.* (2008) and Salomon (2011), argue that continuous grazing systems can be as productive as rotational grazing systems and that conventional indices of overgrazing are subjective and are based largely on commercial indicators of how a rangeland should look in a particular area (Maura et al, 2003). Some experts have advised farmers to implement continuous grazing with a light stocking rate to improve production (Vanton, 2001). Animal performance can initially be high in continuous grazing systems, however, as range condition decreases so will animal production, reducing LWP (Munyai, 2012). Continuous grazing can be responsible for widespread range deterioration (O'Reagain and Turner, 1992; O'Reagain, 1994). It can promote area and species selective grazing, thus leading to a decline in the vigour and eventual death of palatable species (Munyai, 2012). Livestock have the ability to physically damage plants by cutting, bruising, breaking, debarking and even uproot them (Owen-Smith, 1999). Sheep for example often uproot large quantities of *Themeda triandra* tufts when stocking rates are high. Therefore intensive grazing for extensive periods (overgrazing) can result in negative impacts such as such as a reduction in photosynthetic leaf area. This negatively affects the root system by reducing available energy to support existing root biomass and new root production (Briske *et al.* 2008). This grazing pressure can result in degradation and erosion of various parts of a grazing area due to the removal of the protective vegetation layer (van Oudtshoorn, 2012). This reduces the total grazing area and can lead to the sedimentation of downstream rivers and dams, decrease infiltration, reduced pasture production, disrupts aquatic ecosystems and

disrupt hydraulic characteristics of water channels (Descheemaeker *et al.* 2009; Thornton and Herrero, 2010). If appropriate management techniques are not implemented, rangeland and livestock production are likely to decline, hence reducing LWP.

In terms of commercial rangeland management techniques, continuous grazing is not recommended. Resting of veld is critical as intense grazing reduces grass vigour and yield (Smith, 1997). A period of rest allows forage plants to renew energy reserves, deepen root systems and provide livestock with long-term maximum production (Undersander *et al.* 1993). Rests are designed to provide vegetation an uninterrupted period of development to complete processes necessary for their survival and health and ensure sufficient biomass production (Tainton and Danckwerts, 1999; Mapiye *et al.* 2009). It is critical to rest veld at critical growth stages irrespective of the type of grazing system to restore vigour (Smith, 1997). The duration of these rests are determined by the condition and nature of the veld (Smith, 1997). Resting of veld is probably the most important aspect of rangeland management (Tainton and Danckwerts, 1999; Descheemaeker *et al.* 2006). This helps prevent land degradation and soil erosion and restore productivity of rangelands and contribute positively to LWP (Thornton and Herrero, 2010; Palmer and Bennett, 2013). Grazing management systems can result in and influence water conservation and improve hydrological processes. Correct management can result in significant water productivity improvement (Herrero *et al.* 2009), and has the potential to reduce additional water use by 45% by 2050, hence aiding LWP (Rockström *et al.* 2007; Thornton *et al.* 2009). The application of rest is capable of maintaining long-term veld and animal production, which is recommended for all types of veld (O'Reagan, 1994). Stocking density, stocking rate and carrying capacity are variables that can aid rangeland management.

2.9.2.1. Stocking density, stocking rate and carrying capacity.

Stocking density is the amount of animals which are allocated to a unit area of land compared to stocking rate which accounts for time (Morris *et al.* 1999). If livestock numbers exceed suggested stocking densities, rangeland degradation can occur, negatively affecting livestock production and LWP. Vendramini and Sollenberger (2007) state, that the application of the correct stocking rates is more important than a specific grazing method. It is the most consistent management variable influencing both plant and animal responses to grazing (Briske *et al.* 2008). If the stocking rate is incorrect, neither rotational nor continuous grazing regimes will correct the problem (Vendramini and Sollenberger, 2007). Animal performance is closely related to stocking rates of livestock. According to Teague *et al.* (1981), average

daily gain per animal unit decreased when the stocking rate exceeded a critical level. The different rationale of commercial and communal cattle production influences stocking rate (Barret, 1992). In commercial beef production the optimum stocking rate maximises beef production per hectare i.e. having fewer fat animals is better than having many skinny ones. On the contrary, communal cattle production emphasis is placed on higher animal numbers and stocking rates (Barret, 1992). Stocking rate does not reflect or include the effect of grazing on vegetation and soil properties (Sprinkle and Bailey, 2004). Stocking rate is an operator-dependant variable and is an expression of the number of animals that a farmer has on his veld (Danckwerts, 1989). Carrying capacity can be utilised to help inform stocking density and rate.

Carrying capacity is a more complex parameter and numerous attempts have been made to define it, however, with numerous inconsistencies. It is termed the number of animals that can be sustained on an area without causing deterioration of vegetation and soil (Danckwerts, 1989; Benjaminsen *et al.* 2006). It is a quantitative measure of a man-made system which can be calculated and predicted with reasonable accuracy (Sayre, 2007). Estimates of carrying capacity are based on the assumption that livestock require a daily dry matter intake of 2.5 to 3.0 % of their body weight (De Leeuw and Tothill, 1993). Numerous conflicting thoughts have surfaced with regards to the concept. A shortcoming of the carrying capacity concept is that it is regarded as a static assessment, while it should be seen as varying in space and over time (De Leeuw and Tothill, 1993). Variability can be caused by differences in soil type, rainfall, climate, grazing pressure, application of fire which affects species composition and plant cover (De Leeuw and Tothill, 1993). Additionally carrying capacity assumes that livestock are kept within fixed areas demarcated by defined boundaries (De Leeuw and Tothill, 1993). Within smallholder farming systems, especially in communal rangelands of South Africa, this is not the case. A problem with applying carrying capacity in communal tenure land is that it is based on commercial livestock production systems, where a recommended carrying capacity has been established based on empirical data and where it is assumed that the farmer is using some form of rotational grazing. A study conducted in Namaqualand, located in the Northern Cape of South Africa, indicated that the range is capable of sustaining livestock densities far greater than those recommended based on commercial carrying capacities and stocking densities.

The debate between continuous and rotational grazing systems is an ongoing one. According to Briske *et al.* (2008), evidence obtained from grazing experiments over the past 60 years

indicates that rotational grazing is not superior to continuous grazing. Morris (2002), states that research has not demonstrated beyond doubt the superiority of any grazing systems over another. Maintaining livestock in smallholder communal management systems are not aimed at financial benefits to the farmer but rather provide households with food products, raw materials, draught power, dung and bride price (Waters-Bayer and Bayer, 1992; Hardy, 1994). Due to different production objectives, it is not possible to apply the same recommendations or management techniques utilised in commercial farms to communal rangelands. The dynamics are vastly different and each system is unique hence specific management strategies need to be adapted to ensure maximum sustainable production in terms of rangeland, livestock and overall LWP.

2.10 Conclusion

After defining smallholder farming systems, the literature reviews the importance of livestock within these systems. Growing populations have exerted additional pressure on livestock production worldwide. Mixed crop-livestock systems are reviewed in terms of their importance in the smallholder agricultural context. Further, the management of these communal systems in relation to traditional authorities is reviewed. Water scarcity through increased demand, coupled with the effects of climate change, often leaves dryland smallholder farmers within mixed crop-livestock systems vulnerable. Hence, better management systems need to be implemented to sustainably meet the growing demands of human populations. The LWP concept and framework explains and provides such opportunities to focus on specific technical, institutional and policy variables to improve productivity of livestock in mixed crop-livestock systems. The current research focuses on the feed management component of the LWP framework, with emphasis on feed quality and grazing management. A collaborative approach is critical for the success of overall LWP in smallholder mixed crop-livestock systems in developing countries. Although not a focus of the current research, it is acknowledged that institutional structures (traditional authorities) and policies need to reinforce technical interventions to create opportunities for effective change and improvement of LWP. The following section describes the background information, biophysical conditions and the methods utilized for research in Ntshiqo.

3 Chapter Three Methods

3.1 Introduction and Research Design

This chapter outlines the research design and specific methodology that was used to gather and analyse the research data. The aim of this research is to quantify and potentially improve LWP within communal rangeland areas: a case study of Ntshiqo, Eastern Cape, South Africa. This research was conducted in collaboration with the Institute for Natural Resources (INR), and forms part of the Water Research Commission (WRC), Project K5/2177//4. The WRC project title is the ‘up-scaling of rainwater harvesting and conservation (RWH&C) on communal crop, and rangeland through integrated crop and livestock production for increased water use productivity’. The researcher’s work is aligned with the aims and objectives of the project to satisfy components of the greater WRC research deliverables. The researcher chose to adopt a quantitative and qualitative research design to meet the above criteria and research objectives. Quantitative research is defined as a form of research which explains phenomena, by collecting numerical data that are analysed using mathematical methods, statistical methods and computational techniques (Creswell, 1994). Quantitative research involves collecting a sample of numerical data which can be generalized to depict trends. Qualitative data is information that is difficult to obtain through quantitative-orientated methods (Zhang and Wildemuth, 2009). Quantitative design increases the generalization of the findings whereas qualitative method provides a better understanding of contradictory findings (Rittichainuwat and Rattanaphinanchai, 2015). Qualitative research involves understanding the meaning people have created, how they make sense of their world and their experiences in the world (Merriam, 2009). It is characterized by its aims, which relate to understanding some aspect of social life, and its methods which generally generate words rather than numbers for in-depth data analysis (Bricki, 2007). Quantitative research was the focus of the research; however, qualitative research was used to supplement the results obtained.

3.2 Research Setting - Case study community of Ntshiqo, Eastern Cape

The site identified by the WRC for research purposes was the community of Ntshiqo in the Eastern Cape near Umthatha (Figure 3.1). The main criteria for site selection were location, agricultural system, biophysical and socio-institutional factors. The location of the research site needed to be less than 500km from the INR, with communal tenure systems and active extension support in close proximity. The agricultural systems were required to be mixed-crop livestock systems. Within the biophysical criteria, rainfall needed to be between 550-

750mm annually, with soil depth above 500mm. Under socio-institutional criteria, there needed to be a combination of individual and communal cultivation plots. The overall WRC project objective is to review and demonstrate rainwater harvesting and conservation methods for integrated crop and livestock production at field scale for increased crop and livestock water use productivity at two or more selected sites in communal rural areas of South Africa (WRC, 2013). The objective pertaining to the current research is to determine and improve current levels of Livestock Water Productivity at the selected case study community.

The following sections describe the location of the respective case study community, biophysical characteristics (rainfall, vegetation type, agricultural potential, grazing). Additionally the institutional arrangements in Ntshiqo are described.

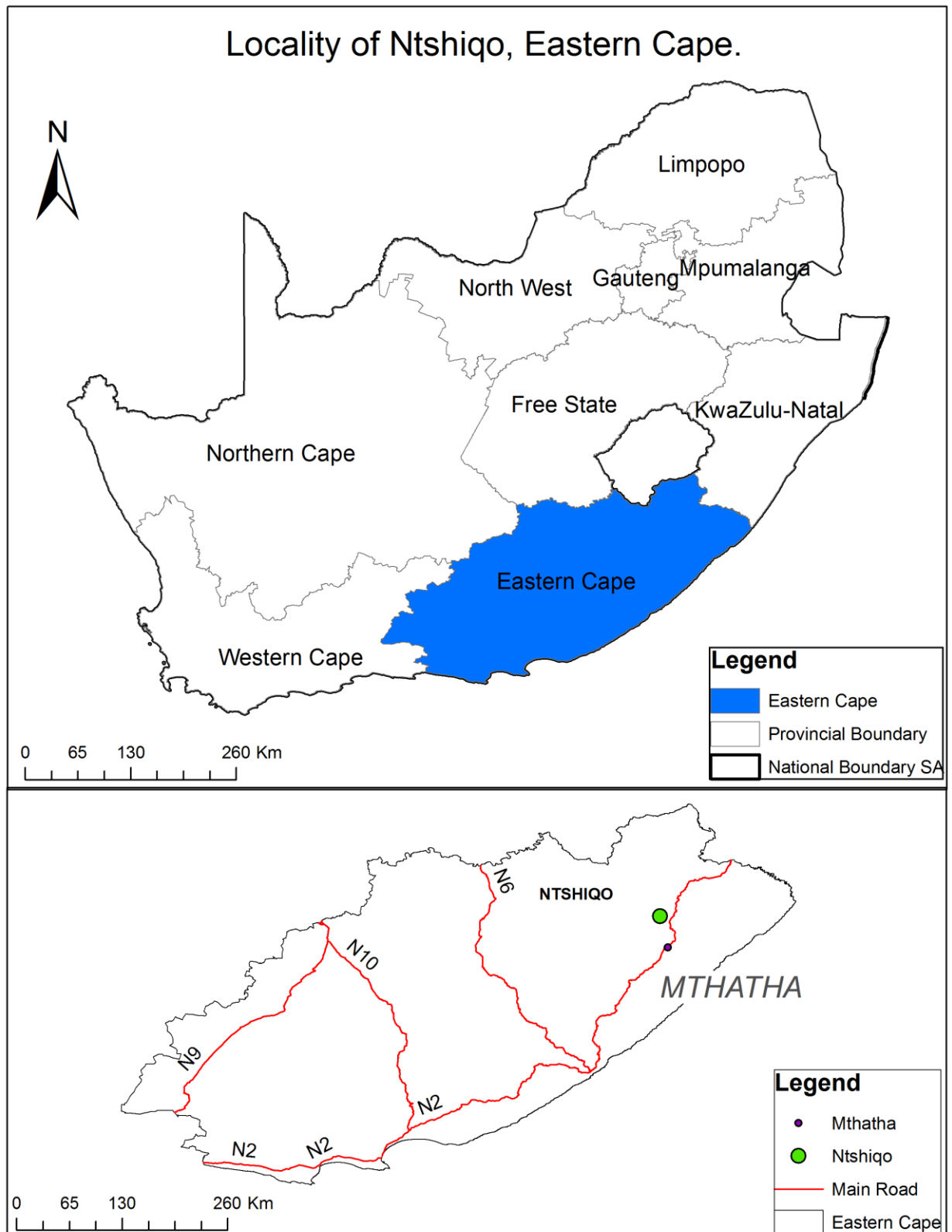


Figure 3.1. Locality of the Ntshiqo case study community in South Africa.

3.2.1 Geographical Context

The Ntshiqo community is part of Ward 7 of the Mhlontlo Local Municipality, OR Tambo District, in the Eastern Cape. Ntshiqo is near to the town of Tsolo, accessible via the N2 national road between Kokstad and Umthatha, approximately 50km North-West from Umthatha. The area has been subject to betterment planning with distinct grouping of homesteads, rangelands and crop fields (Tau, 2005). In South Africa, betterment planning was implemented in the former homeland areas from the 1930s onwards, in an attempt to regulate these areas, control land usage, control erosion, conserve the environment, initiate natural resource management and develop agriculture in the 'homelands' (De Wet, 1989; Tau, 2005). People were dispossessed of arable and grazing land through the process of betterment (De Wet, 1989). Traditional leadership is still the main form of authority in Ntshiqo (McCosh *et al.* 2013).

3.2.2 Biophysical characteristics and current farming practices

The area experiences summer rainfall with a mean annual precipitation that ranges between 600-700 mm per annum. Mean annual temperature is 16⁰C. Frost incidences range from 2-14 days. Altitude varies from 600-1080m.

The Bioresource Program is a natural resources classification system for KwaZulu-Natal (KZN). The BRU is an ecological unit which displays factors such as soil type, climate, altitude, terrain and vegetation (Camp, 1997b; DAEA, 1998). The BRG is defined as a vegetation type characterised or influenced by factors such as climate, altitude and soil which consists of one or more BRUs and is very useful in determining the biophysical characteristics of a specific area within KZN (DAEA, 1998). The Ntshiqo community falls within the greater Mthatha Moist Grassland unit. For veld condition and benchmark comparisons, the Moist Highland Sourveld, Bioresource Group (BRG) 8, was utilised (Everson, 2015: personal communication). No Bioresource Unit (BRU) was specified as only the general BRG information was used for comparative purposes. Due to similarities between the Highland Moist Sourveld and Mthatha Moist Grassland, the Highland Moist Sourveld was used to compare current veld condition to the benchmarks. Benchmarks studies have only been conducted in KwaZulu-Natal by Camp, hence such comparisons were utilised for the Eastern Cape. The Mthatha Moist Grassland is comprised of Highland Sourveld, Dohne Sourveld and Moist Upland Grassland. Over 40% of this region is transformed for cultivation and plantations or by dense rural human settlements. Additionally previously cultivated or fallow lands comprise an estimated 25% of land use (Mucina *et al.* 2006).

The agricultural potential in this BRG is rated as 'Semi-extensive farming areas' in which the soil, slope and climatic conditions are such that the farmer can supplement the grazing of veld with intensification of the limited available arable land (DAEA, 1998). Productivity is limited due to soil, slope, temperature and rainfall (DAEA, 1998). The climate of the area is termed C4, which entails a moderately restricted growing season due to low temperatures and severe frost. Erosion is a serious problem in 34% of the Mthatha Moist Grassland, moderate erosion in 35% and low erosion in the remainder (Mucina *et al.* 2006).

Ntshiqo is characterised by continuous grazing which has resulted in overgrazing in a mixed crop-livestock system. There is a high level of utilisation, which has led to degradation and transformation of the vegetation (Mucina *et al.* 2006). Poor grazing management has led to the dominance of unpalatable grass species (*Eragrostis plana* and *Sporobolus africanus*) and invasion of alien forb species (Mucina *et al.* 2006). Veld in good condition is dominated by *Themeda triandra* (Shackleton, 1990). No resting or grazing interventions have been implemented. The most common livestock are sheep, cattle, goats and horses (4088 sheep, 806 cattle, 952 goats and 81 horses). Homestead gardens are characterised by crops such as maize, pumpkins and beans. Mixed crop-livestock systems sustain the livelihoods of many people in developing countries, hence careful management is required (Descheemaeker *et al.* 2010a).

3.2.3 Institutional Arrangements

Within South African smallholder agricultural communities, there are numerous local organisations³ which contribute directly to peoples' livelihoods. These include local municipalities; Department of Economic Development, Tourism and Environmental Affairs (EDTEA); Department of Agriculture, Forestry and Fisheries⁴ (DAFF) with respective extension support and traditional authorities (McCosh *et al.* 2013). The Municipal Systems

³ Organisations are social groupings formed by likeminded people, to achieve special goals and purposes (Arellano *et al.* 2011).

⁴ In the State of the Nation Address on 11 February 2010, President Jacob Zuma emphasised the government's commitment to rural development and hence improving productivity and the lives of people living in rural areas. As part of this strategy there was an amalgamation of national agriculture, forestry and fisheries known as the Department of Agriculture, Forestry and Fisheries (DAFF). This restructuring process took place in 2009/10. The agricultural function was transferred from the former Department of Agriculture (DoA), the forestry function from the former Department of Water Affairs and Forestry (DWAF) and the marine aquaculture function from the Department of Environmental Affairs and Tourism (DEAT). This restructuring process focused on food security, rural development, land reform and skills development (DAFF, 2010).

Act (MSA) of 2000 provides core principles, mechanisms and processes for local municipalities to upgrade infrastructure such as schools, roads and clinics and social services such as burials in local communities (MSA, 2000). Their roles in land allocation in communal tenure systems is generally very limited (McCosh *et al.* 2013). The DAFF can offer support through the provision of tractors for land preparation or advice on land use. Both these local organisations tend to offer insufficient support to reduce poverty and increase agricultural production in these smallholder agricultural systems (Williams *et al.* 2008). Post 1994 the Department of Agriculture was restructured and new provincial Departments of Agriculture were established (DAFF, 2012). The role of extension services includes promoting linkages between agricultural development institutions and smallholder farmers, linking farmers with service providers and credit facilities, provide information on new agricultural technologies and ensure farmers adopt it, provide education and advice and aid in rural development (Ogunkoya, 2014). These Departments have expressed weaknesses in terms of limited extension staff and hence their capacity to deliver support services and resources to farmers has been compromised (Vink and Kirsten, 2003). South Africa has approximately one-third of the required extension officers to meet development targets and 80% of the current extension staff are not adequately trained (Williams *et al.* 2008, Ogunkoya, 2014). Factors which increase the difficulty of service delivery is the distance between farmers, the vast areas covered by extension workers, client literacy and the level of practical functioning of local farmer groups and associations (Williams *et al.* 2008). Additionally, extension staff have adopted the role of project managers and are spending majority of their time planning, developing business plans, writing status reports and collecting quotations, instead of practically getting involved with local farmers and providing direct assistance (Williams *et al.* 2008). In Ntshiqo, extension staff were found to be inefficient, not providing sufficient assistance to smallholder farmers, in terms of rangeland, crop and livestock management (LWG, 2015). Therefore traditional authorities remained the key role-player in Ntshiqo, in terms of decision making, access and use of land (McCosh *et al.* 2013). For any research to occur in Ntshiqo, meetings needed to be conducted to explain and inform traditional authorities, and interested and affected parties of proposed project developments.

A meeting was held with representatives of the Mhlontlo Local Municipality and DAFF, situated in Tsolo village in June 2013. This was to inform them of research objectives, establish a good working relationship and seek the best advice for approaching appropriate residents in the Ntshiqo community in setting up the research. Subsequent to the initial

meeting held with the Mhlonto Local Municipality and DAFF, meetings were held with the land users and traditional authorities at Ntshiqo in September and October 2013 to gain permission to conduct the research. These meetings involved informal gatherings and were arranged in advance, via numerous cell phone calls between the respective INR project team members and project participants to avoid any potential inconveniences from occurring, or disruptions of work schedules. The meetings were open to any interested local community members (men and women) that had a say or who were involved in the farming practices at Ntshiqo. They focused on explaining the aim and objectives to the land users and interested community members so as to increase their understanding of the WRC project and associated research. These informative gatherings were conducted in the agricultural lands or regular meeting venues (church, school, chiefs house), where the local inhabitants had the opportunity to raise any questions or concerns relating to the proposed WRC project. It was critical to form good relationships with the local community members, being very humble and respectful in the way that these new proposed techniques were explained to the smallholder farmers. It was important to involve the farmers in the discussions and to ensure that the INR representatives conducted the meetings in a way that would not offend the local inhabitants or impact their traditional farming techniques. Therefore forming relationships with the local farmers was important to ensure the willingness and ‘buy-in’ of the proposed research techniques (Krishnaswamy, 2004; Christopher *et al.* 2008; Bergold and Thomas, 2012). To simplify communication between the INR and community members, a livestock working group (LWG) was initiated.

This LWG was elected by fellow community members (Appendix 1, Plate 3.1). This was done for achieving research objective 4. This committee was comprised of 9 local Ntshiqo community members (chairman, deputy chairman, secretary, deputy secretary, treasurer and four ordinary members). Additionally two representatives of the Eastern Cape Department of Rural Development and Agrarian Reform (ECDRDAR) were also part of this working group, as they are situated about 10 minutes from Ntshiqo in Tsolo, which allowed continuous collaboration. This LWG formed a platform for the engagement with local community members, which acted as an institutional mechanism for accessing the research sites and gathering data. Although there was no need for the researcher to examine in depth traditional authorities, extension officers and the LWG in relation to the institutional and policy components of the LWP framework, they were important in providing context for the case study community. Furthermore, the LWG provided anecdotal evidence which supplemented the results of technical interventions.

3.3 Sampling and Data Collection

The data collection involved both quantitative and qualitative methods. The quantitative aspects included the fieldwork such as veld condition assessments, implementing exclosures and rotational resting schemes, disc pasture meter readings, grass clippings, global position system (GPS) data collection and supplemental feeding. The purpose of the quantitative methods was to satisfy objective 2 and 3. The qualitative component encompassed FGDs for added insights, which aided the quantitative results.

Primary data is data collected directly by a researcher for their specific objectives (Church, 2001). Secondary data entails searching for existing data that was conducted by someone else (Church, 2001). Hence primary data collected for this research included all the fieldwork and FGDs. Secondary data collection involved the literature, documents and reports collected for the documentary analysis. Additionally, it involved analysing the collected GPS points and producing map outputs through the use of Geographic Information System (GIS) applications.

3.3.1 Fieldwork

Numerous techniques or procedures were utilised in the fieldwork conducted for the research project, namely veld condition and species composition; selection of exclosures and marked grazed areas; GPS data collection; a rotational resting experiment; monthly disc pasture meter readings; grass clippings and a supplemental feeding experiment. These were conducted for the purpose of achieving research objectives 2 and 3. These are described in detail below.

3.3.1.1. Veld Condition and Species Composition

The consideration of grasses is important during grazing management (Barbour *et al.* 1987; O'Connor *et al.* 2010; Van Oudtshoorn, 2012). Grasses are good indicators of veld condition and grasses also differ in grazing values (Van Oudtshoorn, 2012). Hence grasses are used to determine the condition of veld (Reed and Dougill, 2010). Veld condition information is essential when planning a rangeland management system (Camp, 1997c). Factors such as species composition, the vigour of the palatable species and basal cover play a role in determining veld condition (Camp, 1997c). However, only species composition can be determined objectively, hence the veld condition assessment procedure is based on this factor (Camp, 1997c). Grass species composition play a vital role in determining rangeland condition as grasses vary significantly in their acceptability by livestock due to palatability differences and also due to phenological differences (rhizomatous, stoloniferous, tufted grass)

(Solomon, 2003; Scott and Reynolds, 2007). A species composition assessment was conducted as a requirement to determine the veld condition of specific areas. This was done for the purpose of achieving research objective 2. Two methods were utilised to satisfy this objective, namely the Levy Bridge to obtain species composition, and the Benchmark Method to obtain veld conditions.

Levy Bridge

The levy bridge point intercept method was utilised for this research to determine species composition (Fidelibus and MacAller, 1993). It is the oldest method to measure vegetation cover (Mapako, 2011). A levy bridge consists of a platform which holds ten metal spokes upright at an even distance across a metre span, thereby marking ten points when placed on the ground (Appendix 1, Plate 3.2). The levy bridge was placed at a starting point, with each spike representing a point. The levy bridge was spread out about 5m between the previous collection point until 200 points had been collected. Each spike which came into contact with a grass, plant specimen, rock or bare ground was recorded as a point (Mapako, 2011). Based on this, the grasses were divided into their respective ecological status of grasses (percentage of increaser I, II ,III and decreaseers). The scores were added up for each group to obtain a final score to determine species composition. These points were used to calculate the richness, diversity, cover by species and veld condition of the respective sites (Marx, 2011).

Benchmark Method

This method of veld condition assessment compares veld condition of a site to one which is in excellent condition in the same ecological zone. After the species were classified into their ecological status, each plot was given a total score based on the grazing values and species composition found at the site (Marx, 2011). Once the final scores of the ecological status of grass species were added up, the totals were compared to the benchmark of the respective BRGs of each community (Camp, 1997c). A benchmark is defined as veld in optimum condition for sustainable livestock production (Tainton, 1981). A benchmark is an area which is productive and stable, capable of supporting animal production, whilst conserving water and soil resources (Tainton, 1999). These comparisons indicated in what condition the specific areas of the rangelands were at both study sites (Mapako, 2011).

In Ntshiqo, both methods were utilized before the final research sites were decided upon. Five pilot studies were conducted to determine the spread of veld conditions of the entire grazing area in the community.

3.3.1.2. Selection of Exclosures and Marked Open Areas

Due to the continually overgrazed state of the veld in the Nthsiqo community, exclosures⁵ were implemented to test the effect of rest on veld condition. According to Camp (1997d), periods of absence within a grazing cycle in a season, are inadequate to restore the vigour of plants lost during grazing periods. The only way to restore vigour of veld, especially palatable species, is to provide long term or full growing season rests (Camp, 1997d). Therefore this experiment was conducted to observe changes in biomass production (quantity) and quality of forage over a period of 17 months (June 2014 - October 2015). The data from the exclosures, simulated a long term rest.

After completing the five pilot studies, three final sites were selected for conducting the research. The entire grazing area was divided into three areas namely site 1, site 2 and site 3 according to their respective veld condition scores (best, medium and worst respectively) obtained from species composition (Fig 3.2). Site 1 was the only area of natural rangeland that has been purely utilized for grazing and not cropping purposes (Fig 3.2). This was recognized as the best grazing area by local informants (LWG, 2015). Site 2 had a dense covering of vegetation, comprised of moribund and unpalatable material (Fig 3.2). Site 3 was characterized by land degradation and poor basal cover (Fig 3.2). In each respective site, three 5x5m exclosures were erected using 1.2m high bonnox fencing. This was done to increase the number of samples to achieve statistically acceptable results. Additionally, three corresponding open 5x5m grazed areas were marked in each area (Appendix 1, Plate 3.3 – 3.20). The aim of these exclosures was to compare them to open access areas which were not rested, in terms of biomass production (quantity) and feed quality over a one-year period, hence accounting for seasonality.

⁵ These are fenced areas of specified size, to restrict livestock access.

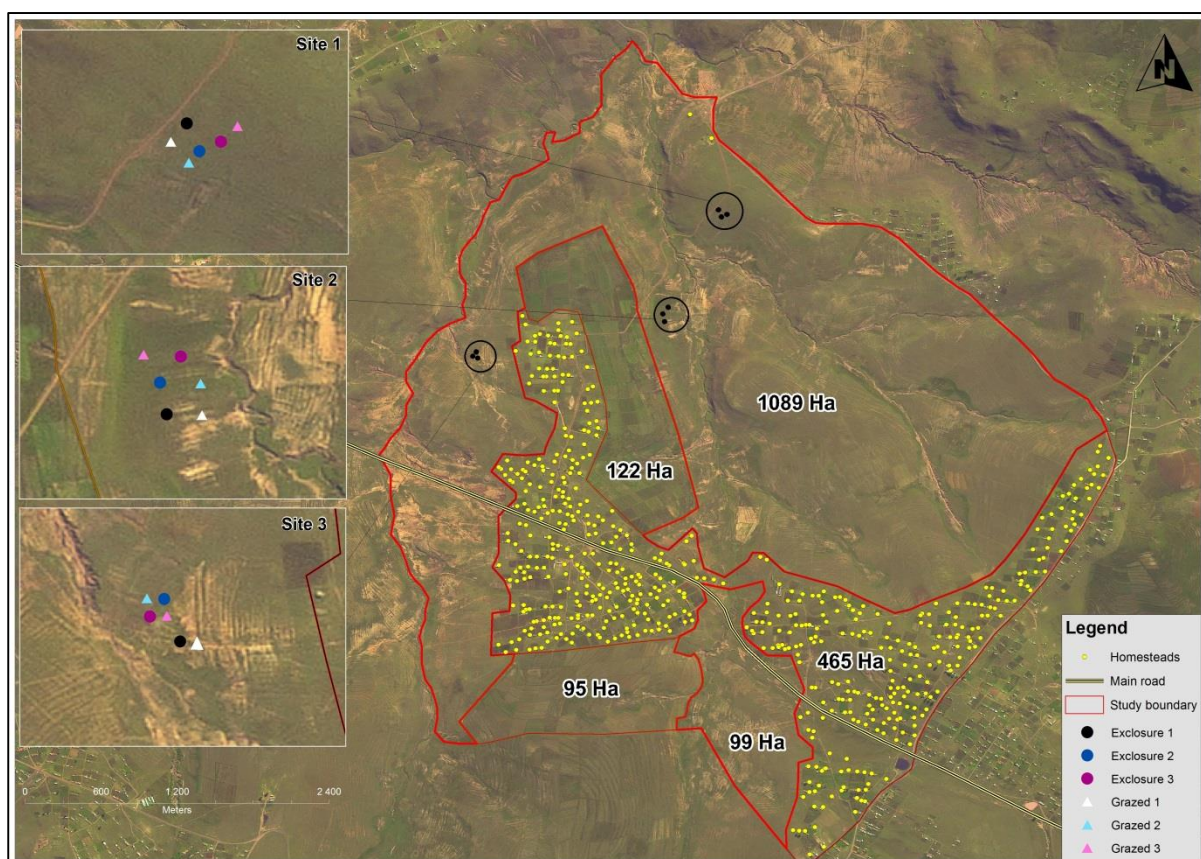


Figure 3.2. Depiction of the exclosures and grazed areas for Sites 1-3 in Ntshiqo.

Global Positioning System

Global Positioning System (GPS) points were obtained for each corner of the respective exclosures and marked open areas, with the use of a handheld Trimble GeoExplorer 6000 Series. This was done to clearly represent their positioning in each community. The readings were taken at a constant height of 1m to keep them constant in relation to the earth's surface (Appendix 1, Plate 3.21). At each recorded point, the researcher obtained GPS readings for one minute, to increase the accuracy and reliability of the points. The boundary of the Ntshiqo community was marked out by a local informant on horseback.

3.3.1.3 Rotational Resting

Resting of veld is the most neglected of all the important principles of grazing management in rangelands (Camp, 1997d). Rotational resting experiments propose that veld should receive a full season's rest once every four years (Smith, 1997). Generally a quarter of the veld is rested, with the remainder available for grazing. This allows veld an uninterrupted time of growth and recovery, which can improve the vigour of grass tufts.

In Ntshiqo, after numerous meetings with local livestock owners and traditional authorities, an additional area was selected for a rotational resting experiment. This had the same aim as

the exclosure experiments, however, was conducted on a larger scale. A 90ha area was selected for the purpose of a summer rest. This specific area was selected in relation to veld condition assessments and knowledge provided by local inhabitants. The area had the best veld condition and highest percentage of palatable species. Hence resting this area was seen as an opportunity to potentially improve biomass production, feed quality and vigour of grass species. The area was divided into two similar halves, with area 1 (41ha) rested for a short period (October 2014 - January 2015) and area 2 (48ha) rested for an entire growing season (October 2014 - June 2015), which equated to 4 and 9 months respectively (Figure 3.3). Three (5x5m) marked grazed areas were selected for each half to monitor the above variables (Fig 3.3). Additional 15 disc pasture meter (DPM) readings were taken for biomass comparisons in these marked open areas on a monthly basis for the duration of the rotational resting experiment. No fencing was implemented to separate the specific grazing areas. This was done for two reasons: firstly it was logistically unfeasible, and secondly to test the effectiveness of management systems in Ntshiqo, in controlling livestock movement. Marked stones, roads and river beds were utilized to demarcate the rested areas. Four local community members were selected as rangers by the LWG to monitor the rested area and prevent any livestock from entering over the entire growing period. Integrating technical interventions with local institutional management structures and policies, promotes success of such interventions (Amede *et al.* 2009).

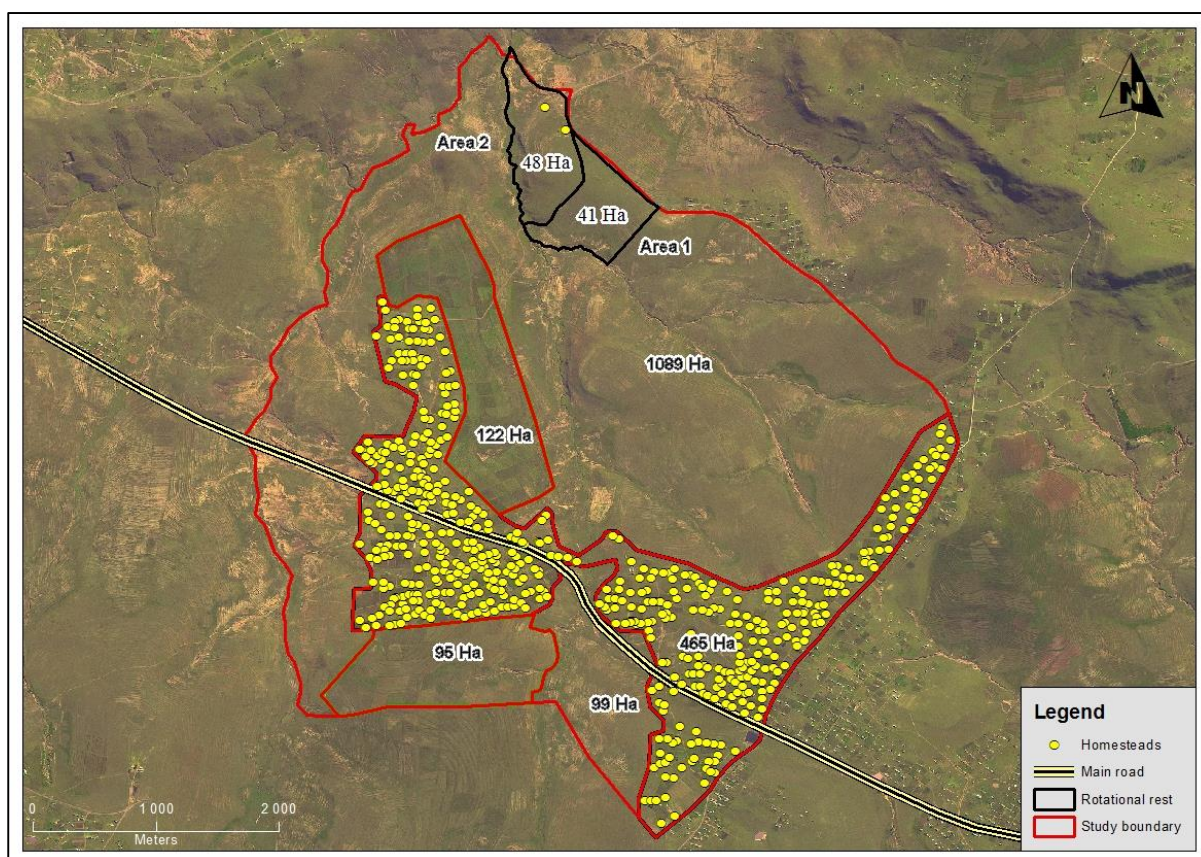


Figure 3.3. Depiction of Area 1 and 2 of the Rotational Resting Experiment in Ntshiqo.

3.3.1.4. Disc Pasture Meter Readings

For this study, monthly biomass readings were taken in the exclosures and corresponding marked grazed areas, to compare biomass production over a year and a half period. The disc pasture metre is a simple, inexpensive instrument which is used to make rapid estimates of standing biomass. This provides an efficient representation of biomass alterations in response to seasonality. It assists rangeland managers in deciding on the most crucial periods to implement rests, hence ensuring sufficient grazing for livestock. It consists of three main components, namely a central rod which is marked at 1cm intervals and an aluminium sleeve that slides freely on the central rod which is attached to a disc (Appendix 1, Plate 3.22). To operate the disc, the central rod was held perpendicular to the ground surface while the sleeve with the attached disc was released on to the vegetation. The settling height of the disc was read off the rod from the position corresponding with the upper end of the sleeve.

A total of 15 monthly DPM readings were taken, within each of the 3 exclosures and corresponding marked grazed areas, for the 3 respective sites. This allowed for the comparison of biomass production between the exclosures and open access areas over a one

and a half year period. The same procedure was followed for the larger rotational resting areas for the duration of that experiment.

Grass clippings were also conducted in these exclosures and corresponding marked grazed areas.

3.3.1.5. Grass Clippings

Grass clippings were obtained to observe biomass production changes in relation to seasonality. This aided the analysis of the feed management component of the LWP framework for the purpose of achieving research objective 2. This was done to illustrate potential positive effects of resting veld and to encourage smallholder farmers to implement similar systems, potentially on a larger scale.

In Ntshiqo, grass clippings were obtained for calibration purposes in relation to monthly biomass readings. Three clippings were taken in each exclosure and in the corresponding marked grazed areas of identical size at each site (Figure 3.3). The clippings were obtained in February 2015 which represented summer, June 2015 represented winter (after the first frost) and October 2015 represented spring (Table 3.1).

Table 3.1. Dates of grass clippings used in full feed analyses (Sites 1 -3).

Clippings	Ntshiqo
1	February 2015
2	June 2015
3	October 2015

A total of 162 clippings were obtained (54 in each season) (Fig 3.4). Each clipping was the size of the disc pasture meter ring (0.167 m^2) and the grass was clipped to approximately 3cm from the soil simulating the grazing height of livestock (Appendix 1, Plate 3.23 and 3.24). These clipped samples were dried for 48 hours at 60°C , weighed and used to construct a calibration graph by plotting dry weight (t/ha) against the related pasture metre disc readings (cm). The average height of the monthly disc pasture readings was utilized to determine the mean biomass for the each exclosure and marked open area, by entering it into the formula obtained from the calibration graph (Fig 3.4). The graph depicted an R^2 value of 0.9031, which indicates that there is a 90.31% linear relationship between disc metre height and mean biomass (Fig 3.4). A p value of < 0.0001 was evident, indicating a statistically significant relationship between the variables (Table 3.2). This allowed for the construction of biomass accumulation curves with the influence of seasonality.

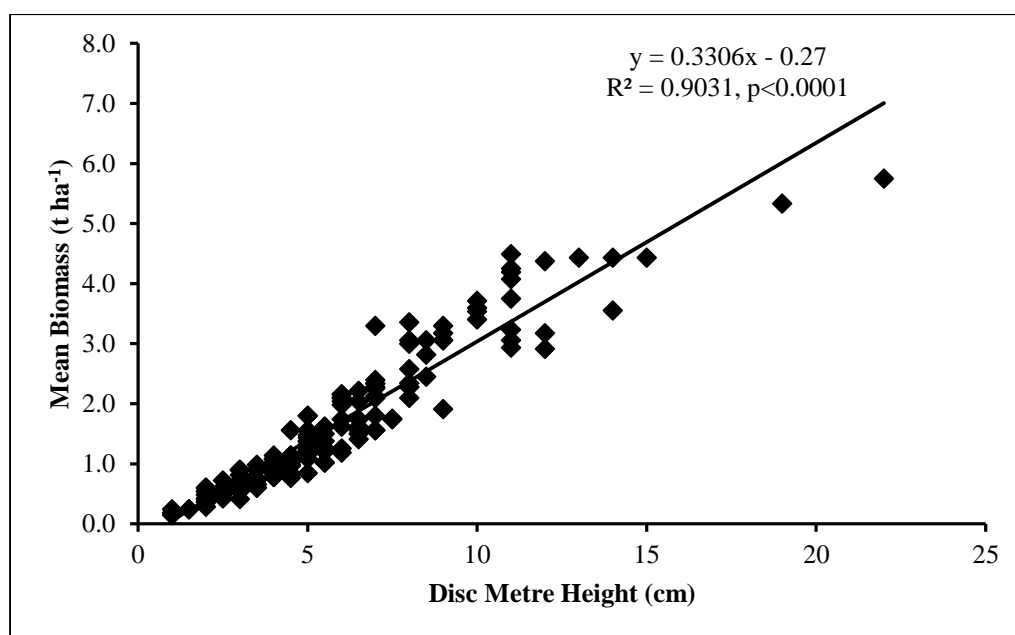


Figure 3.4. Combined calibration graph (n=162) illustrating Disc Metre Height (cm) and Mean Biomass (t ha⁻¹).

Table 3.2. ANOVA results for the regression between Disc Metre Height (cm) and Mean Biomass (t ha⁻¹).

ANOVA								
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>			
Regression	1	201.8453543	201.8454	1491.577	5.23281E-83			
Residual	160	21.65175373	0.135323					
Total	161	223.497108						
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	-0.269989755	0.057426784	-4.70146	5.54E-06	-0.383401998	-0.156577512	-0.383401998	-0.156577512
Height (cm)	0.330644161	0.008561267	38.62094	5.23E-83	0.313736502	0.34755182	0.313736502	0.34755182

Clippings were also taken in the rotational resting areas at Ntshiqo. Three clippings were conducted in each of the marked grazed areas. The first clippings were taken in the second week of January 2015. Both areas had been rested for four months (October-January 2014). Area 1 was opened to livestock grazing the week after the readings were taken. Area 2 remained closed until the first frost in June, which marked the end of the growing season (Fig 3.3). This procedure was repeated again before Area 2 was opened for grazing after the first frost (June 2015).

3.3.1.6. Supplemental Feeding

The lack of supplementary feeding poses as a major constraint to livestock production in sourveld regions of South Africa (Van Niekerk and Jacobs, 1985; Israel and Pearson, 2000). A protein lick supplementary feeding experiment was conducted for sheep to achieve research objective 3. Sheep were chosen for the supplementary feeding experiment due to

their high numbers, economic and general importance for sustaining livelihoods in the Ntshiqo community.

Body Condition Scoring

A body condition scoring method was introduced to compare sheep with and without access to supplementary feeding. The experiment did not focus on individual sheep, but rather on the effect of protein supplementation on the entire flock. Body condition scoring (BCS) is an effective management tool for distinguishing differences in nutritional needs of livestock (Hall, 2000). It is a subjective approach and utilizes a numeric system to estimate energy reserves, relative fatness and general body condition of livestock (Hall, 2000). BCS has been accepted as the most practical way to measure changes in energy reserves in livestock (Bewley and Schutz, 2008). Research indicates that there is a strong correlation between body condition and reproductive performance (Hall, 2000). BCS can be used to determine whether more feed is required to maintain or increase condition of livestock for specific objectives (Suiter, 1994). Additionally the correct management of BCS has implications for milk yield, herd health, animal well-being and overall farm profitability (Bewley and Schutz, 2008).

BCS is a technique which is easily learned, requires no equipment and whilst it is a subjective approach, it has given reliable results when related to subcutaneous fat cover (Morris *et al.* 2002). BCS is an inexpensive method of improving feed and animal management (Morris *et al.* 2002). It allows essential management decisions to be made to enable high standards of husbandry to be achieved (DEFRA, 2001). The use of BCS has been limited due to concerns related to its subjective nature and time required for scoring (Bewley and Schutz, 2008). Due to its subjectivity, the score of an animal may be influenced by the previous animal examined (Halachmi *et al.* 2008).

The experiment was conducted from June to September 2015. A total of 54 sheep which were being fed (treatment) were condition-scored and 50 without access to supplementary feeding (control) were scored. Livestock owners from the treatment and control were asked to keep their livestock in their kraals to speed up the BCS process. The condition scoring was conducted on a monthly basis, to observe any potential differences in body condition of livestock subject to feeding and ones being not fed.

The BCS for sheep was a physical method, which involved determining the condition by hand (Appendix 1, Plate 3.25). It was based on feeling the level of muscling and fat deposition around the vertebrae and loin region (Thompson and Meyer, 1994). In addition to

the spinal column, loin vertebrae have a vertical bone protrusion (spinous process) and a short horizontal protrusion on either side (transverse process) (Thompson and Meyer, 1994). Both of these protrusions are also felt and used to assess the body condition score of sheep.

This condition scoring technique ranged on a scale from 1 to 5. Half scores were utilised if animals were in-between condition scoring categories. Body Condition Score 1 was distinguishable by spinous processes which were sharp and prominent (Fig 3.5). Additionally the transverse processes were sharp, and fingers could pass under the ends. There was no fat cover in the loin eye muscle area. Body condition score 2 was also characterised by sharp and prominent spinous processes (Fig. 3.6). The loin area had a thin fat covering, however it was full. The transverse processes were smooth and slightly rounded. It was still possible to place fingers underneath the transverse processes. The spinous processes for body condition score 3 were smooth and rounded (Fig 3.7). Individual processes could be felt by applying little pressure. The loin eye muscle area was full with a good fat cover. Transverse processes were smooth and well covered. The spinous processes for body condition score 4 could only be detected as a hard line, due to thick fat covering (Fig 3.8). Transverse process could not be felt. Body condition score 5 was characterised by spinous and transverse processes which could not be detected (Fig 3.9). The loin eye muscle area was very full with a thick fat covering (Suiter, 1994; Thompson and Meyer, 1994)

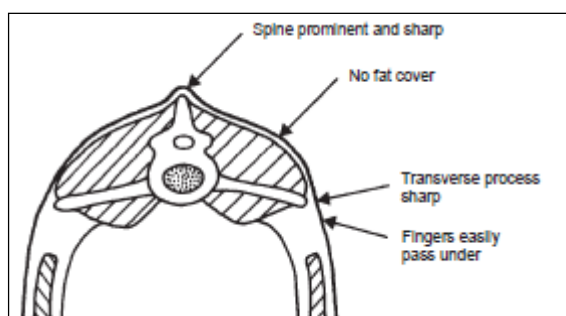


Figure 3.5. Body Condition Score 1 (Emaciated).

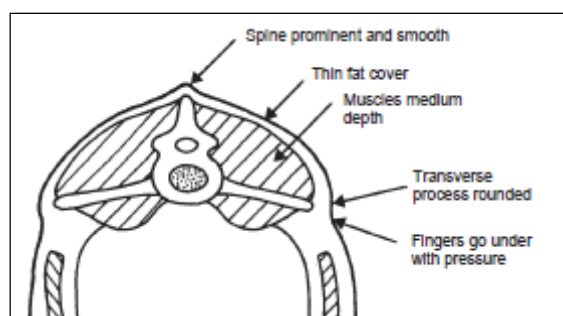


Figure 3.6. Body Condition Score 2 (Thin).

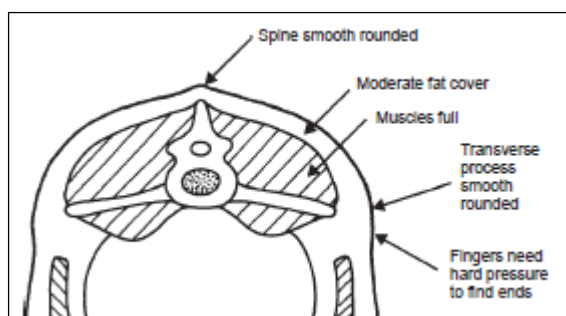


Figure 3.7. Body Condition Score 3 (Average).

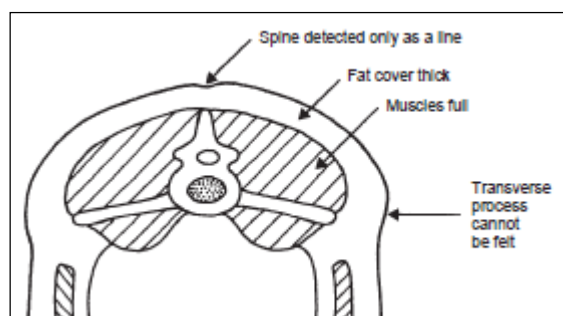


Figure 3.8. Body Condition Score 4 (Fat).

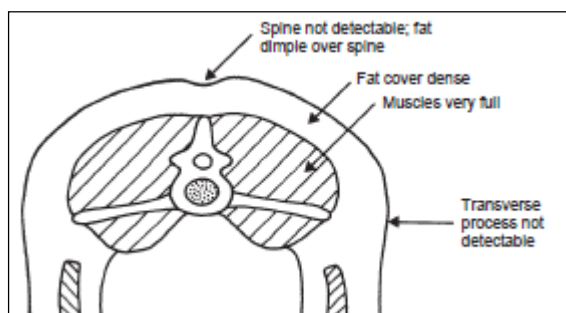


Figure 3.9. Body Condition Score 5 (Obese).

Protein lick

Supplementation of sourveld is necessary for the maintenance of animal production especially over the winter period (Barnes, 1989b). This is due to a decrease in forage acceptability over the dormant period (Barnes, 1989b). Protein is often the primary limiting nutrient in these areas (Van Niekerk and Jacobs, 1985).

Voermol Protein licks were provided to the sheep over the winter months, from June to September 2015 (Appendix 1, Plate 3.26). Sufficient grazing or roughage was required for this product to be effective. These licks supplied protein, minerals and Vitamin A for sheep on protein deficient pasture. They are molasses based which increased the palatability and intake of dry matter (Cleasby, 1963). Each sheep was required to have a 100g intake over the duration of the feeding experiment. The amount of licks required by each livestock owner was calculated according to the daily intake required and the number of sheep owned. The

licks were made available to livestock when they were put into their kraals at night (Appendix 1, Plate 3.27). In Ntshiqo, there was no shortage of forage in the rangelands, however, due to the area being sourveld (grass loses nutritional value over the winter months), the lick was implemented to supplement important minerals and nutrients required for animal health and production. The BCS method was used to monitor the effect of protein licks on the body condition of the sheep over a four month winter period.

3.3.1.7. Vetch and Oats

The planting of fodder crops was introduced in Ntshiqo. This was done for the purpose of satisfying research objective 2 and 3, and to inform smallholder farmers of techniques to increase the quality and quantity of feed for livestock during winter. Four smallholder farmers were selected for the RWH&C trials and hence were involved in this trial. The selection process of the RWH&C trials, involved two initial community meetings. This was an interactive process, where community members could provide recommendations and volunteer for selection. Additionally criteria for selection required farmers to be actively farming on a yearly basis. Site inspections were conducted and 4 homestead gardens were selected for the RWH&C trials. A mix of vetch and oats were intercropped as a winter fodder with the RWH&C trials comprised of locally grown crops such as maize, beans and pumpkins. Vetch and oats were selected according to a few criteria: firstly they were both winter growing crops which had the potential to address forage shortages in winter. Secondly they were identified as the hardiest winter fodder crops and could grow well with little management. These fodder crops excelled at the Ntshiqo community (Appendix 1, Plate 3.28). Fodder crops have the potential to increase forage intake and account for important nutrient deficiencies especially during winter in sourveld regions (Keftasa, 1988; Descheemaeker *et al.* 2010a).

3.3.2 Focus Group Discussions

As part of the greater WRC project, detailed structured livestock questionnaires were administered to livestock owners to understand current levels of animal productivity. These questionnaires aimed to identify current management systems and did not show the benefits of the rangeland management interventions per se, but provided a good understanding of the livestock production system and productivity of livestock. They were initiated on a monthly basis to households with varying livestock numbers. This was done to observe differences in livestock management and to provide important information on herd structure and livestock productivity. They considered calving/kidding rates, mortality rates and off-take of cattle,

sheep and goats through sales, slaughter and other cultural uses. Furthermore, the questionnaires monitored the use and dosage of medicinal products given to livestock and prevalence of supplemental feeding. These questionnaires were outside the scope of the current research focus, however, the general findings were utilised to provide insight and inform the results obtained. Through the formation of the livestock working group (LWG), Focus Group Discussions (FGDs) were administered. This incorporated the qualitative component of the research.

A focus group is a group discussion which focuses on a particular topic organised for research (Gill *et al.* 2008). The group is 'focused' in that it involves a form of collective activity such as debating a particular set of questions (Kitzinger, 1994). The discussion is guided, monitored and recorded by a researcher or facilitator (Gill *et al.* 2008). These FGDs are used for generating information on collective views and the meanings behind those views (Kitzinger, 1994; Gill *et al.* 2008). Focus groups can work successfully with as little as three and as many as fourteen participants. Small groups risk limited discussions and compromises information gathering and large groups can be difficult to manage for the researcher or facilitator and frustrating for participants who feel they get insufficient time to speak (Gill *et al.* 2008).

The LWG was initiated to reduce numbers at FGDs, so that information could be exchanged and issues discussed on a more personal basis. These discussions aimed at gaining valuable insight and information on processes related to livestock productivity. Additional information on institutions and social aspects were targeted, explaining what rules and regulations governed livestock management at a community level. The FGDs were conducted in an informal manner outside in the fields, rangelands, the houses of community members, schools or churches. All issues regarding livestock and the planning of proposed research, (exclosures, rotational resting and supplemental feeding experiments) were discussed with these members, who then informed other community members of project developments and information. Once information had reached all interested and affected parties and feedback was received, decisions in relation to project developments were made. Follow up discussions were crucial as additional information was uncovered each time previous topic discussions were revisited. There was no consistent meeting schedule. These discussions were scheduled, either when the INR had issues to discuss or share information with community members. Additionally, the FGDs were scheduled if community members had questions, suggestions or required clarity in relation to research that was being conducted. To provide research

participants with feedback was an important component of this collaborative research (Gill *et al.* 2008).

3.4 Data Analysis

The data analysis was comprised of laboratory, GIS-related, qualitative data obtained from FGDs, documentary and statistical analyses. The laboratory analysis involved drying grass samples and sending them to Cedara Agricultural College in KwaZulu-Natal, for full feed analyses. The collected GPS data points were processed and transformed into map outputs using GIS application thereby making visualizations easier. Important data obtained from the FGDs which aided the quantitative results. A documentary analysis was done by reviewing a plethora of literature in relation to LWP. Statistical analyses were conducted for the resting (feed quantity and quality) and supplementary feeding experiments.

3.4.1 Field measurements

3.4.1.1 Laboratory work

Once the grass clippings had been obtained, they were dried in the Grassland Science ovens (University of KwaZulu-Natal Agricultural Campus) at 60°C for 48 hours until all moisture was removed. The samples were weighed using a Libror EB-3200D digital scale for biomass calculation purposes (refer to 3.3.1.4).

3.4.1.2 Full feed analysis

Producing suitable quality forage requires knowing the factors that affect forage quality (Ball *et al.* 2001). Monitoring and analysing nutrient content is vital to determine whether forage quality is of a sufficient standard to support animal production (Ball *et al.* 2001). Grass clippings were obtained for the purpose of feed quality analyses in relation to objective 2.

The dried grass samples were taken to Cedara Agricultural College to conduct full feed analyses. The analyses determined the palatability and nutrient composition of the grass samples. These included moisture, fat, acid detergent fibre (ADF), neutral detergent fibre (NDF), crude protein, calcium, magnesium, phosphorus, sodium, potassium / calcium + magnesium (K/Ca+Mg), phosphorus, copper, manganese and iron content (Appendix 2, Full Feed Analysis). A detailed breakdown of full feed analyses provided a good indication of feed quality over the study period. These monitored any changes in feed quality between the rested and open access areas, with the influence of seasonality.

Additionally full feed analyses were conducted on the vetch and oats. This was done to determine the feed quality of these fodder crops, as a potential source of supplemental feed.

3.4.2 Image processing

The use of Global Positioning Systems (GPS) was initially only used for military purposes, however, today the applications have expanded into a variety of different avenues such as cartographic uses, navigation applications in cars and aeroplanes, banking, tracking and surveillance and disaster management (Marais, 2008). For the purpose of this study, a handheld Trimble GeoExplorer 6000 Series GPS was used for positioning and location measurements. The primary step that was conducted was to connect the GPS to the computer and download all the raw collected GPS points. Leica GIS Data Pro was used to download the data. The South African network of Trigonometrical Beacons (Trignet) consists of a number of active base/reference stations, which are spaced 100 to 300 km apart and provide both post-processing and real time correction services (Hedling *et al.* 2000). “The official coordinate reference system, used in South Africa as the foundation for most surveying, engineering and geo-referenced projects and programs, is known as the Hartebeesthoek94 Datum” (Marais, 2008, pg 28). This Datum was based on the World Geodetic System 1984 ellipsoid, referred to as WGS84 (Marais, 2008). It is a network of base stations, which are very accurate receivers and log continuously. These stations log every second based on trilateration, which is the use of intersecting range or distance measurements to determine position (Bond and Nyren, 2012). Each respective base station records positional measurements and corrects them based on known positions using correction factors. They are required to fix errors for latitude, longitude and height measurements between the reference and rover positions (Marais, 2008).

After all the points had been collected, a base file or station in the closest proximity namely Umthatha for Ntshiqo was downloaded. The correction factor was then applied to account for or correct errors within the data collection process. This is classified as a post processing differential correction application of a GPS, as the processed data points were then used in GIS software for various purposes. ArcMap version 10.1 was utilized. Once all the points were corrected, they were exported as an Ascii file into Excel. Here final corrections were conducted, such as decimal places and the names of the columns. The Excel data was exported into ArcGIS as a geographic shapefile, where the data was re-projected from Geographic to a Transverse Mercator (Data Management Tools → Projections and Transformations → Project), which is a meter based projection. Map outputs were created to provide the reader with a more realistic sense of each site and respective exclosures.

3.4.3 Focus Group Discussions

From the FGDs, the main trends and information were obtained by performing a perfunctory analysis, which were integrated with the quantitative results. Further, the response of community members to specific interventions was revealed, which determined the overall success or failure. Ensuring positive responses and ‘buy-in’ of locals to interventions, promoted the success of LWP. This ensured integrated research, vital for the success of LWP in smallholder farming systems.

3.4.4 Documentary analysis

A comprehensive documentary analysis was undertaken by reviewing WRC reports, policy documents and a plethora of literature. The analysis firstly focused on explaining the importance of livestock within the rural context. The significance of livestock was highlighted in terms of their multipurpose benefits. Mixed crop-livestock systems were discussed in the smallholder agricultural context highlighting the role of traditional authorities. Additionally the impact of water scarcity in terms of increasing demand and climate change on agriculture was discussed. The focus then shifted to introducing the LWP concept and framework. The LWP framework which is comprised of numerous variables, was explained through the use of the Descheemaeker *et al.* (2010a) framework. The different components of the model included biophysical (feed, water and animal management), supportive institutions and enabling policies that govern LWP in specific areas. Different strategies and interventions that improved LWP were discussed in greater detail. The documentary analysis provided an in-depth platform of LWP and related variables, which aided in the understanding of the researcher. Throughout the analysis case studies of SSA were provided, with specific focus on the South African smallholder agricultural context.

3.4.5 Statistical analysis

For all the analyses the data was organized into separate Microsoft Excel spreadsheets to simplify the statistical procedures. The statistical analyses were conducted in Microsoft Excel 2010, through the Data Analysis application, accessed by activating an ‘Add-in’ known as Analysis Toolpak. This provided data analysis for statistical and engineering analysis. Under data analysis, numerous statistical tests were provided. A paired t-test and independent t-test were conducted.

A paired t-test was conducted for the 17 month experiment comparing the mean fodder quantity (biomass) and quality values of the exclosures and grazed areas. This was done due

to the presence of 9 paired samples across the 3 sites (Site 1, enclosure 1 and grazed area 1). In relation to the fodder quantity, the mean biomass produced in the peak (May 2015) and end of growing season (August 2015) were analysed. This was to obtain a biomass production range, in comparing the highest and lowest biomass production. The fodder quality focused on the mean ADF, NDF, CP and P values in summer 2015 (February), winter (June 2015, after the first frost) and spring 2015 (October). This was to obtain information on the quality of veld simultaneously accounting for seasonality. This was important to identify periods when supplementation should be implemented.

An independent t-test was performed for the rotational resting experiment to compare the mean fodder quality and quantity values of a short (Oct 2014 - Jan 2015) and full (Oct 2014 - June 2015) summer rest. This was done to determine whether a rotational resting experiment was a viable management intervention for Ntshiqo.

An independent t-test was done for the supplementary feeding experiment comparing the mean body condition score of sheep which had access to the lick (n=54) compared to those without access (n=50). This was conducted to test the significance of protein supplementation over the winter months.

3.5 Methodological Reflections

3.5.1 Language Barrier

Despite having a local informant and facilitators whilst conducting research, the language barrier remained an issue. On numerous occasions, specific, finer details were not able to be passed on from INR representatives to community members or vice versa. This led to a degree of confusion and difficulties in conducting research.

3.5.2 Livestock Working Group

The information obtained from the FGDs may have been biased, as the LWG (9 people) represented the entire Ntshiqo community's perspective. Nonetheless, evidence obtained from the FGDs, was valuable in supplementing results obtained from the technical interventions.

3.5.3 Supplemental feeding

The protein supplementary feeding experiment in relation to BCS was not implemented in the first year of the study period. The BCS method had not been finalised, hence results were obtained only in the winter months (June-September 2015) of the second year of research.

This may have reduced the accuracy or reliability of data recorded due to a lack of replication. However, this experiment was successful in terms of improving body condition of sheep during winter, and revealing positive feedback from participants.

3.5.4 Rotational Resting

The exclusion of animals from the rotational resting areas was effectively conducted by the four appointed rangers. This promoted the success of this experiment.

3.5.5 Exclosures and Grazed Areas

Site 1 was situated in the rotational resting Area 1 (Figs 2.2, 2.3), hence the short summer resting experiment (October 2014 – January 2014). Therefore the grazed areas in Site 1, had a 4 month rest during the 17 month experiment between the exclosures and corresponding grazed areas. This could have biased the results. Regardless, the data provided valuable information on the effect of resting in communal rangelands.

3.5.6 Broader Research

The above components were specific aspects pertaining to the current research. These findings fed into the bigger WRC project, which focused on a wider range of LWP framework components. Research obtained in a specific area should not be analyzed in isolation, but should inform other research elsewhere and vice versa. Such an integrative research approach is promoted for effective LWP research.

3.6 Conclusion

Quantitative and qualitative data were vital in assessing and understanding LWP. The following fieldwork was conducted: veld condition and species composition; selection of exclosures and marked grazed areas; GPS data collection; a rotational resting experiment; monthly disc pasture meter readings; grass clippings and a supplemental feeding experiment. The fieldwork that was conducted aimed to achieve research objectives 2 and 3. FGDs were administered on a continuous basis to help the researcher gain important information, understand current management practices and inform community members of research progress to ensure collaborative research and aid quantitative results. This was done for the purpose of achieving research objective 4.

4 Chapter Four Results

This chapter provides and describes general trends obtained from analysing the collected data. The results play a vital role in providing a visual representation of phenomena, which portray important information (Tau, 2005; Mapako, 2011). Each figure and table are described and explained, thereby providing an in depth understanding of current rangeland conditions, the impact of resting on the quantity and quality of veld, and the influence of supplementary feeding (protein lick) on the Body Condition Scores of sheep. Although not the focus of the current research, the chapter includes the perspectives of smallholder farmers, obtained from FGDs via the LWG in relation to the implemented technical interventions. These interventions fall under feed management of the broader LWP framework, to improve LWP, specifically for smallholder farmers in mixed crop-livestock systems (Amede *et al.* 2009; Descheemaeker, 2009; Descheemaeker *et al.* 2010a; Descheemaeker *et al.* 2010b).

4.1 Rangeland Condition

The success of livestock production of an area is determined by the condition of the rangeland (Tau, 2005). Rangeland condition or rangeland health can be determined by species composition (Tainton, 1999). Other factors which affect the condition are grazing capacity and stocking density (Tainton, 1981). Classification of grasses into their ecological status based on their reaction to different levels of grazing is important in determining the species composition and veld condition of rangelands (Van Oudsthoorn 2012). This aids in identifying rangeland management interventions.

4.1.1 Species Composition

Across all the sites, the Increaser I species were well below that of the benchmark indicating that underutilization of the veld has not been a problem (Table 4.1) (Tainton, 1981; Mapako, 2011). In Ntshiqo, the most common ecological group were the Increaser II grass species, which are grasses abundant in overgrazed veld (Tables 4.1, 4.2). These species are classified as less palatable plants with low grazing value that have an extreme drop in palatability during winter (Table 4.1) (Tau, 2005). The veld condition index revealed that all sites have lost high proportions of desirable species when compared to the benchmark, especially sites 2 and 3. Sites 1, 2 and 3 comprised 60.5%, 95.5% and 89% of the Increaser II composition respectively. These values were significantly higher than the BRG 8 benchmark of 19%, which indicates that overgrazing has occurred over an extended period of time. The most

common Increaser II species were *Sporobolus africanus* and forb species. *Sporobolus africanus* is considered a moderate to poor grazing grass due to its strong, tough leaves and low forage yield (Van Oudtshoorn, 2012). The dominance of these species in veld is not recommended (Tau, 2005; Mapako, 2011; Van Oudtshoorn, 2012). By contrast, Decreaser species, which are abundant in good veld, were significantly lower than the benchmark of 49%. Sites 1, 2 and 3 had a Decreaser species composition of 27.5%, 0% and 5% respectively indicating that overgrazing has taken place (Table 4.1). Site 1 was the only area of natural rangeland that has been purely utilized for grazing and not cropping purposes, hence the higher Decreaser species composition.

Table 4.1. Species composition and veld condition scores of Sites 1, 2, and 3 in Ntshiqo

Group	Species	Grazing Value	Benchmark (%)	Benchmark Score	Site 1 (%)	Score	Site 2 (%)	Score	Site 3 (%)	Score
Decreaser	<i>Brachiara serrata</i>	3	1	3	0.5	1.5	0	0	0	0
	<i>Diheteropogon amplexans</i>	8	1	8	0	0	0	0	0	0
	<i>Monocymbium cerasiiforme</i>	6	2	12	0	0	0	0	0	0
	<i>Themeda triandra</i>	10	45	450	26	260	0	0	5	50
	<i>Panicum natalense</i>	2	0	0	1	2	0	0	0	0
	Sub-total		49	473	27.5	263.5	0	0	5	50
Increaser I	<i>Alloteropsis semialata</i>	3	2	6	0	0	0	0	0	0
	<i>Eulalia villosa</i>	3	1	3	0	0	0	0	0	0
	<i>Trachypogon spicatus</i>	3	2	6	0	0	0	0	0	0
	<i>Tristachya leucothrix</i>	9	20	180	0	0	0	0	0	0
	<i>Hyperrhenia filipendula</i>	5	0	0	12	60	2	10	6	30
	Sub-total		25	195	12	60	2	10	6	30
Increaser II	<i>Eragrostis capensis</i>	2	1	2	0	0	0	0	0	0
	<i>Harpochloa falx</i>	3	3	6	0	0	0	0	0	0
	<i>Heteropogon contortus</i>	6	4	24	0	0	0	0	0	0
	<i>Eragrostis curvula</i>	5	1	5	1.5	7.5	3	15	1	5
	<i>Eragrostis plana</i>	3	1	3	0	0	4.5	13.5	3.5	10.5
	<i>Eragrostis racemosa</i>	2	1	2	1	2	0	0	0	0
	<i>Hyparrhenia hirta</i>	3	1	3	0	0	0	0	0	0
	<i>Microchloa caffra</i>	1	1	1	4	4	0	0	3.5	3.5
	<i>Forbs</i>	0	5	0	33.5	0	6	0	37.5	0
	<i>Sedges</i>	0	1	0	1.5	0	2.5	0	1.5	0
	<i>Sporobolus africanus</i>	3	0	0	12	36	51.5	154.5	31	93
	<i>Digitaria ternata</i>	2	0	0	1	2	0.5	1	0	0
	<i>Aristida bipartita</i>	0	0	0	6	0	0	0	4	0
	<i>Cynodon dactylon</i>	3	0	0	0	0	27.5	82.5	3.5	10.5
	<i>Paspalum dilitatum</i>	7	0	0	0	0	2.5	17.5	0	0
	<i>Eragrostis chloromelas</i>	2	0	0	0	0	0	0	3.5	7
	Sub-total		19	46	60.5	51.5	98	284	89	129.5
Increaser III	<i>Diheteropogon filifolius</i>	0	2	0	0	0	0	0	0	0
	<i>Elionurus muticus</i>	0	5	0	0	0	0	0	0	0
	Sub-total		7	0	0	0	0	0	0	0
	Total		100	714	100	375	100	294	100	209.5
	Veld Condition Score (%)					52.52		41.18		29.34

Table 4.2. The Percentage of the Ecological Status of Grasses, for Sites 1-3

Ecological Status of Grasses (%)	Site 1	Site 2	Site 3	BRG 8 Benchmark
Decreaser	27.5	0	5	49
Increaser I	12	2	6	25
Increaser II	60.5	98	89	19
Increaser III	0	0	0	7
Total (%)	100	100	100	100

An assessment of the species composition of an area allowed for the calculation of current grazing capacity, veld condition and stocking density which are important components for rangeland management (Tau, 2005; Mapako, 2011).

4.1.2 Grazing Capacity, Veld Condition and Stocking Density

The potential grazing capacity is termed the veld which is in ideal veld condition, referred to as the Benchmark (Tau, 2005). This is the highest amount of animals that can be supported on the veld without deterioration (Danckwerts, 1989). The following example depicts the calculations of current grazing capacity for Site 1, based on the veld condition (Table 4.1; Box 4.1).

Box 4.1. Veld Condition and Current Grazing Capacity calculations for Site 1

$$\begin{aligned}
 \text{Veld condition} &= (\text{total sample score} / \text{total benchmark score}) \times 100\% \\
 &= (375 / 714) \times 100\% \\
 &= 52.52\% \\
 \\
 CF \text{ (composition factor)} &= 0.25[(\text{veld condition score} + \text{number of units of Increaser 1 species in excess of the benchmark}) / 100] \\
 &= 0.25[(52.52 + 0) / 100] \\
 &= 0.13 \\
 \\
 TF \text{ (topographic factor)} &= 0.20 \text{ as slope is 5-15\% (The topography is gentle to moderate)} \\
 SEF \text{ (soil erodibility factor)} &= 0.15 \text{ (The site has a moderate erodibility rating)} \\
 \\
 PGC \text{ (potential grazing capacity)} &= 0.67 \text{ AU ha}^{-1} \text{ (1.5ha AU}^{-1}\text{)} \\
 \text{Numerical rating for the site} &= CF + TF + SEF \\
 &= 0.13 + 0.20 + 0.15 \\
 &= 0.48 \\
 \\
 CGC \text{ (current grazing capacity)} &= PGC \times \text{numerical rating for the site} \\
 &= 0.67 \times 0.48 \\
 &= 0.32 \text{ AU ha}^{-1}
 \end{aligned}$$

Table 4.3. Comparison of the Veld Condition Scores, Potential Grazing Capacities and Current Grazing Capacities for Sites 1-3

Sites	Veld Condition (%)	Potential Grazing Capacity (AU ha ⁻¹)	Current Grazing Capacity (AU ha ⁻¹)
Site 1	52.52	0.67	0.32
Site 2	41.18	0.67	0.30
Site 3	29.34	0.67	0.28
Mean	41.01	0.67	0.30

Due to continuous overgrazing of this veld, the average current grazing capacity of the three sites has been reduced to 0.30 AU ha⁻¹ from a potential 0.67 AU ha⁻¹ (Table 4.3). Sites 1, 2 and 3 had a veld condition of 52.52%, 41.18% and 29.34% respectively, with an overall average veld condition of 38.94% (Table 4.3). The low veld condition scores were largely attributed to the predominance of Increaser II species (60.5-89%) when compared to the benchmark site (19%). Site 1 had the highest veld condition due to a 27.5% Decreaser composition (Tables 4.1-4.3). A reduced veld condition in site 2 was because of dense, moribund biomass primarily consisting of Increaser II (98%) species (Tables 4.1-4.3). This made fodder unacceptable to animals. Site 3 had the lowest veld condition potentially due to land degradation and poor basal cover (Table 4.3). Furthermore, local community members classified this site as having the lowest productivity (LWG, 2015). The low grazing values of these species indicated a low potential of the land to support a large number of animals. This was verified by the following calculation of stocking density that the site can support:

$$\begin{aligned}
 \text{Stocking Density} &= \text{Total Grazing area} \times \text{Average Current Grazing Capacity} \\
 &= 1454 \text{ ha} \times 0.30 \text{ AU ha}^{-1} \\
 &= 436 \text{ Animal Units (AU)}
 \end{aligned}$$

An Animal Unit (AU) is defined as the forage requirement of livestock (Scarnecchia, 1985). The results of this study indicated that the stocking density for Ntshiqo (1454 ha) that can be supported by veld in this condition was 436 AU. In Ntshiqo there were 5846 animals (806 cattle, 4088 sheep, 952 goats). The carrying capacity is generally based on the standard biomass (i.e. 450kg) and forage requirement of one AU for commercial cattle (Meissner, 1982). For communal cattle, this value was adjusted to 0.75 Animal Unit Equivalent (AUE) (i.e. 375 kg) as they have lower forage requirements (Meissner, 1982). AUE is based on a percentage of the standard AU and takes into account physiological differences of livestock (Scarnecchia, 1985). Therefore the cattle population was comprised of 604.5 AU (806*0.75). The AUE for sheep, goats and horses were 0.20, 0.15 and

1.25 respectively. In Ntshiqo, the actual stocking density was 1666 AU, which is just under four times the recommended stocking density.

The high stocking density at Ntshiqo has resulted in severe overgrazing. This resulted in poor veld condition of the area. There were no resting or grazing initiatives, which indicated that appropriate management interventions were lacking (LWG, 2015). To make suitable recommendations, an assessment of the production of the veld is required to determine the biomass available for livestock.

4.2 Forage Quantity and Quality

The forage quantity and quality produced in the exclosures and continuously grazed areas, and the rotational resting experiments are presented below.

4.2.1 Exclosures and grazed areas

4.2.1.1 Forage Quantity

Biomass production of the continuously grazed sites (representing the grazing regime practised by the livestock owners) was low in all sites with a maximum biomass of $<2.1 \text{ t ha}^{-1}$ (Figs 4.1-4.3). Following the first frost in June, mean biomass production decreased in all sites with no significant differences between the exclosures and grazed areas at the start of the experiment (0.26 to 1.56 t ha^{-1}). These low values were expected due to the high utilization of forage utilised by the livestock for winter grazing. However, continued exclusion of livestock in the exclosures resulted in significant increases in biomass. In site 1, the peak mean biomass production in the exclosures (1.30 t ha^{-1}) was reached in May 2015 with a corresponding value of 0.49 t ha^{-1} in the grazed areas (Fig 4.1). Peak mean biomass production for the grazed areas of 0.84 t ha^{-1} was produced in March 2015.

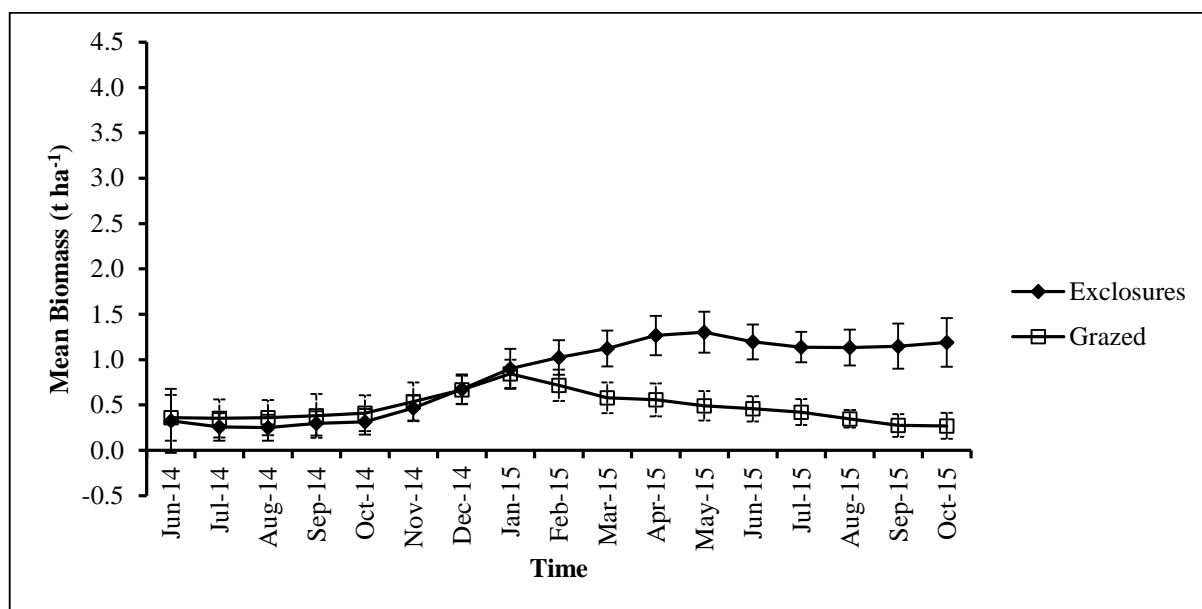


Figure 4.1. Site 1: Mean (\pm se) biomass for exclosures and grazed areas over time.

In site 2, the peak mean biomass production of the exclosures (3.97 t ha^{-1}) was reached in May 2015 compared to 1.87 t ha^{-1} produced in March 2015 in the grazed areas (Fig 4.2). Peak mean biomass production for the grazed areas of 2.08 t ha^{-1} was produced in March 2015.

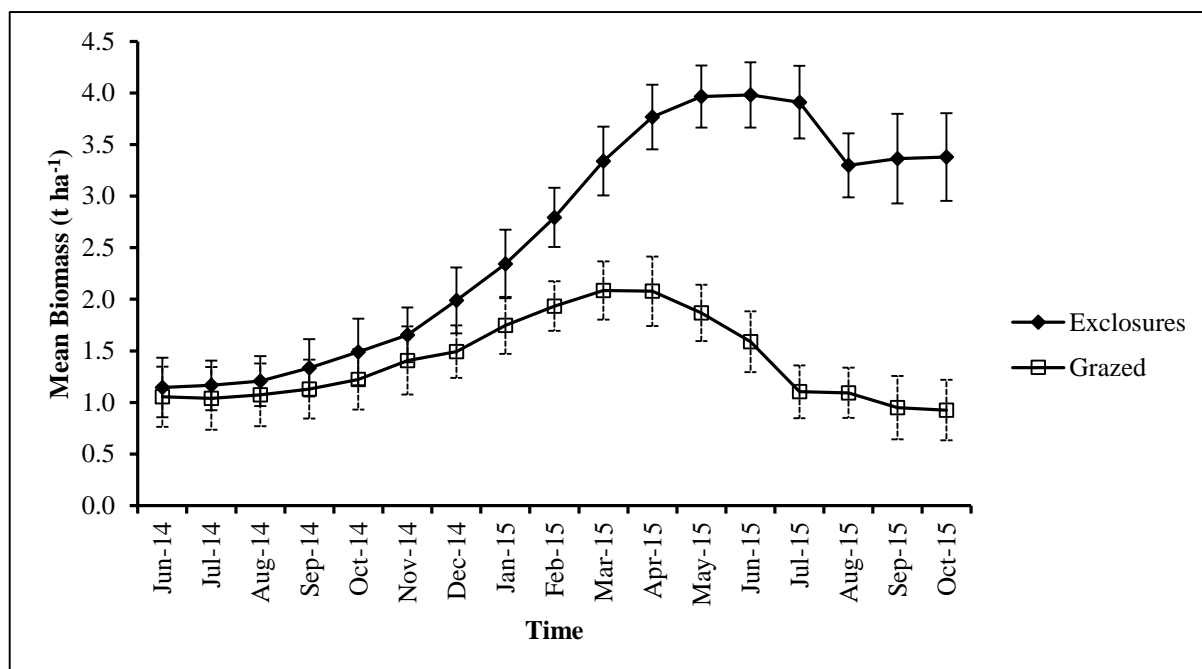


Figure 4.2. Site 2, mean (\pm se) biomass for exclosures and grazed areas over time.

In site 3, the peak mean biomass production in the exclosures (2.43 t ha^{-1}) was reached in May 2015 compared to 1.29 t ha^{-1} in the grazed outside areas (Fig 4.3). Peak mean biomass production for the grazed areas of 1.46 t ha^{-1} was produced in April 2015.

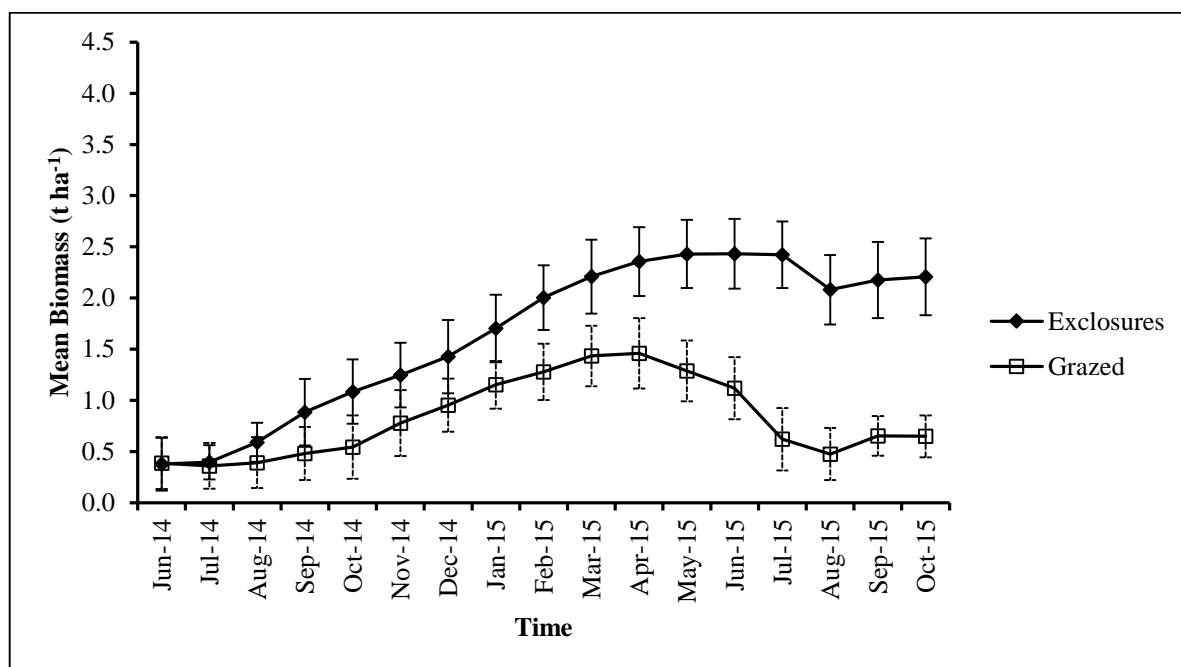


Figure 4.3. Site 3, mean (\pm se) biomass for exclosures and grazed areas over time.

The peak (May) and end (August) of the growing seasons were compared to obtain the range of biomass produced in the Ntshiqo rangeland. The mean biomass produced in the exclosures and grazed areas was 2.57 and 1.22 t ha⁻¹ (Table 4.4). The exclosures during the peak growing season produced significantly more ($t = 4.34$, $p < 0.001$, $df = 8$) biomass when compared to continuously grazed areas (Table 4.4). This depicted a four-fold increase in biomass production in the exclosures during the peak growing season, compared to the initial values at the start of the experiment. The mean difference in yield was 1.35 ± 0.311 t ha⁻¹, approximately twice as much as the continuously grazed areas (Table 4.3). The mean biomass produced during the end of the growing season in the exclosures and grazed areas was 2.17 and 0.65 t ha⁻¹ respectively (Table 4.4). The exclosures during the end of the growing season produced significantly higher ($t = 5.56$, $p < 0.001$, $df = 8$) biomass compared to the grazed areas (Table 4.4). The mean difference in yield was 1.52 ± 0.273 t ha⁻¹, over three times as much as the continuously grazed areas (Table 4.4). The difference in biomass between adjacent continuously grazed and protected areas is highlighted in Figure 4.4. Site 2 produced much higher biomass compared to the other sites, due to the high composition of Increaser II (98%) species (Table 4.2). This resulted in reduced grazing of biomass thereby promoting the growth of mature and moribund material (Table 4.4). This is unacceptable to livestock, hence higher biomass production. There was a consistent directional change between the 9 replicates of paired samples, with the exclosures having a higher biomass than the grazed areas in both the peak and end of the growing season (Fig 4.4).

Table 4.4. Mean biomass (t ha⁻¹) produced at the peak (May) and end of the growing season (August), in the exclosures and grazed areas for Sites 1-3

	Site	Mean Grazed Biomass (t ha ⁻¹)	Mean Exclosures Biomass (t ha ⁻¹)	Mean difference (t ha ⁻¹)	sd	se	t-value	p-value
Peak of Growing Season (May)	Site 1	0.49	1.30	0.81	0.227	0.131		
	Site 2	1.87	3.97	2.10	1.445	0.834		
	Site 3	1.29	2.43	1.14	0.052	0.030		
	Overall	1.22	2.57	1.35	0.933	0.311	4.34	0.001
End of Growing Season (August)	Site 1	0.35	1.13	0.79	0.291	0.168		
	Site 2	1.09	3.30	2.20	0.983	0.568		
	Site 3	0.52	2.08	1.56	0.336	0.194		
	Overall	0.65	2.17	1.52	0.818	0.273	5.56	p<0.0001

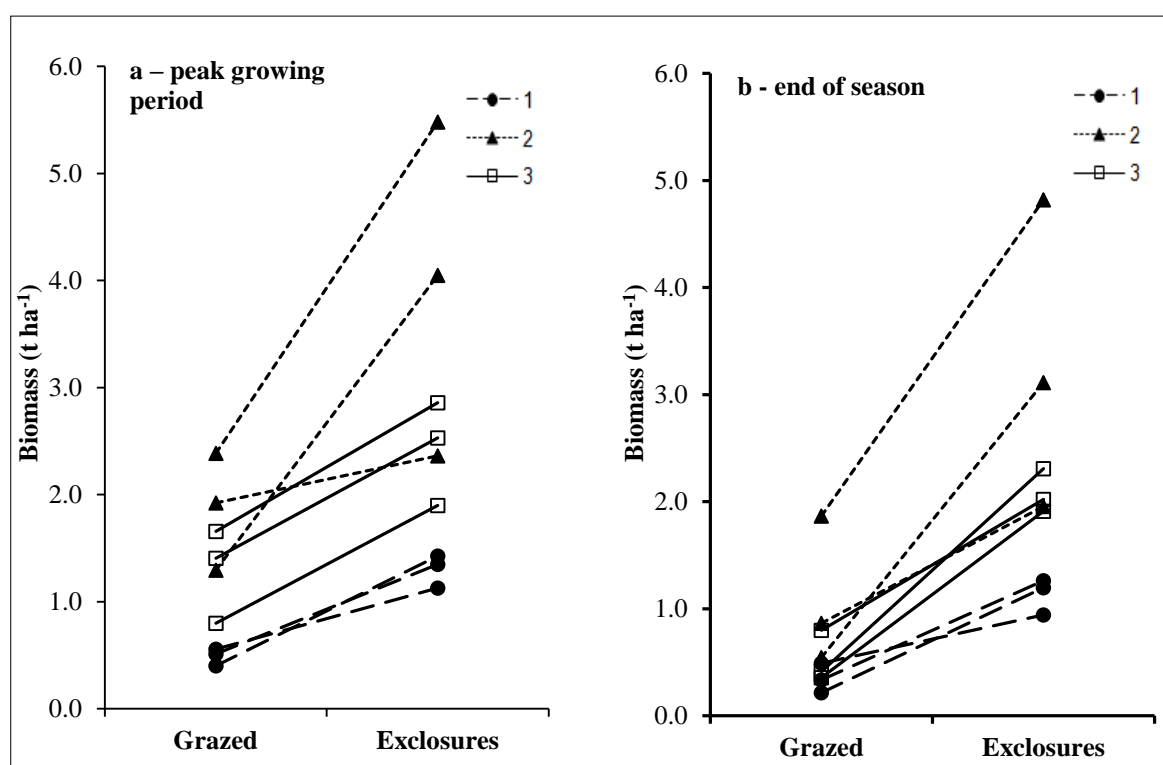


Figure 4.4. Mean biomass comparisons between 9 replicates of paired samples of exclosures and grazed areas in (a) – peak of growing season (May), and (b) – end of growing season (August) (1 = Site 1, 2 = Site 2, 3= Site 3).

Local community members in Ntshiqo were satisfied with the results, realising the positive impacts of resting on biomass production (LWG, 2015). While this has long term rest (17 months) had the potential to have a positive effect on livestock production, determining the quality of this biomass was critical. Sourveld is characterised by poor digestibility, intake and forage quality during the winter months, negatively affecting animal productivity (O'Reagain and Mentis, 1988; Danckwerts, 1989; De Bruyn and Koster, 2000; Kirkman and De Faccio Carvalho, 2003).

4.2.1.2 Forage Quality

The amount of fibre in the grass is an indication of its quality with high fibre reducing the digestibility and intake of forage (Beauchemin, 1996; Ball *et al.* 2001). The digestibility and intake of forage are important components affecting the diet of livestock.

During summer (February) the mean Acid Detergent Fibre (ADF) values across all the exclosures and grazed areas was 47.85 and 47.44%, respectively (Table 4.5). These are high values, indicating mature forage with low digestibility and high fibre content (De Bruyn and Koster, 2000; Newman *et al.* 2006; Mapako, 2011). There was no significant difference ($t = 0.42$, $p = 0.685$, $df = 8$) in ADF values between the exclosures and grazed areas (Table 4.5). During winter (June) the mean ADF values in the exclosures and grazed areas were 49.40 and 48.22% respectively. No significant difference ($t = 0.80$, $p = 0.447$, $df = 8$) was evident between ADF values in exclosures and grazed areas in winter (Table 4.5). The mean difference in ADF values is 1.18 ± 1.477 % (Table 4.5). In spring (October) the mean ADF values in the exclosures and grazed areas were 46.10 and 45.07% respectively (Table 4.5). No significant difference ($t = 0.49$, $p = 0.639$, $df = 8$) was evident, with a mean difference in ADF values between the treatments of 1.03 ± 2.111 % (Table 4.5). No consistent directional change between the 9 replicates of paired samples was evident (Fig 4.5).

Table 4.5. Summary table comparing the mean ADF (%) values produced in summer (February), winter (June) and spring (October) in the exclosures and grazed areas for Sites 1-3

	Site	Mean ADF Grazed (%)	Mean ADF Exclosures (%)	Mean difference (%)	sd	se	t-value	p-value
Summer (February)	Site 1	48.76	47.10	-1.66	1.243	0.718		
	Site 2	47.90	48.11	0.21	2.985	1.723		
	Site 3	45.66	48.33	2.68	3.058	1.765		
	Overall	47.44	47.85	0.41	2.915	0.972	0.42	0.685
Winter (June)	Site 1	48.77	46.70	-2.06	0.734	0.424		
	Site 2	51.17	50.32	-0.85	2.931	1.692		
	Site 3	44.71	51.17	6.46	2.381	1.375		
	Overall	48.22	49.40	1.18	4.431	1.477	0.80	0.447
Spring (October)	Site 1	46.18	51.24	5.06	5.479	3.163		
	Site 2	46.95	43.93	-3.03	1.211	0.699		
	Site 3	42.08	43.13	1.05	8.937	5.160		
	Overall	45.07	46.10	1.03	6.333	2.111	0.49	0.639

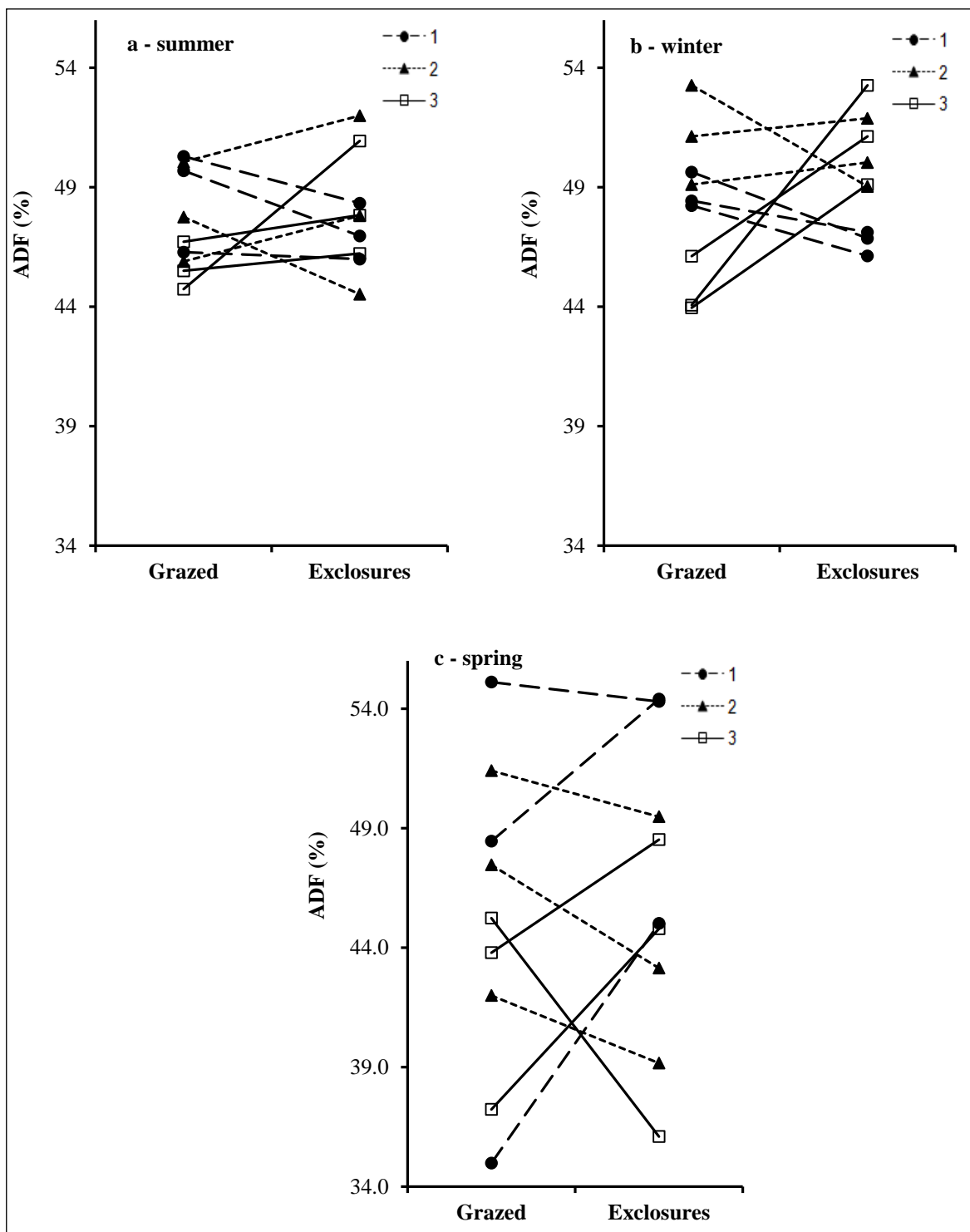


Figure 4.5. Comparison between the mean ADF values in 9 paired samples of exclosures and grazed areas in (a) summer (February), (b) winter (June) and (c) spring (October).

The mean Neutral Detergent Fibre (NDF) values across all the exclosures and grazed areas during summer, was 78.10 and 80.80% respectively (Table 4.6). These are high NDF values which depicted mature forage, with a high fibre content and low intake (Beauchemin, 1996; Ball *et al.* 2001). There was no significant difference ($t= 2.07$, $p= 0.072$, $df= 8$) between NDF values in exclosures and grazed areas (Table 4.6). During winter the mean NDF values in the exclosures and grazed areas were 80.71 and 82.03%. There was no significant difference ($t= 1.20$, $p= 0.266$, $df= 8$) between NDF values in the treatments (Table 4.6). The mean difference in NDF values was -1.32 ± 1.102 % (Table 4.6). In spring (October) the mean NDF values in the exclosures and grazed areas were 83.16 and 84.01% respectively (Table 4.6). No significant difference ($t= 0.54$, $p= 0.601$, $df= 8$) was evident, with a mean difference in NDF values between the treatments of -0.85 ± 1.563 % (Table 4.6). No consistent directional change between the 9 replicates of paired samples was evident (Fig 4.6).

Table 4.6. Summary table comparing the mean NDF (%) values produced in summer (February), winter (June) and spring (October) in the exclosures and grazed areas for Sites 1-3

	Site	Mean NDF Grazed (%)	Mean NDF Exclosures (%)	Mean difference (%)	sd	se	t-value	p-value
Summer (February)	Site 1	79.97	74.03	-5.94	4.669	2.696		
	Site 2	80.83	78.71	-2.12	3.031	1.750		
	Site 3	81.60	81.56	-0.03	1.736	1.002		
	Overall	80.80	78.10	-2.70	3.904	1.301	2.07	0.072
Winter (June)	Site 1	79.49	76.61	-2.89	3.696	2.134		
	Site 2	84.29	83.13	-1.16	2.306	1.331		
	Site 3	82.31	82.40	0.09	4.250	2.454		
	Overall	82.03	80.71	-1.32	3.307	1.102	1.20	0.266
Spring (October)	Site 1	86.29	82.52	-3.78	3.568	2.060		
	Site 2	83.27	87.27	4.00	4.198	2.424		
	Site 3	82.48	79.70	-2.78	1.978	1.142		
	Overall	84.01	83.16	-0.85	4.690	1.563	0.54	0.601

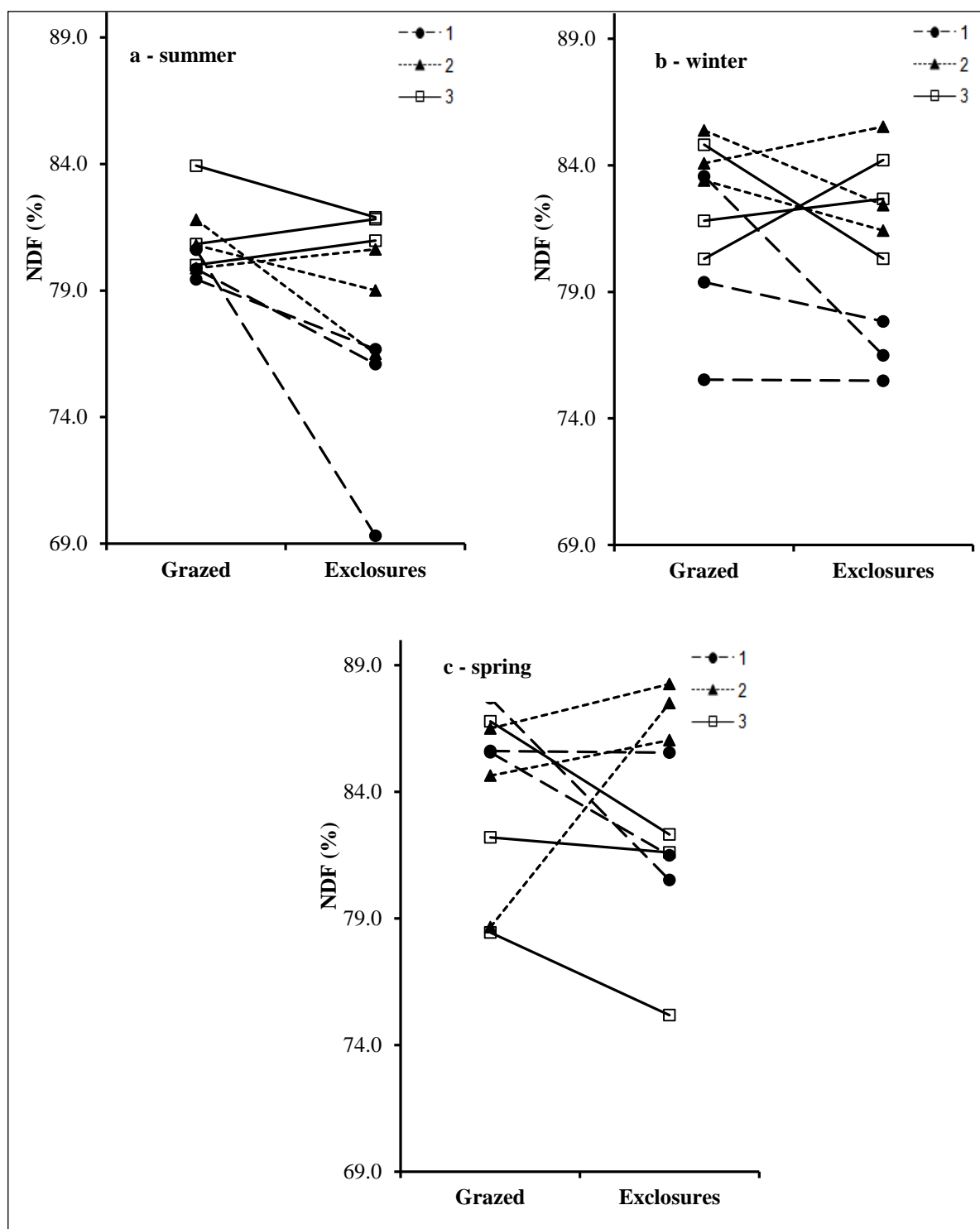


Figure 4.6. Comparison between the mean NDF values in 9 paired samples of exclosures and grazed areas in (a) summer (February), (b) winter (June) and (c) spring (October).

Crude protein (CP) is a critical nutrient for livestock health (Van Niekerk and Jacobs, 1985). The crude protein content in forage is vital in determining livestock production (Sprinkle, 2001).

The mean CP values in the exclosures and grazed areas during summer were 5.04 and 5.57% respectively (Table 4.7). These depicted low CP values (Newman, 2006; Mapako, 2011; Munyai, 2012). There was no significant difference ($t= 2.26$, $p= 0.054$, $df= 8$) between CP values in exclosures and grazed areas (Table 4.7). During winter the mean CP values in the exclosures and grazed areas were 2.52 and 2.90% respectively (Table 4.7), indicating that the quality of the forage was critically low. No significant difference ($t= 1.39$, $p= 0.202$, $df= 8$) was found between CP in values in the treatments (Table 4.7). The mean difference in CP values was -0.38 ± 0.273 % (Table 4.7). In spring (October) the mean CP values in the exclosures and grazed areas were 4.55 and 4.50% respectively (Table 4.7). No significant difference ($t= 0.14$, $p= 0.891$, $df= 8$) was evident, with a mean difference in CP values between the treatments of 0.05 ± 0.327 % (Table 4.7). No consistent directional change between the 9 replicates of paired samples was evident (Fig 4.7). According to Sprinkle (2001), when CP drops below 6.25%, protein supplementation is required. It is evident that protein supplementation is required in Ntshiqo to improve animal productivity especially during winter (Table 4.7).

Table 4.7. Mean CP (%) values produced in summer (February), winter (June) and spring (October) in the exclosures and grazed areas for Sites 1-3

	Site	Mean CP Grazed (%)	Mean CP Exclosures (%)	Mean difference (%)	sd	se	t-value	p-value
Summer (February)	Site 1	5.30	5.13	-0.18	0.124	0.072		
	Site 2	5.80	4.72	-1.08	0.374	0.216		
	Site 3	5.62	5.27	-0.35	1.082	0.625		
	Overall	5.57	5.04	-0.53	0.709	0.236	2.26	0.054
Winter (June)	Site 1	2.63	2.41	-0.22	0.086	0.049		
	Site 2	2.65	2.81	0.17	0.473	0.273		
	Site 3	3.42	2.33	-1.08	1.110	0.641		
	Overall	2.90	2.52	-0.38	0.819	0.273	1.39	0.202
Spring (October)	Site 1	4.39	4.54	0.15	1.500	0.866		
	Site 2	4.38	4.48	0.10	1.038	0.599		
	Site 3	4.74	4.63	-0.11	0.680	0.393		
	Overall	4.50	4.55	0.05	0.981	0.327	0.14	0.891

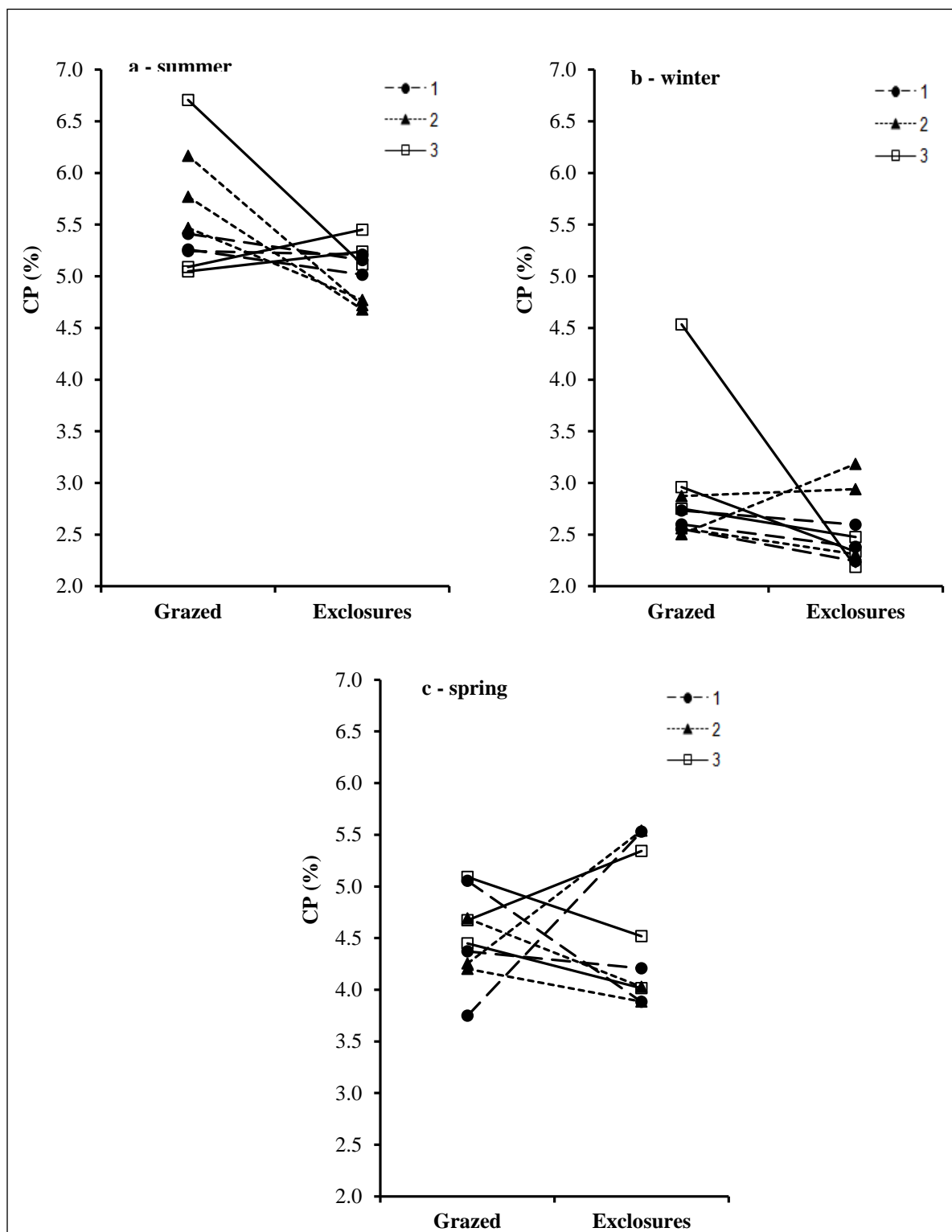


Figure 4.7. Comparison between the mean CP values in 9 paired samples of exclosures and grazed areas in (a) summer (February), (b) winter (June) and (c) spring (October).

Phosphorus (P) is a vital limiting plant nutrient which impacts on animal performance (Van Niekerk and Jacobs, 1985; Miller and Gardiner, 1998).

During summer, the exclosures and grazed areas had mean P values of 0.06 and 0.07% respectively (Table 4.8). This depicted significantly low values (Mapako, 2011). According to the NRC (1984), a lactating cow requires 0.27% P in a pasture. Therefore these values indicated a P deficiency (De Brouwer *et al.* 2000). There was no significant difference ($t= 2.38$, $p= 0.051$, $df= 8$) between P values in exclosures and grazed areas (Table 4.8). The mean P values in the exclosures and grazed areas during winter were 0.06 and 0.04% respectively. There was no significant difference ($t= 0.68$, $p= 0.515$, $df= 8$) between values in exclosures and grazed areas (Table 4.8). The mean difference in P values was 0.02 ± 0.030 % (Table 4.8). Exclosure 1 at Site 2 had a high P value for unknown reasons (Fig 4.8b). In spring (October) the mean P values in the exclosures and grazed areas were 0.06 and 0.06% respectively (Table 4.8). No significant difference ($t= 1.00$, $p= 0.348$, $df= 8$) was evident, with a mean difference in P values between the treatments of 0.01 ± 0.007 % (Table 4.8). No consistent directional change between the 9 replicates of paired samples was evident (Fig 4.8).

Table 4.8. The mean P (%) values produced in summer (February), winter (June) and spring (October) in the exclosures and grazed areas for Sites 1-3

	Site	Mean P Grazed (%)	Mean P Exclosures (%)	Mean difference (%)	sd	se	t-value	p-value
Summer (February)	Site 1	0.08	0.06	-0.01	0.013	0.007		
	Site 2	0.07	0.05	-0.02	0.010	0.006		
	Site 3	0.07	0.07	0.00	0.011	0.006		
	Overall	0.07	0.06	-0.01	0.012	0.004	2.38	0.051
Winter (June)	Site 1	0.04	0.04	-0.01	0.012	0.007		
	Site 2	0.04	0.12	0.08	0.149	0.086		
	Site 3	0.05	0.04	-0.02	0.015	0.009		
	Overall	0.04	0.06	0.02	0.089	0.030	0.68	0.515
Spring (October)	Site 1	0.05	0.07	0.02	0.035	0.020		
	Site 2	0.06	0.05	0.00	0.008	0.004		
	Site 3	0.06	0.07	0.00	0.008	0.005		
	Overall	0.06	0.06	0.01	0.021	0.007	1.00	0.348

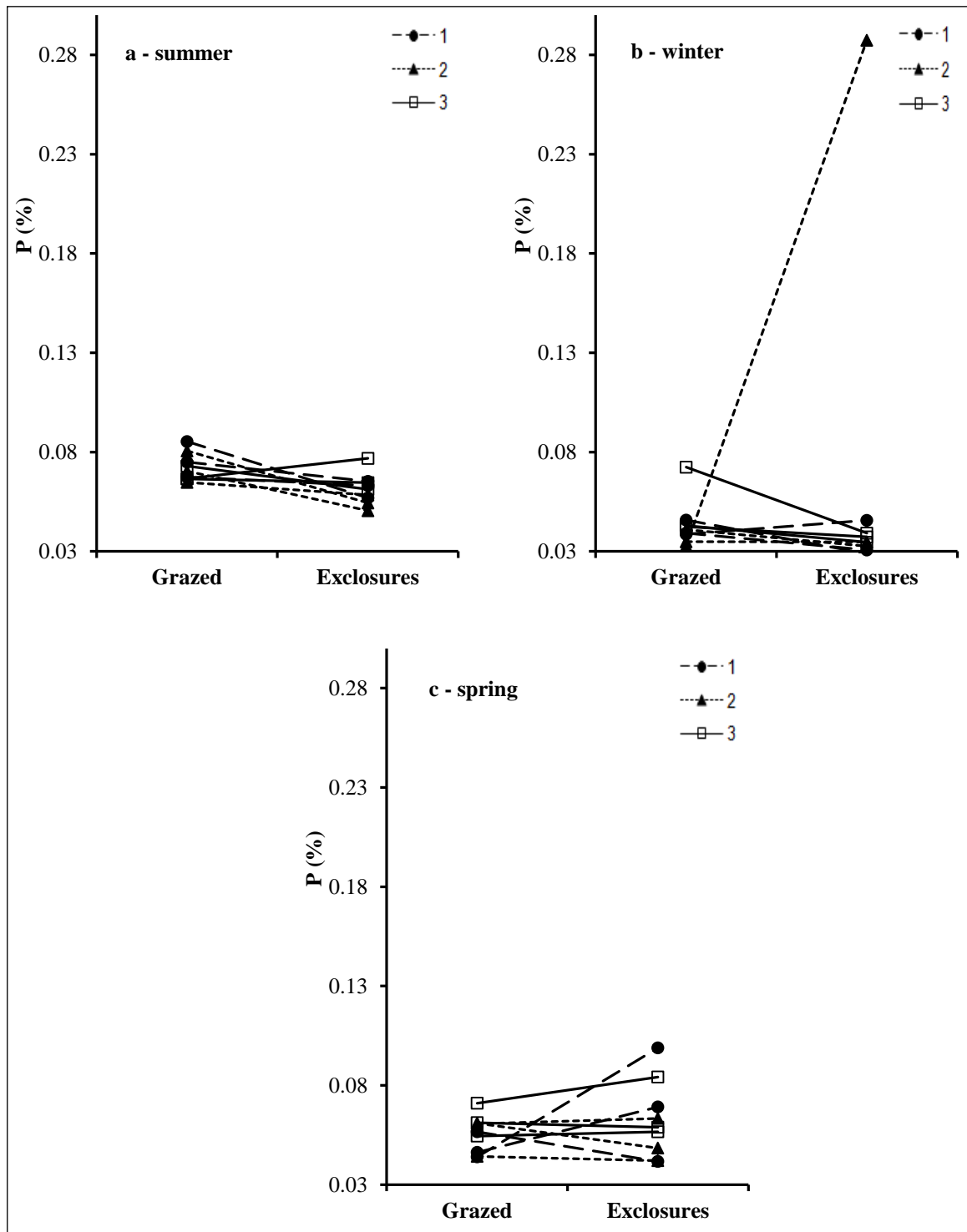


Figure 4.8. Comparison between the mean P values in 9 paired samples of exclosures and grazed areas in (a) summer (February), (b) winter (June) and (c) spring (October).

No additional information was provided by the Ntshiqo community members regarding the quality of the veld, due to the complex nature of such feed analyses (LWG, 2015). The resting of veld is considered a vital intervention for good rangeland management in all types of veld (O'Reagain,

1994; Tainton and Danckwerts, 1999; Descheemaeker *et al.* 2006). The impact of a short and full summer rest on forage quantity and quality was assessed.

4.2.2 Rotational Resting

4.2.2.1 Forage Quantity

It was evident that resting for a full summer period (October 2014 – June 2015) produced significantly more biomass compared to a short summer rest (October 2014 – January 2015) (Figure 4.9). The mean biomass in the short summer rested area increased from 0.41 to 0.84 t ha⁻¹, indicating a two-fold increase in biomass production. Once the short summer rested area was opened for grazing in January the biomass decreased to the pre-rest levels (Figure 4.9). The increase in mean biomass in the full summer rested area from 0.40 to 1.97 t ha⁻¹ indicated that resting the grass for the full growing season resulted in a five-fold increase in biomass production.

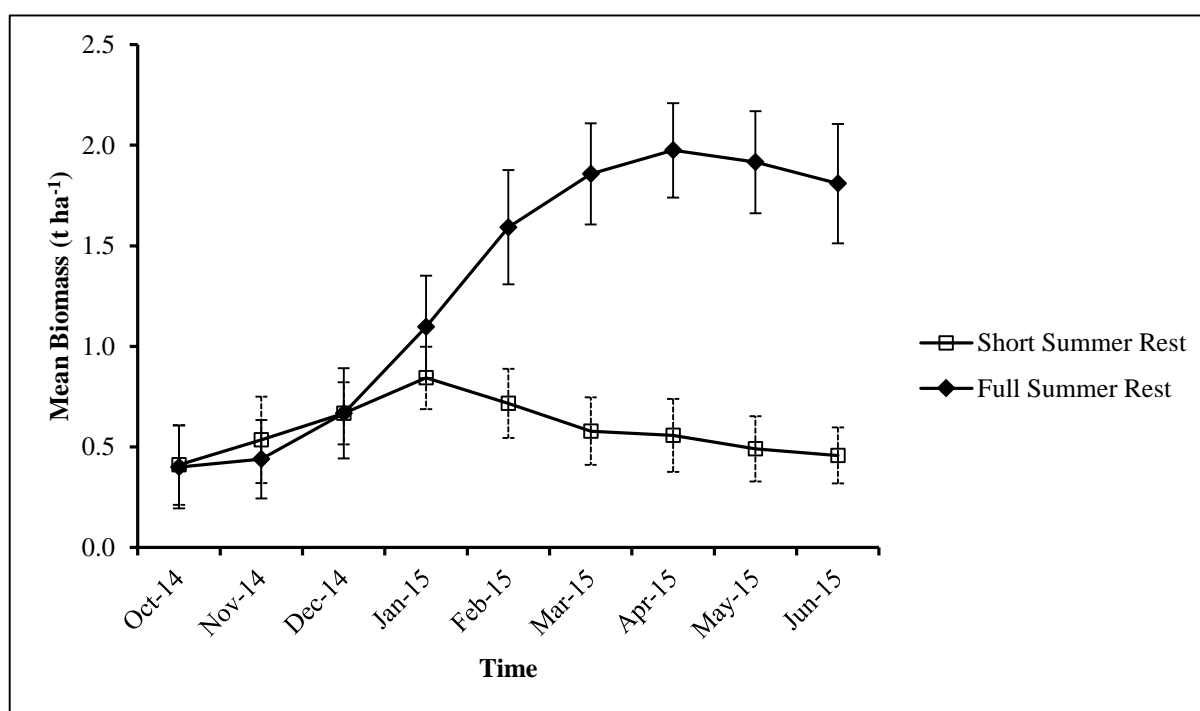
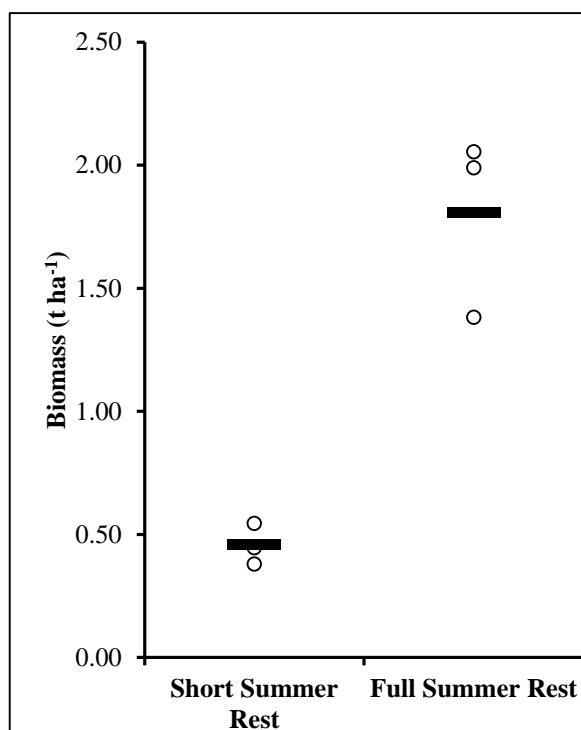


Figure 4.9. Mean (\pm se) biomass in the rotational resting treatment for a short and full summer rest.

The mean biomass values for a short (October 2014 - January 2015) and full (Oct 2014 - June 2015) summer rest were 0.84 and 1.81 t ha⁻¹ respectively (Table 4.9). A full summer rest produced significantly more biomass ($t= 4.37$, $p= 0.001$, $df=2$) than the short summer rest (Table 4.9). The mean difference in yield was 0.97 ± 0.222 t ha⁻¹, which indicated that the full summer rest produced over twice as much biomass than the short summer rest (Table 4.9, Fig 4.10). Again, the community members revealed a positive attitude towards the rotational resting experiments and realised the potential of resting on biomass production (LWG, 2015).

Table 4.9. Biomass (t ha⁻¹) produced in a short and full summer rotational resting experiment

	Mean Biomass (t ha ⁻¹)	Difference in Biomass (t ha ⁻¹)	Standard error for the difference between means (s.e.d.m)	sd	se	t-value	p-value
Short Summer Rest	0.84	0.97	0.222	0.101	0.059	4.37	0.001
Full Summer Rest	1.81			0.370	0.214		

**Figure 4.10. Mean biomass (t ha⁻¹) values for a short and full summer rotational resting experiment.**

4.2.2.2 Forage Quality

There was a significant difference ($t= 7.94$, $p= 0.004$) between ADF values after a full summer rest compared to a short summer rest (Table 4.10). The mean difference in ADF values was 4.02 ± 0.506 % (Table 4.10, Fig 4.11a). There was no significant difference ($t= 0.09$, $p= 0.934$, $df= 2$) between NDF values after a full summer rest compared to a short summer rest (Table 4.10, Fig 4.11b). There was no significant difference ($t= 2.11$, $p= 0.126$, $df= 2$) between CP values after a full summer rest compared to a short summer rest (Table 4.10, Fig 4.11c). No significant difference ($t= 1.00$, $p= 0.423$, $df= 2$) was found between P in a full summer rest compared to a short summer rest (Table 4.10, Fig 4.11d).

Table 4.10. The mean ADF, NDF, CP and P (%) values in a short and full summer rotational resting experiment

	Mean (%)	Mean difference (%)	Standard error for the difference between means (s.e.d.m)	sd	se	t-value	p-value
ADF Short Summer Rest	48.77	4.02	0.506	0.759	0.438	7.94	0.004
ADF Full Summer Rest	52.79			0.439	0.253		
NDF Short Summer Rest	79.50	0.25	2.860	4.016	2.319	0.09	0.934
NDF Full Summer Rest	79.75			2.899	1.674		
CP Short Summer Rest	2.63	-0.29	0.254	0.093	0.054	2.11	0.126
CP Full Summer Rest	2.34			0.429	0.248		
P Short Summer Rest	0.04	0.00	0.003	0.006	0.003	1.00	0.423
P Full Summer Rest	0.04			0.000	0.000		

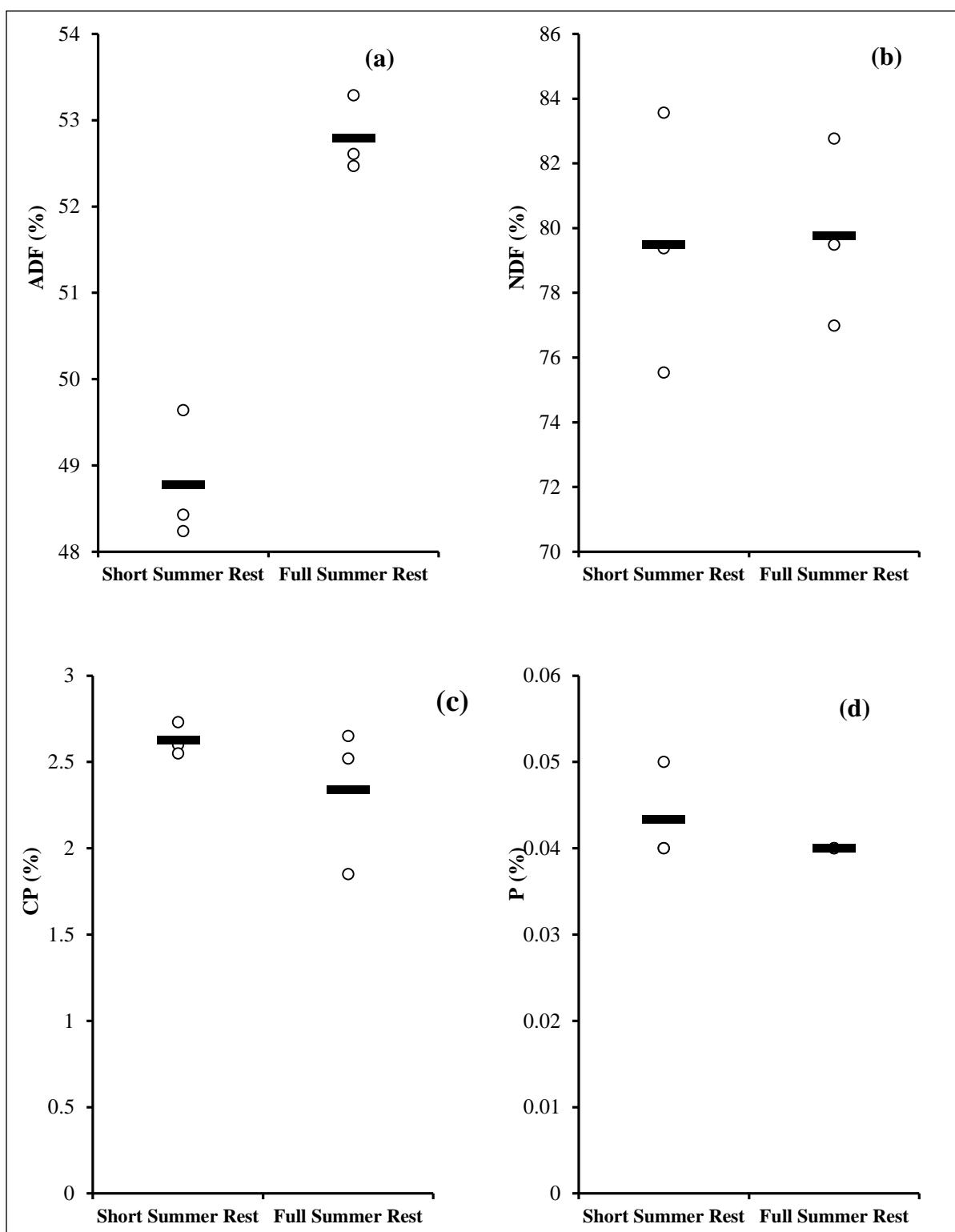


Figure 4.11. Mean (a) ADF, (b) NDF, (c) CP and (d) P (%) values for a half and full summer rotational resting experiment.

Nutrient deficiencies negatively affect animal health, condition and productivity (De Brouwer *et al.* 2000). CP was critically low, especially during winter. To address this problem an experiment was initiated to determine the effect of protein licks on the body condition of sheep.

4.3 Protein lick

Sheep which had access to the protein lick (treatment) and those without (control) had mean body condition scores of 1.80 and 1.54 in June, 1.76 and 1.35 in July, 2.01 and 1.48 in August and 2.03 and 1.53 in September respectively (Table 4.11). A body condition score of 2 is required for maintenance of sheep (Grainer, 2012). During June, there was a significant difference ($t= 2.07$, $p<0.05$, $df= 102$) in the body condition scores of sheep in the treatment compared to those in the control (Table 4.11). The mean difference in body condition was 0.26 ± 0.124 (Table 4.11). The body condition scores of sheep in the treatment were significantly higher in the months of July ($t= 4.17$, $p= <0.0001$, $df= 102$) with a mean difference of 0.41 ± 0.097 , August ($t= 4.59$, $p= <0.0001$, $df= 102$) with a mean difference of 0.53 ± 0.115 and September ($t= 4.13$, $p= <0.0001$, $df= 102$) with a mean difference of 0.50 ± 0.120 (Table 4.11). Additional information was obtained from FGDs, revealing the responses of participants on effectiveness of the protein lick on the body condition of sheep (LWG, 2015). The LWG (2015) confirmed an increase in body mass and condition of sheep, reduced deaths and ewes produced sufficient milk yields for their lambs (LWG, 2015). Benefits were also realised in improved animal health and productivity, which resulted in improved livelihoods and vulnerability (LWG, 2015). The results obtained from the body condition scoring experiment indicate that a protein lick had a significant positive impact on the body condition of sheep (Fig 4.12). The response of the participants on the protein supplementation was positive, indicating that they wanted to continue this in subsequent years (LWG, 2015). This was important in ensuring the ‘buy-in’ of interventions by smallholder farmers, an integral part of improving LWP (Descheemaeker *et al.* 2009).

Table 4.11. Mean body condition scores of sheep in a control (n=50) and treatment (protein lick, n=54) over four months (June - September)

	Mean BCS Scores	Difference between means	Standard error for the difference between means (s.e.d.m)	sd	se	t-value	p-value
June Control (n=50)	1.54	0.26	0.124	0.613	0.087	2.07	0.021
June Treatment (n=54)	1.80			0.648	0.088		
July Control (n=50)	1.35	0.41	0.097	0.455	0.064	4.17	<0.0001
July Treatment (n=54)	1.76			0.539	0.073		
August Control (n=50)	1.48	0.53	0.115	0.562	0.079	4.59	<0.0001
August Treatment (n=54)	2.01			0.610	0.083		
September Control (n=50)	1.53	0.50	0.120	0.601	0.085	4.13	<0.0001
September Treatment (n=54)	2.03			0.625	0.085		

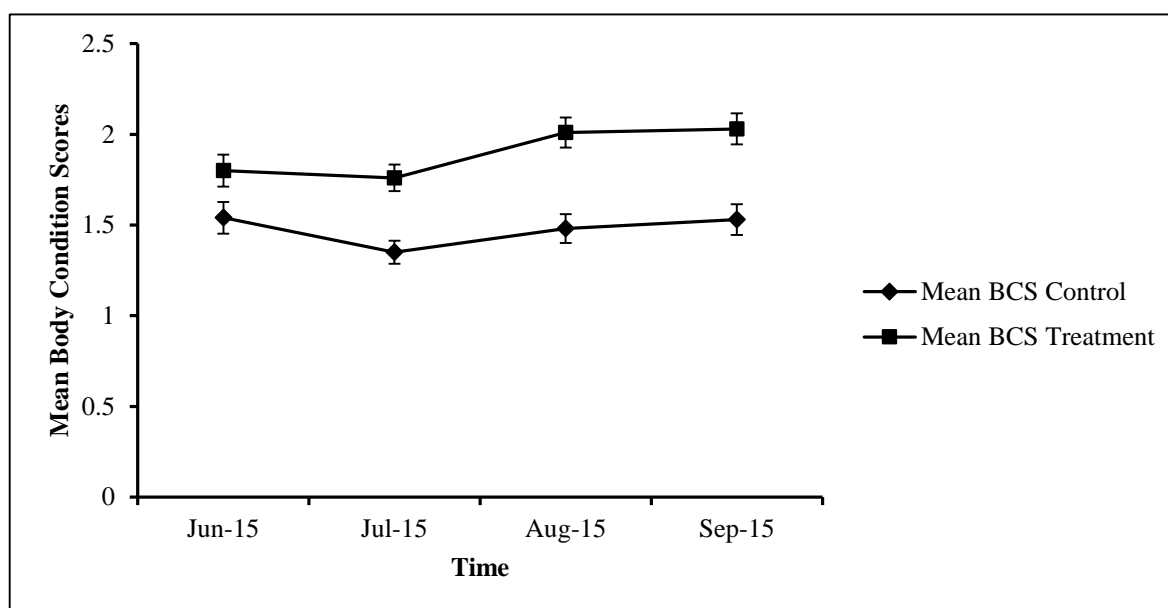


Figure 4.12. Mean (\pm se) body condition scores for sheep in a control and treatment over time (June - September).

Fodder crops can be utilised by livestock as another source of supplementary feed, to account for nutrient deficiencies and to improve animal production (Tau, 2005; Descheemaeker *et al.* 2009; Dube, 2012).

4.4 Fodder Crops (Vetch and Oats)

Fodder crops play an important role in improving forage digestibility, intake and nutrient levels thereby aiding livestock production (Keftasa, 1988; Descheemaeker *et al.* 2010a; Yami *et al.* 2013). Both the ADF and NDF of the vetch and oats had mean values of 37.15 and 59.32% respectively,

depicting relatively reduced fibre content compared to the rangeland (Table 4.12). Mean crude protein values of 14.65% indicated high protein content (Mapako, 2011). Phosphorus values were low with a mean value of 0.21% (Mapako, 2011). The fodder crops thrived in the homestead gardens and participants expressed interest in these fodder crops as a future source of supplementary feed (LWG, 2015).

Table 4.12. ADF, NDF, Crude Protein and Phosphorus values for vetch and oats

Homestead	ADF (%)	NDF (%)	Crude Protein (%)	Phosphorus (%)
Quvile	40.48	60.77	14.36	0.16
Sokhombela	35.36	56.58	15.02	0.20
Mjali	39.10	60.11	16.93	0.29
Madusini	33.66	59.80	12.41	0.17
Mean	37.15	59.32	14.68	0.21

4.5 Conclusion

All the resting experiments, namely the exclosures (17 months), short (4 months) and full (9 months) summer rests had a significant ($p < 0.05$) positive effect on biomass production. The longer the period of rest, the higher the biomass production. No significant ($p > 0.05$) difference was evident between the forage quality components (ADF, NDF, CP, P) between the exclosures and grazed areas in summer, winter and spring. In the rotational experiment, there was a significant ($p < 0.05$) difference between ADF in the full summer rest compared to the short summer rest. No significant ($p > 0.05$) difference was observed between the remaining forage quality components in the rotational resting experiment. Collectively, research participants revealed positive feedback from the various feed management interventions (resting, protein supplementation and fodder crops) applied throughout the study period. The following chapter discusses the results obtained. Furthermore, appropriate management interventions are proposed to improve LWP in Ntshiqo.

5 Chapter Five Discussion

Sourveld in South Africa constitutes a valuable resource by providing cheap grazing for cattle and sheep production (Kirkman and Moore, 1995). Sourveld in communal rangelands generally experiences high grazing pressure, low veld condition and poor carrying capacities (Martindale, 2007). This typically results in forage of low digestibility, intake and quality contributing to low productivity of livestock in South Africa (Tau, 2005). Fodder shortage and low quality forage especially during the dry winter season constrain livestock production (meat, milk, health, offspring, wool) in sourveld regions (Waters-Bayer and Bayer, 1992; Tau, 2005; Dovie *et al.* 2006). Therefore understanding the components of feed management (feed type selection, feed quality, feed water productivity and grazing management) is crucial in improving LWP in smallholder farming systems in South Africa, especially in the face of water scarcity and climate change (Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a). The research focused specifically on feed quality and grazing management. The following sections discuss the findings of current practices and rangeland condition in Ntshiqo, the impact of resting on fodder quantity and quality, supplementary feeding and suggested management interventions for improved LWP. It is important in understanding community dependence and vulnerabilities, which guide the formulation of appropriate interventions to improve resilience and long-term improvement of LWP in smallholder mixed crop-livestock systems. Although not the focus, the integration of technical, institutional and policy aspects for improved LWP, are discussed (Fig 2.3).

5.1 Rangeland Condition, Grazing Capacities and Stocking Density

Veld condition is a measure of the health of the veld, in terms of susceptibility to erosion and its ability to provide forage for livestock (Trollope *et al.* 1990). Apart from health, it also indicates predominant functional grass types, and the degree and type of grazing pressure exerted on the system (Tainton, 1999). Currently in Ntshiqo, continuous grazing without a seasonal rest is practiced. It is evident that palatable climax species such as *Themeda triandra* are subject to high grazing pressure due to their palatability. Only site 1 had a reasonable percentage of *Themeda triandra* (27.5%), with the other two sites having less than 6% respectively (Table 4.1). Sites 2 and 3 were previously planted with crops and hence experienced an intense form of disturbance caused by ploughing. This is a form of rangeland degradation as it negatively affects the natural functioning of these ecosystems and animal productivity (Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a), and has become a problem in the communal rangelands across South Africa (Everson *et al.* 2009). These species have decreased in abundance and are being replaced by

less palatable species (Barnes, 1992; Kirkman and Moore, 1995; Snyman, 2006; Martindale, 2007). This type of degradation is common in sourveld regions of South Africa (Kirkman and Moore, 1995), and can be attributed to the low dispersal and germination success of these palatable species particularly in sourveld regions (Everson *et al.* 2009). Palmer and Bennett (2013) confirm that rangelands under common management in South Africa continue to experience transformation, as defined by species composition and productivity. Additionally, tillers have an upright rather than decumbent growth habit, contributing to the slow recolonization process (Everson *et al.* 2009). Therefore due to high grazing pressure, it may take these species a long time to return (Everson *et al.* 2009). The restoration of grasses such as *Themeda triandra* is important to increase livestock production for dryland smallholder farmers and conserve biodiversity (Everson *et al.* 2009). The Increaser II species were the most common grass species with a composition exceeding 60% across the three sites (Table 4.1, 4.2). These species increase in abundance with severe overgrazing (Tainton, 1999; Descheemaeker *et al.* 2010; Van Oudtshoorn, 2012), with the results indicating overgrazing over an extended period of time in Ntshiqo. The species compositions indicate uniformly poor veld conditions with an average 41.01%. The study showed a recommended stocking density of 436 AU, compared to the current 1666 AU, which is just under four times the recommended stocking density. It is evident that stocking densities are not being controlled. Poor veld condition, coupled with a high stocking density, has resulted in low grazing capacities across the sites, with an average of 0.30 AU ha⁻¹ reduced from a potential grazing capacity of 0.67 AU ha⁻¹ (Table 4.3). This has reduced the carrying capacity and potential of the land to support a large number of animals (Table 4.2) (Munyai, 2012). The results indicate that the Mthatha Moist rangeland in Ntshiqo is degraded, possibly due to historic overgrazing (Martindale, 2007; Mapako, 2011). To prevent economic losses due to poor livestock production, farmers need to reduce livestock numbers or adopt a form of resting regime (Mapako *et al.* 2011). The tested technical interventions implemented in Ntshiqo, can inform the management practices of the smallholder farmers, which potentially have the ability to curb negative impacts of overgrazing and high stocking densities, and ultimately improve the natural functions of the ecosystem and rangeland, animal productivity and overall LWP (Descheemaeker *et al.* 2010a; Mapako *et al.* 2011).

5.2 Forage Quantity

5.2.1 Exclosures and Grazed Areas

The results showed significant differences in biomass production between all the exclosures and grazed areas (Figs 4.1-4.3). The grazed areas reached peak biomass earlier (March and April)

compared to the exclosures (May), due to the effect of grazing by livestock, especially leading into winter. Biomass decreased in the exclosures in June, following the first frost (Figs 4.1-4.3). In the peak growing period (May), the exclosures produced a mean difference of 1.35 t/ha more biomass than the grazed areas ($p = 0.001$), with a mean maximum biomass production of 2.57 t ha^{-1} (Table 4.4). This depicted a four-fold increase in biomass production in the exclosures compared to the initial values at the start of the experiment. At the end of the growing season (August) exclosures produced a mean difference of 1.52 t/ha more biomass than the grazed areas ($p = 0.0002$) (Table 4.4). This was done for the purpose of achieving research objective 2 which was to analyse the feed management component of the LWP framework by investigating the effect of resting on the quantity and quality of fodder produced from rangelands at the case study site. Biomass production was low for all the continuously grazed sites ($<2.1 \text{ t ha}^{-1}$). Mapiye *et al.* (2009) state that feed shortage was the biggest constraint to cattle production in smallholder farming systems in the Eastern Cape of South Africa. This showed the benefits of total exclosure of portions a rangeland by increasing the above ground biomass production which serves as additional feed for livestock (Descheemaeker *et al.* 2009; Mapako, 2011). This has important implications for improving net livestock benefits such as food production (milk, meat) (Pratt, 1984; Waters-Bayer and Bayer, 1992; Smith *et al.* 2013; Okungoya, 2014), raw materials such as wool (De Beer, 2012), provision of labour (Waters-Bayer and Bayer, 1992; Dovie *et al.* 2006; Tarawali *et al.* 2011), which can lead to resilience against external shocks in smallholder farming systems.

The mean difference in biomass production was the lowest for Site 1 in May and August, which had the highest percentage of *Themeda triandra* composition. This indicates a reduction in the vigour of the plants (Kirkman and Moore, 1995). With no appropriate rangeland management techniques implemented in Ntshiqo, it is evident that defoliation of these palatable species is occurring during the growing season, which is detrimental to the vigour of plants (Barnes, 1989c; Barnes and Dempsey, 1992). According to Martindale (2007), there is an inverse relationship between *Themeda triandra* and stocking density and a direct relationship in species such as *Sporobolous africanus*. This reinforces that Decreaser species would be expected to decline in abundance with increasing grazing pressure (Martindale, 2007). Evidence suggests that the intensity, frequency and timing of defoliation have a greater impact on the vigour of plants compared to the grazing procedure (Barnes, 1989c; Barnes and Dempsey, 1992).

The biomass produced in Site 2 and 3, was both significantly higher than in Site 1 (Fig 4.2, 4.3; Table 4.4). This, however, does not necessarily translate into more productive veld that provides

livestock with higher feed quantity. On the contrary, these areas depict lower veld condition and grazing capacities compared to Site 1 (Table 4.3). Dominant grasses have become moribund and died out through self-shading, which have been succeeded by less palatable (Increaser II) species (Morris and Tainton, 2002). Therefore these areas are preferred less by livestock, due to the maturity of less palatable species making them unacceptable for consumption (Tainton and Danckwerts, 1989).

The type and ratio of livestock contributes to the overall management interventions required. Sheep and cattle graze veld differently. Sheep prefer short, leafy grass, free of moribund material whereas cattle graze more uniformly and less intensively than sheep, and perform satisfactorily on veld which is relatively mature (Barnes, 1992; Kirkman and Moore, 1995). Sheep can be detrimental to rangelands through continued selective overgrazing, by removing or reducing the vigour of the palatable species creating a vacuum which is filled by less desirable species (Barnes, 1992). According to Barnes (1989a), the yields of *Themeda triandra* in the season after the one in which the veld was grazed intensely by sheep, were only 48% of those rested in the previous season. This grazing negatively influences the regrowth potential by reducing the amount of stored reserves, and reducing the amount of growing points on plants (Lütge *et al.* 1996). In sourveld regions, selective grazing may initiate the rangeland degradation process from which arguably overall rangeland degradation proceeds (O'Reagain and Turner 1992; Lütge *et al.* 1996). Therefore sheep and cattle should be grazed together to ensure uniform grazing of the veld (Hardy *et al.* 1994; Martindale, 2007). Cattle remove tall, relatively mature grass material thereby stimulating new growth from a large portion of plants which would otherwise be rejected by sheep (Hardy *et al.* 1994). Therefore it is important to have a mixed species grazing regime, consisting of a higher cattle-to-sheep ratio, to reduce selective grazing (Martindale, 2007). Currently in Ntshiqo there is a 1:5 cattle-to-sheep ratio. This explains the high degree of grazing pressure especially at Site 1, as sheep prefer the palatable grass species, potentially contributing to poor veld conditions and carrying capacities. This long term rest (17 months) increased forage quantity to a mean of 2.57 t ha⁻¹ across the three sites. Increasing the forage quantity in an area of forage deficit is important for livestock production in smallholder mixed crop-livestock systems (Descheemaeker *et al.* 2009; Everson and Smith, Undated). Implementing rangeland management techniques, such as rotational resting, is important for long term veld and animal productivity, especially in communal smallholder farming systems in South Africa (Tainton, 1999; Tainton and Danckwerts, 1999; Smith, 1997; Descheemaeker *et al.* 2010a).

5.2.2 Rotational Resting

The short and full summer rests depicted a mean biomass production of 0.84 and 1.97 t ha⁻¹, which is a two-fold and five-fold increase in biomass production respectively, compared to the initial biomass values at the start of the experiment (Fig 4.9; Table 4.9). The rotational resting experiment indicated that biomass produced in a full summer rest is significantly higher ($p=0.013$) compared to a short summer rest, with a mean difference of 1.35 t ha⁻¹ (Fig 4.9; Table 4.9). This was conducted for the purpose of achieving research objective 2. Grazing during the growing season has revealed that livestock can have a severe negative impact on both the vigour and species composition of veld (Kirkman, 2002a; Kirkman, 2002b). According to a review of grazing research in South Africa, sustained heavy stocking densities in sourveld regions has a negative impact on vegetation, particularly its ability to recover after grazing (O'Reagain and Turner, 1992; Tau, 2005). During the dormant season, grazing has a negligible effect on the vigour of plants (Wolfson, 2000; Kirkman and De Faccio Carvalho, 2003). Results from Barnes and Dempsey (1992) and Peddie *et al.* (1995), indicate that a rest for a full growing season is adequate for vigour of plants to recover. Contrastingly, Lütge *et al.* (1996) argue that in sourveld regions over a number of grazing cycles, the vigour of plants may not recover sufficiently during a full summer rest due to constant depletion of stored reserves. A study conducted by Morris *et al.* (1992) in the Southern Tall Grassveld of KwaZulu-Natal, indicated an invasion of *Aristida junciformis* (Increaser III) after a continuous grazing scheme at high stocking rates was interrupted by a full summer rotational rest. However, a full summer rest ensures entire plant production and provides an uninterrupted period of development to renew energy reserves, which is vital for the health and survival of plants (Undersander *et al.* 1993; Tainton and Danckwerts, 1999). During spring, leaf and above-ground biomass production is favoured (Tainton and Danckwerts, 1989; Smith, 1997). This provides an uninterrupted period of photosynthesis, to produce sufficient carbohydrates and replace those utilised to initiate spring growth (Tainton and Danckwerts, 1989). In summer, seed production is promoted as well as vigour and productivity of veld (Tainton and Danckwerts, 1989; Kirkman and Moore, 1995). Root production is favoured during autumn (Smith, 1997; Snyman, 2006). A full summer rest provides sufficient time to improve root mass, build-up and storage functions (Snyman, 2006). Good root production improves the resilience of a plant to drought, improves the capacity of obtaining minerals from the soil, promotes biomass production and potentially improves veld condition (Undersander *et al.* 1993; Snyman, 2006). Regular full summer rests should be implemented to improve vigour of plants, seed, root and biomass production of palatable species (Teague *et al.* 1981; Kirkman and Moore, 1995; Snyman, 2009). Simultaneously improving these

variables promotes ecosystem functioning through the prevention of land degradation, soil erosion, which ultimately can result in rehabilitation and improved rangeland productivity, water conservation and improved hydrological processes, thereby improving livestock production and contributing to the overall improvement of LWP (Kirkman and Moore, 1995; Descheemaeker *et al.* 2006; Thornton *et al.* 2009; Thornton and Herrero, 2010). Smallholder farmers are dependent on livestock production (Waters-Bayer and Bayer, 1992). Improving livestock production is important through increasing food production, raw materials and resilience against water scarcity and climate change for the livelihoods of smallholder farmers (Thornton and Herrero, 2015). Therefore resting is vital not only for increasing forage quantity but also for the natural functioning of ecosystems, which aids long-term livestock production in mixed crop-livestock systems in developing countries (Descheemaeker *et al.* 2009).

5.3 Forage Quality

5.3.1 Exclosures and Grazed Areas

Understanding nutrient content of plants is vital for animal production (Munyai, 2012). Nutrient analysis can be used to determine whether forage quality is sufficient for animal production and to indicate whether supplementation is required (Ball *et al.* 2001). The ADF and NDF values in the exclosures and grazed areas were not different ($p > 0.05$) in February and June (Table 4.5, 4.6). The overall mean ADF values in the exclosures and grazed areas ranged from 45.66 - 51.17 % (Table 4.5). ADF is inversely related to digestibility. The ADF values are high indicating low energy, poor feed quality with a low digestibility (De Bruyn and Koster, 2000; Newman *et al.* 2006; Mapako, 2011). These high values indicate mature forage, with a high percentage of indigestible plant material such as lignin and cellulose, with low energy content (Beauchemin, 1996; Ball *et al.* 2001). Forage digestibility is important because the higher the digestibility, the more nutrients are released for use by the animal and feed intake increases (Cheeke, 2005). The overall mean NDF values in the exclosures and grazed areas ranged from 74.03 - 84.29 % (Table 4.6). These are high NDF values, typical of mature forage, depicting a high percentage of indigestible plant material such as hemicellulose, lignin and cellulose (Beauchemin, 1996; Ball *et al.* 2001). Robinson *et al.* (1998) state that an NDF value greater than 45%, reduces forage quality significantly. Hemicellulose and cellulose are slowly digested by ruminants, whereas lignin is indigestible (Beauchemin, 1996). The NDF percentage in feed determines the forage intake of an animal, through an inverse relationship (Newman *et al.* 2006). Therefore due to high percentages, feed intake of animals is low potentially decreasing the average daily gain in animals, negatively affecting livestock production (Tainton and

Danckwerts, 1989). According to Meissner *et al.* (1999), feed intake is twice as important as digestibility in determining animal performance. Both ADF and NDF values are high, depicting forage with a high fibre content, low energy, digestibility and intake, reducing the overall palatability and forage quality of feed (Trollope *et al.* 1990; Ball *et al.* 2001). This reinforces the need for animals to graze palatable species or plant material (leaf and new growth), in an attempt to maintain body condition (Hatch, 1991).

The CP values in the exclosures and grazed areas were not different ($p > 0.05$) in February and June (Table 4.7). The overall mean CP values ranged from 2.33 - 5.80 %. These are low values which are below animal requirement (Newman, 2006; Mapako, 2011; Munyai, 2012). Protein is undoubtedly the primary limiting nutrient in the diet of livestock (Van Niekerk and Jacobs, 1985; Ball *et al.* 2001). In sourveld during the winter months, the drop in the quality of the veld becomes the most limiting factor and intake of livestock declines (Danckwerts, 1989; Sprinkle, 2001; De Bruyn and Koster, 2000; Kirkman and De Faccio Carvalho, 2003). If CP is deficient in livestock diets, rumen microbes will be unable to degrade fodder especially that of poor quality, hence a decrease in forage intake (Ball *et al.* 2001; Newman *et al.* 2006). This can result in weight loss and reduced productivity as livestock must break down tissue to supply the required protein (Sprinkle, 2001). CP is below 6.25%, therefore it is evident that livestock in Ntshiqo require protein supplementation, especially over the winter months to account for poor forage quality and protein deficiencies of fodder (Sprinkle, 2001). Providing protein supplementation is vital to increase forage intake and digestibility, lactation, reduce weight loss before calving and ultimately increase conception rate, livestock production and profitability (Lalman, undated; Sprinkle, 2001).

The P values in the exclosures and grazed areas were not different ($p > 0.05$) in February and June (Table 4.8). The overall mean P values ranged from 0.04 - 0.12 %. This indicates low P values, which are below animal requirement, as a lactating cow requires 0.27% phosphorus in a pasture (NRC, 1984; Mapako, 2011). As previously stated in section 2.8.1.1 check numbering, P is the second most important and limiting plant nutrient in forage (Van Niekerk and Jacobs, 1985; Miller and Gardiner, 1998). The nucleus of each plant cell contains P, therefore cell division and growth depend on adequate amounts of this element for plant production (Oliver, 2007). P is required for the functioning of energy metabolism in livestock, ensuring conception rates and milk production (De Brouwer *et al.* 2000; De Bruyn and Koster, 2000). P supplementation has been found to increase animal performance during periods when animals are gaining body mass, however when fed in isolation, cannot prevent the loss of animal condition during the winter months (Van Niekerk

and Jacobs, 1985). This form of supplementation is most effective when combined with protein (Van Niekerk and Jacobs, 1985). Improving forage quality is significant in terms of digestibility, forage intake and nutrient content, which aids livestock production and overall LWP (Van Niekerk and Jacobs, 1985; De Brouwer *et al.* 2000; Descheemaeker *et al.* 2010a; Descheemaeker *et al.* 2011).

5.3.2 Rotational Resting

The ADF values in the full and short summer rotational resting experiments were ($p = 0.004$) (Table 4.10). The ADF values in the full summer rest had a higher mean difference of 4.02 % compared to the short summer rest. No clear reasons were evident as to why there was a significant difference in ADF values between the rotational resting experiments and not the exclosures and grazed areas. This is potentially one negative aspect of resting, in that no defoliation takes place, plants mature, increasing cell wall contents such as cellulose and lignin, thereby decreasing the digestibility of forage (Beauchemin, 1996; Ball *et al.* 2001; Newman *et al.* 2006; Mapako, 2011). The positive aspects of resting do outweigh the negatives, in providing an uninterrupted period of growth for entire plant development, which ultimately improves plant vigour, production and resilience to defoliation (Tainton and Danckwerts, 1989; Kirkman and Moore, 1995; Snyman, 2006). The NDF, CP and P values in the full and short summer rotational resting experiment were not significantly different ($p > 0.05$) (Table 4.10). The NDF values are high, again indicating mature plant material with high fibre content. Both the CP and P values were below animal requirement (Mapako, 2011). It is evident that a half and full summer rest have no significant effect on the forage quality of plants but are critical for biomass production, overall plant development and restoration of vigour.

5.4 Protein Lick

During winter in sourveld regions in South Africa, the drop in forage quality is the most limiting factor which negatively influences intake (O'Reagain and Mentis, 1988; Danckwerts, 1989; De Bruyn and Koster, 2000; Kirkman and De Faccio Carvalho, 2003). Protein typically drops below animal requirements during the dry season (Mapako, 2011). The results of the protein supplementation (Voermol Protein Lick) experiment in June depict a significant difference between sheep in the treatment and control ($p < 0.05$) (Table 4.11). A study conducted by Mvinjelwa *et al.* (2014) in the Eastern Cape Province of South Africa, confirms that protein supplementation over the winter months in sourveld areas positively affects the body condition of sheep. This was done for the purpose of achieving research objective 3 which was to analyse the effect of protein supplementation on the body condition score of sheep at the case study site. Highly significant

differences ($p < 0.0001$) and larger mean differences in body condition scores were recorded for sheep in the treatment compared to the control from July to September. This indicates that protein supplementation becomes more effective over longer periods of utilisation (Sprinkle, 2001). Data obtained in the FGDs for the current research, revealed that protein supplementation had numerous positive effects on sheep in the treatment (LWG, 2015). Firstly, there was an increase in body mass and body condition of sheep (Ball *et al.* 2001; Sprinkle, 2001). Additionally reduced deaths occurred, indicating that the sheep were not losing body condition (LWG, 2015). Lactation places the greatest nutrient demands on animals (Ball *et al.* 2001). Lastly, the ewes produced sufficient milk yields for their lambs which are critical for survival and growth (Ball *et al.* 2001; LWG, 2015). According to Moore and Müller (1994), pregnant ewes can successfully be wintered on poor quality, through protein supplementation at a low cost. Evidence indicates that sufficient supplementation improves conception and lambing percentages (O'Reagain and Mentis, 1988; Sprinkle, 2001). According to a study conducted by Van Niekerk and Jacobs (1985), protein supplementation has a significant effect on poor quality forage intake by livestock. Protein licks and supplementary feed should never substitute feed, but rather supplement poor quality feed (Cleasby, 1963; De Bruyn and Kosta, 2000; Ball *et al.* 2001). This is to account for nutrient deficiencies, ensure optimal utilization of feed, reduce weight loss and hence improve animal performance and productivity (health, milk and meat production). The participants of the protein lick experiment were all satisfied with the positive results obtained (LWG, 2015). A community member participating in the trial stated: "I will carry on feeding my sheep with a protein lick next year over winter" (LWG, 2015: personal communication). This promoted important 'buy-in' of the community in potentially adopting such a technical intervention for improving long-term livestock productivity and LWP in Ntshiqo (Descheemaeker *et al.* 2009). This is an important intervention in improving LWP (Descheemaeker *et al.* 2010a), and is detailed in the next section.

5.5 Recommended Management Interventions

The veld in Ntshiqo is highly overgrazed characterized by forage quantity deficiencies and veld of poor quality, hence interventions such as fire, rotational resting and re-seeding are required to promote the growth of more palatable species and improve the overall veld condition of the veld (Everson and Tainton, 1984; Kirkman and De Faccio Carvalho, 2003; Everson *et al.* 2009). Additionally, protein supplementation and the introduction of fodder crops (vetch and oats) are assessed in terms of improving forage quality and intake (Assefa and Ledin, 2001). It is considered that the technical management interventions (implemented and proposed) discussed below are

viable and could be beneficial in aiding the correct management of sourveld, improve livestock production and LWP (Kirkman and Moore, 1995; Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a; Descheemaeker *et al.* 2011). It is important to target interventions which can bring real benefits and improve livelihoods in smallholder farming systems (Fig 2.3) (Amede *et al.* 2009). This was done for the purpose of achieving research objective 4, which was to determine the influence of these specific management interventions on LWP, and the implications for the environment and livelihood dependencies of smallholder farmers

5.5.1 Role of Fire

Fire plays an important role in the maintenance of sourveld (Kirkman and Moore, 1995). Controlled burning of sourveld during the dormant season or early spring is an accepted practice (Barnes, 1992). The main objectives of burning are to remove mature, moribund and dead plant material and promote new palatable growth (Trollope, 1989; Barnes, 1992; Marx, 2001; Morris and Tainton, 2002; Mapiye *et al.* 2008; Everson *et al.* 2009). This can be used to reduce selective grazing and promote uniform utilisation of the veld (Kirkman and Moore, 1995). Sourveld areas require regular burning especially in areas of low utilisation where growth conditions are favourable (Trollope, 1989). This reinforces the need of fire intervention especially as Sites 2 and 3, which are characterised by moribund and unpalatable growth, poor species composition and veld condition (Tables 4.1 - 4.3).

In a study conducted in the Cathedral Peak area in KwaZulu-Natal, Everson and Tainton (1984), found that a regular fire regime maintained sourveld veld condition whereas protection from fire resulted in a 42% drop in veld condition. The treatment means for Decreaser species were 48.8% in the annual winter burning, 36.6% in the biennial spring burning and 26% in the protected treatments (Everson and Tainton, 1984). Another study conducted in the Cathedral Peak area by Everson *et al.* (2009), revealed that a biennial spring burn increased seed production of *Themeda triandra* which promotes the spread of this species, thereby improving rangeland condition. A biennial spring burn provides enough time for the growth of reproductive tillers and avoids damaging plants during the important summer growth season which would negatively affect reproductive the output (Everson *et al.* 2009). This reinforces the fact that *Themeda triandra* is a fire-climax species (Everson *et al.* 2009). Additionally, the majority of grass species would be palatable in the early season following fires, thereby promoting intake of forage and livestock productivity (Martindale, 2007).

In Ntshiqo, the role of fire in rangeland management is misunderstood, and is associated as a negative aspect which reduces the amount of forage available for animals (LWG, 2015). On the

contrary, if certain areas of the rangeland are not burnt, fodder availability and intake will decrease further, due to mature, indigestible forage of poor quality. Therefore institutional change is required in Ntshiqo (Fig 2.3) (Amede *et al.* 2009), so that burning can be used as a tool to improve veld condition, digestibility and vigour of forage, and to ensure correct rangeland management (Everson and Tainton, 1984; Kirkman and Moore, 1995; Mapiye *et al.* 2008). When a new technical intervention is introduced some degree of institutional change is required to improve components of the LWP framework (Amede *et al.* 2009; Descheemaeker *et al.* 2010a). Replacing old paradigms formulated by traditional authorities, with new management techniques remains a challenge in communal smallholder farming systems in South Africa (Lemaire *et al.* 2014; LWG, 2015). Nevertheless, a biennial spring burn is recommended and veld should not be grazed within 6 to 8 weeks of burning or until it has recovered to a height of 100 mm to 150 mm (Trollope, 1989; Trollope, 1999).

5.5.2 Grazing and Resting

Resting of veld is one of the most important management interventions recommended for all types of veld (O'Reagain, 1994; Tainton and Danckwerts, 1999; Descheemaeker *et al.* 2006). This can aid in maintaining long term veld and animal production (O'Reagain, 1994; Tainton and Danckwerts, 1999). In Ntshiqo, controlling the movement of livestock should ensure uniform utilization of the rangeland (Tau, 2005). Three different resting experiments were initiated in Ntshiqo, namely a long term rest (17 months), a full (9 months) and short (4 months) summer rest. Research on resting in smallholder communal rangelands in South Africa is lacking (Shackleton, 1993), hence this information is valuable in filling this research gap. The longer the rest applied, the higher the forage quantity produced. However proposing appropriate grazing management interventions for communal rangelands, requires a consideration of production objectives (Kotze *et al.* 2013). The production objectives in communal rangelands, focus on high animal numbers that account for multipurpose livelihood benefits (draught, food production, manure, cultural purposes, cash income), compared to commercial systems which are focused purely on high turnovers and profit (Waters-Bayer and Bayer, 1992; Masika *et al.* 1998; Kotze *et al.* 2013). To support high animal numbers and hence obtain net livestock benefits, continuous full summer rotational rests are proposed especially for Site 1 in Ntshiqo. This is to allow palatable plant species to improve their vigour and biomass, which positively contributes to the natural functioning and condition of rangelands, and promotes long-term livestock production (Teague *et al.* 1981; Trollope *et al.* 1990; Kirkman and Moore, 1995; Snyman, 2006; Descheemaeker *et al.* 2009). Community members had

appointed rangers to exclude livestock from the rested area (LWG, 2015). This system was successful and is advised for subsequent years (LWG, 2015). The FGDs revealed a positive response from Ntshiqo community members regarding rotational resting (LWG, 2015), which is vital, because without ‘buy-in’ such technical interventions will not be successful (Amede *et al.* 2009). However, there are no fences in Ntshiqo which may pose as a problem in controlling animal movement in the long term (Munyai, 2012). The reduction of grazing during the growing season is critical in terms of correct rangeland management. Heavier utilisation of the veld during the dormant season (after first frost and before spring growth) is advised coupled with protein supplementation to account for nutrient deficiencies (Kirkman and Moore, 1995; Kirkman and De Faccio Carvalho, 2003). Improving the grazing management component of the LWP framework (Descheemaeker *et al.* 2010a), contributes significantly to the overall feed management, and hence the net livestock benefits (Pratt, 1984; Waters-Bayer and Bayer, 1992; Dovie *et al.* 2006; Tarawali *et al.* 2011; De Beer, 2012; Smith *et al.* 2013; Okungoya, 2014). Such benefits produced from livestock improves the resilience of smallholder farmers against vulnerabilities such as drought, crop failure, water scarcity and climate change in smallholder farming systems (Kazianga and Udry, 2006; Stringer, 2009; Tarawali *et al.* 2011; Turpie and Visser, 2012; Vrieling *et al.* 2014; Thornton and Herrero, 2015). The majority of mixed crop-livestock systems in South Africa are rainfed, hence food security and livelihoods are threatened by climate change (Turpie and Visser, 2012). Rangelands in South Africa are expected to decline in productivity due to changing rainfall patterns and temperatures. Therefore, there is a need to implement effective grazing management strategies to improve net livestock benefits against external vulnerabilities.

5.5.3 Re-seeding

Themeda triandra has poor dispersal ability and it can take a long time for this species to return to an area. Therefore actively harvesting seeds is an essential management intervention in re-introducing this species to areas where it has disappeared. Additional research is required to increase seed longevity and to store seeds in a dormant stable state. The physical re-introduction through reseedling may be the only option to ensure the return of such palatable species, due to low dispersal in sourveld. Hence a reseedling rehabilitation programme could be beneficial in restoring lost palatable species in degraded areas such as Ntshiqo (Everson *et al.* 2009). A possible way forward is to facilitate collaboration between smallholder farmers, Non-Governmental Organisations (NGOs), Non-Profit Originations (NPOs) such as the INR and local government end extension staff which can provide solutions to current problems (Descheemaeker *et al.* 2009;

Descheemaeker *et al.* 2011). In South Africa, extension staff have found to be limited in their capacity to deliver support services and resources to smallholder farmers (Vink and Kirsten, 2003; Williams *et al.* 2008). In Ntshiqo, extension staff provided insufficient support in terms of providing information and educating community members on possible management interventions to improve rangeland, crop and livestock production (LWG, 2015). Nonetheless, re-seeding remains an option in increasing palatable grass species composition, positively influencing rangeland condition and hence livestock production and LWP.

5.5.4 Protein supplementation

A protein lick is a relatively inexpensive form of supplementary feed (Akbar *et al.* 2006), therefore delaying the introduction of such a management intervention to save money is merely false economics and can only reduce animal production in the long term (O'Reagain and Mentis, 1988). Although biomass production is low in Ntshiqo, forage is available throughout the entire year, making protein licks a viable form of supplementation. It promoted sheep production during the winter months, by enabling animals to consume forage of poor quality. Making unpalatable feed acceptable and digestible can be the difference between life and death for livestock. As stated in section 5.4, the protein supplementation had a significantly positive effect on the body condition score of sheep. This was important in terms of improving the forage quality under the feed management component of the LWP framework (Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a). Additionally, the response from the participants was positive (LWG, 2015), which is vital for the long-term adoption of such a technical intervention, that contributes to the improvement of LWP (Amede *et al.* 2009).

5.5.5 Fodder Crops (Vetch and Oats)

In addition to protein licks, fodder crops were introduced to smallholder farmers in Ntshiqo. In the majority of smallholder regions in South Africa, livestock are fed entirely on low quality veld or maize stover during winter months (Tau, 2005). Fodder crops have shown to increase the intake, digestibility and quality of forage that livestock consume (Keftasa, 1988; Descheemaeker *et al.* 2010a). Providing good quality forage is key for any livestock production system (Newman *et al.* 2006). Improving the digestible protein and nutrient content are important in improving animal productivity (Eskandari *et al.* 2009). Fodder crops are key components which influence feed management and livestock productivity. Selecting suitable feed type for livestock is an important component of feed management which has the potential of increasing LWP (Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a). Growing compatible vetch and oats mixtures can be practically

relevant in increasing forage productivity per unit area, digestibility, crude protein content and the intake by livestock (Assefa and Ledin, 2001). Both the mean ADF and NDF values were less than 45 and 65% respectively, indicating lower fibre content aiding improved digestibility and forage intake (De Bruyn and Koster, 2000; Newman *et al.* 2006; Mapako, 2011; Munyai, 2012) (Table 4.12). Mean CP values of 14.65% are well over the minimum required level of 7% to meet the requirements of rumen microbes to digest fibre (Sprinkle, 2001; Munyai, 2012) (Table 4.12). This will aid livestock in Ntshiqo to digest the poor quality veld. A study conducted in the Free State in South Africa during winter, indicated that gestating cows subjected to vetch pastures, significantly reduced the required forage intake due to increased levels of digestible protein (Fair, 2013). P values were low with a mean value of 0.21%, however, these values are not as important as the required CP values (Van Niekerk and Jacobs, 1985; Mapako, 2011). The cultivation of vetch and oats is a viable option in improving forage intake and CP levels aiding the utilisation of poor quality veld. Further, it can reduce additional expenditure normally spent on other protein supplementation, especially in smallholder farming systems with limited inputs such as Ntshiqo (Eskandari *et al.* 2009; Yami *et al.* 2013). Vetch and oats cultivation can significantly improve the nutrient content in the diet of livestock, alleviate feed deficit, promoting and maintaining animal production during winter and positively contributing to overall LWP (Tau, 2005; Descheemaeker *et al.* 2010a). Again, the response from the participants in the fodder crop experiment was positive (LWG, 2015). A local farmer stated: “the fodder crops improved the production of my lambs and ewes over the winter months” (LWG, 2015: personal communication). It is important for farmers to observe positive influences of technical interventions, which promotes the long-term adoption of these techniques. This was important in promoting the forage quality and feed type selection component of the LWP framework in Ntshiqo.

5.6 Collective management for improved LWP

Suitable technical interventions such as rotational resting (Tainton and Danckwerts, 1999; Kirkman and Moore, 1995), protein supplementation (Van Niekerk and Jacobs, 1985; Sprinkle, 2001) and the introduction of fodder crops (Assefa and Ledin, 2001) were proposed to improve rangeland and livestock production in Ntshiqo. These aspects formed part of the feed management component of the LWP framework (Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a; Descheemaeker *et al.* 2011).

The three resting experiments (exclosures, short and full summer rest) significantly increased forage quantity. Such rests have the potential to increase livestock production in smallholder mixed crop-

livestock farming systems in the long-term, through increased forage production (Everson and Smith, Undated; Tainton and Danckwerts; 1989). Additionally the improved grazing management was important due to the degraded and overgrazed condition of the Ntshiqo rangeland. This restores the vigour of palatable plant species (Tainton and Danckwerts, 1989; Kirkman and Moore, 1995; Snyman, 2006), improves the vegetative cover which ensures soil management by reducing runoff and erosion, and hence promotes water management (Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a, Descheemaeker *et al.* 2011). The feed quality of this sourveld veld was poor especially in winter in terms of digestibility, characterized by CP and P deficiencies (Van Niekerk and Jacobs, 1985; Trollope *et al.* 1990 De Brouwer *et al.* 2000; De Bruyn and Koster, 2000; Newman *et al.* 2006; Mapako, 2011). Through protein supplementation the body mass and condition of sheep improved, as well as milk yields and reduced deaths over the winter period (LWG, 2015). Therefore there is potential in translating such benefits into cattle production. Fodder crops (vetch and oats) were seen as an additional form of supplementary feeding which could improve animal productivity through better feed quality. The successful implementation of the specified feed management components of the LWP framework (Descheemaeker *et al.* 2010a), were important in improving the livelihoods of smallholder farmers in Ntshiqo. Improved food products produced (meat, milk) by livestock is important as animal source foods are nutritionally dense sources of energy, amino acids protein and essential micronutrients which are vital for normal human development, growth and health, and preventing under-nutrition and nutrient deficiencies in mixed crop-livestock smallholder farming systems (Smith *et al.* 2013). This is crucial in combating food security challenges in these systems especially in the face of growing populations and demand for livestock products (Descheemaeker *et al.* 2009; Herrero *et al.* 2009; Ndoro *et al.* 2014). Improved animal production can result in the provision of raw materials (Waters-Bayer and Bayer, 1992; Sani, 2009). In Ntshiqo, wool production was an important economic activity (LWG, 2015). Through higher animal production and improved animal health, the quality of wool could be improved thereby generating higher revenue and positively benefiting livelihoods in Ntshiqo (De Beer, 2012). This can be used to buy staple foods and basic household products, fertilizer, cover medical costs or house repairs (Water-Bayer and Bayer, 1992; Smith *et al.* 2013). Therefore net livestock benefits can be used by smallholder farmers to increase resilience against external shocks (water scarcity, drought, climate change) and when other livelihood strategies fail such as crop failure (Thornton and Herrero, 2015) (Fig 2.3). Livestock can act as a source of security and insurance (Kazianga and Udry, 2006; Vrieling *et al.* 2014). Therefore it is evident that technical interventions can act as a sphere of influence, in improving livestock and rangeland production and hence LWP in

smallholder farming systems in developing countries, by managing the same resources more effectively (Figs 2.2; 2.3) (Amede *et al.* 2009; Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a, Descheemaeker *et al.* 2011).

As previously stated, the overall response of Ntshiqo inhabitants in relation to the implemented technical feed management interventions was positive (LWG, 2015). Ensuring ‘buy-in’ from local smallholder farmers was a key step promoting adoption. Obtaining the support from these farmers was the most important aspect in implementing interventions aimed at improving LWP, because without their support no intervention would be viable (Amede *et al.* 2009). All of the implemented interventions were relatively cheap which is vital for adoption, especially in resource poor smallholder mixed crop-livestock systems such as Ntshiqo. For these technical interventions to be successful a degree of change was required.

Behavioural change is thus required through appropriate institutional structures which are classified as traditional authorities in Ntshiqo (Fig 2.3) (North, 1993; Hodgson, 2006). Institutions are essential in introducing change, as they are the rules which govern a society (North, 1993; Amede *et al.* 2009). Rules within social institutions should not be rigid but fluctuating through time and space, as conditions change (drought, disease) and new opportunities emerge (Cleaver, 2000). The actions of people are influenced by the structural characteristics of societies in which they were brought up (Cleaver, 2000). Therefore effective institutional policies should govern crop, livestock and natural resource management in smallholder farming systems, so that a culture of correct management can be embedded into successive generations (Fig 2.3) (Amede *et al.* 2009; Descheemaeker *et al.* 2009). In Ntshiqo, traditional authorities need to develop policies that promote and support the adoption of feed management interventions in years to come. This is in response to ineffective extension staff (LWG, 2015). These need to be built on the momentum gained from introducing new interventions such as those tested in this research, in Ntshiqo. Numerous studies (Amede *et al.* 2009; Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a, Descheemaeker *et al.* 2011) have indicated that the implementation of technical interventions need to be accompanied by appropriate institutional structures and supportive policies (Fig 2.3). Such collaborative or integrative management, will ensure long term crop, livestock, land and water management which are crucial in improving LWP in smallholder mixed crop-livestock farming systems (Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a, Descheemaeker *et al.* 2011). Furthermore, this can improve the resilience of these South African rain-fed smallholder systems to

vulnerabilities such as poverty, crop failure, water scarcity and climate change (Tulu, 2006; Helmreich and Horn, 2009; Turpie and Visser, 2012; Thornton and Herrero, 2015).

6 Conclusion

In conclusion, four objectives were formulated to meet the aim of understanding the effect of specific technical interventions on LWP in smallholder mixed crop-livestock systems in South Africa, through a case study analysis of Ntshiqo.

The first objective of the dissertation was to develop an understanding of the Descheemaeker *et al.* (2010a) LWP concept and framework, and critically review documented interventions for improving LWP. The context of the study is on developing countries with specific focus on South Africa. This concept is still fairly new having been formulated by Peden *et al.* (2007) to investigate ways to improve livestock production but simultaneously reduce the water utilised per unit input. The LWP framework accounts for the multiple benefits from livestock, the different water flows and the many factors influencing LWP in mixed crop-livestock systems (technical, institutional and policy) (Amede *et al.* 2009; Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a). A number of studies have revealed the value of utilising such frameworks in improving LWP, natural resource management and the livelihood benefits of smallholder farmers (Amede *et al.* 2009; Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a). Overall, the integration of technical interventions, institutional structures and policies are required for LWP success (Amede *et al.* 2009; Descheemaeker *et al.* 2009; Descheemaeker *et al.* 2010a; Descheemaeker *et al.* 2011)

The second objective was to analyse the feed management component of the LWP framework by investigating the effect of resting on the quantity and quality of fodder produced from rangelands at the case study site. Biomass production was found to be significantly higher in the exclosures compared to grazed areas during the peak and end of the growing season. The levels of plant ADF, NDF, CP and P were found to be below that of animal requirement across all the sites in summer (February), winter (June) and spring (October) (Mapako, 2011). No difference in ADF, NDF, CP and P values was found between the exclosures and grazed areas during the same time frames. The full summer rest produced significantly higher biomass than the short summer rest. Continuous full summer rotational rests are proposed for Ntshiqo, to increase forage quantity. There was no difference in NDF, CP and P values between the short and full summer rest. The ADF values in the full summer rest were significantly higher than in the short summer rest, indicating lower digestibility, increased maturity and fibre content of forage in response to rest (Kirkman and Moore, 1995). However, the positive aspects of resting do outweigh the negatives, in providing an uninterrupted period of growth for entire plant development, which ultimately improves plant vigour, production and resilience to defoliation (Tainton and Danckwerts, 1989; Kirkman and

Moore, 1995; Snyman, 2006). Furthermore, grazing management promotes ecosystem functioning through the prevention of land degradation and soil erosion, which ultimately can result in rehabilitation and improved rangeland productivity, water conservation and improved hydrological processes, thereby improving livestock production and contributing to the overall improvement of LWP.

The third objective was to analyse the effect of protein supplementation on the body condition score of livestock (sheep). There was a significant difference between sheep in the treatment and control in all the months (June-September). From the second month, the treatment body condition scores of sheep were significantly higher than those in the control. This indicated that protein supplementation became more effective over longer periods of utilisation (Sprinkle, 2001). Data obtained in the FGD's additionally revealed protein supplementation decreased the number of deaths of sheep during winter, improved the body mass of sheep and milk yields of ewes. This was supported by published literature. Protein supplementation is a relatively cheap and viable from of supplementation to account for nutrient deficiencies of poor quality forage, ensure intake and optimal utilization of feed, reduce weight loss and hence improve animal performance and productivity of (health, milk and meat production). Therefore, it is a feasible and viable intervention to improve livestock production and LWP in smallholder farming systems.

The fourth objective was to determine the influence of specific management interventions on LWP overall, and to understand the implications for the environment and livelihood benefits for smallholder farmers. Numerous technical interventions were proposed for improved LWP in the sourveld of Ntshiqo, such as rotational resting, decreased stocking rates, application of fire, re-seeding of veld, protein supplementation and the introduction of fodder crops.

Based on the findings of this study it was concluded that the veld in Ntshiqo was severely overgrazed. This was evident through the replacement of palatable Decreaser species (*Themeda triandra*) by unpalatable Increaser II species (*Sporobolous africanus* and *Chenopodium* forb species). This resulted in a low average veld condition and poor grazing capacity, due to a stocking density tenfold of the recommended. This indicated a lack of appropriate management interventions. Destocking of livestock numbers with a simultaneous light grazing pressure is advised. A continued full summer rotational resting scheme was proposed especially for Site 1, to improve the vigour of plants, seed, root and biomass production of palatable species. A biennial spring burn was recommended especially for sites 2 and 3, to remove mature and moribund plant material, promoting new palatable growth and ensuring uniform grazing in Ntshiqo. Due to poor

dispersal and long recovery times of *Themeda triandra* in overgrazed sourveld regions, re-seeding can be utilised to rehabilitated degraded rangelands. During the winter months, protein supplementation was recommended to improve the intake and account for nutrient deficiencies in the poor quality veld. The introduction of fodder crops (vetch and oats) was an avenue to significantly improve the nutrient content in the diet of livestock, promoting and maintaining animal production during winter. These technical interventions can be beneficial in aiding the correct rangeland management of sourveld and livestock production. Numerous net livestock benefits can be achieved such as higher food (milk, meat) and raw materials (wool) production, draught and manure. These benefits are important in combating food security issues in developing countries especially in the face of growing populations. Livestock provide smallholder farmers with cash and insurance which can aid poverty alleviation and improve resilience against external shocks (water scarcity, drought, climate change, crop failure). More food and income from livestock per unit of investment, of labour, water and land is important in contributing to LWP. This is important in improving the livelihoods of people living in smallholder farming systems in South Africa.

Ntshiqo inhabitants revealed positive feedback regarding the tested technical interventions. Ensuring 'buy-in' and support from local smallholder farmers are key for the adoption and success of specific interventions. However, a degree of behavioural change is required by local community members through efficient institutional structures which need to be driven by traditional authorities to create a policy environment which promotes the adoption of the technical interventions in the long term. Ultimately, a collaborative management approach through integrating technical, institutional and policy interventions remains the key to improve LWP, safeguard the environment and improve the livelihood benefits of smallholder farmers in Ntshiqo.

For the LWP concept to be widely and successfully applied, numerous research gaps need to be filled. Theoretical strategies have been proposed for improving LWP, however, there is a need for real-world assessment on the effectiveness of such interventions. Research needs to identify incentive mechanisms for communities to enhance the adoption and invest in land and water management strategies which improve LWP. Additional research is required on resting in communal rangelands. Furthermore, future research is required to test the potential effects of the integration of various technical, institutional and policy interventions on LWP in developing countries.

The LWP concept and framework have proved to be useful in identifying viable technical interventions to improve livelihoods, environmental health, livestock production and overall LWP.

This is important in increasing the resilience of smallholder farmers in mixed crop-livestock systems against vulnerabilities such as water scarcity, livelihood failures and climate change.

References

- Abramovitz, J., 1996: Imperiled waters, impoverished future: The decline of freshwater ecosystems (Worldwatch Paper No. 128). Washington, DC: Worldwatch Institute.
- Adams, B., Brockington, D., Dyson, J. and Vira, B., 2002: Common Pool Resource Policy Paper. Analytical Framework for Dialogue on Common Pool Resource Management. Cambridge, UK: University of Cambridge.
- Adie, H., Richert, S., Kirkman, K. P. and Lawes, M. J., 2011: The heat is on: frequent fire in bracken (*Pteridium aquilinum*) drives mortality of the sprouting tree *Protea caffra* in temperate grasslands. *Plant Ecology*, 212, 2013-2022.
- Akbar, M. A., Ahmed, T. U. and Mondal, M. M. H., 2006: Improving Animal Productivity and Reproductive Efficiency: Development and Testing Medicated Ureamolasses Multi-Nutrient Blocks in Rural Farms of Bangladesh. In: *Improving Animal Productivity by Supplementary Feeding of Multi-Nutrient Blocks, controlling Internal Parasites, and enhancing utilization of alternate feed resources*. Vienna: International Atomic Energy Agency (IAEA), Pg 13-28.
- Allen, M. R., Stott, P. A., Mitchell, J. F. B., Schnur, R. and Delworth, T. L., 2000: Quantifying the uncertainty in forecasts of anthropogenic climate change. *Nature*, 407, 617- 620.
- Alliber, M. and Hart, T., 2009. Should subsistence farming be supported as a strategy to address rural food security. *Agrekon*, 48, 434-458.
- Allred, B. W., Scasta, J. D., Hovick, T. J., Fuhlendorf, S. D. and Hamilton, R. G., 2014: Spatial heterogeneity stabilizes livestock productivity in a changing climate. *Agriculture, Ecosystems and Environment*, 193, 37-41.
- Altieri, M. A., 2004: Linking ecologists and traditional farmers in the search for sustainable agriculture. *Frontiers in Ecology and the Environment*, 2, 35-42.
- Amede, T., Geheb, K. and Douthwaite, B., 2009: Enabling the uptake of livestock-water productivity interventions in the crop-livestock systems of SSA. *The Rangeland Journal*, 31, 223-230.
- Amede, T., Tarawali, S. and Peden, D., 2011: Improving water productivity in crop-livestock systems of drought-prone regions: Editorial comment. *Experimental Agriculture*, 47, 1-5.

-
- Anteneh, A., Sandford, S. and Anteneh, B., 1988: Policy, finance and technology in livestock development in SSA: some critical issues. *ILCA Bulletin*. No 31, 2-13.
- Arellano, D., Friedberg, E. and March, J., 2011: Institutions and Organizations: Differences and Linkages from Organization Theory. *Gestion Politica Publica*, 20, 235-246.
- Asaad, C. O., De Vera, A. C. and Ignacio, L. M., 2006: Urea-Molasses Multi-Nutrient Block (UMMB) Supplementation of Dairy Cows raised by Smallholder Farmers in Sariaya, Quezon, Philippines. In: *Improving Animal Productivity by Supplementary Feeding of Multi-Nutrient Blocks, controlling Internal Parasites, and enhancing utilization of alternate feed resources*. Vienna: International Atomic Energy Agency (IAEA), Pg .111-118.
- Assefa, G. and Ledin, I., 2001: Effect of variety, soil type and fertiliser on the establishment, growth, forage yield, quality and voluntary intake by cattle of oats and vetches cultivated in pure stands and mixtures. *Animal Feed Science and Technology*, 92, 95-111.
- Ball, D. M., Collins, M., Lacefield, G. D., Martin, N. P., Mertens, D. A., Olson, K. E., Putnam, D. H., Undersander, D. J. and Wolf, M. W., 2001: Understanding forage quality. Park Ridge, Illinois: American Farm Bureau Federation Publication 1-01.
- Barbour, M. G., Burk, J. H. and Pitts, W. D., 1987: *Terrestrial Plant Ecology*. Menlo Park, Calif: Benjamin Cummings.
- Barnes, G. R., 1989a: Grazing Management Principles and Practices: Types of Grazing Management. In: J. E. Danckwerts and W. R. Teague, eds. *Veld Management in the Eastern Cape*. Pretoria: Department of Agriculture and Water Supply.
- Barnes, G. R., 1989b: Management of Veld Types: Sour Grassveld. In: J. E. Danckwerts and W. R. Teague, eds. *Veld Management in the Eastern Cape*. Pretoria: Department of Agriculture and Water Supply.
- Barnes, D. L., 1989c: Reaction of three veld grasses to different schedules of grazing and resting. 1. Patterns of shoot growth. *South African Journal of Plant and Soil*, 6, 1-7.
- Barnes, D. L., 1992: A critical analysis of veld management recommendations for sourveld in the south-eastern Transvaal. *Journal of the Grassland Society of Southern Africa*, 9, 126-134.
-

-
- Barnes, D. L. and Dempsey, C. P., 1992: Influence of period of deferment before stocking spring-burnt sourveld on sheep performance and veld productivity. *Journal of the Grassland Society of Southern Africa*, 9, 149-157.
- Barrett, J. L., 1992: The economic role of cattle in communal farming systems in Zimbabwe. Pastoral Development Network Paper No 32b. London: Overseas Development Institute.
- Barrett, C. B., Place, F., Aboud, A. Brown, D. R., 2002: The challenge of stimulating adoption of improved natural resource management practices in African agriculture. In: C. B. Barrett, F. Place and A. A. Aboud, eds. *Natural resources management in African agriculture: Understanding and improving current practices*. 1-21.
- Bär, R., Rouholahnejad, E., Rahman, K., Abbaspour, K. C. and Lehman, A., 2015: Climate change and agricultural water resources: A vulnerability assessment of the Black Sea catchment. *Environmental Science and Policy*, 46, 57-69.
- Baudron, F., Jaleta, M., Okitoi, O. and Tegegn, A., 2014: Conservation agriculture in African mixed crop-livestock systems: Expanding the niche. *Agriculture, Ecosystems and Environment*, 187, 171-182.
- Bayer, W., Alcock, R., Dladla, F., Gilles, P., Masondo, M., Mkhize, P., Mtshali, E. and Ntombela, L., 2004: A study of indigenous livestock management in rural KwaZulu-Natal, South Africa. Unpublished report. Mdukatshani: Mdukatshani Rural Development Project.
- Beauchemin, K. A., 1996: Using ADF and NDF in dairy cattle diet formulation- a western Canadian perspective. *Animal feed Science Technology*, 58, 101-111.
- Benjaminsen, T. A., Rohde, R., Sjaastad, E., Wisborg, P. and Lebert, T., 2006: Land Reform, Range Ecology, and Carrying Capacities in Namaqualand, South Africa. *Annals of the Association of American Geographers*, 96, 524-540.
- Bennett, J. E., 2013: Institutions and governance of communal rangelands in South Africa. *African Journal of Range & Forage Science*, 30, 77-83.
- Bennett, J., Ainslie, A. and Davis, J., 2013: Contested Institutions? Traditional leaders and land access and control in communal areas of the Eastern Cape province, South Africa. *Land Use Policy*, 32, 27-38.
-

-
- Bennie, A. T. P. and Hensley, M., 2001: Maximizing precipitation utilization in dryland agriculture in South Africa - a review. *Journal of Hydrology*, 241, 124-139.
- Bergold, J. and Thomas, S., 2012: Participatory Research Methods: A Methodological Approach in Motion. *Forum: Qualitative Social Research*, 13, 1-33.
- Bewley, J. M. and Schutz, M. M. 2008: Review: An Interdisciplinary Review of Body Condition Scoring for Dairy Cattle. *The Professional Animal Scientist*, 24, 507-529.
- Biazin, B., Sterk, G., Temesgen, M., Abdulkedir, A. and Stroosnijder, L., 2012: Rainwater harvesting and management in rainfed agricultural systems in SSA- A review. *Physics and Chemistry of the Earth*, 47-48, 139- 151.
- Blümmel, M., Samad, M., Singh, O.P. and Amede, T., 2009: Opportunities and limitations of food-feed crops for livestock feeding and implications for livestock water productivity. *The Rangeland Journal*, 31, 207–212.
- Bogale, S., Melaku, S. and Yami, A., 2008: Potential use of crop residues as livestock feed resources under smallholder farmers conditions in bale highlands of Ethiopia. *Tropical and Subtropical Agroecosystems*, 8, 107-114.
- Bond, J. and Nyren, R., 2012: Remote monitoring of deformation using Differential Global Positioning System (D-GPS). *Geotechnical News*, 30, 28.
- Bonsch, M., Popp, A., Biewald, A., Rolinski, S., Schmitz, C., Weindl, I., Stevanovic, M., Högner, K., Heinke, J., Ostberg, S., Dietrich, J. P., Bodirsky, B., Lotze-Campen, H. and Humpenöder, F., 2015: Environmental flow provision: Implications for agricultural water and land-use at the global scale. *Global Environmental Change*, 30, 113-132.
- Bossio, D., 2009: Livestock and water: understanding the context based on the ‘Comprehensive Assessment of Water Management in Agriculture’. *The Rangeland Journal*, 31, 179-186.
- Bransby, D. I., 1981: Forage Quality: The Value of veld and pasture as animal feed. In: N. M. Tainton, ed. *Veld and Pasture Management in South Africa*. Pietermaritzburg: Shuter & Shooter.
- Bricki, N., 2007: A guide to using qualitative research methodology. Rome: Medicins Sans Frontiers.
-

-
- Briske, D. D., Derner, J. D., Brown, J. R., Fuhlendorf, S. D., Teague, W. R., Havstad, K. M., Gillen, R. L., Ash, A. J. and Willms, W. D., 2008: Rotational Grazing on Rangelands: Reconciliation of Perception and Experimental Evidence. *Rangeland Ecology and Management*, 61, 3-17.
- Brundyn, L., Brand, T. S., Ferreira, A. V., Aucamp, B. B. and Durand, A., 2005: The effect of frequency of supplementation on the production of South African Mutton Merino ewes grazing wheat stubble. *South African Journal of Animal Science*, 6, 13-18.
- Camp, K. G. T., 1997a: Planning a Closed Veld Management System. In: K. G. T. Camp and J. M. B. Smith, eds. *Veld Management Planning in KwaZulu-Natal*. KwaZulu-Natal Department of Agriculture. Cedara, Cedara Report No. N/A/97/5.
- Camp, K. G. T., 1997b: The Bioresource Groups of KwaZulu-Natal. KwaZulu-Natal Department of Agriculture. Cedara, Cedara Report No. N/A/97/6.
- Camp, K. G. T., 1997c: Veld Condition Assessment. In: K. G. T. Camp and J. M. B. Smith, eds. *Veld Management Planning in KwaZulu-Natal*. KwaZulu-Natal Department of Agriculture. Cedara, Cedara Report No. N/A/97/5.
- Camp, K. G. T., 1997d: Resting of Veld. In: K. G. T. Camp and J. M. B. Smith, eds. *Veld Management Planning in KwaZulu-Natal*. KwaZulu-Natal Department of Agriculture. Cedara, Cedara Report No. N/A/97/5.
- Castellanos-Navarrete, A., Tittonell, P., Rufino, M. C. and Giller, K. E., 2014: Feeding, crop residue and manure management for integrated soil fertility management- A case study from Kenya. *Agricultural Systems*, Journal in Press, 1-12.
- Chakraborty, S., Tiedemann, A. V. and Teng, P. S., 2000: Climate change: potential impact on plant diseases. *Environmental Pollution*, 108, 317- 326.
- Chawatama, S., Ndlovu, L. R., Richardson, F. D., Mhlana, F. and Dzama, K., 2003: A simulation model of draught animal power in smallholder farming systems. Part I: Context and structural overview. *Agricultural Systems*, 76, 415-440.
- Cheeke, P. R., 2005: *Applied animal nutrition: feeds and feeding (3rd edition)*. Upper Saddle River, N. J: Prentice Hall Inc.
- Chopra, K. and Dasgupta, P., 2002: Common Pool Resources in India: Evidence, Significance and New Management Initiatives. Mimeo under the UK DFID Project R7973.
-

-
- Church, R. M., 2001: The Effective Use of Secondary Data. *Learning and Motivation*. 33, 32-45.
- Christopher, S., Watts, V., McCormick, A. and Young, S., 2008: Building and Maintaining Trust in a Community-Based Participatory Research Partnership. *American Journal of Public Health*, 98, 1398-1406.
- Cleasby, T. G., 1963: The Feeding Value of Molasses. Proceedings of The South African Sugar Technologists Association, 113-117.
- Cleaver, F., 2000: Moral ecological rationality, institutions and the management of common property resources. *Development and Change*, 31, 361-383.
- Cook, S. E., Anderson, M. S. and Fisher, M. J., 2009: Assessing the importance of livestock-water use in basins. *The Rangeland Journal*, 31, 195-205.
- Corti, S., Molteni, F. and Palmer, T. N., 1999: Signature of recent climate change in frequencies of natural atmospheric circulation regimes. *Nature*, 398, 799-802.
- Creswell, J.W., 1994: Research Design: Qualitative & Quantitative Approaches. 2nd edition. London: SAGE Publications, 1994
- Dahlstein, D. L. and Garcia, R., 1989: *Eradication of Exotic Pests: Analysis with Case Histories*. New Haven, Conn: Yale University Press.
- Danckwerts, J. E., 1989: Animal Performance. In: J. E. Danckwerts and W. R. Teague, eds. *Veld Management in the Eastern Cape*. Pretoria: Department of Agriculture and Water Supply.
- De Beer, L., 2012: The Wool Development Program in Communal Areas of South Africa. In: *Strategies to Overcome Poverty and Inequality- Towards Carnegie III*. 3 – 7 September 2012. University of Cape Town.
- De Brouwer, C. H. M., Cilliers, J. W., Vermaak, L. M., van der Merwe, H. J. and Groenewald, P. C. N., 2000: Phosphorus supplementation to natural pasture grazing for beef cows in the Western Highveld region of South Africa. *South African Journal of Animal Science*, 30, 43-52.
- De Leeuw, N. P. and Tothill, J. C., 1993: The Concept of Rangeland Carrying Capacity in SSA- Myth or Reality. In: R. H. Behnke, I. Scoones and C. Kerven, eds. *Range ecology*
-

at Disequilibrium. New Models of Natural Variability and Pastoral Adaptation in African Savannas. London: Overseas Development Institute.

Department of Agriculture and Environmental Affairs (DAEA), 1998: Bioresource Program: A natural resource classification system for KwaZulu-Natal. KZN: DAEA.

Department of Agriculture, Forestry and Fisheries (DAFF)., 2010: Annual report 2009/10. South Africa: Department of Agriculture, Forestry and Fisheries.

Department of Agriculture, Forestry and Fisheries (DAFF)., 2012: The Extension Recovery Plan (2008/9-2010/11): Assessment and Evaluation Report. Alcinof Resources Management (PTY) Ltd.

Department for Environment, Food and Rural Affairs (DEFRA), 2001: Condition scoring of dairy cows. London: DEFRA publications.

Deressa, T., Hassan, R. and Poonyth, D., 2005: Measuring the Impact of Climate Change on South African Agriculture: The Case of Sugarcane Growing Regions. *Agrekon*, 44, 524-542.

Descheemaeker, K., Nyssen, J., Poesen, J., Raes, D., Haile, M., Muys, B. and Deckers, S., 2006: Runoff on slopes with restoring vegetation: A case study from the Tigray highlands, Ethiopia. *Journal of Hydrology*, 331, 219-241.

Descheemaeker, K., Amede, T. and Hailelassie, A., 2009: Livestock and Water Interactions in Mixed Crop-Livestock Farming Systems of SSA: Interventions for Improved Productivity. Working Paper 133. Colombo: International Water Management Institute.

Descheemaeker, K., Amede, T. and Hailelassie, A., 2010a: Improving water productivity in mixed crop-livestock farming systems of SSA. *Agricultural Water Management*, 97, 579-586.

Descheemaeker, K., Mapedza, E., Amede, T. and Ayalneh, W., 2010b: Effects of integrated watershed management on livestock water productivity in water scarce areas in Ethiopia. *Physics and Chemistry of the Earth*, 35, 723-729.

Descheemaeker, K., Bossio, D., Amede, T., Ayalneh, W., Hailelassie, A. and Mapedza E., 2011: Analysis of gaps and possible interventions for improving water productivity in crop livestock systems of Ethiopia. *Experimental Agriculture*, 47, 21-38.

-
- De Bruyn, T. and Koster, H., 2000: Application of licks on veld. In: A. Engelbrecht, K. Kirkman and A. Swanepoel, eds, 2004, later date. *Veld and pasture management guidelines for sustainable animal production on the Mpumalanga Highveld*. Mpumalanga, South Africa: Department of Agriculture. pp 23-24.
- Delgado, C., 1999: Sources of growth in smallholder agriculture in SSA: the role of vertical integration of smallholders with processors and marketers of high-value items. *Agrekon*, 38, 165-189.
- Denzau, A. D. and North, D. C., 1994: Shared Mental Models: Ideologies and Institutions. *Kyklos*, 47, 3-31.
- Desler, C., Knutti, R., Solomon, S. and Phillips, A. S., 2012: Communication of the role of natural variability in future North America climate. *Nature Climate Change*, 2, 775-779.
- De Wet, C., 1989: Betterment Planning in a Rural Village in Keiskammahoek, Ciskei. *Journal of Southern African Studies*, 15, 326-345.
- Douthwaite, B., 2002: *Enabling Innovation: A Practical Guide to Understanding and Fostering Technological Change*. London: Zed Books.
- Dovie, D, B. K., Shackleton, C. M. and Witkowski, E. T. F., 2006: Valuation of communal area livestock benefits, rural livelihoods and related policy issues. *Land Use Policy*, 23, 260- 271.
- Dube, E., 2012: Soil fertility enhancement through appropriate fertilizer management on winter cover crops in a conservation agriculture system. Unpublished MSc thesis. University of Fort Hare.
- Dugmore, H., 2015: The golden fleece. National Wool Growers Association. Accessed from: <http://www.nwga.co.za/images/downloads/Sawubona2015.pdf> (Accessed 19 August 2015).
- Duguma, B., Tegegne, A. and Hedge, B. P., 2011: An Assessment of Availability of Livestock Drinking Water Resources, Patterns of Exploitation and Management Strategies at Ginchi Watershed, Ethiopia. *American-Eurasian Journal of Agronomy*, 4, 38-45.
-

-
- Duvel, G. H. and Afful, D. B. 1994: Human constraints in stock reduction and communal land management in a subsistence farming situation in South Africa: Research Report. University of Pretoria: South African Institute for Agricultural Extension.
- Enete, A. A. and Amusa, T. A., 2010: Challenges of Agricultural Adaptation to Climate Change in Nigeria: a Synthesis from the Literature. *Field Action Science Reports*, 4, 1-11.
- Engelbrecht, A., Kirkman, K. and Swanepoel, A., 2004: Veld and pasture management guidelines for sustainable animal production on the Mpumalanga Highveld, pp 24-26. Department of Agriculture, Mpumalanga, South Africa.
- Erkossa, T., Hailelassie, A. and MacAlister, C., 2014: Enhancing farming system water productivity through alternative land use and water management in vertisol areas of Ethiopian Blue Nile Basin (Abay). *Agricultural Water Management*, 132, 120-128.
- Eskandari, H., Ghanbari, A. Javanmard, A., 2009: Intercropping of Cereals and Legumes for Forage Production. *Notulae Scientia Biologicae*, 1, 7-13.
- Everson, C. S. and Tainton, N. M., 1984: The effect of thirty years of burning on the Highland Sourveld of Natal. *Journal of the Grassland Society of Southern Africa*, 1, 15-20.
- Everson, T. M. and Hatch, G. P., 1999: Managing veld (rangeland) in communal areas of South Africa. In: N. M. Tainton, ed. *Veld Management in South Africa*. Pietermaritzburg: University of Natal Press.
- Everson, T. M., Yeaton, R. I. and Everson, C. S., 2009: Seed dynamics of *Themeda triandra* in the montane grasslands of South Africa. *African Journal of Range & Forage Science*, 26, 19-26.
- Everson, T. Senior lecturer at the University of KwaZulu-Natal, Pietermaritzburg. 2015: Personal Communication. 17 February, University of KwaZulu-Natal.
- Everson, T. M. and Smith, J. M. B., Undated: Improving Rural Livelihoods through Biogas Generation using Livestock Manure and Rainwater Harvesting. Water Research Commission. WRC Report No K5/1955/15 (In Press).
- Fair, J., 2013: Producing better Highveld beef. *Farmer's Weekly*.
- Farmer, H., 2010: Understanding Impacts of Water Supplementation in a Heterogeneous Landscape. Unpublished PhD Thesis. University of Witwatersrand.
-

-
- Fidelibus, M. W. and MacAller, R. T. F., 1993: Methods for plant sampling, Restoration in the Colorado Desert: Management Notes. Prepared for California Department of Transportation, San Diego, p. 1-7.
- Foran, B. D., Tainton, N. M. and De V Booysen, P., 1978: The development of a method for assessing veld condition in three grassveld types in natal. *Proceedings of the Annual Congresses of the Grassland Society of Southern Africa*, 13, 27-33.
- Fowler, R., 1999: Animal draft power in South Africa: past, present and future. In: P. Starkey and P. Kaumbutho, eds. Meeting the challenges of animal traction. London: Intermediate Technology Publications.
- Gbetibouo, G. A. and Hassan, R. M., 2005: Measuring the economic impact of climate change on major South African crops: a Ricardian approach. *Global and Planetary Change*, 47, 143-152.
- Gill, P., Stewart, K., Treasure, E. and Chadwick, B., 2008: Methods of data collection in qualitative research: interviews and focus groups. *British Dental Journal*, 204, 291-295.
- Grainer, S. P., 2012: Ewe Body Condition Scoring. Virginia Technicon. www.apsc.vt.edu/extension/sheep/programs/shepherds-symposium/2012/12_symposium_greiner_bcs
- Grandin, B. E., Bekure, S. De Leeuw, P. N. and Neate, P. J. H, 1991: Livestock transactions, food consumption and household budgets. In: S. Bekure, P. N. De Leeuw, B. E. Grandin and P. J. H. Neate, eds. *An analysis of the livestock production system of Maasai pastoralists in eastern Kajiado District, Kenya*. Ethiopia: International Livestock Centre for Africa.
- Greenberg, S., 2010: Status report on land and agricultural policy in South Africa, 2010. Research Report 40. University of the Western Cape: Institute for Poverty, Land and Agrarian Studies.
- Haileslassie, A., Peden, D., Gebreselassie, S., Amede, T. and Descheemaeker, K., 2009: Livestock water productivity in mixed crop-livestock farming systems of the Blue Nile basin: Assessing variability and prospects for improvement. *Agricultural Systems*, 102, 33-40.
-

-
- Haileslassie, A., Descheemaeker, K., Blümmel, M., Craufurd, P. and Ergano, K., 2013: Entry Points to Improve Livestock Water Productivity in Selected Forage Based Livestock Systems. In: *Proceedings of the 22nd International Grasslands Conference*. Sydney, Australia, 1830-1832.
- Halachmi, I., Polak, P., Roberts, D. and Klopčič, M., 2008: Cow body shape and automation of scoring BCS. *Journal of Dairy Science*, 91, 4444-4451.
- Hall, J. B., 2000: Body condition scoring for beef cows. Virginia Tech Beef Cattle Extension. Publication Number: 400795. 1-6.
- Hardy, M. B., 1994: Short term effects of mixed grazing by cattle and sheep in highland Sourveld. Unpublished PhD Thesis. University of Natal: Pietermaritzburg.
- Hardy, M. B. Tainton, N.M. and Morris, C. D., 1994: Defoliation patterns of three grass species in sourveld grazed by cattle and sheep. *African Journal of Range & Forage Science*, 11, 37-42.
- Hassan, R., 2010: The double challenge of adapting to climate change while accelerating development in SSA. *Environment and Development Economics*, 15, 661-685.
- Hatch, G. P., 1991: Species and area selection patterns in the Southern Tall Grassveld of Natal. Unpublished MSc Thesis. University of Natal: Pietermaritzburg.
- Hatfield, J. L., Sauer, T. J. and Prueger, J. H., 2001: Managing Soils to Achieve Greater Water Use Efficiency: A Review Lincoln, Nebraska: USDA Agricultural Research Service. Paper 1341.
- Havemann, T. and Muccione, V., 2011: Mechanisms for agricultural climate change mitigation incentives for smallholders. Copenhagen, Denmark: CCAFS. (CCAFS Report Nr 6). <http://hdl.handle.net/10568/12496> (Accessed 1 October 2015).
- Hedling, G., Parker, A. and Wonnacott, R., 2000: TrigNet The Network of Active GPS Base Stations for South Africa. Proceedings of the 13th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GPS 2000), Salt Lake, Utah. 1865-1870.
- Heeren, A. G., Jemmott III, J. B., Tyler, J. C., Tshabe, S. and Zolani, N., 2011: Cattle for Wives and Extramarital Trysts for Husbands? Lobola, Men, and HIV/STD Risk Behaviour in Southern Africa. *Journal of Human Behaviour in the Social Environment*, 21, 73-81.
-

-
- Hejazi, M., Edmonds, J., Clarke, L., Kyle, P., Davies, E., Chaturvedi, V., Wise, M., Patel, P., Eom, J., Calvin, K., Moss, R. and Kim, S., 2014: Long-term global water projections using six socioeconomic scenarios in an integrated assessment modelling framework. *Technological Forecasting and Social Change*, 81, 205-226.
- Helmreich, B. and Horn, H., 2009: Opportunities in rainwater harvesting. *Desalination*, 248, 118- 124.
- Herrero, M., Thornton, P. K., Gerber, P. and Reid, R. S., 2009: Livestock, livelihoods and the environment: understanding the trade-offs. *Current Opinion in Environmental Sustainability*, 1, 111-120.
- Hinrichsen, D. and Tacio, H., 2002: The coming freshwater crisis is already here. The linkages between population and water. Washington, DC: Woodrow Wilson International Center for Scholars. <http://www.wilsoncenter.org/topics/pubs/popwawa2.pdf> (Accessed 1 October 2015).
- Hodgson, G. M., 2006: What Are Institutions? *Journal of Economic Issues*, 40, 1-25.
- Holechek, J. L., 1992: Financial Benefits of Range Management Practices in the Chihuahuan desert. *Rangelands*, 14, 279-284.
- Homewood, K., Trench, P., Randall, S., Lynen, G. and Bishop, B., 2006: Livestock health and socio-economic impacts of a veterinary intervention in Maasailand: Infection-and-treatment vaccine against East Coast fever. *Agricultural Systems*, 89, 248-271.
- I'Ons, J. H., 1960: Studies on Veld Burning. Unpublished MSc Thesis. University of Natal: Pietermaritzburg.
- (IPCC) IPCC, Intergovernmental Panel on Climate Change., 2001: *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. T. J. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell and C. A. Johnson, eds. Cambridge: Cambridge University Press.
- IPCC, Intergovernmental Panel on Climate Change., 2007a: Climate change 2007: the physical sciences basis. Agenda 6.
- IPCC, Intergovernmental Panel on Climate Change., 2007b: Summary for policy makers. In: *Climate Change 2007: The Physical Science Basis: Report of Working Group I for the*
-

Fourth Assessment Report of the Intergovernmental Panel on Climate Change.
Cambridge: Cambridge University Press.

- IPCC, Intergovernmental Panel on Climate Change., 2014: Summary for Policy Makers. In: C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea and L. L. White, eds. *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. Cambridge: Cambridge University Press.
- Israel, S. and Pearson, R. A., 2000: Strategies to improve the effectiveness of supplementary feeding for working cattle in semi-arid crop/livestock systems. In: P. Kaumbutho, A. Pearson and T. Simalenga, eds. *Empowering farmers with animal traction*. Animal Traction Network for Eastern and Southern Africa (ATNESA). Alice: University of Fort Hare.
- Johnston, P., 2014: Climate Change – Both sides of the coin: How will agriculture in South Africa cope in the future? *Climate Change and Agriculture*, 38-41. <http://www.wrc.org.za/Lists/Knowledge%20Hub%20Items/Attachments/10982/11%20Climate%20p%2038-41.pdf> (Accessed 21 August 2015).
- Kahinda, J. M., Rocksrom, J., Taigbenu, A. E. and Dimes, J., 2007: Rainwater harvesting to enhance water productivity of rainfed agriculture in the semi-arid Zimbabwe. *Physics and Chemistry of the Earth*, 32, 1068- 1073.
- Kahinda, J. M. and Taigbenu, A. E., 2011: Rainwater harvesting in South Africa: Challenges and Opportunities. *Physics and Chemistry of the Earth*, 36, 968- 976.
- Kazianga, H. and Udry, C., 2006: Consumption smoothing? Livestock, insurance and drought in rural Burkina Faso. *Journal of Development Economics*, 79, 413-446.
- Keftasa, D., 1988: Role of crop residues as livestock feed in the Ethiopian highlands. In: B. H. Dzowela, ed. *African Forage Plant Genetic Resources, Evaluation of Forage Germoplasm and Extensive Livestock Production Systems*. Addis Ababa, Ethiopia: ILCA.
- Keulder, C., 2000: Traditional Leaders. In: C. Keulder, ed. *State, society and democracy: A reader in Namibian politics*. Windhoek: Gamsberg Macmillan, 150-170.

-
- Khan, S. and Lootvoet, B., 2001: "Tribal Authority and Service Delivery in the Durban Uni-City". Paper presented at Gouvernance et Gouvenement urbain en Afrique Australe, Novemebr, 2001, Lusaka. <http://iga.ujf-greoble.fr/teo/Innovation?PDF/38%20Khan&Lootvoet%20cor.pdf>.
- Kiage, L. M., 2013: Perspective on the assumed causes of land degradation in the rangelands of SSA. *Progress in Physical Geography*, 37, 664-684.
- Kirkman, K. P. and Moore, A. 1995: Perspective: Towards improved grazing management recommendations for sourveld. *African Journal of Range & Forage Science*, 12, 135-144.
- Kirkman, K. P., 2002a: The influence of various types and frequencies of rest on the production and condition of sourveld grazed by sheep or cattle. 1. Proportional species composition. *African Journal of Range and Forage Science*, 19, 55-62.
- Kirkman, K. P., 2002b: The influence of various types and frequencies of rest on the production and condition of sourveld grazed by sheep or cattle. 2. Vigour. *African Journal of Range and Forage Science*, 19, 93-106.
- Kirkman, K. P. and De Faccio Carvalho, P. C., 2003: Management interventions to overcome seasonal quantity and quality deficits of natural rangelands. In: N. Allsopp, A. R. Palmer, S. J. Milton, K. P. Kirkman, G. I. H. Kerley, C. R. Hurt and C. J. Brown, eds. *Rangeland in the New Millenium*. Proceedings of the VII International Rangeland Congress, Durban. pp. 1289-1297.
- Kitzinger, J., 1994: The methodology of Focus Groups: the importance of interaction between research participants. *Sociology of Health & Illness*, 16, 103-121.
- Kotula, A. W., 1991: By- Products. In: P. A. Putman, ed. *Handbook of Animal Science*. California: Academic Press, Inc.
- Kotze, E., Sandhage-Hofmann, A., Meinel, J.-A., du Preez, C. C. and Amelung, W., 2013: Rangeland management impacts on the properties of clayey soils along grazing gradients in the semi-arid grassland biome of South Africa. *Journal of Arid Environments*, 97, 220-229.
- Kramer, M., Weisbjerg, M. R., Lund, P., Jensen, C. S. and Pedersen, M. G., 2012: Estimation of indigestible NDF in forages and concentrates from cell wall composition. *Animal Feed Science and Technology*, 177, 40-51.
-

-
- Krishnaswamy, A., 2004: Participatory research: strategies and tools. *Practitioner: Newsletter of the National Network of Forest Practitioners*, 22, 17-22.
- Kunene, N. W., 1992: The Contribution of Livestock to the Cash Economy of SNL Farmers of Area between Nkoyoyo and Nkaba in the Hhohho Region of Swaziland. Unpublished MSc Thesis. University of Swaziland.
- Lalman, D., Undated: Nutrient Requirements of Beef Cattle. Oklahoma: Oklahoma Cooperative Extension Service. E-974.
- Lemaire, G., Franzluebbers, A., De Faccio Carvalho, P. C. and Dedieu, B., 2014: Integrated crop-livestock systems: Strategies to achieve synergy between agricultural production and environmental quality. *Agriculture, Ecosystems and Environments*, 190, 4-8.
- Livestock Working Group (LWG)., 2015: Personal communication. Focus Group Discussions: Ntshiqo, Eastern Cape (18 June 2015; 21 July 2015; 13 August 2015; 16 September 2015).
- Louw, G. N., 1979: An Evaluation of the Application of Stock Licks in South Africa. *South African Journal of Animal Science*, 9, 133-144.
- Louw, A., Ndanga, L. and Chikazunga, D., 2008: Restructuring food markets in the SSA region: Dynamics in context of the fresh produce subsector. A synthesis of country findings. *Regoverning Markets - Small scale producers in modern agrifoodmarkets*. University of Pretoria.
- Lütge, B. U., Hardy, M. B. and Hatch, G. P., 1996: Plant and sward response to patch grazing in the Highland Sourveld. *African Journal of Range & Forage Science*, 13, 94-99.
- Lybbert, T. J. and Sumner, D. A., 2012: Agricultural technologies for climate change in developing countries: Policy options for innovation and technology diffusion. *Food Policy*, 37, 114-123.
- Lynch, B. D., 2012: Vulnerabilities, competition and rights in a context of climate change toward equitable water governance in Peru's Rio Santa Valley. *Global Environmental Change*, 22, 364-373.
- Machingura, C., 2007: An analysis of factors that can be used to identify successful smallholder farmers: A case study of Mbashe and Ngqushwa. Unpublished MSc Thesis. University of Fort Hare.
-

-
- Mahanta, R. and Das, D., 2012: Common Property Resources Degradation and Migration: A Case Study of Assam. *Journal of Human Ecology*, 38, 223-230.
- Manta, I. H., Aduba, J. J., Dada, J. T. Onyemize, C. U., 2013: Development of Urea Molasses Multi-nutrient Block (UMMB) Feed for Ruminant Animals as a Supplementary Feed to Cushion the Effect of Draught in Northern Nigeria. *International Journal of Environmental Sciences*, 2, 106-109.
- Mapako, L., 2011: Assessment of Vegetation Diversity and Rangeland Condition in the Highveld Communal Grazing Lands of Swaziland. Unpublished MSc Thesis. Windhoek: University of Namibia.
- Mapiye, C., Mwale, M., Chikumba, N. and Chimonyo, M., 2008: Fire as a Rangeland Management Tool in the Savannas of Southern Africa: A Review. *Tropical and Subtropical Agroecosystems*, 8, 115-124.
- Mapiye, C., Chimonyo, M., Dzama, K., Raats, J. G. and Mapekula, M., 2009: Opportunities for improving Nguni cattle production in the smallholder farming systems of South Africa. *Livestock Science*, 124, 196-204.
- Marshall, K., Quiros-Campos, C., van der Werf, J. H. J. and Kinghorn, B., 2011: Marker-based selection within smallholder production systems in developing countries. *Livestock Science*, 136, 45-54.
- Martin, G. and Magne, M. A., 2015: Agricultural diversity to increase adaptive capacity and reduce vulnerability of livestock systems against weather variability - A farm-scale simulation study. *Agriculture, Ecosystems and Environment*, 199, 301-311.
- Masika, P. J., Mafub, J. V., Goqwana, M. W., Mbuti, C. and Raats, J., 1998: A comparison of goat growth performance in a communal and commercial farming system in the Central Eastern Cape Province, South Africa. In: Webb, Cronje and Donkin eds. *Research and Training Strategies for Goat Production Systems in South Africa*. Proceedings of a workshop held on 22-26 November, 1998. Kings Lodge: Eastern Cape (please check!).
- Marais, T., 2008: Virtual Reference Station (VRS) in South Africa. Unpublished MSc Thesis. Brisbane: University of Southern Queensland, 1-89.
-

-
- Martin, G. and Magne, M. A., 2015: Agricultural diversity to increase adaptive capacity and reduce vulnerability of livestock systems against weather variability – A farm-scale simulation study. *Agriculture Ecosystems and Environment*, 199, 301-311.
- Martindale, G., 2007: Influence of livestock grazing on plant diversity of Highland Sourveld grassland in KwaZulu-Natal. Unpublished MSc Thesis. University of Witswatersrand, Johannesburg.
- Marufu, M. C., 2008: Prevalence of Ticks and Tick-borne Diseases in Cattle on Communal Rangelands in the Highland Areas of the Eastern Cape Province, South Africa. Unpublished MSc Thesis. University of Fort Hare.
- Marx, D. L., 2011: An assessment of ecological impacts of community-based restoration on communal grasslands in the Drakensberg foothills. Unpublished MSc Thesis. University of Cape Town.
- Mati, B. M., Muchiri, J. M., Njenga, K., Pennning de Vries, F. and Merrey, D. J., 2005: Assessing water availability under pastoral livestock systems in drought-prone Isiolo District, Kenya. Working Paper 106. Colombo: International Water Management Institute (IWMI).
- Maurya, V. N., Singh, B., Reddy, N., Singh, V. V., Maurya, A. K., Arora, D. K., 2014: Cost-Effective Perspective and Scenario Development on Economic Optimization for Multiple-Use Dry-Season Water Resource Management. *American Open Journal of Agriculture*, 2, 1-21.
- Maura, A., Ainslie, A. and Shackleton, C., 2003: Land use and livelihoods. In: S. Heyns, ed. *Programme for Land and Agrarian Studies*. Cape Town: Programme for Land Agrarian Studies. (Evaluating Land and Agrarian Reform in South Africa, occasional paper series, No. 8).
- McCosh, J., Malinga, M. and Dedekind, L., 2013: Social and Cultural, Institutional and Organisational Status Quo and Dynamics Influencing Access to Communal Crop and Rangelands, Site 2: Muden, KwaZulu-Natal (Deliverable 7: Interim Report). Draft Document. K5/2177//4. Report prepared for WRC Project: Up-Scaling of Rainwater Harvesting and Conservation on Communal Crop and Rangeland Through Integrated Crop and Livestock Production for Increased Water Use Productivity. Pietermaritzburg: Institute of Natural Resources.
-

-
- McDermott, J. J. and Arimib, S. M., 2002: Brucellosis in SSA: epidemiology, control and impact. *Veterinary Microbiology*, 90, 111-134.
- McKenzie, R. S. and Bhagwan, J. N., 1999: Some recent development in water demand management in South Africa. Ninth South African Hydrology Symposium: Cape Town: University of the Western Cape.
- Meer, T. and Campbell, C., 2007: Traditional Leadership in Democratic South Africa. Accessed from: <http://ddp.org.za/informationmaterial/articles/Traditional%20Leadership%20in%20Democratic%20South%20Africa.pdf>. (Accessed 2 September 2015).
- Meissner, H. H., 1982: Substitutions values of various classes of farm and game animals in terms of a biologically defined large stock unit. Farming in South Africa. Beef Cattle C3/1982.
- Meissner, H. H., Zacharias, P. J. K. and O'Reagain, P. J., 1999: Forage Quality (feed value). In: N. M. Tainton, ed. Veld Management in South Africa. Pietermaritzburg: University of Natal Press.
- Meissner, H. H., Scholtz, M. M. and Palmer, A. R., 2013: Sustainability of the South African Livestock Sector towards 2050 Part 1: Worth and impact of the sector. *South African Journal of Animal Science*, 43, 282-297.
- Mekonnen, S., Descheemaeker, K., Tolera, A. and Amede, T., 2011: Livestock water productivity in a water stressed environment in northern Ethiopia. *Experimental Agriculture*, 47, 85-98.
- Menke, J. W., 1992: Grazing and Fire Management for Native Perennial Grass Restoration in California Grasslands. *Fremontia*, 20, 22-25.
- Merriam, S., 2009: Qualitative Research: A guide to Design and Implementation. San Francisco: CA: Jossey-Bass.
- Milda, L., 2009: The environmental impact caused by the increasing demand for water. Water and resource management – a case study in Ethiopia. Unpublished MSc Thesis. Finland: TAMK University of Applied Sciences and Environmental engineering.
- Miller, R. W. and Gardiner, D. T., 1998: *Soils in our environment (8th edition)*. New Jersey, USA: Prentice-Hall Inc.
-

-
- Mkhabela, T. S., 2006: A review of the use of manure in small-scale crop production systems in South Africa. *Journal of Plant Nutrition*, 29, 1157-1185.
- Mkhize, N. R., 2008: Diet Selection and Foraging Efficiency of Nguni Goats in the Zululand Thornveld, KwaZulu-Natal. Unpublished MSc Thesis. University of Zululand.
- Molden, D., Owies, T., Steduto, P., Bindraban, P., Hanjra, M. A. and Kijne, J., 2010: Improving agricultural water productivity: Between optimism and caution. *Agricultural Water Management*, 97, 528-535.
- Moore, A. and Müller, O., 1994: Poster abstract: Lupin supplementation for pregnant ewes on winter veld at Nooitgedacht A. D. C. *Bulletin of the Grassland Society of southern Africa*, 5, 54.
- Morris, C. D., Tainton, N. M. and Hardy, M. B., 1992: Plant species dynamics in the Southern Tall Grassveld under grazing, resting and fire. *Journal of the Grassland Society of Southern Africa*, 9, 90-95.
- Morris, C. and Tainton, N., 2002: Lessons from Africa Long-term rangeland trials in an African grassland offer insight on the role fire, fertilizer and rotational grazing play in management of tall grasslands. *Rangelands*, 24, 8-12.
- Morris, C. D., Hardy, M. B. and Bartholomew, P. E., 1999: Stocking Rate. In: N. M. Tainton, ed. *Veld Management in South Africa*. Pietermaritzburg: University of Natal Press.
- Morris, C., 2002: Using considered grazing strategies for flourished veld. Veld burning and management. *Farmers Weekly*, August: pp 26-28.
- Morris, S. T., Kenyon, P. R. and Burnham, D. L., 2002: A comparison of two scales of body condition scoring in Hereford x Friesian beef breeding cows. *Proceedings of the New Zealand Grassland Association*, 64, 121-123.
- Morton, J. F., 2007: The impact of climate change on smallholder and subsistence agriculture. *Proceedings of the National Academy of Sciences*, 104, 19680- 19685.
- Motsi, K. E., Chuma, E. and Mukamuri, B. B., 2004: Rainwater harvesting for sustainable agriculture in communal lands of Zimbabwe. *Physics and Chemistry of the Earth*, 29, 1069- 1073.
-

-
- Moyle, P. B., Kiernan, J. D., Crain, P. K. and Quinones, R. M., 2013: Climate Change Vulnerability of Native and Alien Freshwater Fishes of California: A Systematic Assessment Approach. *PloS One*, 8, 1-13. E63883.
- Mucina, L., Hoare, D. B., Lötter, M. C., Du Preez, P. J., Rutherford, M. C., Scott-Shaw, R. C., Bredenkamp, G. J., Powrie, L. W., Scott, L., Camp, K. G. T., Cilliers, S. S., Bezuidenhout, H., Mostert, T. H., Siebert, S. J., Winter, P. J. D., Burrows, J. E., Dobson, L., Ward, R. A., Stalmans, M., Oliver, E. G. H., Siebert, F., Schmidt, E., Kobisi, K. and Kose, L., 2006: Grassland Biome: In: L. Mucina and M. C. Rutherford, eds. *The vegetation of South Africa, Lesotho and Swaziland*. Pretoria: South African National Biodiversity Institute, 348-437.
- Municipal Systems Act (MSA)., 2000: Act No. 32 of 2000. www.acts.co.za/municipal-systems-act-2000/ (Accessed 19 August 2015).
- Munyai, F.R., 2012: An Evaluation of Socio-Economic and Biophysical Aspects of Small-Scale Livestock Systems Based on a Case Study from Limpopo Province: Muduluni Village. Unpublished PhD Thesis. University of Free State.
- Mvinjelwa, S. A., Mapekula, M., Maphosa, V. and Muchenje, V., 2014: Body and fleece weights of woollen sheep in veld communal rangelands of the Eastern Cape Province. *Tropical Animal Health and Production*, 46, 913-918.
- Nair, P. K. R., 1998: Directions in tropical agroforestry research: past, present, and future. *Agroforestry Systems*, 38, 223-245.
- National Research Council (NRC)., 1984: *Nutrient requirements of beef cattle*. 6th ed. Washington D. C: National Academy Press.
- Navarro, T., Alados, C. and Cabezudo, B., 2006: Changes in plant functional types in response to goat and sheep grazing in two semi-arid shrublands of SE Spain. *Journal of Arid Environments*, 64, 298-322.
- Ndlovu, L. R. and Mugabe, P. H., 2002: Nutrient Cycling in Integrated Plant-Animal Systems: Implications for Animal Management Strategies in Smallholder Farming Systems. In: C. B. Barrett, F. Place and A. A. Aboud, eds. *Natural Resources Management in African Agriculture: Understanding and Improving Current Practices*. United Kingdom: CAB International.
-

-
- Ndoro, J. T., Mudhara, M. and Chimonyo, M., 2014: Cattle Commercialization in Rural South Africa: Livelihood Drivers and Implications for Livestock Marketing Extension. *Journal of Human Ecology*, 45, 207-221.
- Neves, D. and Du Toit, A., 2013: Rural Livelihoods in South Africa: Complexity, Vulnerability and Differentiation. *Journal of Agrarian Change*, 13, 93-115.
- Newman, Y. C., Lambert, B. and Muir, J. P., 2006. Defining forage quality. Texas Cooperative extension. The Texas A & M University System.
- Nin, A., 2007: Chapter 47 Livestock Productivity in Developing Countries: *An Assessment. Handbook of Agricultural Economics*, 3, 2461-2532.
- North, D. C., 1993: Institutions and Credible Commitment. *Journal of Institutional and Theoretical Economics*, 149, 11-23.
- Notenbart, A., Herrero, M., De Groote, H., You, L., Gonzalez-Estrada, E. and Blummel, M., 2013: Identifying recommendation domains for targeting dual-purpose maize-based interventions in crop-livestock systems in East Africa. *Land Use Policy*, 30, 334-346.
- Ntshona, Z. and Lahiff, E., 2003: Rural development, institutional change and livelihoods in the Eastern Cape, South Africa: a case study of Mdudwa village. Sustainable Livelihoods in Southern Africa Research Paper no. 5. Brighton: Institute of Development Studies.
- O'Connor, T. G., Kuyler, P., Kirkman, K. P. and Corcoran, B., 2010: Which grazing management practices are most appropriate for maintaining biodiversity in South African grassland? *African Journal of Range & Forage Science*, 27, 67-76.
- Ogunkoya, F. T., 2014: Socio-Economic Factors that affect Livestock Numbers: A Case Study of Smallholder Cattle and Sheep Farmers in the Free State Province of South Africa. Unpublished MSc Thesis. University of South Africa.
- Okorogbona, A. O. M. and Adebisi, L. O., 2012: Animal Manure for Smallholder Agriculture in South Africa. In: E. Lichtfouse, ed. *Farming for Food and Water Security*. Dordrecht: Springer Science and Business Media.
- Oliver, S. M., 2007: Small-Scale Feeding and Habitat Preferences of Herbivore Game Species in the Grassland of the Central Free State. Unpublished MSc Thesis. University of Free State: Bloemfontein.
-

-
- O'Reagain, P. J. and Mentis, M. T., 1988: Seasonal changes in the quality of diet selected by cattle grazing the natal sour sandveld. *Journal of the Grassland Society of Southern Africa*, 5, 48-51.
- O'Reagain, P. J. and Turner, J. R., 1992: An evaluation of the empirical basis for the grazing management recommendations for rangeland in Southern Africa. *Journal of the Grassland Society of Southern Africa*, 9, 39-49.
- O'Reagain, P., 1994: Veld management: re-examining the evidence. *Farmers Weekly*, October: 4-6.
- Owen, E. and Jayasuriya, M. C. N., 1989: Use of crop residues as animals feeds in developing countries. *Research and Development in Agriculture*, 6, 129-138.
- Owen-Smith, N., 1999: The animal factor in Veld Management. In: N. M. Tainton, ed. *Veld Management in South Africa*. Pietermaritzburg: University of Natal Press.
- Palmer, A. R. and Bennett, J. E., 2013: Degradation of communal rangelands in South Africa: towards an improved understanding to inform policy. *African Journal of Range and Forage Science*, 30, 57-63.
- Paraiwa, M. G., 1992: Communal Grazing Management in Zimbabwe's Resettlement Schemes. In: B. Cousins, ed. *Institutional Dynamics in Communal Grazing Regimes in Southern Africa*. Proceedings of a workshop held at the University of Zimbabwe 10th to 12th December 1990. Centre for Applied Social Sciences.
- Parthasarathy Rao, P., BIRTHAL, P. S. and Ndjeunga, J., 2005: Crop livestock economies in the semi-arid tropics: Facts, trends and outlook. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.
- Pathak, P. K. and Nath, B. G., 2013: Rural Poultry Farming with Improved Breed of Backyard Chicken. *Journal of World's Poultry Research*, 3, 24-27.
- Pearson, R. A., 1993: Resource requirements for draught animal power. In: M. Gill, E. Owen, G. E. Pollott and T. L. J. Lawrence, eds. *Animal Production in Developing Countries*. Edinburgh: British Society of Animal Production.
- Peddie, G. M. and Tainton, N. M. and Hardy, M. B., 1995: The effect of past grazing intensity on the vigour of *Themeda triandra* and *Tristachya leucothrix*. *African Journal of Range & Forage Science*, 12, 111-115.
-

-
- Peden, D., Undated: Improving Livestock Water Productivity: Lessons from the Nile River Basin. Ethiopia: International Livestock Research Institute.
- Peden, D., Tadesse, G. and Misra, A., 2007: Water and livestock for human development. In: *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. London, UK: Earthscan and Colombo, Sri Lanka: International Water Management Institute. Pp 485-514.
- Peden, D., Faki, H., Alemayehu, M., Mpairwe, D., Herrero, M., Van Breugel, P., Hailelassie, A., Tadesse, G. and Bekele, S., 2008: Opportunities for increasing livestock water productivity in the Nile River Basin. Proceedings, Nile Basin Development Forum, 1-19.
- Peden, D., Tadesse, G. and Hailelassie, A., 2009: Livestock water productivity: implications for sub-Saharan Africa. *The Rangeland Journal*, 31, 187-193.
- Peden, D., Amede, T. and Hailelassie, A., 2011: Opportunities for water-efficient livestock production. International Livestock Research Institute. *Livestock Exchange Issue Brief*, 5, 1-5.
- Peden, P., Molden, D., Smakhtin, V. and Awulachew, S. B., 2012: *The Nile River Basin: Water, Agriculture, Governance and Livelihoods*. UK: Routledge.
- Pejovich, S., 1999: The Effects of the Interaction of Formal and Informal Institutions on Social Stability and Economic Development. *Journal of Markets & Morality*, 2, 164-181.
- Peter, I., 2014: Reconsidering Place of Traditional Institutions under the Nigerian Constitution: A Comparative Analysis. *Journal of Law, Policy and Globalization*, 31, 135-148.
- Pienaar, P. L., 2013: Typology of Smallholder Farming in South Africa's Former Homelands: Towards an Appropriate Classification System. Unpublished MSc Thesis. Stellenbosch: Stellenbosch University.
- Powell, J. M. and Williams, T. O., 1994: An overview of mixed farming systems in SSA. In: J. M. Powell, S. Fernandez-Rivera, T. O. Williams, and C. Renard, eds. *Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems of SSA*. Proceedings of an International Conference, 22-26 November, 1993, Vol. II: Technical Papers. Addis Ababa: International Livestock Centre for Africa.
-

-
- Powell, M. J., Pearson, A. R. and Hiernaux, P. H., 2004: Review and Interpretation: Crop-Livestock Interactions in the West African Drylands. *Agronomy Journal*, 96, 469-483.
- Pratt, D. J., 1984: Ecology and Livestock. In: J. R. Simpson and P. Evangelou, eds. *Livestock Development in Sub-Saharan Africa: Constraints, Prospects, Policy*. Colorado: Westview Press.
- Preston, T. R. and Leng, R. A., 1987: Livestock development strategies. In: Matching Ruminant Production Systems with Available Resources in the Tropics and Sub-Tropics. <http://www.utaoundation.org/P&L/chapter2.htm> (Accessed 1 October 2015).
- Rajabu, K. R. M., 2005: The role of participatory problem analysis in performance improvement and sustainable management of rainwater harvesting (RWH) systems: A case study of Makanya village, Tanzania. *Physics and Chemistry of the Earth*, 30, 832-839.
- Ramesh, K., 2010: More Efficient Use of Agricultural Inputs as Part of Adoption of Preparedness Strategies: Multiple Cropping. In: K. Stigter, ed. *Applied Agrometeorology*. Berlin: Springer-Verlag Berlin Heidelberg.
- Reed, M. S. and Dougill, A. J. 2010: Linking degradation assessment to sustainable management: A decision support system for Kalahari pastoralists. *Journal of Arid Environments*, 74, 149-155.
- Rigge, M., Smart, A. and Wylie, B., 2013: Optimal Placement of Off-Stream Water Sources for Ephemeral Stream Recovery. *Rangeland Ecology & Management*, 66, 479-486.
- Rittichainuwat, B. and Rattanaphinanchai, S., 2015: Applying a mixed method of quantitative and qualitative design in explaining the travel motivation of film tourists in visiting a film-shooting destination. *Tourism Management*, 46, 136-147.
- Robinson, P., Putnam, D. and Mueller, S., 1998: Interpreting Your Forage Test Report. *California Alfalfa and Forage Review*, 1, 1-2.
- Rockström, J., Lannerstad, M. and Falkenmark, M., 2007: Assessing the water challenge of a new green revolution in developing countries. *Proceedings of the National Academy of Sciences*, 104, 6253-6260.
-

-
- Rosenzweig, C., Iglesias, A., Yang, X. B., Epstein, P. R. and Chivian, E., 2001: Climate change and extreme weather events; implications for food production, plant diseases and pests. *Global change and human health*, 2, 90- 104.
- Rosenzweig, C., Karoly, D., Vicarelli, M., Neofotis, P., Wu, Q., Casassa, G., Menzel, A., Root, T. C., Estrella, N., Seguin, B., Tryjanowski, P., Liu, C., Rawkins, S. and Imeson, A. 2008: Attributing physical and biological impacts to anthropogenic climate change. *Nature*, 453, 353- 358.
- Rowntree, K., Duma, M., Kakembo, V. and Thornes, J., 2004: Debunking the myth of overgrazing and soil erosion. *Land Degradation and Development*, 15, 203-214.
- Rumsey, A. B. and King, N. D., 2009: Climate Change: Impacts, Adaptation, and Mitigation, Threats and Opportunities. In: H. A. Strydom and N. D. King, eds. *Environmental Management In South Africa*. Cape Town: JUTA Law.
- Russelle, M. P., Entz, M. H. and Franzluebbbers, A. J., 2007: Reconsidering Integrated Crop-Livestock Systems in North America. *Agronomy Journal*, 99, 325-334.
- Ruyle, G., 1993: Nutritional Value of Range Forage for Livestock. In: R. Gum, G. Ruyle and R. Rice, eds. *Arizona Ranchers' Management Guide*. Arizona: *The University of Arizona*. Range Cattle Nutrition 1-2.
- Ryschawy, J., Choisis, N., Choisis, J. P., Joannon, A. and Gibon, A., 2012: Mixed crop-livestock systems: an economic and environmental-friendly way of farming? *Animal*, 6, 1722-1730.
- Salami, A., Kamara, A. B. and Brixiova, Z., 2010: Smallholder Agriculture in East Africa: Trends, Constraints and Opportunities. Working Paper Series No. 105. Tunis, Tunisia: African Development Bank.
- Salomon, M., 2011: Keeping cattle in a changing rural landscape: Communal rangeland management in Okhombe, KwaZulu-Natal, South Africa. Unpublished PhD Thesis. Pietermaritzburg: University of KwaZulu-Natal.
- Sani, A. B., 2009: Raw Material Production for Export in Northern Nigeria: The Experience of the People in the Livestock and Allied Industries under British Rule c. 1900–1960. *African Economic History*, 37, 103-127.
-

-
- Savenije, H. and van der Zaag, P., 2002: Water as an Economic Good and Demand Management Paradigms with Pitfalls. *International Water Resources Association*, 27, 98-104.
- Sayre, N. F., 2007: Carrying Capacity: Genesis, History and Conceptual Flaws. Prepared for the Environmental Politics Colloquium. 26 January 2007. Berkeley: University of California.
- Scarnecchia, D. L., 1985: The Animal-Unit and Animal-Unit-Equivalent Concepts in Range Science. *Journal of Range Management*, 38, 346-349.
- Scott, M. L. and Reynolds, E. W., 2007: Field-Based Evaluations of Sampling Techniques to Support Long-Term Monitoring of Riparian Ecosystems along Wadeable Streams on the Colorado Plateau. U.S. Geological Survey Open-File Report 2007-1266, pp 1-57. Reston, Virginia.
- Seckler, D., 1996: The New Era of Water Resources Management: From 'Dry' to 'Wet' Water Savings. Research Report 1. Colombo, Sri Lanka: International Irrigation Management Institute (IIMI).
- Sere, C. and Steinfield, S., 1996: World livestock production systems: Current status, issues and trends. FAO Animal Production and Health Paper 127. Rome, Italy: Food and Agriculture Organization of the United Nations.
- Shackleton, C. M., 1990: Seasonal changes in biomass concentration in three coastal communities in Transkei. *Journal of the Grassland Society of Southern Africa*, 7, 265-269.
- Shackleton, C.M., 1993: Are the communal grazing lands in need of saving? *Development Southern Africa*, 10 65-78.
- Shackleton, C. M., Shackleton, S. E. and Cousins, B., 2001: The role of land-based strategies in rural livelihoods: the contribution of arable production, animal husbandry and natural resource harvesting in communal areas in South Africa. *Development Southern Africa*, 18, 581-604.
- Simalenga T. E. and Joubert, A. B. D., 1997: Developing agriculture with animal traction. University of Fort Hare, Alice. <http://www.nda.agric.za/docs/infopaks/Animaltraction> (Accessed 1 October 2015) .
-

-
- Simalenga, T. E., Belete, A., Mzeleni, N. A. and Jongisa, L. L., 2000: Profitability of using animal traction under smallholder farming conditions in Eastern Cape, South Africa. In: P. G. Kaumbutho, R. A. Pearson and T. E. Simalenga, eds. *Empowering Farmers with Animal Traction*. University of Fort Hare, Alice: Animal Traction Network for Eastern and Southern Africa (ATNESA).
- Sithole, P. and Mbele, T., 2008: *Fifteen Year Review on Traditional Leadership a Research Paper*. Pretoria: Human Sciences Research Council Press.
- Smith, J. M. B., 1997: Introduction to Veld Management Principles. In: K. G. T. Camp and J. M. B. Smith, eds. *Veld Management Planning in KwaZulu-Natal*. KwaZulu-Natal Department of Agriculture. Cedara, Cedara Report No. N/A/97/5.
- Smith, J., Sones, K., Grace, D., MacMillan, S., Tarawali, S. and Herrero, M., 2013: Beyond milk, meat, and eggs: Role of livestock in food and nutrition security. *Animal Frontiers*, 3, 6-13.
- Snyman, H. A., 2006: Estimating grassland production loss due to fire for a semi-arid climate. *South African Journal of Animal Science*, 36, 38-41.
- Solomon, T., 2003: Rangeland evaluation and perceptions of the pastoralists in the Borana zone of southern Ethiopia. Unpublished PhD Thesis. Bloemfontein: University of the Free State.
- Solomon, T. B., Dlamini, B. J., Dlamini, A. M. and Dlamini, W. M., 2007: Evaluation of vegetation diversity, veld condition, soil seed bank characteristics and diet selection of cattle in Swazi rangelands. Final Research Project Report UNISWA Research Center, University of Swaziland.
- Somda, Z. C., Powell, J. M., Fernandez-Rivera, S. and Reed, J. D., 1995: Feed factors affecting nutrient excretion by ruminants and the fate of nutrients when applied to soil. In: J. M. Powell, S. Fernandez-Rivera, T. O. Williams and C. Renard, eds. *Proceedings of an International Conference of International Livestock Centre for Africa (ILCA) on Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems of Sub-Saharan Africa*. Ethiopia, Addis Ababa, 22-26 November 1993, pp. 227-243.
- Sonder, K., Astatke, A., El Wakeel, A., Molden, D. and Peden, D., 2003: Strategies for increasing livestock water productivity in water stressed agricultural systems. Ethiopia: International Livestock Research Institute.
-

-
- Sow, M., Hely, C., Mbow, C. and Sambou, B., 2013: Fuel and fire behaviour analysis for early-season prescribed fire planning in Sudanian and Sahelian savannas. *Journal of Arid Environments*, 89, 84-93.
- Sprinkle, J., 2001: Protein Supplementation. In: R. Tronstad, G. Ruyle, and J. Sprinkle, eds. *Arizona Ranchers' Management Guide*. Arizona: The University of Arizona. Range Cattle Nutrition 49-56.
- Sprinkle, J. and Bailey, D., 2004: How Many Animals can I Graze on my Pasture? Determining Carrying Capacity on Small Land Tracts. Tucson: The University of Arizona.
- Squires, V., 1981: *Livestock Management in the Arid Zone*. Melbourne: Inkata Press.
- Stewart, B. A., Koohafkan, P. and Ramamoorthy, K., 2006: Dryland Agriculture Defined and Its Importance to the World. In: G. A. Peterson, P. W. Unger and W. A. Payne, eds. *Dryland Agriculture*. Madison, Wisconsin: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.
- Stringer, L. C., Dyer, J. C., Reed, M. S., Dougill, A. J., Twyman, C. and Mkwambisi, D., 2009: Adaptations to climate change, drought and desertification: local insights to enhance policy in southern Africa. *Environmental Science and Policy*, 12, 748-765.
- Stroebe, A., Swanepoel, F. J. C. and Pell, A. N., 2011: Sustainable smallholder livestock systems: A case study of Limpopo Province, South Africa. *Livestock Science*, 139, 186-190.
- Suiter, J., 1994: Body condition scoring of sheep and goats. Farmnote 69/1994. Department of Agriculture, Western Australia.
- Sutherst, R. W. and Maywald, F., 1990: Impact of climate change on pests and diseases in Australia. *Search*, 21, 230-232.
- Swallow, B. M. and Brokken, R. F., 1987: *Cattle Marketing Policy in Lesotho*. African Livestock Policy Analysis Network Paper 14. Addis Ababa: International Livestock Centre for Africa.
- Taddese, G., 2005: Increasing Water Productivity: Livestock for food security and poverty alleviation. In: International Livestock Research Institute (ILRI) ed. ILRI Working Papers. Addis Ababa: ILRI.
-

-
- Tainton, N. M., 1981: *Veld and Pasture Management in South Africa*. Pietermaritzburg: Shuter & Shooter.
- Tainton, N. M., 1999: *Veld management in Southern Africa*. Pietermaritzburg: University of Natal Press.
- Tainton, N. M. and Danckwerts, J. E., 1989: Resting. In: J. E. Danckwerts and W. R. Teague, eds. *Veld Management in the Eastern Cape*. Pretoria: Department of Agriculture and Water Supply.
- Tainton, N. M. and Danckwerts, J. E., 1999: Resting. In: N. M. Tainton, ed. *Veld Management in South Africa*. Pietermaritzburg: University of Natal Press.
- Tainton, N. M., Aucamp, A. J. and Danckwerts, J. E., 1999: Grazing Programmes. In: N. M. Tainton, ed. *Veld Management in South Africa*. Pietermaritzburg: University of Natal Press.
- Tanner, J. C., Holden, S. J., Owen, E., Winugroho, M. and Gill, M., 2001: Livestock sustaining intensive smallholder crop production through traditional feeding practices for generating high quality manure-compost in upland Java. *Agriculture, Ecosystems and Environment*, 84, 21-30.
- Tarawali, S., Herrero, M., Descheemaeker, K., Grings, E. and Blummel, M., 2011: Pathways for sustainable development of mixed crop livestock systems: Taking a livestock and pro-poor approach. *Livestock Science*, 139, 11-21.
- Tau, M. S., 2005: Grazing Management in the Communal Rangelands of the Upper Thukela, KwaZulu-Natal. Unpublished MSc Thesis. University of KwaZulu-Natal.
- Teague, W. R., Trollope, W. S. W. and Aucamp, A. J., 1981: Veld Management in the semi-arid bush-grass communities of the eastern cape. *Proceedings of the Annual Congresses of the Grassland Society of Southern Africa*, 16, 23-28.
- Tegegne, S. D., 2012: Livestock Water Productivity (LWP) improvement in the mixed crop-livestock system of Ethiopian Highlands, Amhara Region: a gendered sustainable livelihood approach to target LWP interventions for rural poverty reduction. Unpublished PhD Thesis. Rheinischen Friedrich-Wilhelms-Universität Bonn.
- Thompson, J.M. and Meyer, H., 1994: Body condition scoring of sheep. Corvallis Extension Service, Oregon State University.
-

-
- Thornton, P. K., Van de Steeg, J., Notenbaert, A. M. and Herrero, M., 2009: The impacts of climate change on livestock and livestock systems in developing countries: a review of what we know and what we need to know. *Agricultural Systems*, 101, 113-127.
- Thornton, P. K. and Herrero, M., 2010: The Inter-linkages between Rapid Growth in Livestock Production, Climate Change, and the Impacts on Water Resources, Land Use, and Deforestation. Background paper for the World Development Report 2010, Development and Climate Change. Kenya: International Livestock Research Institute.
- Thornton, P. K. and Herrero, M., 2015: Adapting to climate change in the mixed crop and livestock farming systems in sub-Saharan Africa. *Nature Climate Change*, 5, 830-836.
- Tichit, M., Puillet, L., Sabatier, R. and Teillard, R., 2011: Multicriteria performance and sustainability in livestock farming systems Functional diversity matters. *Livestock Science*, 139, 161–171.
- Tittonell, P., van Wyk, M. T., Herrero, M., Rufino, M. C., de Ridder, N. and Giller, K. E., 2009: Beyond resource constraints- Exploring the biophysical feasibility of options for the intensification of smallholder crop-livestock systems in Vihiga district, Kenya. *Agricultural systems*, 101, 1-19.
- Tlhoale, C. T., 2012: The Interface between Traditional Leadership in Shared Rural Local Governance. Unpublished MSc thesis. Johannesburg: University of Johannesburg.
- Trollope, W. S. W., 1989: Grazing Management Principles and Practices: Veld Burning as a Management Practice in Livestock Production. In: J. E. Danckwerts and N. M. Teague, eds. *Veld Management in the Eastern Cape*. Pretoria: Department of Agriculture and Water Supply.
- Trollope, W. S. W., Trollope, L. A. and Bosch, O. J. H., 1990: Veld and pasture management terminology in southern Africa. *Journal of the Grassland Society of Southern Africa*, 7, 52-61.
- Trollope, W. S. W., 1999: Veld Burning. In: N. M. Tainton, ed. *Veld Management in South Africa*. Pietermaritzburg: University of Natal Press.
- Tschopp, R., Schelling, E., Hattendorf, J., Aseffa, A. and Zinsstag, 2009: Risk factors of bovine tuberculosis in cattle in rural livestock production systems of Ethiopia. *Preventive Veterinary Medicine*, 89, 205-211.
-

-
- Tulu, M., 2006: Estimation of livestock, Domestic Use and Crop Water Productivities of SG-2000 Water Harvesting Pilot Projects in Ethiopia. International Livestock Research Institute and International Water Management Institute, Addis Ababa, Ethiopia. Masters Thesis. The Netherlands: Wageningen University.
- Turpie, J., Winkler, H., Spalding-Fecher, R. and Midgley, G., 2002: Economic Impacts of Climate Change in South Africa: A Preliminary Analysis of Unmitigated Damage Costs. University of Cape Town, Southern Waters & Ecological Research & Consulting & Energy & Development Research Centre.
- Turpie, J. and Visser, M., 2012: The impact of climate change on South Africa's rural areas. Chapter 4 in: Financial and Fiscal Commission: Submission for the 2013/2014 Division of Revenue, Johannesburg, South Africa.
- Undersander, D., Albert, B., Cosgrove, D., Johnson, D. and Peterson, P., 1993: Pastures for Profit: A Guide to Rotational Grazing. Pub. No. A3529. Madison, WI: University of Wisconsin Cooperative Extension.
- Urassa, J. K. and Raphael, E., 2004: The contribution of small scale dairy farming to community welfare: A case study of Morogoro municipality. Tanzania: Sokoine University of Agriculture.
<http://www.fiuc.org/esap/MOROG/MOROG5/General/dairyfarming.pdf> (Accessed 1 October 2015).
- Valbuena, D., Erenstein, O., Tui, S. H. K., Abdoulaye, T., Claessens, L., Duncan, A. J., Gerard, B., Rufino, M. C., Teufel, N., Van Rooyen, A. and Van Wijk, M. T., 2012: Conservation Agriculture in mixed-crop livestock systems: Scoping crop residue trade-offs in SSA and South Asia. *Field Crops Research*, 132, 175-184.
- Vandramini, J. and Sollenberger, L., 2007: Impact of Grazing Methods on Forage and Cattle Production. Publication SS-AGR-133. Gainesville, FL: Agronomy Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.
- Van Averbeke, W. and Khosa, T. B., 2007: The contribution of smallholder agriculture to the nutrition of rural households in a semi-arid environment in South Africa. *Water SA*, 33, 413-418.
-

-
- Van Niekerk, B. D. H. and Jacobs, G. A., 1985: Protein, energy and phosphorus supplementation of cattle fed low-quality forage. *South African Journal of Animal Science*, 15, 133-136.
- Van Oudtshoorn, F., 2012: *Guide to Grasses of Southern Africa*. Pretoria, Briza.
- Van Wijk, M. T., Titttonell, P., Rufino, M. C., Herrero, M., Pacini, C., De Ridder, N. and Giller, K. E., 2009: Identifying key entry points for strategic management of smallholder farming systems in SSA using the dynamic farm-scale simulation model NUANCES-FARMSIM. *Agricultural Systems*, 102, 89-101.
- Vanton, J. 2001. Strength in numbers: veld management. *Farmers Weekly*, September: 16–18.
- Van Dyne, G. M., Brockington, N. R., Szocs, Z., Duek, J., and Ribic, C. A., 1980: Large herbivore system. In: A. I. Brey Meyer and G. M. Van Dyne, eds. *Grasslands, systems analysis and Man*. Cambridge: Cambridge University Press, 269-538.
- Vetter, S., 2009: Drought, change and resilience in South Africa's arid and semi-arid rangelands. *South African Journal of Science*, 105, 29-33.
- Vetter, S., 2013: Development and sustainable management of rangeland commons- aligning policy with the realities of South Africa's rural landscape. *African Journal of Range & Forage Sciences*, 30, 1-9.
- Vink, N. and Kirsten, J., 2003: Agriculture in the national economy. In L. Niewoudt and J. Groenewald, eds. *The Challenge of Change: Agriculture, Land and the South African Economy*. Pietermaritzburg: University of Natal Press.
- Vrieling, A., Meroni, M., Shee, A., Mude, A. G., Woodward, J., de Bie, C. A. J. M. and Rembold, F., 2014: Historical extension of operational NDVI products for livestock insurance in Kenya. *International Journal of Applied Earth Observation and Geoinformation*, 28, 238-251.
- Waters-Bayer, A. and Bayer, W., 1992: The Role of Livestock in the Rural Economy. *Nomadic Peoples*, 31, 3-18.
- Waters-Bayer, A. and Bayer, W., 2009: Enhancing local innovation to improve water productivity in crop-livestock systems. *The Rangeland Journal*, 1, 1-8.
-

-
- Wensing, M., Van Der Weijden, T. and Grol, R., 1998: Implementing guidelines and innovations in general practice: which interventions are effective? *British Journal of General Practice*, 48, 991-997.
- Williams, B., Mayson, D., De Satge, R., Epstein, S. and Semwayo, T., 2008: Extension and smallholder agriculture: Key issues from a review of the literature. First Draft. Phuhlisani - clear thinking for change.
- Wilson, T, R., 2003: The environmental ecology of oxen used for draught power. *Agriculture, Ecosystems and Environment*, 97, 21-37.
- WOCAT (World Overview of Conservation Approaches and Technologies), 2007: Where the land is greener: Case studies and analysis of soil and water conservation initiatives worldwide. H. Linger and W. Critchley, eds. Rome: Food and Agriculture Organisation.
- WRC., 2013: Demonstration of appropriate techniques and practices of rainwater harvesting and conservation at and rangeland scale for improved crop-livestock water use productivity (Site 1, Ntshiqo, Eastern Cape). Deliverable 13: Interim Report (Unpublished). Up-Scaling of Rainwater Harvesting and Conservation on Communal Crop and Rangeland through Integrated Crop and Livestock Production for Increased Water Use Productivity. Prepared by: McCosh, Gasa, Dedekind, Khuzwayo. INR: UKZN, Pietermaritzburg.
- Wright, I. A., Tarawali, S., Blümmel, M., Gerard, B., Teufel, N. and Herrero, M., 2012: Integrating crops and livestock in subtropical agricultural systems. *Journal of the Science of Food and Agriculture*, 92, 1010-1015.
- Wright, I. A., 2013: Improving Livestock Water Productivity. Paper presented at the conference on Food Safety, Security and Defense (FSSD). Nebraska, United States. 20-23 October 2013.
- Yami, M., Begna, B. and Teklewold, T., 2013: Enhancing the productivity of livestock production in highland of Ethiopia: Implication for improved on-farm feeding strategies and utilization. *International Journal of Livestock Production*, 4, 113-127.
- Youn, S., Chung, E. S., Kang, W. G. and Sung, J. H., 2012: Probabilistic estimation of the storage capacity of a rainwater harvesting system considering climate change. *Resources, Conservation and Recycling*, 65, 136- 144.
-

Zhang, Y. and Wildemuth, B. M., 2009: Qualitative analysis of content. In: B. M. Wildemuth, ed. *Applications of Social Research Methods to Questions in Information and Library Science*. Cape Town: Libraries Unlimited.

Appendices

Appendix 1: Plates



Plate 3.1: Livestock Working Group



Plate 3.2: Levy Bridge



Plate 3.3: Site 1, Exclosure 1



Plate 3.4: Site 1, Grazed 1



Plate 3.5: Site 1, Exclosure 2



Plate 3.6: Site 1, Grazed 2



Plate 3.7: Site 1, Exclosure 3



Plate 3.8: Site 1, Grazed 3



Plate 3.9: Site 2, Exclosure 1



Plate 3.10: Site 2, Grazed 1



Plate 3.11: Site 2, Exclosure 2



Plate 3.12: Site 2, Grazed 2



Plate 3.13: Site 2, Exclosure 3



Plate 3.14: Site 2, Grazed 3



Plate 3.15: Site 3, Exclosure 1



Plate 3.16: Site 3, Grazed 1



Plate 3.17: Site 3, Exclosure 2



Plate 3.18: Site 3, Grazed 2



Plate 3.19: Site 3, Exclosure 3



Plate 3.20: Site 3, Grazed 3



Plate 3.21: GPS data collection (Trimble GeoExplorer 6000 Series).



Plate 3.22: Disc Pasture Meter



Plate 3.23: Disc Pasture Meter Ring



Plate 3.24: Conducting grass clippings



Plate 3.25: Body Condition Scoring of Sheep



Plate 3.26: Protein lick (Multi Block 28).



Plate 3.27: Sheep eating the Protein lick



Plate 3.28: Vetch and Oats (winter fodder crop)

Appendix 2: Full Feed Analysis

Data on 100% dry matter basis																	
Lab No.	Sample No.	Moisture	Ash	Fat	ADF	NDF	Crude Protein	Ca	Mg	K	Na %	K/Ca+Mg	P	Zn	Cu	Mn	Fe
														mg/kg or ppm			
F136/15	S1 Exc - 1	5.08	10.60	2.68	48.33	76.68	5.16	0.30	0.15	0.65	0.02	0.60	0.07	14	4	100	267
F137	S1 Exc - 2	5.56	11.61	2.31	46.97	69.32	5.21	0.35	0.19	0.64	0.01	0.50	0.06	14	4	88	230
F138	S1 Exc - 3	3.80	10.87	2.48	46.00	76.09	5.02	0.25	0.15	0.57	0.02	0.57	0.06	20	5	67	287
F139	Outside A	4.35	8.55	1.97	50.29	79.44	5.41	0.19	0.13	0.89	0.02	1.13	0.08	16	3	71	251
F140	Outside B	3.57	8.22	1.88	49.69	80.62	5.24	0.23	0.11	0.76	0.01	0.94	0.07	14	4	123	184
F141	Outside C	4.55	9.78	2.08	46.29	79.86	5.26	0.25	0.14	0.59	0.03	0.62	0.09	14	4	146	355
F142	S2 Exc - 1	4.65	9.91	2.00	44.52	79.01	4.68	0.21	0.12	0.74	0.02	0.93	0.06	18	3	76	233
F143	S2 Exc - 2	5.63	7.76	1.69	47.81	80.63	4.72	0.19	0.10	0.66	0.07	0.93	0.05	16	4	197	226
F144	S2 Exc - 3	3.03	8.78	1.73	52.00	76.51	4.77	0.16	0.08	0.46	0.03	0.78	0.05	18	4	113	522
F145	Outside A	4.41	8.08	2.14	47.76	80.80	5.77	0.19	0.09	0.57	0.03	0.85	0.06	12	4	115	221
F146	Outside B	6.10	7.31	2.12	45.89	79.89	6.17	0.19	0.11	0.76	0.04	1.06	0.08	14	3	153	179
F147	Outside C	5.56	7.85	1.81	50.06	81.81	5.47	0.18	0.10	0.63	0.02	0.95	0.07	12	3	123	155
F148	S4 Exc - 1	4.44	7.01	2.14	47.83	81.89	5.45	0.19	0.07	0.63	0.02	1.06	0.08	14	4	125	287
F149	S4 Exc - 2	5.21	7.95	1.80	46.23	81.82	5.24	0.23	0.08	0.58	0.02	0.82	0.06	14	6	143	317
F150	S4 Exc - 3	5.26	7.97	2.55	50.94	80.97	5.11	0.25	0.11	0.81	0.02	0.98	0.06	14	5	98	194
F151	Outside A	5.08	7.76	2.03	46.72	83.93	5.09	0.21	0.08	0.53	0.02	0.80	0.07	12	5	168	444
F152	Outside B	3.92	7.22	2.44	45.51	80.84	5.05	0.20	0.10	0.73	0.05	1.02	0.07	14	5	141	351
F153	Outside C	5.71	7.06	2.24	44.74	80.01	6.71	0.22	0.07	0.73	0.02	1.10	0.07	12	6	192	249
1 - Moisture % of sample as received by laboratory. 2 - NPN is non-protein nitrogen 3 - ADFN and NDFN are calculated as nitrogen 4 - Nitrogen% is calculated by dividing Protein by 6.25 5 - The K / Ca + Mg should not be more than 2.																	