DEVELOPMENT OF SUSTAINABLE COMMUNITY GRAZING AND CLIMATE-SMART FODDER BANKS FOR SMALLHOLDER LIVESTOCK ENTERPRISES IN LIMPOPO AND MPUMALANGA PROVINCES OF SOUTH AFRICA

Report to the

WATER RESEARCH COMMISSION

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EXECUTIVE SUMMARY

A study was carried out with the aim of co-developing community grazing associations and climate-smart fodder banks with selected rural communities. This was to relieve pressure on vulnerable, yet valuable, communal rangeland resources, thereby enhancing the resilience of communal livestock farmers to drought. The objectives were: (a) to investigate user-friendly functional and sustainable practices and technologies for application to community-based grazing and fodder banks for livestock production systems in the context of climate change, (b) to co-develop drought-coping strategies and cultivated pastures-crop models that incorporate underground water resources, use of agro-meteorology and climate information with communal livestock farmers in the selected villages of Limpopo & Mpumalanga Provinces, (c) to develop fodder flow plans, identify gaps and build resilience to mitigate the impact of drought within the specific agro-ecosystems of Limpopo and Mpumalanga, and (d) to investigate the pathways to the creation and sustainable use of community (Smallholder Livestock Farmer Enterprises) climate-smart fodder banks. Key integrated chapters developed showed the following synopsis of the results:

(a) Desktop Review on Fodder Bank Practices and Technologies for Smallholder Farmers in the Context of Climate Change

This chapter reviews fodder bank practices and technologies for Smallholder Livestock Farmers in the context of climate change. The review covered the overall aim of establishing a fodder bank, which was primarily to bridge the disparity between the availability of fodder and its demand, particularly in regions reliant on rainfall. Such an establishment should include site selection, planting material, and aftercare. The very purpose of fodder banks is to provide quality fodder and nutrition for livestock for beef and milk production, especially during periods of scarcity in winter and/or during drought spells.

For fodder banks to be sustainable, preservation methods and techniques for hay, straw, stover, browse, and shrubs need to be employed. The review also covered technologies that can be used to improve forage preservation. The technologies include improved forage varieties and storage techniques. For this project, the review covered the level of adoption of the fodder bank concept. This included lack of skills and knowledge, ineffective extension services, inadequate participation and consultation to end-users, the farmers, gender alignment, land tenure, market access, and attitude towards the technologies.

(b) The Geospatial Development of Cultivated Pastures Crop (Tree Lucerne – Chamaecytisus Palmensis) Model Incorporating Underground Water – a Case of Limpopo and Mpumalanga Province, South Africa

Climate change has resulted in a drastic shortage of pasture on communal rangelands for livestock farming. The chapter aimed to assess the suitability of tree lucerne as a potential source of additional feed for ruminants. The parameters used to assess the suitability for tree lucerne included rainfall, soil type, soil depth, soil drainage, soil pH, and groundwater level.

These parameters were reclassified into three classes, class 1, class 2, and class 3, in proportion to how they influence this plant species. The spatial suitability model was established through an equal-weighted overlay of the rasterized layers. The resultant suitability map spatially characterizes the potential as optimal, suitable, or unsuitable. Each of the consequent classes had a spatial extent of 6,516,732 ha (32,22%), 1,253,058 ha (61,96%), and 1,177,591 ha (5,82%), respectively. The model suggested that introducing tree lucerne would improve farmers' resilience to the impacts of climate change. Most importantly, cattle farming could be expanded to over one million cattle if pastures are expanded with tree lucerne throughout the study area. The crop also bears the potential to improve the sustainability and profitability of smallholder livestock farmers.

(c) The Use of Agro-meteorology and Climate Information as Drought-coping Strategies

Grazing is an essential exercise for smallholder livestock farmers, as it provides the feed needed to raise healthy and productive livestock. Subsequently, the purpose of this study was to appraise the importance of agro-meteorology and climate information as drought-coping strategies. The use of agro-meteorology and climate information bears the potential to prepare and mitigate the impact of climate change on smallholder farmers. There is a diverse array of climatic information available in the public domain (rainfall, temperature, aridity, and projected climate). Such information was entered into the geographic information system to assess the spatial variability of these parameters. The continuous monitoring data was subjected to the climate and earth system models to project the future climate. The subsequent thematic layers revealed spatial differences in rainfall across the two provinces. The eastern side experiences the optimal rainfall of about 1800 mmpa and decreases moving westward to the value of about 300 mmpa. The temperatures exhibit a similar trend.

The projected rainfall indicates that rainfall intensity will increase in the study area for the most part, and temperatures will also increase. Smallholder livestock farmers may use climate information to plan their annual operations. Climate forecasts guide farmers in establishing a timeline that specifies which activities should be performed at what time, depending on water availability. Nonetheless, climate change has a significant impact on rangelands. Ultimately, this negatively affects the quality and quantity of the feeds. As global temperatures rise, pastures become drier and warmer, making it more difficult for plants to grow and thrive. This can make it more difficult for pastures to adapt to changing environmental conditions, further exacerbating the impact of climate change.

(d)The Development of Fodder Flow Plans and Gaps to Build Resilience Against Drought

The study was about the development of fodder flow plans and how to build resilience against drought. Grazing is an essential practice for smallholder livestock farmers, as it provides the forage needed to raise healthy, productive livestock. Cleared woody vegetation material is often not used, despite a shortage of feed for livestock by smallholder farmers, particularly during times of feed scarcity. Smallholder and resource-poor livestock producers occasionally use protein-rich supplementary feeds and concentrates during these dry periods to supplement the poor veld conditions; these sources are often expensive and inaccessible to financially constrained farmers. There is, therefore, a pressing need to create greater value from the harvested bush, i.e., strategic supplementation or use of encroaching woody species in livestock diet formulation, which has the potential to control increasing woody plant encroachment and improve livestock production. Edible *V. nilotica* shoots in this study were found to contain insufficient crude protein content for maintaining livestock conditions during the dry season.

However, adding seed pods to the shoots significantly increased the nutritional quality. The results of this study indicate that V. nilotica can be effectively preserved as silage during the wet season for use in feeding livestock during the dry season. It is concluded that *V. nilotica* can be preserved as silage with or without the inclusion of seed pods and molasses. In the second part of the study, to address feed gaps, alternative forages that require less water must be established at a lower cost. Perennial, warm-season/tropical C4 grasses such as Chloris gayana, Digitaria eriantha, and *Panicum maximum*, and 4 Grazer are alternatives for enhancing the sustainability of fodder. Estimation of aboveground biomass provides information on the primary plant productivity, contribution to fodder banks, as well as making decisions such as setting stocking rates.

Panicum maximum was the leading producer among the four perennial tropical C4 grasses that were studied. 4 Grazer as a grass mixture comprising *Brachiaria brizantha, Chloris gayana, Panicum maximum,* and Mombasa has shown a significant biomass production. As a result, *Panicum maximum* and 4 Grazers showed a high potential for contributing more than 8000 kg/ha of biomass to the fodder bank in their first year of growth.

(e) Context-Specific Decision-Making Tool to Assist Farmers in Adjusting Stocking Rates with Weather Information

This study focused on farmer coping strategies and developed a context-specific decision-making tool to help farmers adjust their stocking rates based on weather information. It utilized tangible, research-based data to illustrate the effects of climate variability and extremes on livestock. The study also aimed to assess farmers' awareness and knowledge, which could guide them in making appropriate interventions in response to the impacts of climate change (CC).

Nearly all farmers surveyed (96%) reported having heard about climate change, with only a small percentage (4%) unaware of it. The primary medium for disseminating information about climate change was radio, reaching 94.32% of the farmers. Newspapers and television were also noteworthy sources, with 16.76% and 32.67% reach, respectively. Concerning the effects of climate change on livestock production, 77.87% of farmers noted a decrease in both the quantity and frequency of rainfall.

Similarly, 80.87% of the farmers outlined that the most imperative predicament correlated to CC was the drought. Central to the impact of the drought was that 90% of the farmers confirmed a change in grass availability. They said the lack of natural pastures contributed to major livestock fatalities, of which over half of the farmers (55.19%) attested as the cause. It was also found that 86.67% of the farmers who attended awareness meetings indicated that the

discussions prioritized the importance of adapting to CC. However, the farmers (80.77%) did not have an early warning system. This was coupled with a lack of contingency plans by 84.36% of the farmers to deal with the impact of the said drought on their farms.

Among farmers (19%) who had facilitated contingency plans, the plan should include the provision of feed, the drilling of boreholes, and the erection of dams. These could be the packages that can be facilitated for the destocking program. For farmers to cope with and adapt to climate change, there is a great need for an early warning system.

Different institutions in the country, including the South African Weather Services, the Agricultural Research Council, and the Limpopo Provincial Department of Agriculture, issue and circulate seasonal forecast information to farmers. Most of the time, the information has been disseminated to end-users in simple ways, but finding out more about end-users' needs is still required. However, early warning and disaster-related matters have not been fully assimilated into the provincial organograms of the Department of Agriculture. Agricultural advisors also need to be trained on Early Warning systems, while being assigned functions of disaster management individually and collectively. The coping strategies that farmers use during drought and climate extremes are central to the context-specific decision-making tool to assist farmers in adjusting stocking rates with weather information.

The majority of these small–scale farmers are vulnerable to all types of climate risk. This is due to their low adaptive capacity, lack of access to technology as a result of their level of education, lack of financial resources and also, among other things, low level of resilience and high level of poverty amongst them. However, the majority small-scale farmers use different adaptive strategies as a way of preserving assets for future livelihoods, including (a) drought-resistant varieties, (b) crop diversification, (c) planting crops that require less water, (d) some of these small-scale farmers use local climate indicators to monitor climate risk, (e) adjusting fertilizer input, (f) using rainwater harvesting

techniques. There is also a need for strategic shifts from natural pastures to small-scale feedlots. The shift should be coupled with the need to establish a dedicated fodder bank as a specialized business.

The context for the decision-making tool that assists farmers in adjusting stocking rates based on weather information is that they may not wish to sell their livestock for various reasons. There is a dearth of information on the practice of destocking in South Africa.

(f) Adoption of Community Grazing Associations and Fodder Banks Innovation

The section presents a progress report on the adoption of Community Grazing Associations and Fodder Bank Innovation. The narrative was about the institutional arrangement regarding the expected development of the Grazing/Livestock Association, the adoption of Fodder Bank Innovation, and the establishment of fodder banks. Good practices that encourage farmers to be organised and self-sustainable are central to the ability of farmers to adopt fodder banks. However, the reason for livestock farmers' poor adoption of fodder banks worldwide is not fully understood. Nevertheless, why livestock farmers did not adopt new technologies is complex and requires a comprehensive understanding. Literature has demonstrated that the failures of early community grazing schemes were due to a prescriptive, top-down approach that is often derived from the commercial livestock sector, emphasising fencing, rotational grazing and stock control. Also, communities often do not consider rangeland degradation a priority.

It is associated with rainfall patterns rather than with stocking numbers, and with where and when it occurs. The failure to provide benefits to communities and community conflicts were impediments to the success of the grazing schemes. Extension and donor support have disguised the true costs of the schemes. 'New' communities were reluctant to invest after withdrawing financial support. Lastly, there is reluctance to adopt new management strategies because livestock mobility has been restricted. Fenced grazing

schemes will likely succeed only when communities initiate them and articulate their management plans (with advice from extension workers). The report explains the best practices implemented in the Mmakgatle and Mbahela Livestock Farmers Associations.

(g) Taking to Scale the Production, Harvesting, and Preservation of Fodder for Drought Mitigation

The report presented a strategy for scaling up the production, harvesting, and preservation of fodder for drought mitigation, preparedness and response, and rural pastoral area rehabilitation. The narrative was premised on the drivers of the changes currently facing smallholder farmers. Central to these in Limpopo was the loss of grazing land. Also, there was a lack of organizational structure to harness social innovation. Good practices that encourage farmers to be organized and self-sustainable are key to the ability of farmers to adopt fodder banks. Critical to the smallholder farmers at the centre of community grazing was their demography in relation to their vulnerability. The scenario was focused on the possibility of zero grazing, which was increasing with the loss of land through crop production and, in some instances, desertification. Farmers identified four significant crops in the irrigation schemes that could be used as crop residues for livestock feeding: sweet potato, dry beans, peanuts, and maize. Desktop studies of the chemical composition of each crop residue were well-documented based on research by scholars. The chosen crop residues have sufficient protein content to supplement the grass or any roughage on which ruminant livestock feed.

(h) The Enabling Policy Environment

The section presents a progress report on the policy environment conducive to establishing climate-smart fodder banks in selected rural communities to relieve pressure on vulnerable, yet valuable communal rangeland resources, thereby enhancing the resilience of communal livestock farmers to drought. Current government policies were analysed to identify aspects that positively

or negatively affect drought management in agriculture, crop, and livestock production. Special interest was placed on policies that specifically address drought management and support for livestock production. Seven significant policies were analyzed, including an assessment of each policy's objectives and the aspects that address livestock and drought.

A desktop benchmarking of drought-related policies was conducted for the SADC region. All these plans shared the same structure, titled National Drought Plans, supported by the United Nations Convention to Combat Desertification. The country's plans were intended to protect land, water, and other environmental resources from overuse and drought, ensuring the provision of required ecosystem services and mitigating the risk of compromising food security. The plans include an overview of drought characteristics, monitoring and forecasting, impact and vulnerability assessments, communication and response coordination and action, drought mitigation and preparedness strategies, organizational responsibilities and recommendations. The plans identify the drought impacts on the agricultural, rangeland, and environmental sectors. The rationale of such plans will be motivated by the fact that most droughts are particularly evident in the farming sector and for vulnerable communities in the country. Food insecurity and the livelihood of farmers are the most significant associated impacts of drought, as the level of food is usually reduced during drought disasters, increasing people's vulnerability. The paper also learns from the SADC's experiences in running grazing schemes. Lessons learned will assist in crafting a dedicated Drought Management Policy for Livestock Crops in rural areas. Based on desktop analysis, this report articulates that there may be a need for a National Drought Plan focused on an agricultural mix of crop, pasture and livestock. Aspects of the policy are described in policy recommendations.

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ABBREVIATIONS AND ACRONYMS

AA	-	Acetic acid
ADF	-	Acid detergent fiber
AEZs	-	Agro-ecological zones
AIC	-	African Initiated churches
AMA	-	Agricultural Management Association
AMSL	-	Above mean sea level
ANOVA	-	Analysis of Variance
AOAC	-	Association of Official Analytical Chemists
APRU	-	Animal Production Resource Unit
ARC	-	Agricultural Research Council
ARC-ISCW	-	Agricultural Research Council–Institute for Soil, Climate and Water
ARDC	-	Agricultural & Rural Development Cooperation
BA	-	Butyric acid
Ca	-	Calcium
CAHW	-	Community-based animal health workers
CBNRM	-	Community-based natural resource management
CBO	-	Community-based organisation
CC	-	Climate change
CFB	-	Community Fodder Bank
CMIP5	-	Coupled Model Intercomparison Project 5
CP	-	Crude Protein
Cu	-	Copper
DAFF	-	Department of Agriculture, Forestry and Fisheries
DALRRD	-	Department of Agriculture, Land Affairs and Rural Development
DM	-	Dry matter
DDM	-	Digestible dry matter
DEA	-	Department of Environmental Affairs
DFE	-	Digestible forage energy
DLUSM	-	Land Use and Soil Management
DM	-	Dry matter
DDM	-	Digestible dry matter
DOM	-	Digestible organic matter
EWSETA	-	Energy & Water Sector Education Training Authority

FAO	-	Food and Agricultural Organization of the United Nations
Fe	-	Iron
FID	-	Flame Ionization Detector
Fm	-	Frequency modulation
Freq.	-	Frequency
GA	-	Gibberellic Acid
GDP	-	Gross domestic product
GIS	-	Geographic Information System
GLM	-	Grazing Land Management
ha	-	hectare
HD	-	Harvest day
ICP-OES	-	Inductively Coupled Plasma Optical Emission Spectrometer
ICRAF	-	World Agroforestry
ILO	-	International Labor Organization
ILRI	-	International Livestock Research Institute
IPCC	-	Intergovernmental Panel on Climate Change
ISMEA	-	Institute of Mathematics and Economic Sciences Applied
K	-	Potassium
kg	-	Kilogram
km	-	Kilometre
KTDA	-	Kenya Tea Development Agency
LA	-	Lactic Acid
LEDA	-	Limpopo Economic Development Agency
LGP	-	Length of growing period
LADC	-	Limpopo Agricultural Development Corporation
LDARD	-	Limpopo Department of Agriculture and Rural Development
LIMDEV	-	Limpopo Development Agency
MAT	-	Mean annual temperature
ME	-	Metabolizable energy
Mg	-	Magnesium
MJ	-	MegaJoule
Mn	-	Manganese
mm	-	Millimetres
mmpa	-	Millimetres per annum
N	-	Nitrogen

Na	-	Sodium
NAC	-	National Agro-meteorology Committee
NDF	-	Neutral detergent fiber
NDVI	-	Normalized Difference Vegetation Index
NDWI	-	Normalized Difference Water Index
NEG	-	Net energy for gain/growth
NEL	-	Net energy for lactation
NEM	-	Net energy for maintenance
NEPAD	-	New Partnership for Africa's Development
NGO	-	Non-governmental Organization
NH3-N	-	Ammonia nitrogen
NOLIDEP	-	Northern Regions Livestock Development Project
NPV	-	Net present values
P	-	Phosphorus
PA	-	Propionic acid
PDA	-	Provincial Department of Agriculture
PG	-	Postgraduate
PS	-	Pasture species
PTO	-	Permission to Occupy
RCP	-	Representative Concentration Pathway
RMA	-	Range Management Areas
SAARC	-	South Asian Association for Regional Cooperation
SADC	-	South African Development Community
SAFTA	-	South Asian Free Trade Agreement
SAPTA	-	South Asian Preferred Trading Agreement
SAWS	-	South African Weather Service
SDG	-	Sustainable Development Goals
SHLF	-	Smallholder Livestock Farmers
SLA	-	Sustainable Livelihood Approach
SPI	-	Surface Precipitation Index
SSA	-	Sub-Saharan Africa
StatsSA	-	Statistics South Africa
SWOT	-	Strengths, Weaknesses, Opportunities and Threats
Tmax	-	Maximum temperature
TDN	-	Total digestible nutrients

TGLP	-	Tribal Grazing Land Policy
TIL	-	Trade Investment Limpopo
TSFS	-	Three Strata Forage System
TTC	-	Tshivhase Tribal Council
UFS	-	University of the Free State
VADP	-	Village Area Development Program
WRC	-	Water Research Council
WSC	-	Water-soluble carbohydrates
Y&M	-	Yeast and molds
Zn	-	Zinc

CHAPTER 1 - INTRODUCTION

This study was a follow-up to the completed study on "Vulnerability Assessment and Adaptive Response for Smallholder/Small-scale Livestock Sector to the Changing Climate" (WRC report no. 2766/1/24). The geophysical profile of the country, and especially Limpopo and Mpumalanga, is that 85% of the land falls under semi-arid environments, of which 82% is used for agriculture. Only 14% of the available agricultural land receives sufficient rainfall for arable crop production. The remainder of the agricultural land is used for extensive livestock production, forestry, and wildlife/nature conservation (Jordaan et al. 2013).

Under these semi-arid and arid conditions, the most extensive agricultural activities are livestock farming (sheep, goats, cattle, and ostriches) on rangelands, where livestock use the natural veld. However, along with low annual precipitation, these semi-arid and arid rangelands are, in many instances, also subjected to recurrent droughts, cyclic long-term droughts, extreme temperatures, marginal edaphic conditions and encroaching woody species (Jordaan et al. 2013).

The impacts of drought continue to be devastating for vulnerable rural communities, particularly those that are heavily reliant on livestock for their livelihoods. Some of the worst droughts in the country occurred between 2012 and 2018, with the 2015/16 drought regarded as the worst since 1992. Livestock production is primarily conducted under extensive rangeland conditions, where livestock rely on natural vegetation to meet their daily dietary requirements (Jordaan et al., 2013). Rangelands are complex systems characterised by linkages and feedbacks between ecological and social processes across a range of temporal and spatial scales (Vetter, 2009). Rangeland in good condition provides a more stable basal cover and better soil moisture retention, thereby mitigating the risks associated with drought, particularly with respect to the intensity and frequency of seasonal droughts.

However, the productivity of rangelands in many parts of South Africa continues to decline due to overgrazing and overstocking, as well as the interaction of climatic and soil conditions. The impacts of drought on rural livestock production systems are further exacerbated by poor rangeland conditions, which limit the capacity to support livestock production and store water in the soil. Location-specific climate data are vital for the sustainable management of rangelands, particularly for grass biomass production (Rust and Rust, 2013). Compounding the challenge is woody plant encroachment (also called bush or shrub encroachment), the replacement of grasses by trees or shrubs. Tree and shrub densities have increased in many areas of southern Africa by 30–50% (Ward 2005; Kraaij and Ward 2006; Tjelele et al. 2015a).

Furthermore, indigenous woody plants and alien invasive plants cost billions of rand in annual damage to South Africa's economy and likely other developing countries through their negative impacts on water resources, grass production and biodiversity. This, in turn, forces farmers to constantly put pressure on the already degraded rangeland resources, resulting in them (especially the emerging small-scale and communal farmers) often experiencing low livestock productivity due to their over-dependence on poor quality and inadequate feed supply from these natural pastures (Samuels et al. 2016, Müller et al. 2019). These challenges exacerbate land degradation and deepen the poverty of farmers and communities who rely on farming for income.

Although numerous studies have examined woody plant encroachment (Brits et al. 2002; Smit 2004), they have not yielded a comprehensive understanding of the problem or an integrated approach to managing increasing woody plant dominance (Ward 2005; Wiegand et al. 2005, 2006). The cost to clear the bush exceeds the immediate benefits of increased agricultural productivity (Sweet and Burke 2006). Cleared woody vegetation is often not used, despite smallholder farmers' livestock feed shortages, particularly during periods of feed scarcity.

Smallholder and resource-poor livestock producers occasionally use protein-rich supplementary feeds and concentrates during these dry periods to mitigate the adverse effects of poor veld conditions. These are often expensive and inaccessible to financially-constrained farmers.

There is, therefore, a pressing need to create greater value from the harvested bush, i.e., the strategic supplementation or use of encroaching woody species in livestock diet formulation, which has the potential to control increasing woody plant encroachment and improve livestock production. On the other hand, the Department of Agriculture, Land Affairs and Rural Development (DALRRD) has long recognized the need to promote sustainable rangeland management as an important component of drought management strategies for the livestock sector, dating back to 1922/23 (Drought Investigation Commission Report). This is now supported by a body of knowledge; for example, some of the recent documents include the draft National Drought Management Plan (2005), draft Climate Change Sector Plan for Agriculture, Forestry and Fisheries (Notice 38851 of 2015, Government Gazette), and draft Climate-Smart Strategic Framework (Notice 41811 of 2018). In an effort to assist farmers in managing the effects of drought, the DALRRD disseminates drought-coping strategies quarterly through the National Agro-meteorology Committee (NAC) Advisory Bulletin to provide early warning information and strategies for drought preparedness, coping and recovery, in line with climate and weather conditions.

The NAC advisory report provides information on interventions undertaken by the DALRRD through the Drought Relief Scheme, in accordance with the Disaster Management Act (Act 57 of 2002). The implementation framework for the Drought Relief Scheme states that relief assistance should be granted only to farms that adhere to the correct stocking rate and show no signs of overgrazing, as guided by the National Grazing Capacity Norms (Conservation of Agricultural Resources Management Act 43 of 1983).

However, most drought-preparedness and coping strategies do not distinguish among different rangeland users. The strategies are largely applicable to commercial, individually-owned farms (large-scale commercial farmers) and are not well aligned with the realities of communally managed rangelands (small-scale and emerging farmers), who face complex governance issues related to land and water security, i.e., the "tragedy of the commons". The capacity of land users to cope with drought is influenced by the resilience of their agro-ecosystems, the

diversity of livelihood options, access to resources, and institutional support (Vetter, 2009).

Therefore, there is a need to develop drought-coping strategies applicable to communally managed rangelands to ensure that government drought relief efforts have a meaningful impact on rural livelihoods. Effective implementation of the drought relief scheme should aim to prevent livestock herds from starving due to a lack of grazing and water.

Farmers have expressed concerns over the turnaround time for the drought relief scheme implementation, as the relief efforts were provided long after the disaster had occurred (Ngaka, 2012). Rural livestock farmers require timelier and more appropriate drought-relief support to enable sound rangeland management. A study conducted in high-rainfall districts in the Eastern Cape found that climate is not necessarily linked to ecological vulnerability to drought; rather, poor planning and management of water supply, poor grazing practices and land management are the primary drivers of serious land degradation.

Consequently, drought relief efforts should adopt a long-term, proactive strategy that enables rural communities to practice sustainable rangeland management within the constraints imposed by a changing, variable climate. Rangelands in many communal areas of South Africa are severely degraded; thus, it is important to rehabilitate them to enhance soil water retention and establish climate-smart fodder banks using drought-tolerant pasture species.

It is important that farmers develop a culture of establishing fodder banks (within their own farms) that can be used strategically during periods of limited feed supply, to promote all-year-round fodder flow within the constraints imposed by climate (erratic rainfall) and sustainable utilization of natural resources (soil and veld). This will further help reduce farmers' dependence on government fodder-provision subsidies.

A fodder bank is an integral component of sound veld management practices, as its availability on a farm helps alleviate pressure on valuable, yet vulnerable, veld resources. It represents the only reliable counter to the disruption of the fodder flow

caused by drought and other calamities. The other added benefit of a fodder bank is that it reduces the use of concentrates, which are expensive.

This project aimed to co-develop community grazing associations and climate-smart fodder banks with selected rural communities to relieve pressure on vulnerable, yet valuable, communal rangeland resources, thereby enhancing the resilience of communal livestock farmers to drought.

CHAPTER 2 - REVIEW ON FODDER BANK PRACTICES AND TECHNOLOGIES FOR SMALLHOLDER LIVESTOCK FARMERS IN THE CONTEXT OF CLIMATE CHANGE

2.1 INTRODUCTION

Livestock production is the backbone of agricultural development in many developing countries of sub-Saharan Africa. It plays a significant role in creating income, especially for smallholder farmers from rural areas. Livestock production serves an essential role in the provision of nutrition, social and economic development for smallholder farmers globally (Dolberg, 2001). Livestock production contributes about 40% of the Gross Domestic Product (GDP) in Africa (Panel, 2020). In South Africa, the Eastern Cape Province produces about 3.1 million beef cattle, which is almost a quarter of total cattle production in South Africa (NDA, 2009). The annual meat and milk consumption in sub-Saharan Africa is projected to rise to 26 kg and 64 L, respectively by the year 2050 (Kampala, 2009). The increase in human population has increased the demand for animal-sourced foods; thus, there is more demand for feed and fodder provision for sustaining livestock production.

In southern Africa, livestock production is an integral part of smallholder farming systems. Cattle are the most dominant species supplying draft power, milk, meat and manure. They are also a main storage system for capital and buffering food shortages in years of poor crop harvest and meeting the social and religious obligations of farmers (Powell, Pearson and Hiernaux, 2004). Cattle production in the region is dependent on range grazing as its major source. However, due to seasonal fluctuations in feed quality and quantity, cattle are prone to weight changes in winter, with rapid gains in early summer. Maintenance of weight in late summer and losses in the winter season impact livestock productivity (Otsyina *et al.*, 2004). Some deaths can occur during severely dry seasons. Additionally, due to rapid population growth, the availability of land for cattle grazing has decreased as cropping extends to areas used for grazing purposes (Powell, Pearson and Hiernaux, 2004). Therefore, under smallholder production systems, grazing cattle require protein supplements, particularly in the dry seasons.

The protein gap is especially acute in the rapidly growing smallholder dairy sector, where farmers can easily increase the cash profits for milk sales by investing in protein supplements. However, the bought–in supplements are expensive and smallholder farmers are seeking affordable alternatives. In the last two decades, the International Livestock Research Institute (ILRI) and World Agroforestry (ICRAF), working in southern Africa in partnership with national stakeholders, have been implementing integrated research programs for development, which address low livestock production due to fodder shortages. The details of these technologies are detailed by Nyadzi *et al.* (2003) and Dzowela *et al.* (1997). One of these technologies is called the fodder bank.

Fodder banks offer a feed management option, particularly useful during periods of drought. The fodder bank is a small area enclosed by a fence and planted with herbaceous legumes and tree legumes as fodder species. A farmer uses the fodder bank as a pantry, drawing on its fresh food as green biomass at the time when it is not available to animals. This review synthesizes the progress that has been made on fodder bank innovations. It will emphasize the use of fodder trees and shrubs, here referred to as forage species, as protein supplements for livestock production in southern Africa. Case studies are taken from work contracted from ICRAF, Tanzania, Malawi and Zimbabwe, drawing lessons and approaches in scaling up the adoption of the fodder technology by smallholder farmers.

2.2 COMMUNITY FODDER BANK

Venugopolon *et al. (*2016) articulated the need for the establishment of community banks for communities. The main aim is to bridge the gap between fodder availability and demand, especially in rainfed areas. A village-level community fodder bank is one workable option available to meet the fodder demands in periods of scarcity, using wastelands and other available uncultivated lands.

A community fodder bank is simply a group of farmers coming together to raise multiple fodder crops consisting of trees, grasses and legumes, largely in non-arable land or wastelands, to meet the fodder requirement—especially during lean periods. The idea of fodder banks emerged with the aim of replenishing arable lands that have lost their fertility due to continuous intercropping. Thus, a fallow land is

sown to leguminous perennial forages or self-seeding perennials to rebuild the nitrogen content of the soil through biological nitrogen fixation, and at the same time, for the production of high-quality fodder (Venugopolon *et al* 2016).

The system is like a forage/crop rotation except that the forage phase may last for three or more years until the desired fertility level of the soil is reached. Planting of high-biomass-yielding and fast-growing grasses and shrubs suitable for fodder in these areas not only increases fodder availability but also reduces soil erosion. These fodder banks also help in the preservation and storage of surplus fodder, availability of nutritious fodder during the period of fodder scarcity and enhance the nutritive value of crop residue and other cellulosic waste for animal feeding by conventional and nonconventional fodder (Venugopolon *et al* 2016).

2.2.1 Site selection

The site under which fodder banks are set up should include, but not be limited to, all available open lands around a farmer's homestead, including land bordering crop fields, sloped or stony pieces of land and bottomlands that are not suited for normal crop production. These can include wasteland and grazing lands; uncultivated lands could also be a better choice for a community fodder bank (CFB) establishment. On such lands, intensive fodder crops are grown as a dry-season feed reserve, green or conserved feed banking (Venugopolon *et al* 2016).

2.2.2 Planting material

Identification of fodder crop species suitable for soil and moisture availability is crucial. Emphasis has been on irrigated areas with less focus on rainfed situations. The possibility of some of the irrigated fodder species performing better under rainfed conditions cannot be ignored. Hence, a mixture of tree, grass and legume fodder species of both annual and perennial nature, suitable for rainfed conditions, is highly preferable to meet the nutritional demand of livestock and ensure the supply of fodder throughout the year. Fodder crops with the following characteristics are ideal for this purpose: ease of establishment; quick growing; out-compete weeds; produce high-quality fodder; remain productive under repeated harvesting;

withstand dry season with limited water sources; survive on poor soils (Venugopolon *et al* 2016).

Quality of the planting material is crucial. Seeds like fodder sorghum (Sorghum bicolor), hedge lucerne (Desmanthus virgatus), guinea grass (Panicum Maximum), Stylo (Stylosanthes scabra), deenath grass (Pennisetum pedicellatum), buffel grass (Cenchrus ciliaris) and some varieties of fodder maize (Zea mays) have problems with availability; hence, the seeds should be treated for increasing the germination percentage. Sowing depth, as a thumb rule, is 1–2 times the seed width and most adopted planting methods can be followed (see Table 1 and Table 2).

Table 1: Fodder bank species and their ecological zones

Arid & semi-arid tropics	Humid tropics	Highland tropics	Arid & semi-arid temperate
Albizia lebbeck	*Acacia angustissima*	*Calliandra calothyrsus*	*Chamaecytisus palmensis*
Cajanus cajan	*Albizia lebbeck*	*Calliandra tetragona*	
Sesbania sesban	*Cajanus cajan*	*Erythrina arborescens*	
	Calliandra calothyrsus	*Erythrina burana*	
	Calliandra tetragona	*Erythrina edulis*	
	Desmodium spp.	*Sesbania sesban*	
	Erythrina berteroana	*Leucaena diversifolia*	
	Erythrina poeppigiana		

Arid & semi-arid tropics	Humid tropics	Highland tropics	Arid & semi-arid temperate
	Flemingia macrophylla		
	Gliricidia sepium		
	Leucaena leucocephala		
	Leuceana diversifolia		
	Sesbania grandiflora		
	Sesbania sesban		

Table 2: Seed dormancy treatment methods

Method	Description
Mechanical scarification	Pounding seeds in a large-sized mortar with a pestle. However, scarification injures the seeds and induces susceptibility to pathogenic organisms; hence, recommended at the time of sowing or a few days before sowing.
Acid scarification	Concentrated sulphuric acid (95%) is added at twice the volume of seeds. The duration of the seed treatment varies from six minutes to six hours or more, depending on the thickness or hardness of the seed coat. Further, seeds are mixed with a large volume

Method	Description
	of water with a small amount of sodium bicarbonate (baking soda) to neutralise any adhering acid. The extra acid can also be removed by washing the seeds in running water for 10–20 minutes. The acid-treated seeds can be sown at once or dried and stored for subsequent use.
Hot water treatments	Seeds are dropped in water of 75° to 95°C. The ratio of water: seeds must be 4:1 or 5:1. The seeds are soaked in the gradually cooling water for 12 to 24 hours. The seeds must be sown within a few days after hot water treatment.
Leaching	Place seeds in running water or by placing them in frequent changes of water. The length of leaching time is 12 to 24 hours.
Hormonal treatment	Seeds are treated with gibberellic acid (GA), cytokinins and ethylene at recommended concentrations, which depend on the hardness of the seed coat.

2.2.3 Establishment and management of fodder trees

The major determinant of the choice of planting materials in any environment is tree type. High survival rate, ease of propagation, tolerance to frost and drought, pests, and diseases, tolerance to periodic pruning, high leaf yield and good nutritional value are emphasized in this type. Seed production is important; therefore, prolific seeders should be avoided, as such fodder species can become invasive weeds. Normally, raising seedlings in a nursery is recommended; the seeds must be soaked

in water and scarified to assist good germination. The fodder bank must be kept weed-free for up to six months to avoid competition for light, moisture and soil nutrients. Thereafter, trees are generally able to smother any growing weeds. Fodder production is improved by using double rows of fodder trees at a wider spacing of 50 cm apart, with 1.5 in between the double rows (Patterson et al., 1998). Once a fodder bank is established, grass may be allowed to grow in the area between the double rows and be managed for fodder provision. In most cases, the first harvest should be delayed until trees are nine to 21 months of age. However, most farmers growing fodder trees use them for cut-and-carry feeding. Key factors to consider include cutting height, cutting frequency and dry season management. This is influenced by temperature, soils, species and plant spacing. The recommended cutting height is between 10 and 150 cm (Hove, 2004).

The trees should not be defoliated completely. The cutting frequency of 6–12 weeks maximises fodder yield and quality. Repeated cuttings over a short period decrease the longevity of fodder banks.

2.2.4 Planting niches of fodder trees in smallholder farming systems

With the rapid increases in human and livestock populations, the landholding per farm in southern Africa is becoming smaller. Dzowela *et al.* (1997) estimated that land holding per family in southern Africa is less than 2–3 hectares. In such circumstances, farmers cannot afford to block out any area for fodder tree planting. Identified niches should ensure that trees are planted in areas like boundary demarcation and soil conservation structures to make the technology more attractive to farmers. The following niches are suggested for planting fodder trees:

- Scattered trees in the crop land
- Along boundary lines
- Along permanent contour bunds, which are a common feature of sloppy areas in many parts of southern Africa (Hove, 2004).
- Intercrop with grasses in the grazing areas.

Establishing fodder trees in these niches will minimise the conflict with the competition of land for crop production.

2.2.5 Spacing and design

To maximize dry season production, fodder banks should be dense, nearly pure stands. Recommended spacings vary from 5 x 5 cm to 1 x 1 m. Choice of spacing depends on management goals. Total biomass yields per area increase at higher densities. Wider spacing is generally used when both fodder and small-diameter wood, for fuel or poles, are desired.

Closer spacing maximises fodder production, but may make access for harvest or grazing difficult. Spacing of 1 x 1 m is common for many species. *Closer spacing encourages maximum fodder production.* Fodder production and accessibility can be improved by using double rows of fodder trees at wider spacing. Rows are set up about 50 cm apart with 1–1.5 m between double rows. The row spacing of trees varies from 5 to 50 cm. Ideally, rows are oriented along the contours in an east-west direction. This orientation provides the best fodder bank sun exposure and erosion control. Of course, this is not always possible.

Row establishment should conform to site geography. When the slope is steep, it is best to set up rows along the contours. Control of soil erosion improves with closer in-row spacing. Once the fodder bank is well established, grass should be allowed to grow between the double rows. Competition between bank trees and grass will not be as severe as during the establishment period. Tree roots will feed from deep in the soil, whereas grass will feed from near the surface. Their difference in height will also decrease competition for sunlight. This two-tiered system produces more fodder per area than either plant type alone. The grass grown in the inter-row area should be an excellent fodder species. Competition between trees and grass should be checked constantly so that fodder bank productivity does not decrease. The natural establishment of poor-quality fodder grasses should be tightly controlled.

Researchers in Bali, Indonesia, have designed a Three Strata Forage System (TSFS) which has full-sized trees, maintained as hedges and grasses. Respectively, the components produce fodder for the late dry season, the middle dry season and the

wet season. Tree spacing is five meters, hedge species spacing is 10 cm and grass is planted the entire length and width of the area. The TSFS is planted in five-metre-wide strips around crop land (Nitis et al. 1987).

2.3 AFTERCARE

2.3.1 Weed management

Though most fodder species are fast-growing, their initial growth is often slow. In general, perennial fodders take about six months to set up. During this time, weeds often compete with fodder seedlings for light, moisture and soil nutrients. Hence, proper care should be taken to keep the fodder bank weed-free. Weeds should be controlled from the very beginning through the use of pre-emergence herbicides, clean and pure seeds and inter-cultivation practices. Weed threats reduce with the establishment of perennial fodder components (Venugopolon *et al* 2016).

2.3.2 Fertilization

Fodder banks are long-term crops that must be properly maintained to continue high productivity. If the soil is depleted of nutrients due to erosion or degradation, basal application of macro nutrients is essential, especially nitrogen, phosphorous and potassium. Application of macro- and micronutrients should be site-specific, based on soil test. The nitrogen requirement may be self-provided if the species used is nitrogen-fixing. If available, it could be a better choice. Fertilizer application as top dressing is also preferable for the robust growth of the crops. Even under direct grazing, fodder banks remove substantial amounts of soil nutrients from the site. These nutrients must be replenished by the application of manure or chemical fertilizers. However, little is known of the nutrient requirements of most fodder bank species (Venugopolon *et al* 2016).

Under rural small-scale systems, the use of fertilizers to improve fodder bank establishment is not generally recommended. Fertilizers are expensive, and if available, may be better used for food crop production. Fertilizer requirements of many fodder bank species are not well documented.

2.3.3 Irrigation

Most of the fodder crops require enough soil moisture to set up. There are a few annuals and perennials that are suitable for rainfed conditions. Annual fodder crops like cowpea, guar, bajra, and perennial crops like stylo, blue buffel and hedge lucerne can come up very well in rainfed situations, provided the sowing is taken up well in time, coinciding with sufficient rains. But with unpredictable onset and distribution of rainfall, the initial establishment of fodder crops could be an issue. Research experience has shown that rainfed systems in fodder crops are cost effective, with higher water productivity. Emphasis should then be focused on selecting fodder grass and legumes that are drought-tolerant and suitable for rainfed systems (Venugopolon *et al* 2016).

2.3.4 Harvesting

The first harvest would depend upon the species that is planted. In the case of perennials, it takes about 12 months for establishment. However, if it is an annual, it can be harvested within 3-4 months. Under poor soil conditions, growth will be slow, and the first harvest will be further delayed. The aim is to allow fodder bank species to set up deep roots and thick trunk diameters. This is an important consideration in arid and semi-arid environments (Venugopolon *et al* 2016).

2.3.5 Grazing

Fodder banks can be directly grazed by livestock. Fodder banks set up over a large area can be very well fragmented into paddocks and allowed for grazing. Livestock should be restricted to one paddock until the available fodder resource is fully utilized. Animals should then be moved to the next paddock. This system saves labor and effort, and should be made to prevent plant damage and fodder waste from trampling. If environmental and plant growth conditions are favorable, fodder banks may be grazed year-round. Grazing periods are generally 1–2 weeks, followed by recuperation periods of 3–6 weeks (or three times the grazing period). In rainfed arid and semi-arid situations with poor soil, it would generally take about four weeks. Goats and sheep often eat the bark of the tree; hence, proper care

and monitoring should be taken while allowing grazing inside the fodder bank (Venugopolon *et al* 2016).

To stimulate tree growth, fodder banks should be cut to a uniform height after the grazing period. Cutting height is discussed in more detail below. With most species, complete defoliation during the grazing period is permissible if cutting and grazing are excluded during recuperation. To ensure adequate recuperation, paddocks should be fenced or protected in a similar manner. After long recuperation periods, tree height may make fodder inaccessible to animals. This is often a problem when fodder banks are not grazed all year. Periodic cutting of sections of each paddock may be necessary to improve animal access. The cut fodder is left on the ground where livestock can reach it. The area cut should correspond to what will be eaten before the next cutting. Goats and sheep often eat the bark as well as the leaves of fodder trees. This can lead to tree mortality and decreased long-term fodder bank productivity. Unless closely checked, goats and sheep should not be allowed to graze fodder banks. Cattle generally do not cause this problem.

2.3.6 Cut and carry approach

The cut-and-carry approach method is highly advisable where the total area of the fodder bank is small. The animals may be a great distance from the fodder bank or just across a protective fence. A cut-and-carry system reduces fodder waste from animal damage and the necessity to check animals. However, when animals are kept a long distance from the fodder bank, this may not be achievable or viable. However, labor inputs may be greater than with direct grazing systems. Important management factors to consider in this system are cutting height, frequency and dry season management (Venugopolon *et al* 2016). Special harvesting equipment should be available for fodder banks, but all that is necessary is a sharp machete.

Important management factors to consider for a cut-and-carry system are cutting height, cutting frequency, and dry season management. These factors are all influenced by precipitation, temperature, soils, species, plant spacing, as well as each other. Interactions are unique for each situation, resulting in effective management prescriptions that differ at each site. However, general

recommendations are possible for each management factor. Farmers and managers should refine these recommendations to ascertain the best management prescription for their specific situation.

2.3.7 Cutting height

To obtain maximum fodder production, research studies have recommended an array of cutting heights. Review of these results suggests a standard cutting height of 50–150 cm, depending upon the species. Besides fodder production, this height provides other advantages, like keeping adequate foliage to ensure rapid regrowth and plant longevity. Fodder is harvested with a minimum of bending or reaching, allowing for efficient movement by the harvester. This species experiences a high degree of mortality when its main stem is cut. Side branches can be harvested, but the plant should not be completely defoliated or have its main stem pruned below 150 cm (Venugopolon *et al* 2016).

Cutting heights of 50–150 cm often maximise fodder production.

A notable exception to the standard recommendation is the management of *Sesbania grandiflora*. This species experiences a high degree of mortality when its main stem is cut. Side branches can be harvested, but they should not be completely defoliated or have their main stem pruned below 150 cm. After 2–3 years of production, it is recommended to cut *Leucaena* back to 25 cm. This lower height removes much of the dead wood and rejuvenates foliage production. This may be true for other species also. However, regular cutting below 50 cm may cause increased mortality and decreased long-term productivity.

2.3.8 Cutting frequency

With cutting height, research studies have recommended a vast range of cutting frequencies. The most common cutting frequencies are 6–18 weeks. Generally, longer cutting frequencies (12–18 weeks) generate more biomass, but increase the proportion of small wood production. Shorter cutting frequencies (6–12 weeks) favor fodder yields and quality. Younger foliage tends to have a higher nutritive value and palatability. However, repeated cutting after short frequencies decreases longevity.

Under arid, sub-humid, or temperate conditions, regrowth may take longer to reach this height, and cutting frequencies may need to be extended (Venugopolon *et al* 2016).

2.3.9 Dry-season management

Dry-season fodder production is a main goal of fodder bank management. In areas with severe dry seasons, special management practices should be followed. Prior to the start of the dry season, trees should be cut to the recommended height. The new foliage produced over the next few weeks will be retained well into the dry season when it is most needed.

When the dry season is very long, the area of the fodder bank is large, and the pre-dry-season harvest should occur in phases. This will ensure year-long availability of fodder. During the dry season, re-growth will be slow. Therefore, it is better to avoid direct grazing during this period. The cut-and-carry approach would be a better option (Venugopolon *et al* 2016).

2.3.10 Socio-economic issues

In characteristic villages, various socio-economic issues need to be addressed before designing and setting up a fodder bank. The interest and motivation of the farmers involve the very first step. Land availability, initial cost involved and benefit sharing are other issues that could affect the adoption. Once a group of farmers is motivated, it is necessary to have an organized system in place. There should be a selection of a few representatives from the lot who can manage the system well. A few farmer representatives could be involved in the process right from conceptualization to implementation. Transfer of knowledge and development of skill with respect to seed procurement, fodder cultivation, fodder quality, animal needs and dry season management are most important for the success of community fodder banks, which can be addressed through extension services.

Once in place, a village-based community fodder bank would be a viable option in meeting the fodder demand of the village. It can reduce or even totally prevent

buying of fodder from outside, enabling the village to become self-sufficient and thus improve the livelihood security.

2.4 ANIMAL FEED RESOURCES, NUTRITION AND PRODUCTION IN CONTEXT

2.4.1 Feed resources

Various types of feed are cut and carried to livestock, including fodder crops, weeds gathered from cropping areas, crop residues, and agro-industrial bi-products and purchased concentrates. The importance of the nutritive value of these feeds varies seasonally. In wet seasons, the bulk of the seeds consists of fodder crops and weeds, while in the dry season, these feeds are supplemented with crop residues.

Napier grass is the most important fodder crop used as feed by smallholder farmers. This grass is recommended for livestock feed in many developing countries of Africa. This grass may supply green forage throughout the entire year and can feasibly be grown by smallholder farmers, especially poor ones. Napier grass produces about 50 to 150 tons cut per year (Orodho, 2006). However, to improve the nutrition of dairy cattle, mixtures of grasses and herbaceous legumes may be incorporated into the feeding systems. One common recommended blend is Napier grass planted with silver leaf *Desmodium* (*Desmodium intortum*). The legumes generally have a higher nutritive value than grasses, being superior both in protein and mineral content. Such mixtures (grass and legumes) promote higher animal intake of energy and protein, resulting in increased weight gain and milk production. Legumes have been shown to enhance soil fertility due to their ability to improve nitrogen through biological nitrogen fixation.

Despite the clearly demonstrated advantages, herbaceous legumes have not been widely adopted. Farmers have often reported difficulties associated with the establishment and management of stands of grasses and legumes. Particularly when the grass used is a vigorous species, it outcompetes the legume. The other disadvantage of smallholder farmers adopting growing these trees is that they take longer to mature than annual fodder crops. These species take several years to grow, and farmers may not be willing to take longer periods in observation of their effectiveness in sustaining livestock production (Jera and Ajayi, 2008).

2.4.2 Positive aspects of fodder trees

In contrast with pasture grasses and herbaceous legumes, the systematic study of fodder trees and legumes have been developed recently. It is now widely accepted that wood legume species have many advantages for animal production, such as high feed quality in terms of protein and mineral, tolerance to a wide range of management practices, longevity and capacity to provide fodder when other species are dominant in the dry season (Dawson *et al.*, 2014).

Legume trees such as *Moringa Oleifera*, *Sesbania sesban* and *Leucaena leucocephala* have the potential to produce high biomass for livestock feeding and are recommended to be used as feed, particularly in the dry season when feed production is low (Mitiku and Amiha, 2018). Furthermore, *Moringa* spps produces high biomass and adapts well to the climatic conditions of the Limpopo Province. Smallholder farmers may grow this tree in high density as an alternative feed for livestock, especially in the dry season (Ayisi, Bopape-Mabapa and Brown, 2021). Due to climate change affecting livestock production, fodder trees may be used by farmers as a method to adapt to climate change impacts. There is a need to raise awareness of this technique among the majority of smallholder farmers of Limpopo Province to improve livestock production.

Tree and shrub forages have been used in livestock production mainly as protein supplements (Osuji and Odenyo, 1997). These forage legumes provide excellent quality fodder, especially for smallholder farmers with limited land and cash resources. The tree legumes, once established in the field, have deep roots that enable the plant to use moisture and nutrients that are beyond the reach of most herbaceous legumes. Tree legumes also reduce soil erosion, improve water conservation, suppress weed growth, replenish soil fertility and provide additional products, such as fuel wood and construction materials (Nair *et al.*, 1999). The nutritional characteristics of the principal tree forage legumes are given in Table 3.

Table 3: Nutritional characteristics (% of dry matter) of important fodder trees

Shrub forage	Total nitrogen (N)	ADF	NDF	Lignin	NDF-N	IVDOM	Comments
Acacia angustissima	3.1	36.7	50.8	14.3	2.1	34.8	Leaf and browseable twigs, < 10 mm diameter, sundried, Zimbabwe
Cajanus cajan	3.3	42.0	56.6	16.5	2.7	44.3	Leaf and browseable twigs, < 10 mm diameter, sundried
Calliandra calothyrsus	2.0	35.8	46.3	11.4	1.8	33.4	Leaf and browseable twigs, < 10 mm diameter, sundried
Flemingia macrophylla	2.4	44.0	59.4	19.3	1.9	25.4	Leaf and browseable twigs, < 10 mm diameter, sundried
Leucaena diversifolia	3.63	35.5	39.8	14.1	2.76	0.53	Leaves, shoots and petioles, Zimbabwe
Leucaena esculenta	3.9	30.7	43.7	13.5	3.53	51*	Leaves, shoots and petioles, Zimbabwe
Leucaena pallida	3.48	32.6	37.8	15.0	2.99	53*	Leaves, shoots and petioles, Zimbabwe
Acacia angustissima	3.75	15	34.1	7.2	1.34	51.9	Shade dried leaves, Zimbabwe
Calliandra calothyrsus	2.94	14.4	36.0	5.5	1.39	46.0	Shade dried leaves, Zimbabwe
Leucaena leucocephala	4.03	17.4	29.2	9.1	1.07	71.4	Shade dried leaves, Zimbabwe
Calliandra calothyrsus	4.51	22.0	45.5	-	-	41.6*	Dried shoot material cut after 12 weeks
Sesbania grandiflora	4.24	-	45.1	-	-	66.9**	Leaves, Thailand
Leucaena diversifolia	6.14	28.5-42.4	33.5-46.6	-	-	-	Young leaves
Morus alba	2.93	19.23	36.53	-	-	-	Young leaf; harvested in January, Zimbabwe, leaves and stems < 6 mm diameter
Albizia lebbeck	4.10	30.8	35.9	-	-	-	Leaves and stems, harvested in dry season, southwestern

							Nigeria, < 6 mm diameter
Gliricidia sepium	4.06	31.2	38.1	-	-	-	Leaves and stems, harvested in dry season, southwestern Nigeria, < 6 mm diameter
Leucaena leucocephala	4.16	29.3	41.7	-	-	-	Leaves and stems, harvested in dry season, southwestern Nigeria, < 6 mm diameter

Notes: ADF, Acid detergent fiber; NDF, Neutral detergent fiber; NDF-N, Neutral detergent fiber nitrogen; IVDOM, in vitro digestible organic matter; *Dry matter digestibility; **in vitro dry matter digestibility (source: (Chakeredza *et al.*, 2007).

The nitrogen content of these legumes averages around 3.7% and protein content around 23.2% (Chakeredza *et al.*, 2007). Poor quality roughages derived from food residues of sorghum, maize and pearl millet form a major source of feed for ruminant animals in southern Africa. These crop residues are bulky, high in fiber and low in nitrogen and minerals, which results in low intake and poor digestion in the rumen. Use of trees and shrubs as supplements to poor quality forages has increased nutrient intake, improved weight gain, boosted milk production and raised the survival rate of livestock in drought seasons.

2.4.3 Impacts of tree fodder as supplements on animal performance

Forage legume supplements increase total feed intake. Supplementation is recommended at levels less than 30–40% of the total diet. Above 40%, substitution of the basal diet takes place. Studies showed that forage crops such as cowpea have been grown in many countries of sub-Saharan Africa, particularly in western Africa, and have been used as livestock feed (Singh *et al.*, 2003). The demand for forage legumes for livestock feed will remain high in developing countries, due to low animal productivity. The other benefit of forage legume crops is that they contain a higher level of digestible energy compared to grasses, due to the structure and development of their cell wall (Singh *et al.*, 2018).

The protein content in forage legume crops remains beneficial to milk production in livestock, and this may be advantageous to farmers when livestock produce more milk, even in dry seasons.

Besides the nutrient content in forage legume crops, these crops are the main source of biological nitrogen fixation, reducing land degradation. They can be used by farmers to adapt to climate change through improving animal health and increasing the nutritive value of forage-based rations (Singh *et al.*, 2018). A study conducted in Limpopo province showed that legume crops such as cowpea, lablab, and *Mucuna pruriens* have been grown continuously by smallholder farmers for livestock feed. However, although these crops provide high nutrient quality, they require fertilization input to improve soil health, particularly in degraded land (Jani *et al.*, 2022).

2.4.4 Improved animal growth performance

Research work with goats conducted in Zimbabwe by Dzowela, Mafongoya and Hove (1994) and Dzowela *et al.* (1997) showed a substantial increase in total feed intake and improved weight gains using *Acacia angustissima*, *Leucaena* species, and *Calliandra calothyrsus*. Nherera, Ndlovu, and Dzowela (1998) evaluated *Leucaena* species on goats and maize stover as a basal diet in Zimbabwe. Total dry matter intake was significantly increased more than in goats fed a basal diet only. Weight gains were higher in goats supplemented with legume fodder species.

2.4.5 Improved milk production

Work conducted in Kenya, with *Leucaena leucocephala* and Napier grass as a basal diet, increased milk yield. The severity of weight loss was reduced (Muinga, Thorpe and Topps, 1993). The profitability of fodder banks used as cut and carry systems was studied in Tanzania, Kenya and Uganda. In Tanzania, Otsyina *et al.* (2004) showed that by using tree legume fodders to substitute dairy concentrates, farmers could save about R3 100 per cow per year. In Kenya, Franzel *et al.* (2003), found that *Calliandra calothyrsus* was used as a supplement, and the annual net return was increased by R1 420.

Lucerne tree is another alternative that farmers may grow to feed livestock to sustain productivity during dry seasons. The Lucerne tree is not native to South Africa but comes from New Zealand. However, it can be grown in arid and semi-arid regions due to its resistance to drought. This tree is deep-rooted, and it serves to reduce soil erosion, thus conserving soil fertility.

It is a tree rich in protein content, which can be used as a supplement with cereal crops to enhance the meat quality of livestock. The leaves of the lucerne tree contain about 16–22% crude protein (CP) (Rajan *et al.*, 2019). It can remain green all year round. It can be suggested that smallholder farmers, especially those who cannot afford the purchase of feed, grow this tree to improve livestock production. Lucerne tree can be used to feed animals within a period of nine months, if managed correctly; hence, supplying nutrients in the dry season of the year (Mekonnen *et al.*, 2019).

Lucerne tree is regarded as a fertilizer tree, being able to fix about 590 kg of nitrogen per year (Rajan *et al.*, 2019). However, in many developing countries, the adoption of growing lucerne trees by smallholder farmers is below average. The biggest challenge for smallholder farmers is a lack of knowledge, poor research approaches demonstrated to farmers and poor management practices of this tree by farmers (Mekonnen *et al.*, 2019). The majority of smallholder farmers in developing countries have no access to large land and this has impacted the adoption level of growing Lucerne tree (Sisay and Mekonnen, 2013).

To improve the adoption of growing lucerne trees by farmers, extension officers need to identify potential farmers who can grow the tree and demonstrate to them the proper management practices, while at the same time creating an opportunity for farmers to experience and adapt to change (Mekonnen *et al.*, 2019). There are limited studies conducted in Limpopo Province on growing lucerne trees as an alternative for livestock feed to enhance production. Therefore, there is a need to introduce farmers to this opportunity.

2.5 PRESERVATION OF FORAGES AND PRESERVATION TECHNIQUES

Three groups of forages lend themselves for purposes of preservation, which are herbaceous vegetation, natural pastures, crop residues and planted forages (Ajayi, 2011). Poor forage availability and quality during the dry season and winter months constrain livestock productivity in sub-Saharan Africa and beyond. To close the gap in fodder provisioning, haymaking and crop residue preservation could be the most practical solution for developing countries in Africa, coupled with improved preservation techniques.

Rural smallholder livestock systems use a variety of methods to conserve **crop residues**. Some of the methods include baling, stacking, or standing hay. One good practice that is done by herders in developing countries includes setting aside a **portion of grazing land** where grazing is excluded for certain periods for later use (Mwilawa et al., 2008). It has been observed that the practice of growing improved **forage species for hay** is also being adopted by peri-urban production systems. Various improved forage species and cultivars have been introduced to South Africa (Palmer & Ainslie, 2006; Mapiye et al., 2011; Muller, 2017). Table 4 of Scholtz et al. (2009) provides a list of forage species and the commonly practiced conservation methods in different regions of sub-Saharan Africa (SSA).

Table 4: Forage species and methods of conservation practises (From Balehegn et al., 2021)

Type of forage or forage component	Species	Type of preserved forage/ forage components	Challenges	Opportunities	References
Planted grasses	Nile grass (Acroceras macrum Stapf), weeping love grass [Eragrostis	Hay, straw and silage	Limited arable land, insufficient water for forage production, financial	Development of improved cultivars specific for the marginal agro-	Maphane & Mutshewa (1999), Van der Stoep & Tylcoat

Type of forage or forage component	Species	Type of preserved forage/ forage components	Challenges	Opportunities	References
	curvula (Schrad.) Nees], tef [Eragrostis tef (Zuccagni) Trotter], Rhodes grass (Chloris gayana Kunth), buffel grass (Cenchrus ciliaris L.), guinea grass [Panicum maximum (L.) Willd.], elephant grass		constraints, limited access to appropriate infrastructure, equipment, and high costs of forage seeds; use of forage species not adapted to the agro-ecological region	ecological conditions	(2014), Muller (2017), Trytsman et al. (2020)
Cereals/grains and their by-products	Red oat (Avena sativa L.), barley (Hordeum vulgare L. subsp. vulgare), bajra (Pennisetum typhoideum L.), pearl millet [Pennisetum	Hay, straw, stover silage, densified forage, sometimes with urea treatment	Ensiling stovers results in poor-quality forage, especially if commercial silage additives and proper ensiling	Increased resource access for cultivation by, for example, emerging farmers in South Africa; improvement of dual-purpose	Maphane & Mutshewa (1999)

Type of forage or forage component	Species	Type of preserved forage/ forage components	Challenges	Opportunities	References
	glaucum (L.) R.Br.], Sudan grass [Sorghum sudanense (Piper) Stapf], wheat (Triticum aestivum L.), maize (Zea mays L.)		facilities are not available; loss of nutrients through aerobic respiration and leaching; labor and resource-intensive processes. Food/grain is usually the priority, so forage from cereal grain crops are usually available only as low-quality straw	cultivars for both forage and grain. Increased availability of supportive technologies, such as choppers, densifiers, pelleting machines.	
Natural pasture grasses and legumes	Bermuda grass (Cynodon dactylon (L.) Pers.], star grass	Harvested hay, standing hay, silage.	Variable quality depending on botanical composition	Good adaptation to marginal agro-	Muller (2017), Trytsman

Type of forage or forage component	Species	Type of preserved forage/ forage components	Challenges	Opportunities	References
	(Cynodon nlemfuensis Vanderyst), giant star grass [Cynodon aethiopicus Clayton & Harland], Masai love grass (Eragrostis superba Peyr.), jaraguá [Hyparrhenia rufa (Nees) Stapf].		and soil fertility. Low nutritional quality.	ecological regions	et al. (2020)
Legume	Groundnut (Arachis hypogaea L.) haulm, cowpea [Vigna unguiculata (L.) Walp] haulm, Pigeon pea [Cajanus cajan (L.) Huth] residue, lab (Lablab	Conserved alone or in mixtures with grasses as hay or silage.	Significant leaf losses during sun-drying and storage; lack of knowledge to make legume silages; low input availability	High demand for legumes due to their relatively high concentration of CP and low concentration of anti-nutritional factors	Manyawu *et al.* (2016)

Type of forage or forage component	Species	Type of preserved forage/ forage components	Challenges	Opportunities	References
	purpureus (L.) Sweet), alfalfa (Medicago sativa L. subsp. sativa), siratro [Macroptilium atropurpureum (DC.) Urb.], garden pea (Pisum sativum L.), red clover (Trifolium pratense L.), cow pea (Vigna unguiculata (L.) Walp.] cheesytoes [Stylosanthes hamata (L.) Taub], and Townsville stylo (Stylosanthes				

2.5.1 Haymaking

Preservation of forages as baled, stacked loose or standing hay is widely practiced among smallholders and commercial farmers in many countries in Africa. With increasing climate variability, even pastoralists are now practicing storing grass in

the form of hay (FAO, 2013). Determinants of hay quality includes natives' variety with poor forage, late harvesting and improper storage (Kitaba & Tamir, 2007; Feyossa et al., 2013). Hay stored in open fields leads to up to 70% of CP due to leaching (Yayneshet et al., 2009). Common methods of haymaking were found to be loose hay (53%), box baling (47%) and machine baling (6%) (Lukuyu et al., 2013). A wide range of perennial grasses are stored as hay. These include red oat grass, buffel grass (*Cenchrus ciliaris L.*), common star grass (*Cynodon dactylon*), maasai love grass (*Eragrostis superba Peyr.*), guinea grass (*Panicum maximum Jacq.*), Urochloa, horse tail grass (*Chloris roxburghiana Schult*), and wild rye grass (*Enteropogon macrostachyus Munro ex Benth.*). Natural grass species are also left standing in the field and harvested, to be stored in tree branches and household granaries; this makes them subject to fast deterioration due to weather-related conditions (Koech et al., 2016).

Muller, (2017) reported hay moisture concentrations between 8 and 150 g kg^{-1} compared to results by Koech et al., (2016) that stated hay moisture concentration that varies between 52 and 185 g Kg^{-1}, depending on the date after baling and storage conditions. The nutritional quality of the hay differs significantly between different forage species and harvesting times (Muller, 2017).

Legume hay produced in South Africa is generally of higher quality in terms of CP concentration, which ranges between 130 and 210 g kg^{-1}, while that of grasses and cereal hay ranges between 40 and 100 g kg^{-1}(Muller, 2017). In the winter rainfall zone of South Africa, specifically the Western Cape province, hay is mainly made from oat, barley, triticale, and to a lesser extent serradella (*Ornithopus sativus Brot.*), vetch (*Vicia sativa L.*), and lupines (*Lupinus polyphyllus Lindl.*). In the summer rainfall areas, hay is made from alfalfa as well as various grass types such as African lovegrass [*Eragrostis curvula* (Schrad.) Nees] and teff [*Eragrostis tef (Zucc.)*], and in some cases sorghum (Dugmore, 1995). Alfalfa (*Medicago sativa L.*), however, remains the premier hay crop in South Africa, primarily due to its high quality, depending on the phenological stage at which the forage is harvested (Muller, 2017; Scholtz et al., 2009). Digitgrass (*Digitaria eriantha Steud.*) and kikuyu grass (*Pennisetum clandestinum Chiov.*) are the most used species of the summer growing/winter dormant grasses in southern Africa; guinea grass (*Panicum*

maximum Jacq.), Rhodes grass, and Nile grass (*Acroceras macrum Stapf*) are also regarded as good candidates under these conditions. Temperate grasses (i.e., spring, winter, and autumn growing species such as tall fescue [*Festuca arundinacea Schreb*.] and orchard grass [*Dactylis glomerata L*.]) are also good for standing hay for the winter rainfall regions in Saharan Africa (Hardy, 1995).

2.5.2 Preserving forage as straw and stover

Crop Livestock Systems are the most predominant in the south of Saharan Africa. The most important source of livestock feed in the said system is crop residues. The residues such as straw remaining after threshing of cereals is collected and dried for feeding livestock. The practice of harvesting maize, sorghum, millet stover and feeding to livestock is common in many rural systems. Crop residues or straws contribute to a significant amount of the feed for livestock; 95% in Ethiopia, constituted by teff, barley and wheat (FAO, 2018).

In South Africa, crops like wheat, barley, triticale, and oats are the most common sources of straw (Muller, 2017). Maize, sorghum and millet straws are obtained after the crop is harvested and the dried stalks and husks are collected and dried further. These forages are often harvested when they are fully matured, dried and senesced in the field and then stored in sheds or on rooftops for drying and feeding to livestock. This kind of storage system leads to mold infestation, leaf loss and leaching of nutrients (Antwi et al., 2010).

Legume crop residues lose leaf due to sun drying, transportation, and storage, which greatly reduces their nutritional value (Antwi et al., 2010). Such losses also vary with storage methods. Cow pea has been reported to lose DM losses (830 vs. 380 g kg^{-1}) when stored on rooftops instead of sheds (Antwi et al., 2010). In other parts of the world, straw generally is very low in quality, with CP concentration typically below 50 g kg^{-1}, DM digestibility mostly below 600 g kg^{-1}, high fiber concentrations due to the advanced maturity of the forage and low concentration of minerals and vitamins (Muller, 2017). There is a need to train farmers and smallholder agricultural entrepreneurs in handling, management and storage of crop residues. There is also a need to increase research and investment towards these areas (Baltenweck et al., 2020) or to improve the nutritive value.

2.5.3 Browse preservation

A comprehensive study was done by Tjelele (2007). The arid and semi-arid rangelands of South Africa are rich with browse, shrubs and leguminous browses that are used for livestock feeding. Several authors have reported on the use of harvested browse forage (leaves, twigs, and pods) for feeding livestock. Browse leaf meal is produced from harvested seed pods and leaves of trees that naturally occur within rangelands. These pods and leaves are air-dried (primarily in shade) and ground, or fed as is to livestock (Brown et al., 2018; Mapiye et al., 2009).

Foliage and seed pods from several browse plant species are good sources of protein with relatively high nutritive value, with a CP concentration ranging between 10 and 210 g kg^{-1} (Macala et al., 1995) and IVDMD values ranging between 400 and 800 g kg^{-1} (Balehegn et al., 2015). The practice in rural Africa is to collect pods of various Acacia species and long-thorn and store them for use during periods of food scarcity (Hintsa et al., 2015; Mahgoub et al., 2005; Sawal et al., 2004). The use of these browse plants as feed also plays a pivotal role in counteracting the problems of bush encroachment (Tjelele et al., 2014).

2.6 TECHNOLOGIES FOR IMPROVING PRESERVATION AND QUALITY OF FORAGES AND CROP RESIDUES

In this section, the focus is on the technologies that can be used to improve forage preservation. The technologies include improved forage varieties and storage techniques. All of these have been effective, even when evaluated on smallholder farms, implying that more investment and awareness of the importance of such technologies are needed. This information can help scientists and policymakers understand proven forage conservation and prioritise future research and investments. Also, it can help the agricultural industry to understand Indigenous, local resources that may be needed to close the nutritional gap to feed livestock.

2.6.1 Improving crop residue quality

The nutritional value of crop residues can be maintained or enhanced using various interventions, including (a) physical treatment of crop residues such as chopping,

pelleting, and densification, (b) chemical treatment with acids and alkalis, and (c) biological treatment with select micro-organisms or their products.

Reducing the particle size of crop residues and forages usually improves feed intake (Osafo et al., 1997), which often leads to improved livestock performance as compared to livestock fed with coarser crop residues (Fernandez et al., 2004). Forage processing to reduce size involves manual work in many parts of developing countries in Africa. There is a need to manufacture user-friendly fodder processors such as choppers, which are also adapted for women (Fischer et al., 2017, 2018).

Compression of crop residue can also improve its quality, which enhances the way they are handled, managed and stored, and facilitates mixing with other additives (Walli et al., 2012). Compressed or densified crop residues are molded into blocks and pellets augmented with important nutrients like minerals, protein and readily available carbohydrates. The equipment used to compress or densify crop residues is electric or gas-powered, which is most likely inaccessible to many smallholder farmers (Gonzalez-Valadez et al., 2008).

Chemical treatment of crop residues, such as urea treatment, is probably the most endorsed forage preservation. The methods also enhance the nutritive value due to their efficacy at increasing the nitrogen concentration and dry matter digestibility (Sarnklong et al., 2010; Schiere et al., 1993). The benefits of urea treatment to crop residues in livestock performance include an increase in feed intake, digestibility and body weight gain of ruminants (Gashu et al., 2014). The adoption of the use of chemical treatment of crop residues by smallholder farmers is constrained by resource, knowledge and skill limitations (Balehegn et al., 2020), as well as unavailability and hazards involved for more potent chemicals like acids and alkalis.

Studies on the use of biological treatments such as microbes or a combination of microbes and chemicals such as urea have shown increased nutritive value, CP concentration and decreased lignin concentration (Mulugeta, 2015; Ntokome, 2019). However, more research is needed on effective and affordable biological treatments for improving preservation and enhancing crop residue quality.

2.7 ADOPTION OF FORAGE CONSERVATION PRACTICES BY SMALLHOLDER FARMERS

The most commonly practiced forage conservation methods among smallholder farmers are haymaking, rather than silage, which is more usual among commercial farmers (Maleko, Msalya, et al., 2018). The most important challenge with haymaking is low quality and shelf life of the hay, due to inadequate practices for haymaking (Feyissa et al., 2013). The low level of adoption of forage conservation among smallholder farmers is mainly due to ignorance of the value of conservation for aging and poor knowledge and skills to conserve the forages properly (Njarui et al., 2011; Tesfay et al., 2016). Apart from skills and knowledge, other constraints include restricted access to inputs such as machinery for chopping and baling, appropriate silos, land for forage production, and lack of favorable climatic conditions, limited labor availability, financial constraints and poor access to markets for the conserved forages (Kabirizi et al., 2004; Muinga et al., 2015). At the institutional and organisational level, lack of adoption to conservation of forage includes lack of breeding programs that focus on optimal forages for livestock and lack of participation of farmers when improved forage research is conducted, coupled with lack of proper extension support.

2.7.1 Lack of skills and knowledge

The quality of hay produced in rural livestock production systems is most likely moderate to poor due to limited knowledge and skills. The biggest challenge is optimizing hay production, storage, and quality. Quality is reduced by the way hay is prepared, stored, and utilized, resulting in losses through spoilage, waste and nutrient leaching. Quality of hay is also usually below optimum, with natural pasture hay having average CP values of 6.6% and neutral detergent fiber 73.8% (Suttie, 2000). As a result, technical knowledge and skills for identifying the appropriate harvest stage and optimal storage conditions are recommended (Suttie, 2000).

2.7.2 Lack of relevant and effective extension services

Relevant, appropriate and effective extension services are lacking in many developing countries, resulting in limited knowledge and understanding of haymaking. Such support from livestock extension systems is constrained by a lack

of relevant technology. The failure of research and extension to employ participatory methods (involving end-users in problem definition and solution) compounds the challenge. The challenge also manifests when there is a lack of incentives and resources for extension agents. Furthermore, at the institutional level, there are weak linkages between extension, research and farmers (Davis, 2008).

The latter is exacerbated by the location of extension and research in agriculture and livestock and education ministries, respectively, which create silos with different priorities, constrained funding and limited opportunities for crosstalk between extension and research scientists. Although many researchers have realized the importance of conducting on-farm agronomic and animal trials, they are typically short-term in nature and are terminated once funding ends. Consequently, no sustained extension support is provided, and adoption is very limited or absent. The problem is compounded by the fact that support for extension or research is exceptionally low or non-existent.

These factors reveal the need for strengthening long-term extension support for farmers and fostering dialogue among the private sector, researchers, extensionists and farmers.

2.7.3 Lack of or limited participation of farmers in research and development

The practice of forage conservation in rural livestock systems can be a multifaceted activity for smallholder farmers. The development of appropriate technologies that are also user-friendly for women, such as chopping, compaction, silos and additives, requires an understanding of local contexts, which in turn necessitates the participation of farmers in all phases of research and development. Technology development activities are not short-term and are constrained by donor-funded projects that do not accommodate participatory methodologies and approaches to amplify the voices of smallholder farmers. Such technologies, which are developed without an understanding of local contexts and consultation with farmers, can be irrelevant and rejected (Fischer et al., 2017, 2018).

2.7.4 Negative attitudes towards forage conservation technologies

No studies from SSA were found on attitudes toward forage conservation and the factors that limit its adoption, indicating that this is a key area for future research. Studies elsewhere have demonstrated that farmers' socio-psychological attitude towards forage preservation technologies such as silage making is important in determining the level of adoption (García et al., 2021).

2.7.5 Limited supply of conservable forage

Limited supply of conservable forage is also a reason for low adoption of haymaking in Africa. In the semi-arid regions, 33–46% of surveyed farmers indicated that they did not make hay because they lacked adequate forages, though lack of technical skills (59.1%) and high investment requirement (13.4%) were also mentioned (Njarui et al., 2011). The reasons for the limited supply of conserved forage are complex, but most have to do with the lower productivity potential of native range and pasturelands in rural-based livestock production systems and the limited adoption of improved forage production technologies. These include improved forages, pastureland improvement technologies and a disproportionate focus on food crops compared with feed crops (Balehegn et al., 2020).

2.7.6 Systemic limitations with the production system, land tenure and market access

The extent to which conserved forages are used is highly dependent on the production system and livestock species (Mapiye et al., 2011; Scholtz et al., 2009). For instance, apart from commercial farming systems, conservation of forages for ruminant feeding was very uncommon in Botswana because many smallholder farmers relied primarily on natural pastures/rangelands, even when they supplied insufficient nutrients and biomass to optimize livestock production (Maphane & Mutshewa, 1999). However, the demand for forage to bridge the dry season feed gap, which causes loss of body condition, and in some cases, death of the animal, is encouraging farmers in the arable zones of Botswana to harvest, chop and sell cereal crop residues to livestock farmers. Consequently, planted forages and forage conservation are becoming more common in Botswana (Maphane & Mutshewa,

1999). Similar trends are evident in other SSA countries. Land tenure is also an important determinant of adoption of forage conservation practices.

Forage conservation practices differ with the type of land tenure under which livestock production is practiced (Adams et al., 2003; Palmer & Ainslie, 2006). Under communal/subsistence or emerging farming systems (e.g., in eastern and southern Africa), livestock are primarily reared extensively on the natural veld or rangelands, and seldom are forages planted in these communal areas to supplement dry season feed shortages. However, even under these production systems, farmers purchase preserved forages to feed their livestock throughout the periods of feed shortages (Müller et al., 2019; Palmer & Ainslie, 2006; Samuels et al., 2016). In the intensive or commercial livestock production systems, reliance on planted forages as well as conserved forages is greater, particularly in the dairy and beef industries, to which the conserved forages contribute substantially to the diets of this livestock (Muller, 2017). The absence of forage quality regulations in SSA (Dione et al., 2015) and the absence of quality-price relationships (e.g., Ayantunde, 2020; Blümmel, 2019; Jarial et al., 2017) make the commercialization of feeds and adoption of improved forage preservation technologies challenging, as there is currently no financial incentive for preserving feed quality.

2.7.7 Gender-related constraints

Another reason for the low adoption of forage conservation is the unaffordability or inaccessibility of the technology for women, who are key to improved agricultural production in many parts of SSA. Unfortunately, women's roles are often mainly confined to the collection and feeding of forages, activities that do not require much technical know-how (Balehey et al, 2018). For instance, except under the supervision of gender-promoting activities by Non-Governmental Organizations (NGOs), women are not directly involved in ensiling in northern Ghana; rather, they are involved in the collection, drying, and sale of forages (Konlan et al., 2018), establishment of forage-conservation and allied businesses and cooperatives that produce quality hays and silages for smallholders, particularly among women and youth. It is important to note that the adoption of feed technologies requires a different approach from the classic agricultural transfer approaches.

Most adoption of feed technologies is driven by financial incentives; therefore, feed conservation practices are probably going to be more successful in areas where there is an enabling environment, particularly a good market for the feeds, animals and livestock products (Balehegn et al., 2020). Due to the threat of climate change and the predicted effects it will have on forage production in the future, the formation of an SSA Feed Network is recommended to ensure continued research and extension on best practices to improve livestock production, using high-quality and high-yielding conserved forages that are adapted to the agro-ecological conditions of the specific regions.

2.8 CONCLUSION

It is indeed a serious issue that forage production has not been increasing on a large scale, despite significant progress in livestock development. Simply increasing the area under fodder may not be a viable option; it calls out for developing strategies to bridge the huge gap. Taking into consideration the multifaceted constraints faced by rainfed farmers, developing a community fodder bank would be a feasible alternative. Challenges to be considered include: (a) initial rapport with the farmers, (b) identifying a common piece of land under common areas, (c) identification of marginal land and unproductive land for development and (d) selection of suitable fodder crops for growing on marginally unproductive farms. Feed accounts for about 60 per cent of the cost of raising livestock and is a major determinant of profit. Priority should then be given to developing various forage production systems, suitable for rainfed lands.

Hay is perhaps the greatest opportunity to cover the feed gap due to the seasonal variability in feed quality and availability in smallholder livestock systems. It is also fundamental to address the hotspots of overgrazing, bush encroachment and reduction in grazing lands. While forage conservation is increasingly a critical component of commercial livestock production systems, the adoption of forage conservation methods by smallholder farmers who produce most of the livestock on the continent remains very low. This is due to resource, knowledge, labor and skill limitations as well as gender constraints, systemic issues and lack of sufficient land or

conservable forage. Haymaking is practiced in smallholder livestock production systems, but the quality is often low, as is the case for haymaking and crop residues.

In addition to suboptimal management practices, the low quality is partly due to widespread feeding of native forages, particularly stovers and straws. To address these problems, major investments to increase awareness about the need, benefits and best strategies of growing and conserving improved forages are called for across the continent. A paradigm shift in the objective of livestock production from one that sustains large heads of poor productivity herds to a smaller number of well-fed and high productivity animals is needed.

This requires a move away from feeding unimproved crop residues, which are typically poor in quality. Rather, the focus should be on feeding balanced rations containing upgraded crop residues with improved harvested or conserved forages and other ingredients that can sustainably optimize livestock productivity and profitability. This requires on-farm studies with market-oriented farmers and cooperatives that specialize in forage conservation to demonstrate the profitability of forage conservation and proper feeding with well-conserved forages instead of crop residues or native forages.

This must be complemented by sustained extension support that provides technical knowledge to optimize forage production, conservation and quality. Forage-breeding programs that currently focus on dual-purpose legumes and cereals for food and feed consumption should also look at developing high-yielding and quality forages for which the whole plant will be fed to optimize livestock productivity by progressive farmers. In addition, appropriate, accessible and affordable equipment is a fundamental requirement. Emerging appropriate and affordable technologies are beginning to address this problem, including locally developed equipment such as choppers, balers and compressors for making densified feed blocks, various silo options, silage additives, etc. A second paradigm shift is required to include smallholders as buyers rather than makers of conserved forages, because many lack time and other resources to make high-quality conserved forage. Rather, the aim should be to incentivise.

CHAPTER 3 - THE DEVELOPMENT OF CULTIVATED PASTURE CROP MODELS INCORPORATING UNDERGROUND WATER

3.1 INTRODUCTION

3.1.1 The importance of livestock farming globally

Livestock farming is an integral component of the agricultural production system throughout the world. According to Rojas-Downing *et al.* (2017), approximately one billion people rely on livestock for their livelihood. Meanwhile, the Food and Agriculture Organization (FAO, 2021) reveals that the sector accounts for about 40% of the annual global agricultural production in monetary value. Lowder *et al.* (2016) estimated that roughly 500 million livestock farmers directly rely on this segment for their livelihood. However, the actual contribution of the sector is very high, as over a billion people across the value chain are reliant on this segment for their provisions (Thornton, 2010). In addition, Rojas-Downing *et al.* (2017) asserted that the sector plays a pivotal role in food security, global kilocalorie (17%), and protein (33%) consumption. Should there be a decline in the throughput from the smallholder operations, there will be an exponential increase in joblessness, increased food insecurity, malnutrition and starvation.

3.1.2 Role of livestock farming in South Africa

Livestock farming is an invaluable sector of the economy in South Africa (Mare *et al.*, 2018; Rust & Rust, 2013; Mapiye, 2009). This sub-section of the agricultural industry plays an undisputable role in providing a means of living for rural and informal communities in the country (Cheteni & Mokhele, 2019). It exhibits exceptional potential in the combat against food shortage and poverty alleviation (Mapiliyao *et al.*, 2012). According to Bahta (2021) and the Department of Agriculture, Forestry and Fisheries (DAFF, 2016; 2018), this component of the agricultural industry accounts for almost half (48%) of South Africa's agricultural output. It is also one of the principal employers throughout the country (500,000 people) (DAFF, 2016). Apart from the socio-economic contribution, the essence of this marginalised but important industry in South Africa is further reflected in a substantial contribution of 21.4% of the total meat production on the continent and 1% to the global output

(Kirsten *et al.,* 2017). Given these assertions, it is evident that livestock is an important component of agriculture in the country.

3.1.3 Impact of climate change on livestock in South Africa

Nonetheless, climate change is one of the prominent phenomena that is plaguing livestock farming in South Africa. This manifests through a reduction in rainfall amount, increasing temperatures, alteration of rainfall patterns and frequency and increased regularities of climate extremes (drought and floods) (Ziervogel *et al.,* 2014; Kusangaya *et al.,* 2014; Nhemachena & Hassan, 2007; Turpie *et al.,* 2002). According to Kruger & Nxumalo (2017), O'Connor *et al.* (2014), and Kusangaya *et al.* (2014), there is a substantial reduction in the mean annual precipitation in many parts of the country as a result of climate change. In addition, there has also been a considerable expansion of drought-prone areas (Koerner & Collins, 2014). Lehner (2017), presents irrefutable evidence of the increased frequency of prolonged dry spells that are hampering pasture availability (VanderWeide & Hartnett, 2015). Ultimately, overgrazing subsides in smallholder livestock farming. This is mainly because the constituents of the sector are vulnerable to the impacts of climate change. Tshikolomo *et al.* (2022) appraised the demography and adaptability of the smallholder livestock farmers to the impacts of climate change in Limpopo Province. That study revealed that the majority of the smallholder farmers (99%) practice their trade on communal lands and lack access to financial support from government and private institutions. Tshikolomo *et al.* (2022), Omerkhil *et al.* (2020), Matewos (2019), and Jamshidi *et al.* (2019) infer that smallholder livestock farmers are exposed to the impact of climate change.

3.1.4 A need for supplementary feeding for livestock

Moreover, smallholder livestock farming in South Africa is primarily performed in rangelands (Scholtz *et al.,* 2013; Palmer & Bennett, 2013). This farming approach is attributed to the total reliance of livestock on natural vegetation and grasses for their daily nutritional needs (Jordaan *et al.,* 2013). Unfortunately, the productivity of rangelands in many parts of South Africa continues to decline due to overgrazing and marginal rainfall (Stevens *et al.,* 2016; Podwojewski *et al.,* 2011). Insufficient rainfall yields a loss in biodiversity that constricts available food. A reduction of the

grass within the rangelands ushers in malnutrition and loss of livestock. Such occurrences threaten the livelihood of the smallholder operators, since they are solely reliant on farming and are also exposed to the impacts of climate. A study was conducted to develop agro-ecological-based fodder banks to ensure sufficient feed availability for smallholder farmers, despite over-grazing and general pasture shortage due to climate change (Dhyani *et al.,* 2013).

Tree lucerne is an ideal plant to serve as a fodder bank crop because it is rich in protein and pleasant for livestock to eat (Rajan *et al.,* 2019; Bezabih *et al.,* 2016). The added benefits associated with the crop entail retention of soil moisture, reduction of soil erosion, land restoration and soil fertilization (Rajan *et al.,* 2019). Because of such benefits, there is a pressing need for appraisal of the geospatial suitability of this plant in Limpopo and Mpumalanga to develop fodder banks to mitigate the exposure of the smallholder subtropical farmers in these areas to the impact of climate change.

3.2 RESEARCH METHODOLOGY

3.2.1 Description of study area

3.2.1.1 Location

The study area comprises the Limpopo and Mpumalanga Provinces of the Republic of South Africa. The map in Figure 1 shows the geographical location of the two provinces, which are located in the northeastern part of the country, confined to 21° and 26° south, and 26,4° and 32° east. Limpopo Province shares international boundaries with Mozambique (to the east), Zimbabwe (to the north), and Botswana (to the west).

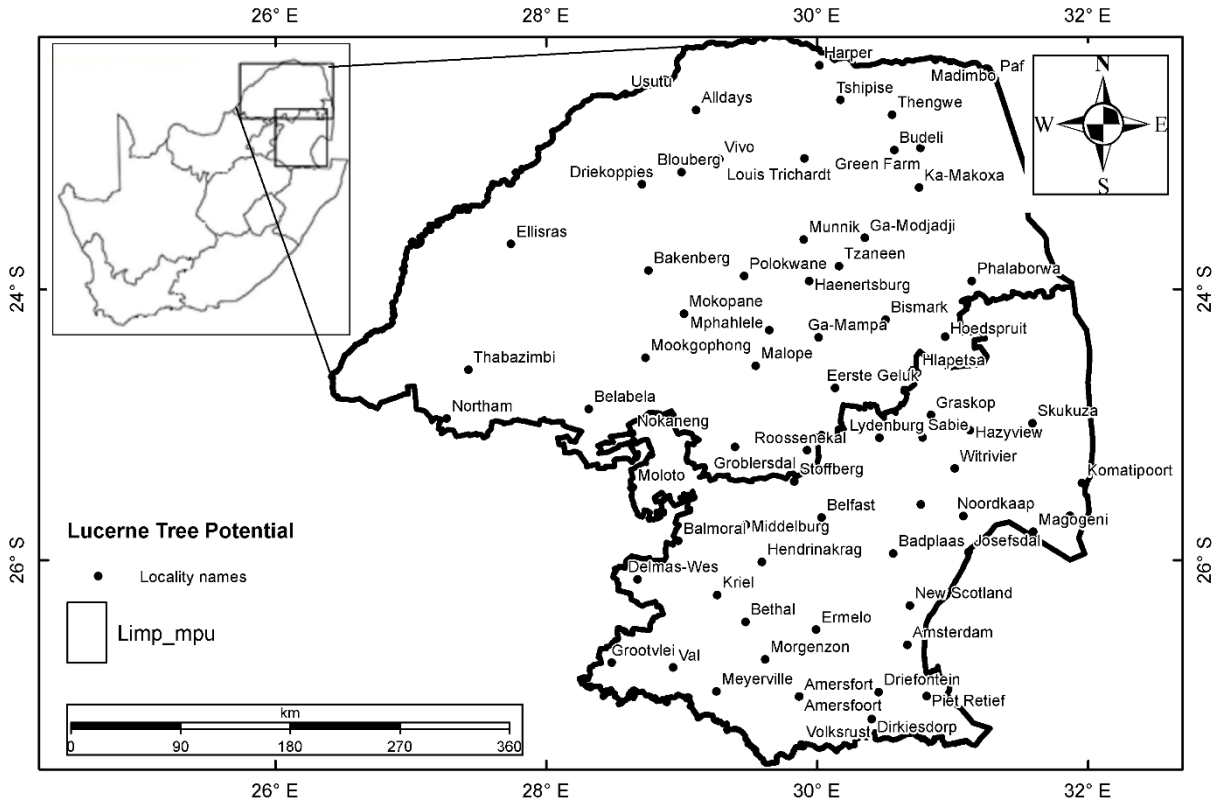

Figure 1: The geographical position of the study area within the layout of the country (South Africa)

3.2.1.2 The physiography

The topographic overview of the Limpopo Province conforms to that of the Lowveld area (an area with an elevation ranging from 150–600 m above mean sea level (AMSL) (Nemukula *et al.,* 2023; Musyoki *et al.,* 2016). Nonetheless, numerous mountain ranges protrude within the province's plateau in the central and southern parts. Subsequently, these make the overall physiographic appearance slightly complex (Nemukula *et al.,* 2023; Musyoki *et al.,* 2016). The most prominent mountains are the Soutpansberg Mountain range, which extends for 130 km from east to west and has an optimal elevation of over 2,000 m (Bouarakia *et al.,* 2023). The Soutpansberg Mountain range is densely covered with thorn trees and shrubs (Ruwanza and Mhlongo, 2020). Meanwhile, the Lowveld extends across the northern part of the province and is covered by semi-desert vegetation (mopani and baobab trees) (Mateyisi *et al.,* 2021).

Mpumalanga contains three major physiographic regions, namely, the Highveld, the Drakensberg Mountains, and the Lowveld (Britannica, 2024). The Highveld constitutes a flat-lying area with an elevation ranging between 1 200 and 1 800 m

AMSL (Britannica, 2024). The Drakensberg Mountains extend on the western side of the province, which constitutes the optimal elevated area with an elevation of up to 2,300 m AMSL (Britannica, 2024). Lastly, there is the Lowveld area, which is characterized by the gently undulating physiography that slopes to the Lebombo Mountains on the Mozambique boundary to the northeast. After the topographic settings of the province, the majority of the streams in the province are drained by the eastward-flowing tributaries of the Limpopo River.

3.2.1.3 Climatological setting

The climatic setting of the Limpopo Province varies from dry sub-humid to semi-arid, attributed to wet-hot summers and dry-cold winters (Kabanda, 2004). The average annual temperature ranges between 18 °C (Winter) and 30 °C (Summer) (Mpandeli & Maponya, 2013; Naledzani, 1999). There is spatial variability in rainfall; the optimal amount is intercepted in the eastern part of the province (> 1,000 millimeters per annum; mm/pa) and decreases with westward advancement to the west (<400 mm/pa) (Mpandeli & Maponya, 2014; Naledzani, 1999). The effects and impacts of climate change are experienced considerably in the agricultural industry. After the impact of climate change, semi-arid is defined by insignificant and unreliable precipitation (< 400 mm/pa) (Mpandeli & Maponya, 2014).

The climatic physiography of Mpumalanga is altitude-dependent. The Highveld is attributed with a mean annual temperature of 16 °C (Netshakhuma, 2021); meanwhile, the subtropical Lowveld has a mean annual temperature of 23 °C. Precipitation portrays a similar trend to the Limpopo Province of westward decrease in frequency and quantity. The Highveld and Drakensberg receive a mean annual rainfall averaging from 510 to 760 mmpa and the Lowveld experiences over 1,000 mmpa (Netshakhuma, 2021). Most of the natural vegetation in the province consists of various types of grassland or savanna parkland, with acacia trees.

3.2.2 Data collection

The study adopted the auxiliary datasets because the required data were available in the archives. The climatological variables that comprised rainfall and temperatures were attained from the South African Weather Services (SAWS). The variables that were considered as input for the suitability assessment of the tree

lucerne were recommended from the literature (Tadesse, 2016; Wiley, 2006; Assefa, 1998; Varvikko and Khalili, 1993; Borens and Poppi, 1990). Meanwhile, the geo-ecological parameters, such as elevation data (slope and altitude), were derived from the Water Resource 2012. Lastly, the pedological attributes (soil type, soil pH, and soil depth) were obtained from the Agriculture Research Council – Institute for Soil, Water and Climate (ARC-ISWC, 2016).

The study adopted the quantitative research design. This was in line with the main research objective, which was to establish a spatial suitability model for the tree lucerne for the study area.

3.2.3 Data processing

Carl (1996) defined data processing as a means of gathering and manipulating data to appraise meaningful narratives and descriptive information. The steps adopted to issue the geospatial suitability of the tree lucerne in Limpopo and Mpumalanga Province encompass data acquisition, preparation and modelling. All the datasets that were treated as input comprised geo-climatological components. Processing was performed in the ArcGIS environment.

3.2.3.1 Ranking the predictive parameters

Data preparation incorporates the reclassification of the input variables for the model. The attributes in the input thematic layers were assigned scores ranging from one to three. The magnitude of the score was allocated in proportion to how the attributes within the map influence tree lucerne development.

Table 5 indicates how the scores were allocated to a different set of attributes within the predictive parameters. The plant requires an optimal rainfall range between 400–700 mm/pa (rank 3); a moderate range of 100–400 and 700–1600 mm/pa (rank 2), and rainfall below 100 mm/pa and greater than 1 600 mm/pa (rank 3) may not suffice for this plant. While the crop may withstand a wide array of temperatures ranging from -9 °C to 50 °C, because of the local temperature ranges that entirely conform within the optimal range, this variable was not considered for geospatial modelling.

Table 5: The predictive variables for the tree lucerne (Tadesse, 2016; Tadesse, 2016; Wiley, 2006; Assefa, 1998; Varvikko and Khalili, 1993; Borens and Poppi, 1990)

	Rank 1	Rank 2	Rank 3
Rainfall (mm/h)	<100 and >1,600	100–400 and 700–1,600	400–700
Soil depth (cm)	<100	100–200	>200
Soil draining	Poorly drained	Moderately drained	Well drained
Soil pH	<4 and >10	4–5,5 and 7,5–10	5,5–7,5
Groundwater level (mg)	<5	5–15	>15
Soil type	Clay soil	Loamy soil	Sandy soil

Soil is a fundamental variable in tree lucerne development. The soil depth ranking reflects how the crop requires a thick soil profile, a rank of three (>200 cm), a rank of two (100–200 cm) and a rank of 1 (<100 cm). The plant relishes well-drained soil as moisture may yield to water clogging and subsequently, root rot; therefore, rank three coincided with well-drained soil, rank two, moderately-drained soil and rank one, poorly-drained soil. Low water requirement also dictates that the tap root should not easily reach the groundwater table. Where the resource occurs beneath 15 m, it had a rank of three; water level ranging between 5–10 m depth had a rank of two, and where the water table was shallower than 5 m, a rank of one was assigned. The ideal soil type for tree lucerne is sandy soil (rank 3), which is characterised by rapid permeability; loamy soil (rank 2) has moderate permeability, and clay soil has the lowest score of one, because of high porosity, which keeps water for longer, posing the threat of water clogging. Soil pH also plays a crucial role in the establishment of tree lucerne plantations. The pH range of 5,5–7 was allocated a rank of three; meanwhile, a rank of two conforms to the values that encompass the optimal values (4–5,5 and 7,5–10 pH), and lastly, the poor rank of one was attributed to the pH values below 4,5 and greater than 10.

3.2.4 Integration of the predictive variables

The geospatial suitability of the tree lucerne was achieved through the integration of the reclassified thematic layers of the predictive variables. These were carried out in the ArcGIS environment. Equation one (1) indicates how the suitability of the tree lucerne was established.

$$Cp_{(\%)} = \sum_{i=3}^{i=6} w_t r_t \quad \text{.....(1)}$$

Where C_P is the crop suitability potential, w_t is the weighting coefficient assigned to each of the thematic layers. The geospatial model was established in ArcGIS. The reclassified thematic layers were overlaid in the spatial analyst feature. Equal weights were assigned to the layers to offset the biases associated with manual assignments of the weights. The resultant geospatial map showed the suitability of the tree lucerne in various parts of the study area

3.3 RESULTS AND DISCUSSION

This section presents the results of the spatial suitability of the tree lucerne in Limpopo and Mpumalanga. The resultant maps define crop suitability in terms of three categories of area: optimal, suitable, and non-suitable.

3.3.1 The spatial potential of the tree lucerne

According to Champ & Dyte (1976), the crop suitability model illustrates how well the piece of land is suited to a particular crop. In the present study, a spatial suitability model was developed based on the integration of climatological and geo-environmental variables. Table 6 indicates the resultant suitability classes and the corresponding extent.

Table 6: A table indicating an area extent conforming to each of the subsequent suitability classes

Lucerne potential	Area (%)	Area (ha)	Colour code
Optimal	32,22133	65167,32	Red
Suitable	61,95619	125305,8	Green
Unsuitable	5,822483	11775,91	Blue

According to Table 6, the tree lucerne potential of the area is divided into three subcategories: the optimal potential (red), the suitable (green), and the unsuitable (blue) areas. The class with the least spatial extent is the unsuitable area with an extent of 11,775 ha (5,8%).

According to Figure 2, a prominent proportion of the non-ideal area for tree lucerne plantations predominates in Mpumalanga, in Hendrinakrag, Middleburg, Ermelo, Driekoppies and Volkrust. Meanwhile, such a potential class is marginal in Limpopo and restricted towards the south. The expression of such poor potentiality may be mainly interpreted in terms of the excess rainfall that the area enjoys 900 mm/pa. Such a significant amount of the mean yearly rainfall highly surpasses the 700 mm/pa that the plant requires.

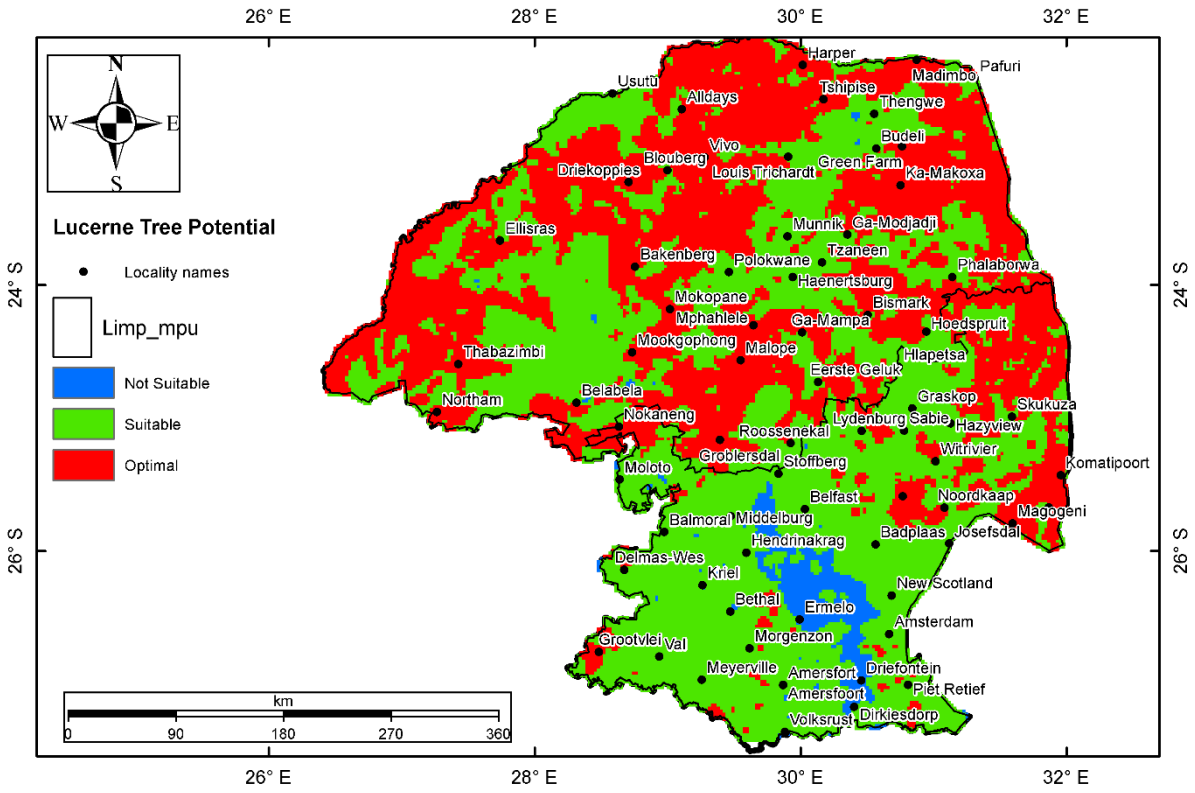

Figure 2: Shows a spatial distribution of the resultant lucerne tree suitability map

The suitable potential defines an area that does not fully exhibit all the desired variables that the crop requires to yield optimally. This class is defined by the overlap of the predictive variables with the crop requirement. Table 6 indicates that such an area has an aerial extent of 125,305,8 square kilometers (61,95%). This has by far the most extensive potential in the area (indicated by the green color). In comparison with the poor production potential, this potential spreads across the two provinces.

The optimal potential area defines the area that exhibits the most ideal geo-environmental and climatological variables for a particular crop to thrive. Crops proliferate when there is congruency between the prevalent agro-ecological conditions of an area and ideal crop requirements. Table 6 indicates that a third of the study area, which is 65167,32 ha (32%), conforms to this class. According to the map in Figure 2, the optimal potential area is dominant in the Limpopo Province. Interestingly, these areas are extensive and coincide with the arid and semi-arid regions.

3.3.2 Simplified tree lucerne potential mapping

Although the tree lucerne suitability potential map was established using equal weights for the predictive variables, it is apparent that the most influential variables for predicting the spatial potential are soil type and rainfall. While temperature was generally considered a crucial element, it was found to be unessential in the present study, mainly because the spatial and temporal variation values were all within the optical crop requirement range values. Therefore, its inclusion did not add any value but rather data redundancy. Meanwhile, rainfall was the most integral component of the climate that was influencing the spatial potentiality. Mpumalanga had higher rainfall intensity (>800 mm/pa) as compared to Limpopo (500 mm/pa). Although the former exhibits exceptionally high precipitation, it shows less potential than the latter. This may be interpreted in terms of lower precipitation that the crop relishes. This assertion is also supported by the prominence of the optimal potential area in most of Limpopo with a significant spatial extent.

On the other hand, soil type was also identified as a prominent variable for suitability. While the study areas possess higher precipitation than what the crop requires, the ideal soil type should be such that possesses high drainage to avoid waterlogging. Such a soil type is prevalent in the northern part of the Limpopo Province.

The integration of the rainfall and soil type may be instrumental in defining the suitability of an area for tree lucerne. A conditional check listing can be established for the extension officers to define the suitability of an area for this crop. An area with a mean annual rainfall ranging between 500–800 mm/pa is ideal for tree lucerne plantation. In cases of higher rainfall (>1000 mm/pa), the soil should be well drained to cope with excess water to avoid clogging.

3.3.3 The benefits of tree lucerne

Tree lucerne is an ideal plant that is renowned as a forage for livestock. It is strongly believed that the ruminants enjoy the taste of this crop. It is also a nutritious plant that is highly rich in protein content. Moreover, it can be grazed directly in the field or be dried for future use (Heuzé *et al.,* 2016). As a fodder crop, it provides approximately 25% of the CP and anywhere between 14–30% of crude indigestible

fiber. This plant has a deep tap root system that enables the crop to withdraw moisture from the deep subsoil. Ultimately, it is an evergreen plant that produces green leaves during the dry season.

According to Bezabih, *et al.,* (2021), approximately 11 tonnes of dry tree lucerne may be obtained from a hectare of land per annum. This translates to the exclusive feeding of precisely three mature cattle per hectare per year. However, for optimal forage production, the planting spacing of 8 m may be implemented, which translates to 144 trees per hectare. Given the total land coinciding with the suitable and optimal potential area, an additional 800 000 cattle may be introduced that are only fed by tree lucerne. Such development would not only provide supplementary feeds or forage to the ruminants, but it would also accelerate the recovery of the pastures after cutting and harvesting of the forage. The regeneration rates are improved by symbiotic relationships with nitrogen-fixing bacteria of the tree lucerne. This unique ability enables it to capture atmospheric nitrogen, enriching the soil with this essential nutrient. The grass and other feeding crops facilitate the development of grass between the tree lucerne.

The prospective implication of tree lucerne-based communal grazing may not be fully comprehended at face value. There is more to this system than what meets the eye. To put this into context, in a conventional communal grazing system, a fully-grown cow requires about 0,4 ha of pasture (Coates, 1992). This implies that 10 cattle require 4 ha of pasture. In terms of the good practice of pasturing, a rotational system is considered an ideal approach. Such a system dictates that pasturing should be sectionalized into smaller compartments; every second day, the livestock should be taken to a new compartment to graze and let the grass recover for about 30–35 days. It is, therefore, necessary to ensure that the rangelands are supplemented with tree lucerne to amplify their grazing capacity (Mthi & Nyangiwe, 2018). The added benefits associated with the crop entail retention of soil moisture, reduction of soil erosion, land restoration and soil fertilization (Rajan *et al.,* 2019), which speed up pasture regeneration after grazing.

The worst undesired predicaments for smallholder livestock farmers involve the emergence of an extended spell of drought. Tshikolomo *et al.* (2022), on the review of the demography of smallholder livestock farmers, discovered that they are

vulnerable to drought and associated impacts. They do not have the financial muscle to obtain bale for their animals; feeding a sheep could cost between R10 and R14 a day, and a cow between R50 and R70 a day in winter (Moorby *et al.,* 2016). This would mean that a farmer with 10 cattle would need about R700/day and about R21 000/month. Such an amount surpasses their net revenue every month.

3.3.4 Increasing kept livestock

The pastures dictate how much livestock should be kept at any given time (Zewdie & Yoseph, 2014). Surpassing that number always leads to environmental degradation, as overgrazing is always accompanied by excessive removal of the grass, which results in erosion and total loss of the pastures (Boles *et al.,* 2019; Cao *et al.,* 2013). As a coping strategy, the farmers tend to sell their produce prematurely and often at a loss (Mthi *et al.,* 2017; Scholtz & Bester, 2010). The introduction of fodder banks in the form of tree lucerne will significantly boost the available food resources for livestock. Tree lucerne is associated with a high proportion of protein content (Rajan *et al.,* 2019). This implies that the plant may be used for exclusive feeding, provided that there is a phosphorus and sulphur supplement to the food. When there is sufficient feeding, then the livestock farmers can hold on to their stock for longer, until such time that they are ready for market.

The high protein content of the tree lucerne means that the livestock will mature and become ready for the market on time. The operators are also able to sell their produce at market price instead of always taking a fall in the trade. Ultimately, the socio-economic status of the farmers improves drastically in proportion to their earnings.

3.3.5 Reduced cost of farming

Tree lucerne will reduce the pressure on the farmers to mitigate the climatic impacts through the provision of sufficient feed during times of need (drought). While the complexity of initiating tree lucerne may take time to be comprehended by the community, it drastically reduces farming costs. This implies that the profitability and sustainability of the practice improve. Tree lucerne is drought resistant, and it is known that some of the adverse predicaments that are associated with livestock

farming are the substantial increase in temperatures, reduction in precipitation and increased frequency of drought. Fortunately, tree lucerne is drought-resistant and not highly affected by the limited rainfall. Approximately 30% of the land surface is optimally suitable, and another 60% is deemed suitable for the plantation. This implies that over 90% of the study area is able to support tree lucerne. This ultimately translates to 190,000 km^2 of land to support smallholder livestock farming. Hence, Bezabih *et al.* (2021) denote that approximately 11 tonnes of dry tree lucerne may be obtained from a hectare of land per annum; the ideal commodity production area has the potential to yield 1.1 million tons per year. This translates to 376 cows solely fed on tree lucerne for a year. However, with the consideration that the crop is mainly required as a supplementary feed, during the dry season, the number of the kept stock may substantially increase, especially considering that some livestock require much less feed per day as compared to cattle.

3.4 CONCLUSION

The geospatial modeling of the geo-climatological variables that comprise rainfall, soil type, soil drainage, soil pH, soil depth and water level is instrumental in the establishment of the prospective potential of the tree lucerne. About 30% of the land surface is optimally suitable, and another 60% is deemed suitable for the plantation of the tree lucerne in the study area. Only a mere 5% is considered non-ideal. The development of the tree lucerne as a fodder bank crop will significantly reduce the smallholder livestock farmers' vulnerability to the impacts of climate change. A fodder bank will improve the sustainability of the smallholder operations and their profitability. It will also amplify the grazing capacity of the rangelands. Because of the climatic setting, groundwater would be key in the sustainable management of the tree lucerne.

3.5 RECOMMENDATIONS

Governments should formally adopt the crop as a supplement to livestock feeding, particularly in the arid and semi-arid regions of the country. The national agricultural ministry should play an integral role in supporting the smallholder operation with the acquisition of the seedlings of this crop to improve their resilience to the impact of climate change. Moreover, the extension officers should be thoroughly trained on

this commodity to ensure excellent support services to the smallholder farmers. With a properly coordinated support system, the smallholder livestock operators will in time operate economically and sustainably.

CHAPTER 4 - THE USE OF AGRO-METEOROLOGY AND CLIMATE INFORMATION AS DROUGHT-COPING STRATEGIES

4.1 INTRODUCTION

Grazing is an essential exercise for smallholder livestock farmers, as it provides the feed needed to raise healthy and productive livestock. Some of the fundamental reasons it is highly regarded include: it is a sustainable source of feed for livestock, as it is renewable and mainly naturally grown using minimal inputs; it can be particularly important in regions where other feed sources, such as grains or concentrates, are expensive or in short supply. Grazing is also a high-quality feed for livestock, as it is rich in nutrients such as protein, minerals and vitamins. This can help to ensure that livestock are healthy and productive, and can provide a valuable source of protein and other nutrients for consumers. Pasture is also key to food security for smallholder farmers, as it can provide a reliable source of feed for livestock throughout the year. Nonetheless, climate change has a significant impact on rangelands. In time, this negatively affects the quality and quantity of the feeds. As global temperatures rise, pastures become drier and warmer, making it more difficult for plants to grow and flourish. This can lead to a reduction in the quantity and quality of feeds available for livestock, which in turn can impact their health, growth and milk production. In addition to changes in temperature and rainfall patterns, climate change also brings with it increased frequency and intensity of extreme weather events such as droughts, floods and storms. These events can cause significant damage to pastures, destroying crops, eroding soil and contaminating water sources. Furthermore, changing climate patterns can also impact the distribution and abundance of plant species that make up pastures, leading to a loss of biodiversity and reduced resilience of the ecosystem. This can make it more difficult for pastures to adapt to changing environmental conditions, further exacerbating the impact of climate change. It is, therefore, critical for the smallholder farmers to be familiar with all aspects of the projected weather to effectively manage their operations. Fortunately, in the context of South Africa, there is the South African Weather Service (SAWS), an entity that has been entrusted with the responsibility of acquiring, storing and interpreting the climatological data

in the country. Along the same line, there has been in-depth research on weather presentation and climate predictions (Klopper et al., 1998; Landman and Manson, 1999; Tennant, 1999; O'Brien *et al.,* 2000). The principal mandate for the institution is the provision of the best climatic information for all the interested stakeholders in the country. In a multi-lingual nation like South Africa, it is imperative to ensure that the disseminated information reaches the intended audience in the most suitable language. If the information that is transmitted cannot reach the target or be comprehended properly, without any room for misinterpretation, it bears no value as it shall not support the decision-making process for smallholder livestock farmers (Glantz, 1977; Chagnon, 1992; Osunade, 1994; Mutiso, 1997; Huber and Pedersen, 1998; Eakin, 2002; Roncoli et al., 1999; Finan and Nelson, 2001; Roncoli et al., 2001a; Roncoli et al., 2002a; Luseno et al., 2000).

The agricultural sector in South Africa is a climate-based operation. This is mainly because the country experiences a relatively low mean annual precipitation, which is even below the global average, so every raindrop counts. Moreover, the dawn of climate change worsens the situation, as the rainfall becomes more erratic and unpredictable with frequent extreme climate events. In this regard, the sector is principally reliant on meteorological information to thrive, survive, prepare and mitigate the impact of climate extremes. Therefore, the application of climate forecasts is a fundamental practice in the management of farming activities. The same information has the potential to alleviate the exposure of farmers to the detrimental effects of climate change on the farming venture. (IRI, 2000). Moreover, climate forecasts represent a significant component of agricultural management, because they reduce the farming costs that are likely to rise after the climate extremes that are easily identified and combated as depicted on climate forecasts (Orlove and Tosteson, 1999; Wilbanks and Kates, 1999; Unganai, 2000; McGee, 2004; Ritchie et al., 2004). Subsequently, the purpose of this study was to appraise the importance of agro-meteorology and climate information as drought-coping strategies.

4.2 RESEARCH AND METHODOLOGY

4.2.1 The study area

The study area consists of the Limpopo and Mpumalanga Provinces. They are located in the north and north-east of the Republic of South Africa. Limpopo Province has a spatial coverage of 125,000 km², and Mpumalanga has 80,000 km². Together, the two provinces occupy a total land size of 205,000 km². According to the map in Figure 3, the study area is located between 26.4° and 32° longitudes, as well as 21° and 26° latitudes. As the study area comprises the northernmost provinces in the country, it shares international boundaries with Namibia, Botswana, Zimbabwe and Mozambique on the progression from west to east.

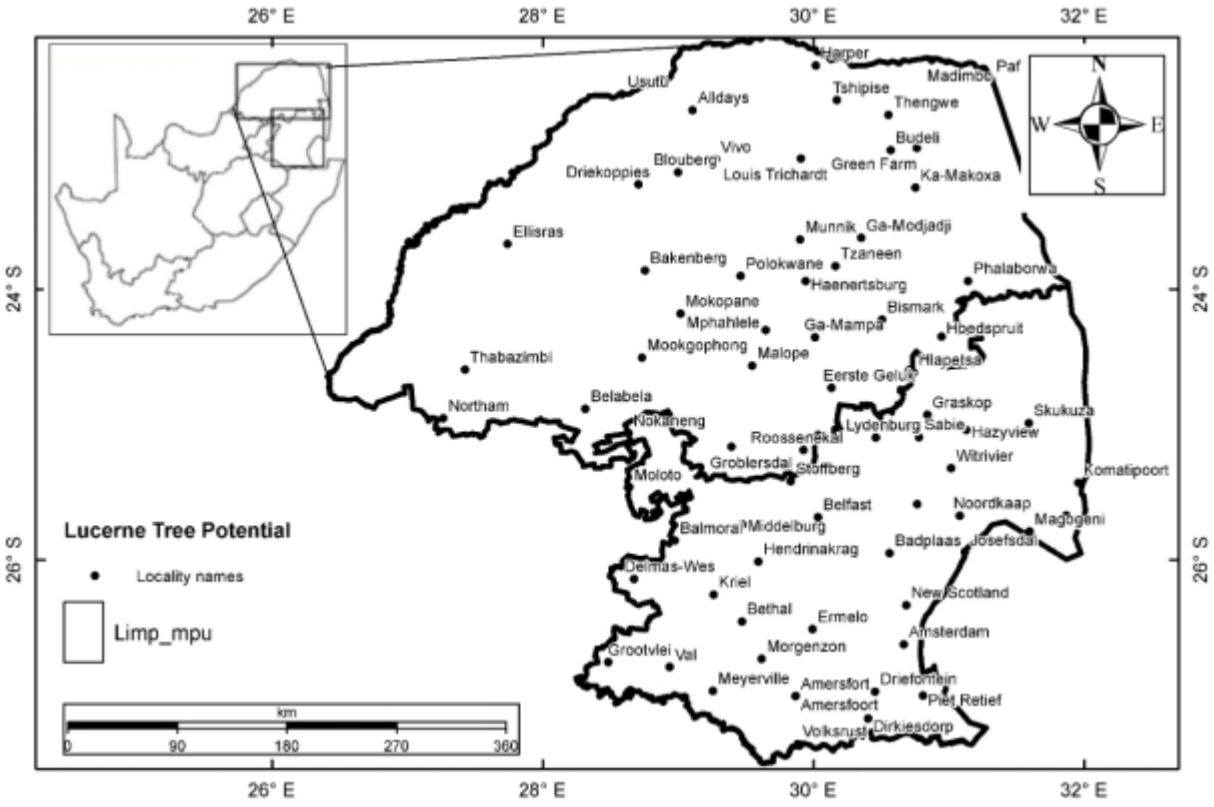

Figure 3: The geographical position of the study area in relation to the layout of the country (South Africa)

4.2.2 Physiography

According to Nemukula, et al., (2023) and Musyoki, et al., (2016), the general topographic layout of Limpopo resembles that of the Lowveld, which is an area that is attributed to the topographic relief that ranges from 150 m to 600 m AMSL. In spite

of the near-perfect flat-land surface in the province, there are some mountains that appear in the central and southern parts. The protruding part in the central portion of the province is subsequent to the development of the Soutpansberg Mountain Range. These mountains extend over a distance of 130 km along the east-west directions, with a peak elevation of 2,000 m AMSL. Furthermore, the Soutpansberg Mountain Range is mainly covered by thicket and bushes, while the low altitude in the northern part is attributed to flat surfaces that are mainly covered with semi-desert vegetation.

Contrary to the physiography of the Limpopo Province, Mpumalanga Province can be divided into three major physiographic topographies which are the Highveld, Drakensberg Mountains and the Lowveld. The Highveld conforms to an area with an elevation that ranges between 1,200 to 1,800 m AMSL. The Drakensberg, which consists of mainly mountains, is attributed to high elevation of up to 2,300 m AMSL Lastly, the Lowveld is characterized by gentle undulating physiographic slopes that make up the Lebombo Mountains. The majority of the streams in the province drain water to the western side, which eventually flows into the ocean.

4.2.3 Climate

The climatological setting of the northern part of South Africa is mainly defined as a dual season. There are two prominent seasons that are the dry-cold winter and the hot-wet summer. There is spatial and temporal variation in the precipitation that is received in the Limpopo Province. The eastern part receives the optimal amount of rainfall (1,800 mmpa), which is accompanied by a gradual decline from the optimum values with westward progression, and the far west receives the lowest amount of about 300 mmpa. The effect of climate change is highly affecting the farming sectors, particularly the smallholder livestock farmers.

The climatic physiography of Mpumalanga is altitude-dependent. The Highveld is attributed with a mean annual temperature of 16 °C (Netshakhuma, 2021; Maponya, *et al.,* 2013); meanwhile, the subtropical Lowveld has a mean annual temperature of 23 °C. Precipitation portrays a similar trend to the Limpopo Province of westward decrease in frequency and quantity. The Highveld and Drakensberg receive a mean annual rainfall averaging from 510 to 760 mm and the Lowveld

experiences over 1,000 mm annually (Netshakhuma, 2021; Maponya, *et al.,* 2013). Most of the natural vegetation in the province consists of various types of grassland or savanna parkland, with acacia trees.

4.2.4 Data collection

The SAWS is the national weather service in South Africa that is responsible for the provision of weather services which include forecasting, warnings and advisories. It also monitors and analyzes weather patterns and climatological trends. One of the SAWS' key roles is to provide the government and other relevant stakeholders with information and guidance on the effects of climate change in South Africa. This includes assessing risks and vulnerabilities in agriculture, water resources and public health, as well as developing adaptation strategies. This is important because it helps to understand and predict climate trends. The SAWS monitors temperature, precipitation and other weather patterns. This is achieved through the data gathered from satellites and ground stations. Such data then becomes instrumental in the establishment of the climate models that estimate different predictive scenarios.

4.2.5 Mean annual rainfall

Rainfall data was sourced from the SAWS. The daily rainfall data and daily temperatures were preferred due to their importance in smallholder farming. The selected weather stations have at least 10 years of monitoring data. The SAWS has been collecting weather data since 1920. During surface development, regression analysis and spatial modeling were used.

4.2.6 SPI time series

This rainfall GIS surface, which covers South Africa, has been created from the data contained in the Agricultural Research Council–Institute for Soil, Climate and Water (ARC-ISCW) climate databank. This databank contains historical rainfall data from the SAWS and ARRC. This monthly rainfall GIS surface has been created from historical rainfall data for the period 1920–2013. The process of producing this rainfall GIS surface is as follows:

(a) rainfall data is extracted from between 1,200 and 3,000 mechanical and automatic stations;
(b) the trend surface for a particular month is used for the interpolation
(c) rainfall at a particular point is expressed in percentage of the previous rainfall trend surface
(d) the rainfall percentage value for a specific 10–day period is interpolated using inverse distance weight.

This method produces monthly rainfall surfaces that are consistent with the locations where precipitation is recorded, while still adhering to the climatological trends resulting from climatological variables, such as topography and distance from the sea. The 2003 rainfall surfaces are generated by combining the above method with satellite rainfall estimates to complement rainfall data over the plateau of South Africa. The resultant monthly rainfall surfaces are summarized into quaternary catchments, each of which is represented by a ±1,700 polygon in a Geographic Information System (GIS) covering the surface of South Africa.

For each of these catchments, the rainfall at the monthly to 48–month time scale is converted into a Surface Precipitation Index (SPI) for the catchment, resulting in a dataset of SPI values for several time scales per month since 1920. This dataset can be used to analyze the time series of the drought intensity classes by considering the traditional classification of SPI ranges.

4.3 RESULTS AND DISCUSSIONS

4.3.1 The role of climate in smallholder livestock farming

South Africa is classified as one of the driest countries in the world, the mean annual rainfall that the country experiences (500 mmpa) being lower than the global average (860 mmpa) (Ingrid, & Rainier, 2012). Unfortunately, the situation is expected to worsen with the intensification of climate change, which is accompanied by significant alteration of the rainfall quantity (Anderegg, et al., 2021) and patterns. In view of these non-ideal circumstances, the country is deprived of surface water resources. The majority of the streams are unsurprisingly

periodic. Therefore, grazing becomes a daunting challenge for smallholder livestock farmers.

The development of the fodder bank is an ideal intervention to tame the aftermath of climate change. This should be able to provide some sort of relief during times of drought or extended drought spells. It should be considered, though, that even the growth of the fodder bank will still be climate-dependent. Hence, smallholder livestock farmers should develop an activity timeline plan that is dependent on the climate forecasts such that the high-water demand activity is reserved for such times as when there is rainfall

The daily weather forecast is provided by the SAWS through both print and electronic media and is published online 24 hours. Forecast information that is useful to farmers is part of a process that includes an examination of the current needs, problems and context in which users operate. Forecasts, moreover, need to be expressed in the language of the users. Seasonal climate forecasts are issued as probabilistic outlooks for the future, usually for a coverage period of three months and with a rather broad spatial coverage. Conveying notions of 'probabilistic' information to a variety of users is not easy. It is important for users to understand that all seasonal forecast information or data are given as probabilities and not as deterministic.

A significant constituent of sub-Saharan Africa is characterised by water-strained localities. This challenge is rooted in the low mean annual precipitation that the area receives, which hinders the development of the surface water resources that the farmers may easily adopt for their farming activities. Ultimately, Kotir (2011), renders rainfall as one of the principal determinants for farming in sub-Saharan Africa, as it is often the only available water resource at the disposal of the farmers.

4.3.2 Rainfall

The rainfall forecasts in South Africa are broadcast on national television on a daily basis, to some extent using the vernacular languages. Figure 4 reflects the mean annual precipitation of the Limpopo and Mpumalanga Provinces. According to Kala (2012), the quantity of rainfall that an area experiences determines the nature

of the agro-ecological framework that will prevail. If an area gets heavy rainfall (greater than 2,500 mm/pa), a tropical forest is likely to form (Butler, 2005). Meanwhile, the area that receives little rainfall, exceeding only 400 mm/pa, will be dry (Butler, 2005). Additionally, rainfall also serves as a tool in making decisions about what type of livestock to pursue. This is also reflected in water availability, the nature of grasslands and their respective resilience during the rainy season (Kochoni, 2019). In South Africa, grasslands are rarely irrigated, meaning they rely on rainwater for their water source (Kotir, 2011). The daily rainfall can provide smallholder farmers with valuable insights into the amount and timing of rainfall in their area, which can help them plan for the needs of their animals. For example, if they know that there is going to be a dry spell, they can plan to supplement their animals' water intake with other sources, such as boreholes or troughs. On the other hand, if they know that there is going to be a lot of rain, they can delay grazing to allow pasture to recover and reduce the risk of overgrazing.

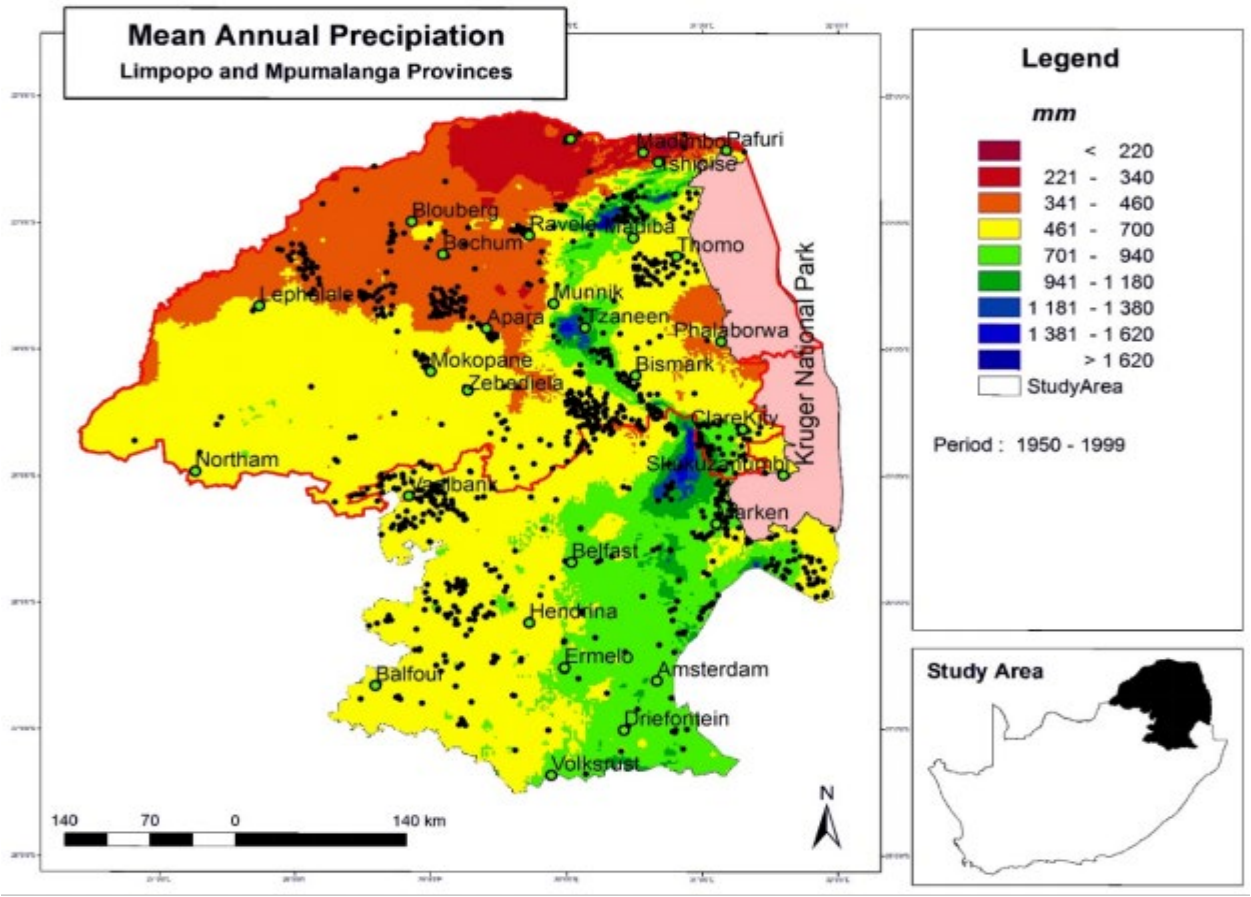

Figure 4: Mean annual rainfall for Limpopo and Mpumalanga

It is worth noting that almost the entire precipitation that the area receives occurs in the summer. The map projects that there is spatial variability in the precipitation that is experienced throughout the aforementioned areas. The trend is denoted by a decrease with southward progression. The driest part occurs in the most northern part of the Limpopo province closer to the Limpopo River. This area experiences a mere 200 mm/pa. Such an area is not ideal for livestock farming because it deprives the animals of adequate pastures, particularly during late summer and the entirety of the dry period. Furthermore, the most depriving variable for the area is the absence of surface water resources.

There are local microclimate zones arranged in the north-south direction that have above 1 000 mm/pa of precipitation. The localities providing optimal rainfall areas include Dzimauli, Tshipise, Valdezia, Tzaneen, and Gateway. The first colour on the map (Figure 4) is represented by light brown and reflects the driest area, while the second colour, symbolised by yellow, represents a relatively wet area. The global average rainfall is 860 mm/pa (Ingrin and Rainier, 2012), and more than 90% of

current studies show rainfall below the global average (Ingrin and Rainier, 2012). Low rainfall causes loss of surface water development; from this perspective, farmers' livestock activities are easily affected by the impacts of climate change. According to SA Explorer (2017), Mpumalanga typically receives about 610 mm of rainfall per year, with the majority of rainfall occurring mainly in mid-summer. It receives the lowest rainfall (8 mm) in June and the highest (89 mm) in January.

Mean total rainfall is the average amount of rain a region receives during the rainy season. In the context of the study area, this period is from October to February. According to the map in Figure 5, there are four types of rainfall. The microclimates of Dzimauli, Tshakhuma and Tzaneen are very localized and small, but benefit from average rainfall greater than 650 mm. Farmers cluster around these localities to obtain a reliable water supply. Skukuza in Mpumalanga also receives significant rainfall in excess of 530 mm. Surprisingly, Mpumalanga is dominated by low rainfall, although the average annual rainfall suggests otherwise. Rainfall in this part only reaches 290 mm. Similar rainfall occurred on the northern edge of Limpopo, extending from Madimbo to Northam via Tshipise in the west of the province. Average rainfall between 290 and 530 mm occurs in the east, extending from the Kruger National Park and covering most of the area.

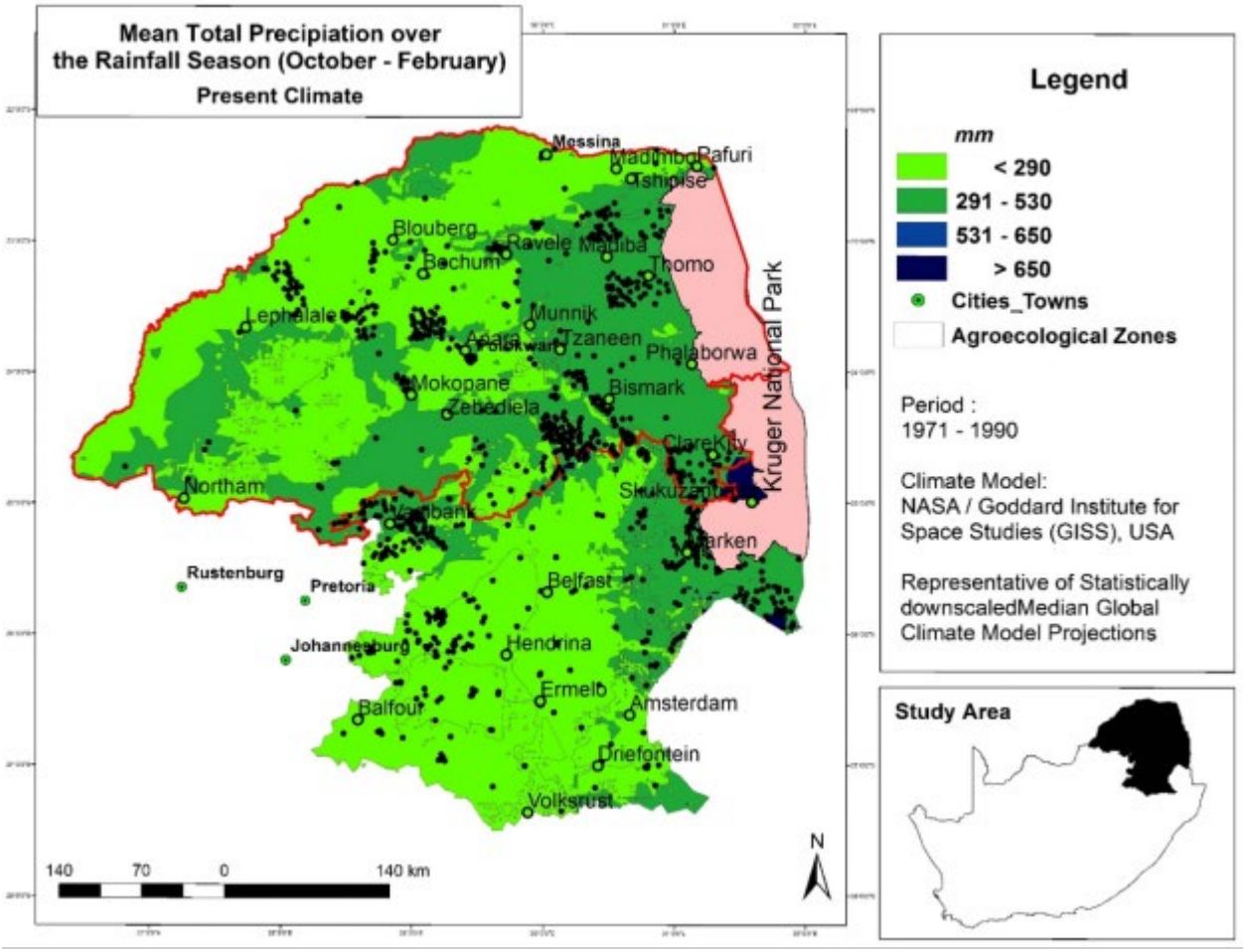

Figure 5: Mean total precipitation for the wet season

4.3.3 Temperature variability

There is a spatial agreement between rainfall and mean annual temperature. The east is generally warmer with temperatures above 24 °C (Figure 6). These temperatures cover the entire Kruger National Park. They also include towns a little further away from the national park, including Musina, The Lost City, and Bismark. The westward movement correlates with a decrease in temperature; temperatures in this part fluctuate between 20 °C–22 °C. The segments that include these temperatures also extend from western Musina to Northam, Lephalale, Swartwater, and Alldays (covering the entire Limpopo basin). Temperatures varied from 18 °C to 20 °C across central Limpopo province, including Vaalwater, Bochum, Tzaneen, and Elim. The cool part of the area matches the microclimate of the two provinces. The lowest average temperatures occurred across Mpumalanga province (Figure 6). Although summers are hot, average temperatures below 10 °C are normal. This implies that livestock susceptible to heat stress (such as dairy cows, beef cattle and

chickens) are most likely to occur in this area. Average maximum temperatures along Mpumalanga are relatively cooler than in Limpopo province. Maximum average temperatures of up to 38 °C spread throughout the space (Figure 6).

The overall average temperature in these regions is about 32 °C. This implies that it is possible to keep many types of livestock without subjecting them to heat stress. In contrast, much of Limpopo province has higher average temperatures.

This supports the view that the province is ideal for drought-tolerance and cold-intolerant livestock. This claim can be supported by the rise in goat farming in many parts of the province, the use of donkeys to plow fields, and the decline of livestock farming. It is generally accepted that climate change causes an increase in temperature and frequency of extreme weather events (Easterling et al., 2000; Seneviratne et al., 2012). The map in Figure 7 shows the spatial distribution of mean maximum temperatures in Limpopo and Mpumalanga. The map shows a general decrease in temperature from east to west. Global temperatures vary from below 30 °C to above 44 °C.

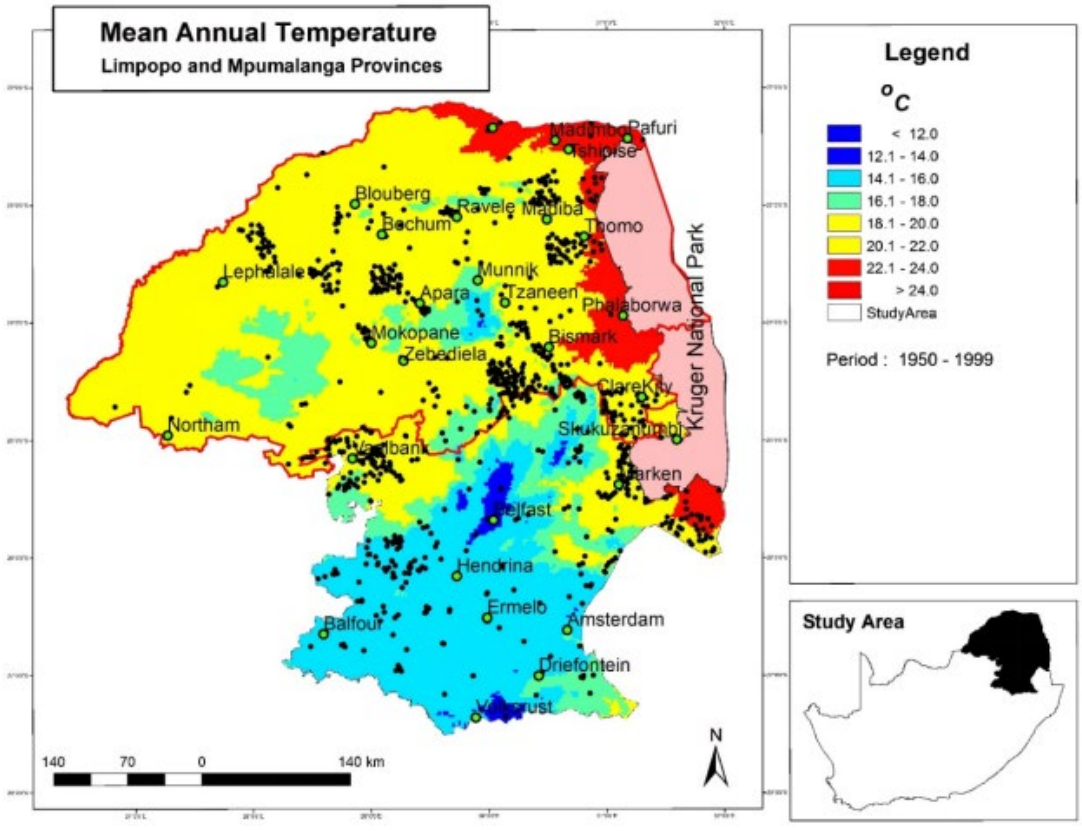

Figure 6: Spatial distribution of the mean annual temperature in Limpopo and Mpumalanga Provinces of South Africa

Climate change will have significant consequences for dairy, meat and wool production, mainly through impacts on pasture and grazing productivity. Heat exhaustion in animals will reduce the animal's food consumption and lead to poor growth (Rowlinson, 2008). According to Alkire (2009), livestock (cattle) appreciate temperatures between 10 °C and 26 °C.

What is surprising is that although livestock farming is the most dominant agricultural activity of smallholders, almost the entire Limpopo province does not have optimal conditions for livestock farming. It is a pity because livestock farming is by far the most practiced type of animal husbandry. This is in response to the high productivity associated with this agriculture. It is also a traditional tool for measuring wealth. Summer has temperatures that are too high, affecting livestock productivity. However, these conditions are ideal for raising goats and donkeys, even if the latter do not have a strong market.

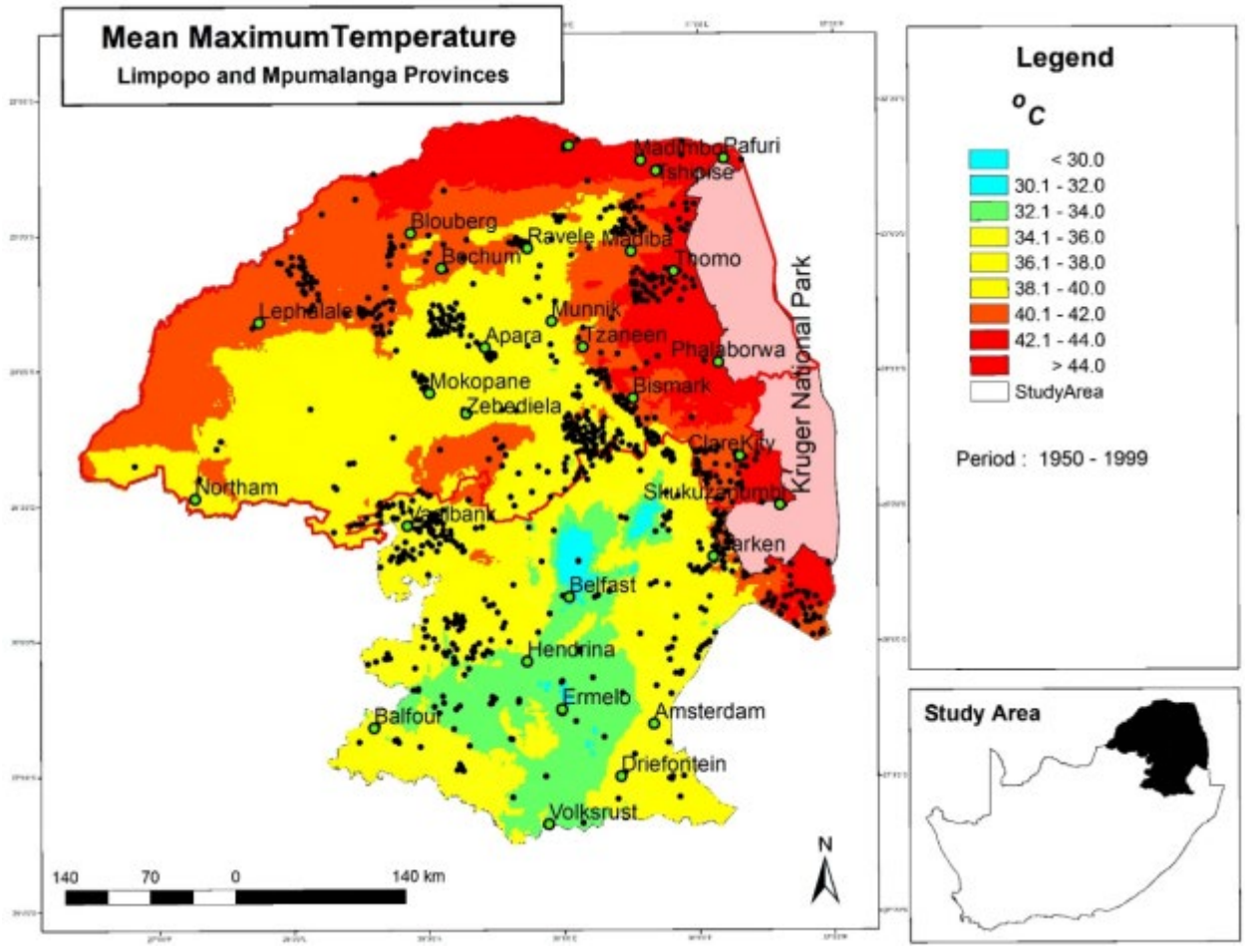

Figure 7: Mean maximum temperatures of Limpopo and Mpumalanga Provinces of South Africa

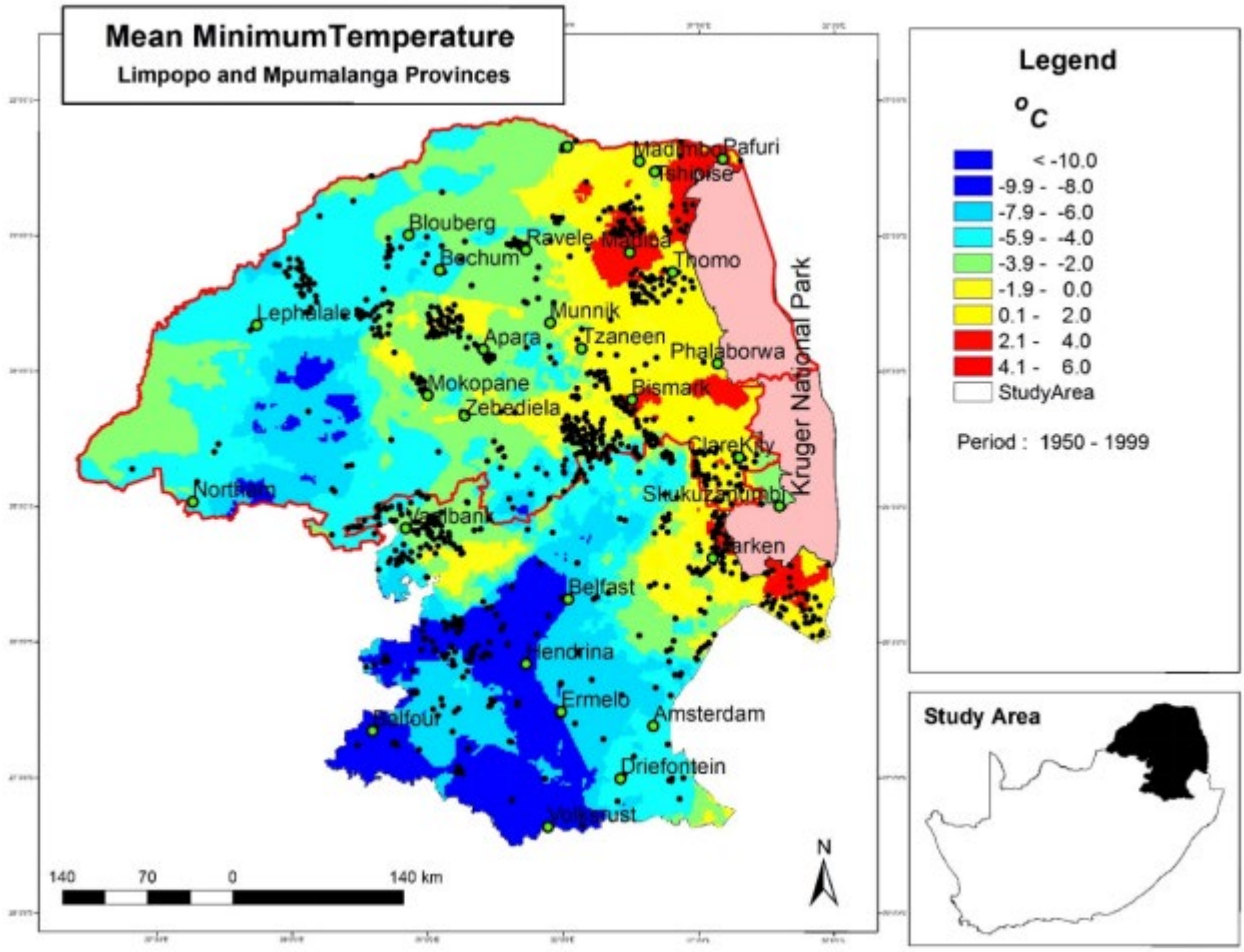

Figure 8: Mean minimum temperatures of Limpopo and Mpumalanga Provinces of South Africa

4.3.4 Climate projections

4.3.4.1 Comparison of the present and future climate projections

The future climatic projections were evaluated and subsequently compared to the present conditions to reflect the future of the Earth. Such a comparison is crucial to the empowerment of the smallholder livestock farmers. The two maps in Figure 9 depict the mean total precipitation over the rainfall season (October–February) for the present climate (on the left) and mid-century (2065) (on the right), over Limpopo and Mpumalanga Provinces. It was calculated using daily medium-term global climate model projections, using the approach that was refined by Lekalakala (2017). Climate and earth system models are used for a variety of purposes, from studying the dynamics of past weather and climate systems to predicting future climate. These models simulate the physics, chemistry and biology of the

atmosphere, land and oceans, and require massive supercomputers to produce climate forecasts. This value represents the average of statistical downscale model forecasts of daily climate conditions. ZAE is used as a spatial unit. According to the map on the right, precipitation is expected to increase mainly in the western part of the study area; this is because the selected or representative climate model shows a wetter climate than current conditions.

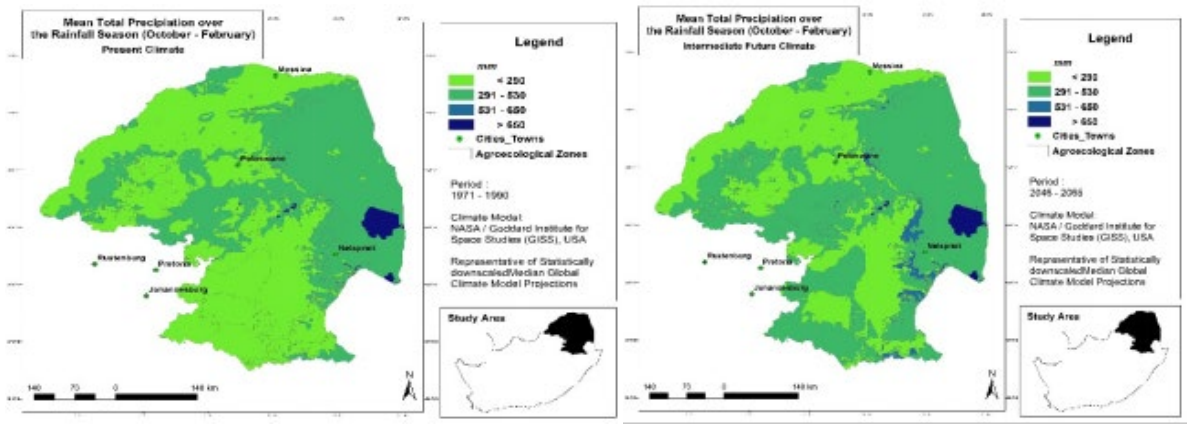

Figure 9: Mean total precipitation over the rainfall season (October–February) for the present climate (on the left) and mid-century (on the right), over Limpopo and Mpumalanga Provinces

The issuing of probabilistic future climate scenarios becomes a crucial instrument for decision-making. If the smallholder farmers adopt such a tool in their long-term planning, they are likely to reap the benefits. If a farmer needs to make a significant investment, then the projections become key. Although the projection may suggest the term in question is 2065, which may seem like the distant future, especially when considering that the majority of the economic people would have retired, smallholder operations are a family initiative. Therefore, investing beyond the timeline of a farmer is never an issue for concern.

4.3.4.2 The frequency of the 14 dry days during the rainy season

The map in Figure 10 shows the assemblage of the frequency of the 14 dry days during the rainy season (October to February) for the current climate (left) and the future climate (2065, right). The frequency of more than 14 dry days during a rainfall season is likely to decrease more than four times on a median rainfall season over most parts of the study area for the projected date. Such a decline is attributed to the increase in rainfall. This implies that, as much as there will be much more frequent

rainfall in some areas, there are places that will be undergoing crucial reductions in precipitation. If there is any prospect of extending an allocated slot for livestock farming, it will be unwise to focus on areas that are losing their rainfall intensity.

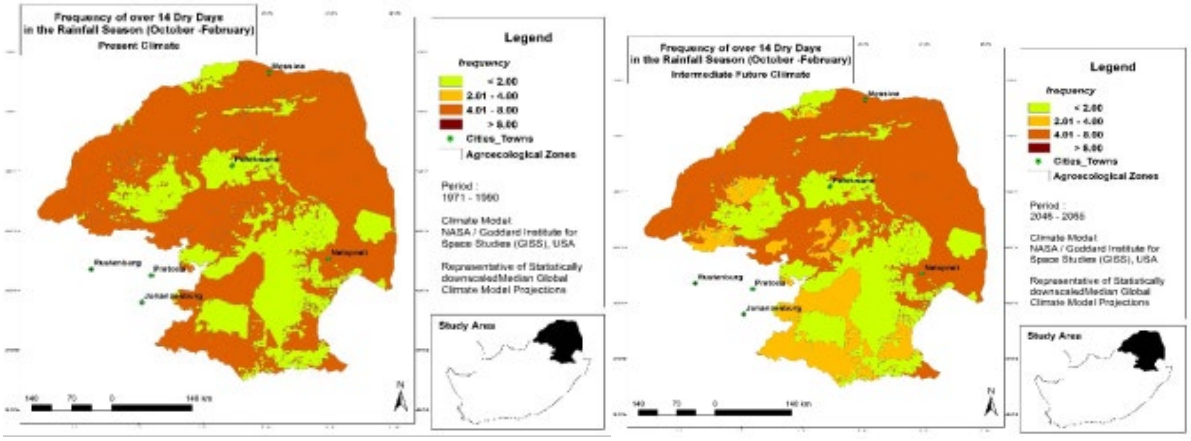

Figure 10: Mean frequency of more than 14 dry days over the rainfall season (October–February), present climate (on the left) and mid-century scenario (on the right)

4.3.4.3 Aridity index within agro-ecological areas

The study region includes the Limpopo and Mpumalanga provincial areas. These provinces are classified as semi-arid, with arid areas along the northernmost border between Limpopo and Botswana and Zimbabwe. The Food and Agriculture Organization of the United Nations (FAO) has established the agro-ecological zones with the mandate to classify the agricultural systems with detailed descriptive demarcation. Such a novel classification system depends on factors such as climate and vulnerability. Accordingly, the study area was divided into agro-ecological zones (AEZs) defined by latitude, altitude, and temperature, as well as seasonality and rainfall distribution throughout the growing season.

The high water-demanding activities in the study area may not be supported due to the prevalent agro-ecological zones. Nonetheless, there are four prominent agro-ecological zones that are classified as hyper-arid, arid, semi-arid and sub-humid. Due to the lower level of water resource availability, the situation can only be expected to worsen with climate change. This is mainly because the phenomenon tends to manifest through the general increase in temperature and drastic reduction of precipitation (DEA, 2013). This recognised significance would include the impacts of reduced water availability, increased occurrence of waterborne

and vectorborne diseases, incidence of invasive species, reduced crop yields, and pests, and many other issues related to human health (Rust & Rouille, 2013). Most of this phenomenon is due to the direct impact of increasing temperature regimes.

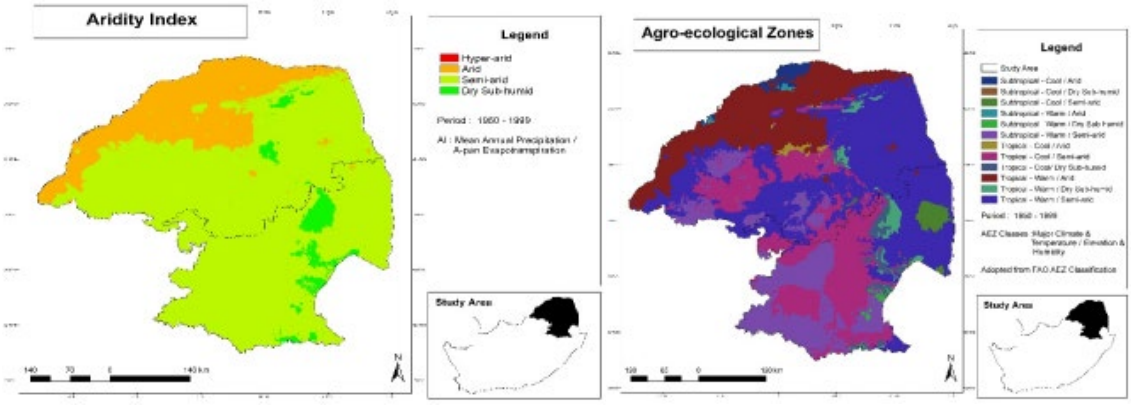

Figure 11: Climate characterization through the aridity index (left) and agro-ecological zones (right)

The aridity index is a numerical indicator that denotes the degree of dryness at a particular location based on the ratio of the evapotranspiration to the precipitation (Derya *et al*., 2009). Maliva and Missimer (2012) define aridity as a lack of moisture and a temporary reduction in the rainfall in an area; meanwhile, the increase in aridity represents a higher frequency of dry years over an area. The aridity indexes that are based on temperature and precipitation are commonly used all over the world (Baltas 2007; Deniz *et al*., 2011; Croitoru *et al*., 2013; Hrnjak *et al*., 2013; Moral *et al*., 2015). A map in Figure 11 portrays the aridity index of the study area.

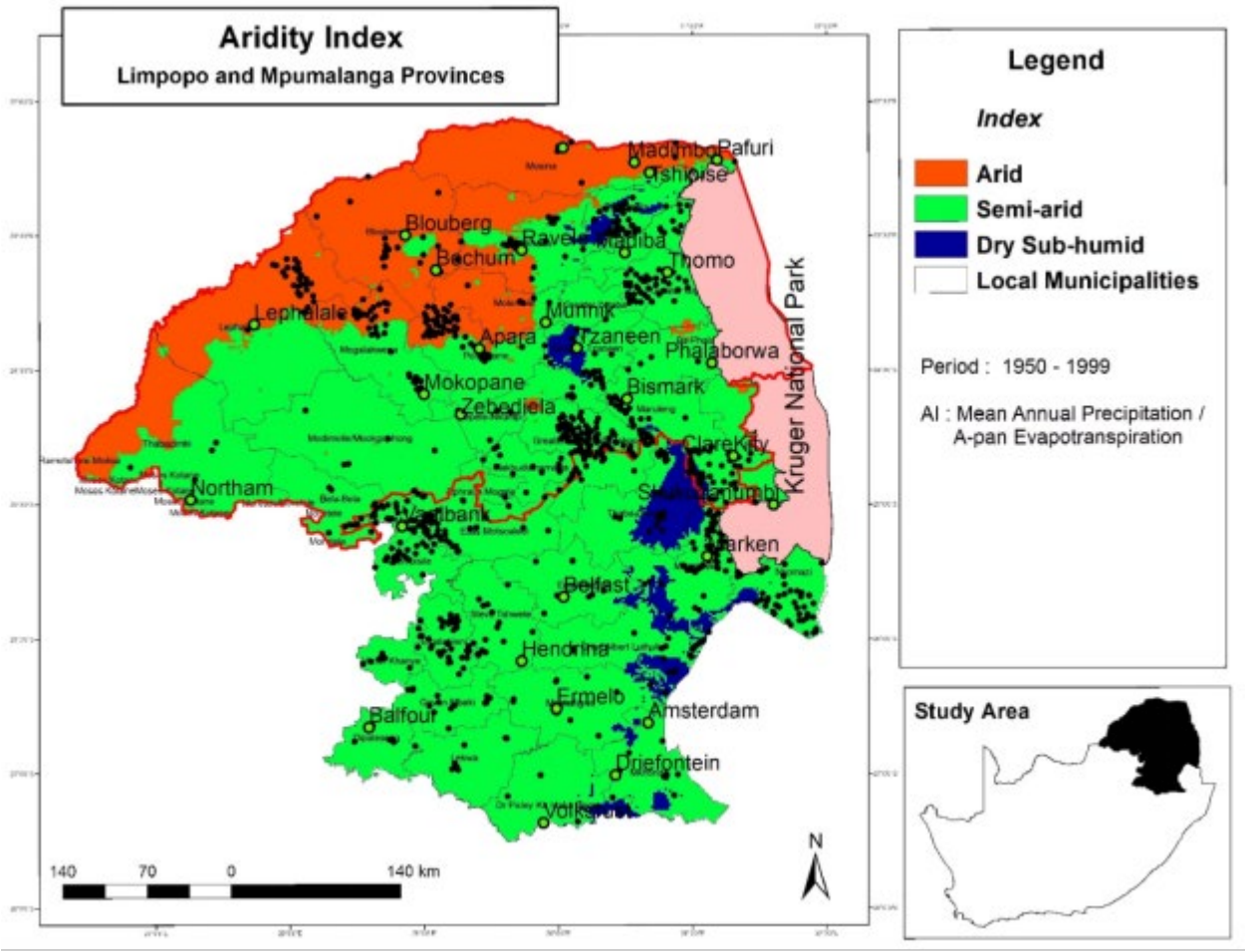

Figure 12: Spatial variability of the aridity index in Limpopo and Mpumalanga Provinces of South Africa

The aridity index values reflect that the study area may be categorised into three discrete subsections, namely the arid, semi-arid and dry sub-humid.

4.3.4.4 The arid area

The arid area stretches all the way from Thabazimbi to the east of Musina, forming an escarpment between the inland and the Limpopo River. According to Griffins, 1985, an arid area is characterised by a severe lack of water resources to the extent of hindering the development of plants and vegetation. Even the livestock may not thrive due to the lack of grazing in the area.

Such a lack is brought forth by the predominance of evapotranspiration over the rate of precipitation (Derya *et al*., 2009). Agricultural production in this category is impossible, with the exception of where there is irrigation, where the recharge of water resources is likely a greater challenge, as the extinction of the water resource

is likely to occur. This part of the area conforms to the Kalahari Desert. The mean maximum temperature map depicts that this section is amongst the hottest regions in the study area, while it is also amongst the driest.

It is logical to assume that no agricultural production is possible in this area; the section shares the boundary with the Limpopo River, which is one of the biggest rivers in Southern Africa. Although water resources to sustain the livestock can be withdrawn from the Limpopo River, the transboundary withdrawal of water from such a source is much more a political rather than a hydrological issue. Furthermore, cattle, as the main livestock production, cannot tolerate high heat stress in the area. In order to lower heat production, farm animals reduce their physical activity as well (Collin *et al*., 2001) and spend less time eating (Brown-Brandl *et al*., 2001). Feed refusal increases with body weight at high ambient temperatures (Quiniou *et al*., 2000). Higher temperatures tend to reduce animal feed intake and lower feed conversion rates (Rowlinson, 2008). Voluntary feed intake decreases curvilinearly with increasing environmental temperature, resulting in reduced animal performance (Collin *et al*., 2001). In these cases, cattle farming in this region is highly exposed to the detrimental effects of climate change.

Should farmers have operations in these areas, they should have already had plans pertaining to the development of the supplementary feeds, as grazing will not be available throughout the year.

4.3.4.5 Semi-arid area

Over 85% of the study area is recognised as a semi-arid area. The lowest mean annual rainfall and erratic precipitation patterns are the main factors that hinder farming in semi-arid regions (Aydın, 1995). Griffins (1985) defines the semi-arid regions as an area whose evapotranspiration exceeds the potential precipitation. Consequently, the area experiences extended spells of the dry season and shorter wet periods. The arid area is characterized by a severe lack of water resources to the extent of hindering plants and vegetation. South Africa is dominated by two seasons, namely winter and summer. In winter, the temperatures are cooler, which conforms to the ideal farming conditions. However, the water supply during this time is very marginal. Therefore, there is a need for water provision to sustain the livestock.

Groundwater is often an obvious alternative to address the insufficient water sources. Even when this is the case, boreholes are likely to fail at some point because of the deficiency in the groundwater recharge.

Pasture availability in this category is a critical issue of concern. This is mainly because it is rain-fed. During the extended spell of dryness, it does not recover and this subsequently strains the livestock. However, the livestock variability also translates to their water and pasture requirements. The animals that graze are likely to suffer the impacts more, while those that feed on bushes will flourish. The ideal livestock type will feed on bushes, which are drought-tolerant, while farmers who practice cattle farming are more exposed to the impacts of climate change.

4.3.4.6 The sub-humid area

The dry sub-humid areas are ideal agricultural zones. Farming in this area is possible with the sole dependence on rain-fed practices. While this area is not immune to drought, dry spells are, however, infrequent. This portion constitutes about 5% of the entire study area. The patches making up this class occur along Thohoyandou, Levubu, Greater Tzaneen, Mbombela, Thaba Chweu, and Chief Albert Luthuli, which conform to the microclimatic regions of the Limpopo and Mpumalanga Provinces. The majority of the commercial farms and agricultural hubs are located within these patches. The sub-humid area is attributed to relatively warm temperatures in comparison with the surrounding environment and comparably higher precipitation. Rainfall becomes a significant contributing factor to the water resource availability. Subsequently, rainfall intensity of over 1,000 mmpa yields to the development of the perennial streams. Pasture is mostly available and rejuvenates following precipitation. Despite these, for the most part, it runs out in response to over-grazing as grazing capacity is often exceeded.

4.4 EARLY WARNING SYSTEM

Wigmore (2019) defined the early warning system as the technology and associated policies and procedures designed to predict and mitigate the harm of natural and anthropogenic disasters and other undesirable events. An early warning system is critical for forecasting disasters prior to their occurrence. In livestock farming, this

enables the authority in place to trigger the relevant procedures and resources in the combat of the disaster. It is essential in the marginalisation of the impacts of climate change. Two approaches are generally involved in the interpretation of early warning signs, which are traditional and scientific techniques. The former is often undocumented and passed on from one generation to the next, and is often practiced at a family or community level.

Table 7 shows the frequencies and the percent of the availability of the early warning system and operational level in Limpopo and Mpumalanga to smallholder farmers. Most of the smallholder livestock farmers (80.77%) do not have any mode of an early warning system. A further 16.76% are not aware of any early warning system, with only 2.47% being aware. Out of those aware of the early warning system, they classified the system into the key stakeholders responsible. Disaster management was reported to be the most well-known early warning system provider at 57.14%. Secondly, the dryness of streams was also an imperative indicator of the start of the drought by 28.57%. Lastly, 14.29% are reliant on the local radio for weather forecasting. In addition, the District Municipality offers an early warning system in the form of weekly and three-monthly weather forecasting. Only a single respondent reported each of the two initiatives.

The inexistence of the early warning system implies that the farmers must absorb the entire shock of the impacts. In this regard, they are highly exposed to the impacts of climate change. Ninety-six percent of the respondents were not entirely informed when the early warning systems were installed. Only 2% outlined that the systems were introduced between 2016 and 2017 concurrently. However, 43.24% indicated that the existing systems are not effective. A further 54.73% were not sure if the system was informative. Only 2.03% believe that the early warning is an effective tool to get them prepared for the increasing of the drought. To curb the dissatisfaction of the farmers with the efficiency of the existing systems, the livestock farmers (30%) require early warning education to stay alert. According to 40% of them, the dissemination of the information is also critical to be prepared to combat climatic extremes. Also, 20% are unaware of how the system should be improved. The limited information on the early warning system implies that most smallholder farmers are caught off-guard when such events unfold. Subsequently, they must absorb the total impacts

of the extreme event due to their unpreparedness. These, therefore, indicate that smallholder farmers are highly exposed to the impacts of the climate extremes that occur after climate change.

Based on the consultations with key agricultural advisors, the early warning system of government is operational and effective at a level of less than 30 percent. The main challenge is the capacity of the government at the provincial level to deliver on the three key areas of the broader Disaster Management function, namely Early Warning, Risk Assessment and Disaster Recovery. Weather and seasonal forecasts are developed and sent to the provinces for dissemination to the end-user, who is the smallholder farmer. Provinces, in the main, have officials at the provincial level, but no dedicated human capacity in districts and local municipalities where the early warning information is supposed to be circulated. Early warning and disaster-related matters have not been fully assimilated into the organograms of the Department of Agriculture in the provinces. Agricultural advisors also need to be trained on Early Warning systems, whilst being assigned functions of disaster management individually and collectively.

Table 7: Frequencies and respective percentages of smallholder farmers' perception of the availability of the early warning system

Availability of Early Warning System		Frequency	Percent
Early warning system?	No	294	80.77
	Not sure	61	16.76
	Yes	9	2.47
	Total	**364**	**100**
National	Disaster management	4	57.14
	Dryness of streams	2	28.57

Availability of Early Warning System		Frequency	Percent
	Local FM Radio (weather)	1	14.29
	Total	**7**	**100**
District	Disaster Management	1	1
	Distance Management	1	1
	Total	**2**	**2**
When was the system established?	2016	1	0.66
	2017	2	1.32
	No	2	1.32
	Not sure	146	96.69
	Total	**151**	**100**
Does the early system function effectively?	No	64	43.24
	Not sure	81	54.73
	Yes	3	2.03
	Total	**148**	**100**
What functions of early warning should be improved?	Drill own borehole	1	10
	Don't know	2	20

Availability of Early Warning System	Frequency	Percent
Information Availability	4	40
Early warning Education	3	30
Total	**10**	**100**

4.4.1.1 Contingency

Since the livestock smallholder farmers lack a robust early warning system, it is only logical that the impacts of the climatic extremes are always in proportion to the phenomenon itself. Therefore, the farmers are usually caught unprepared to deal with such events and have a mountain to climb as a result. Table 8 shows the frequencies and the percentage of the contingency to curb the impacts of climate change on the livestock.

Table 8: Frequencies and respective percentages of smallholder farmers' perception of the availability of Climate Change Contingency plans

Availability of Contingency Plans	Frequency	Percent
No	308	84.38
Yes	57	15.62
Total	**365**	**100**

In spite of the absence of the early warning system, 84.36% of the livestock smallholder farmers indicated that there are no contingency plans to alleviate the impacts of climate change on their farms. Only 15.62% have some sort of plan in place to mitigate the impacts of climate change. This implies that the farmers

absorb all the impacts of the disaster when they strike. This translates to financial losses in the form of livestock death when there is a disaster impending. This requires a serious need for disaster preparedness seminars. The respondents who confirmed the existence of the contingency plan also revealed the intrusive aspects of the plan. Table 9 indicates the evolution that the contingency plan had undergone to deal with the recent challenges. Out of 54 interviewees who responded to this section, (79.63%) indicated that the contingency in place has undergone transformation within the past 5–10 years. This illustrates an attempt to stay relevant to marginalize the impacts of climate change. We are in a global world that is moving very fast; in response, an approach that was established 10 years ago would be outdated today. However, 20.37% insisted that the contingency plans have not been modified since inception. This would not be ideal to curb recent challenges. Although the study focused on the contingency to address climate change, the respondents leaned their response towards the drought.

Of those who indicated that improved aspects of the plan incorporate the provision of the feeds (71.11%), 2.22% are planning to drill a borehole, and 20% are not sure how the improvement should be coupled to their existing models. Some (4.44% and 2.22%) indicated that there was the provision of water resources and the erection of a dam, respectively.

Table 9: Frequencies and respective percentages of smallholder farmers' perception on the dynamic nature of the contingency plans

Contingency to climate change		Frequency	Percent
Has the contingency plan changed in the last 5–10 years?	No	11	20.37
	Yes	43	79.63
	Total	**54**	**100**
How did it change?	Providing feeds	32	71.11

Contingency to climate change		Frequency	Percent
	Plan to drill a communal borehole	1	2.22
	Not sure	9	20
	Water provision	2	4.44
	Building a dam	1	2.22
	Total	**45**	**100**
Describe how the contingency plan has changed	Because of climate change	7	15.56
	Lack of grazing area	31	68.89
	Lack of water	2	4.44
	Others	5	11.11
		45	100
Does the contingency plan include agriculture and food security?	No	345	96.64
	Yes	12	3.36
	Total	**357**	**100**

Four issues were cited for the alterations and adjustment of the contingency plans as answered by 45 respondents. The intensification of climate change was outlined

by 15.56%, 68.89% revealed a lack in the grazing area, while 4.44% and 11.11% suggested a lack of water and other reasons for the evolution of the approach. Agriculture and food security were not part of the contingency (96.64%), while 3.36% suggested otherwise.

4.4.2 Early warning system in context

It can be concluded from the study that the Early Warning system of government is operational and effective at the level of less than 30 percent. The main challenge is the capacity of the government at provincial level to deliver on the three key areas of the broader Disaster Management function, namely Early Warning, Risk Assessment and Disaster Recovery. Weather and seasonal forecastings are developed and sent to the provinces for dissemination to the end-user who is the smallholder farmer. Provinces in the main have officials at provincial level, but have no dedicated human capacity in districts and local municipalities, where the early warning information is supposed to be disseminated.

Early warning and disaster-related matters have not been fully assimilated into the organograms of the Department of Agriculture in the provinces. Agricultural advisors also need to be trained on Early Warning systems, whilst being assigned functions of disaster management individually and as a collective. The study, based on smallholder farmers' perceptions suggests a need for strategic shifts from natural pastures to small-scale feedlots. The shift should be coupled with the need to establish a dedicated fodder bank as a specialized business. For the farmers to cope and adapt to climate change, there is a great need for an early warning system. The government should intervene by providing facilitated water and small-scale feedlot infrastructure for smallholder farmers.

4.5 CONCLUSIONS AND RECOMMENDATIONS

Limpopo and Mpumalanga exhibit a diverse array of climatological conditions that may not be optimal for livestock farming. The dawn of climate change is leading to the increasing frequency of dry spells and erratic rainfall patterns. Smallholder farmers need alternative grazing to sustain their livestock under the present conditions. The adoption of the climatological information bears the potential to

reduce the exposure of the smallholder farmers to the impacts of climate change; it helps the smallholder farmers to manage their practices accurately, based on the information at their disposal.

The climate information also reduces the loss associated with improper practices that expose the farmers to the impact of climate change. The farmers stand a better chance to commercialize their operations through the adoption of the appropriate preparedness plan and mitigation strategies.

CHAPTER 5 - THE DEVELOPMENT OF FODDER FLOW PLANS AND GAPS TO BUILD RESILIENCE AGAINST DROUGHT

5.1 INTRODUCTION

Approximately 80% of South Africa's land surface is classified as semi-arid to arid, of which 82% is used for agricultural activities. Only 14% of the available agricultural land receives sufficient rainfall for arable crop production, with the remainder of the agricultural land being used for extensive livestock production, forestry and wildlife/nature conservation (DEA 2011). Under these semi-arid and arid conditions, the most extensive agricultural activities are livestock (sheep, goats, cattle and ostriches) farming under rangeland conditions where livestock make use of the natural veld. However, along with low annual precipitation, these semi-arid and arid rangelands are, in many instances, also subjected to recurrent droughts, cyclic long-term droughts, extreme temperatures, marginal edaphic conditions and encroaching woody species (DEA 2011).

Woody plant encroachment (also called bush or shrub encroachment) is the replacement of grasses by trees or shrubs. Tree and shrub densities have increased in many areas of southern Africa by 30–50% (Ward 2005; Kraaij and Ward 2006; Tjelele et al. 2015a). Furthermore, indigenous woody plants and alien invasive plants are causing billions of rands of damage annually to South Africa's economy—and probably other developing countries—through their negative impacts on water resources, grass production and biodiversity. This, in turn, forces farmers to put pressure constantly on the already degraded rangeland resources, which results in farmers, especially the emerging (small-scale and communal) farmers, often experiencing low livestock productivity; this is due to their over-dependence on poor quality and inadequate feed supply from these natural pastures (Müller et al. 2019). These challenges exacerbate land degradation and worsen the poverty of farmers and communities who are relying on farming as a source of income.

Although there have been numerous studies on woody plant encroachment (Smit 2004), these studies have not yielded a broad understanding of the problem and an integrated approach to managing increasing woody plant dominance

(Wiegand et al. 2006). The cost to clear bush exceeds the immediate and/or long-term benefits of increased agricultural productivity.

Cleared woody vegetation material is often not used despite a shortage of feed for livestock by smallholder farmers, particularly during times of feed scarcity. Smallholder and resource-poor livestock producers occasionally use protein-rich supplementary feeds and concentrates during these dry periods to supplement the poor veld condition; these sources are often expensive and inaccessible to financially-constrained farmers. There is, therefore, a pressing need to create increased value from harvested bush, i.e. strategic supplementation or use of encroaching woody species in diet formulation for livestock, which has the potential to strategically control the increasing woody plant encroachment and improve livestock production.

Thus, it is important that farmers develop a culture of establishing fodder banks (within their farms) which can be used strategically during periods of limited feed supply, to promote all-year-round fodder flow within the constraints imposed by climate (erratic rainfall) and sustainable utilization of natural resources (soil and veld). This will further help to relinquish farmers' dependency on government fodder-provision subsidies. A fodder bank is an integral component of sound veld management practices as the availability of such a unit on a farm helps alleviate pressure on the valuable, yet vulnerable, veld resources. It represents the only reliable counter to disruption of the fodder flow caused by drought and other calamities. The other added benefit of a fodder bank is that it reduces the use of expensive concentrates. The overarching objectives of this study are to match the production capabilities of the farm with the animal's requirements (fodder-flow planning), specifically to 1) evaluate the quality of *V. nilotica* fodders with and without seed pods and the inclusion of feed additives; and 2) to explore the possibility of ensiling chipped *V. nilotica* shoot material.

These are envisaged to combat the increasing bush encroachment while increasing the production of palatable grasses—improving livestock production, improving the socio-economic (including income generation) factors and building resilience to mitigate the impact of drought within the specific agro-ecosystems.

5.2 METHODOLOGY

5.2.1 Seed collection, preparation and initial viability screening

Vachellia nilotica seed pods were hand-picked at the Agricultural Research Council (ARC) Roodeplaat Experimental Farm (28_190 E, 25_350 S) in Pretoria, South Africa. Seed pods were separated from the shoots and stored in a cool, dry area pending feed formulation. Five replicates of whole seed pods were weighed to a mass of 250 g, and the number of seed pods within each replicate was counted (Lacey et al. 1992; Tjelele et al. 2015). Thereafter, the seeds were extracted from the seed pods, and the number of seeds was counted. Secondly, an additional ten replicates of 250 g seed pods were chipped using a Tandem 6.5 hp chipper, and the number of whole seeds (i.e., undamaged seeds) recovered was quantified after chipping. Then, a representative number of chipped and unchipped seeds were used to determine the initial viability of the seeds. Thirdly, the unchipped seeds were sacrificed by clipping the seed coat with a clipper to expose the embryo. The seeds were immersed in a 1% Tetrazolium chloride solution (3,5-triphenyl chloride) for 18 hours in a dark germination chamber and stored at room temperature. To reveal the embryo, each seed was longitudinally dissected through the endosperm, and evaluated for staining through a light microscope (ISTA, 1985; 2012). Seeds that stained red were regarded as viable, while unstained seeds were regarded as dead.

5.2.2 Feed creation and nutritional quality determination

Edible *Vachellia nilotica* shoots consisting of edible branches and leaves (30 cm long and approximately 1 cm in diameter) were harvested using the tree pruner at the end of the wet season (March–April 2021) at the fruiting stage (i.e., plants with seed pods). During this time, all plant material still containing green leaves was harvested, but the seed pods were harvested towards the end of this period at maturity. The shoots and pods were collected from 70 different trees; seed pods were collected when mature and dry, and were kept separate from shoots and merged differently to form a composite sample. The samples of shoots were chipped using a wood chipper (Tandem 6.5 hp chipper/shredder) and mixed thoroughly to obtain a uniform mixture. A uniform sample of 250 g chipped shoots

was used as the base, and chipped seed pods were included in a 4:1, 4:2, 4:3 and 4:4 ratio. For each feed treatment created, the seed pods were chipped separately and included in the chipped shoots and mixed. Four replicates of each treatment were developed, as well as two control treatments, which consisted of only 250 g chipped shoots and another consisting of only 250 g chipped seed pods. Additionally, a feed additive (Voermol LS33) at a recommended rate of 800 mL/10 kg for the small stock was added in all six treatments, resulting in a total of 12 feed treatments (i.e., six with the feed additives and six without). A sub-sample of 150 g of each feed was collected, oven-dried at 60 °C until a constant mass was achieved and milled to pass through a 3 mm mesh and stored for chemical analyses. From the dried and milled feed samples, a 0.5 g sub-sample was digested using a technique described by Zasoski et al. (1977).

5.2.3 Collection of forage material and ensiling procedure

Fresh plant materials (shoots and seed pods) of *Vachellia nilotica* were harvested separately and chipped at the ARC–Roodeplaat Experimental Farm, which is in Pretoria, South Africa. Edible branches of 30 cm length and a maximum stem diameter of 1 cm were harvested from several *V. nilotica* plants in the wet season using a tree pruner. The harvested plant materials were chipped with a wood chipper (Tandem 6.5hp chipper/shredder) to pass through a 1 cm sieve size. The chipped *V. nilotica* plant materials were mixed thoroughly to obtain a uniform mixture. The chipped and uniformly mixed plant materials were subjected to silage additives (molasses syrup) before ensiling. The additives were added to the chipped materials to achieve four treatment applications: (1) control (shoots only with no molasses), (2) shoots + seed pods (without molasses), (3) shoots + molasses (without seed pods), and (4) shoots + molasses + seed pods. Molasses was added at a recommended inclusion level of 4% (w/w) as part of the plant materials to increase the amount of WSC, which serves as a substrate for the production of lactic acid during the ensiling processes. Molasses has a high viscosity, and to enable ease of its application over the chipped plant materials, it was mixed with warm water at a ratio of 1:2 (w/w). Therefore, 360 g of molasses was mixed with 720 g of distilled water to obtain a mixture of 1,080 g, and applied to 9 kg of fresh plant materials per treatment before ensiling. To ensure uniform application of moisture for all

treatments, the control was treated by applying 1,080 g of distilled water on 9 kg of fresh *V. nilotica* chipped materials. The chipped and uniformly mixed materials were ensiled in 1.5 L anaerobic glass jars (J. Weck, GmBHu. Co., Wehr-Oflingen, Germany) equipped with lids to enable gas release. A total of 48 jars were filled (i.e., 12 jars/treatment) with the chipped materials and stored at a room temperature of 25˚C. Therefore, the chipped plant materials were ensiled in a completely randomized design with three replicates per treatment. Three jars per treatment were opened on days 3, 7, 21, and 60 to determine fermentation characteristics.

After 60 days of ensilage, the aerobic stability of the *V. nilotica* plant silage was determined by aerobic exposure of the silage for five days based on the protocol described by Ashbell et al. (1991).

5.2.4 Chemical analyses of pre-ensiled and ensiled plant materials

Triplicate samples were collected from pre-ensiled plant materials of each treatment for the determination of chemical composition. Furthermore, triplicate samples were collected from each treatment for the determination of fermentation characteristics, aerobic stability and chemical composition of the *V. nilotica* silage. Samples of the silage were also collected for the determination of pH, WSC, volatile fatty acids (VFAs), lactic acid (LA) and ammonia-N (NH_3-N) and prepared according to the protocol described by Suziki and Lund (1980). Water-soluble carbohydrate content was determined by the phenol-sulphuric acid method according to Dubois et al. (1956) and LA was determined by the colorimetric method of Barker and Summerson (1941) as modified by Pryce (1969). Volatile fatty acids were determined with a variant 3,300 Flame Ionization Detector (FID) gas chromatograph (Varian Associates, Inc., Palo Alto, CA, USA) by the procedure of Suziki and Lund (1980). Ammonia-N was determined by distillation using a Buchi 342 apparatus and a Metrohm 65 Dosimat with an E526 titrator according to the Association of Official Analytical Chemists (AOAC) (ID 941. 04, 2016). The technique was based on the method of Pearson and Muslemuddin (1968) for determining volatile nitrogen. Carbon dioxide production, yeast, and mold counts were determined from the aerobically exposed silage at day 60, based on the protocols described by Ashbell et al. (1991). Counts of yeast and mold were conducted

according to ISO 21527-1 (2008). The lactic acid bacteria (LAB) count was conducted according to ISO 15214 (1998). The DM content of fresh *V. nilotica* plant materials and silage was determined by drying the samples at 60 °C until a constant weight was achieved, and only the DM of silage samples was corrected for the loss of volatiles by using the equation of Porter and Murray (2001). After drying, samples from fresh *V. nilotica* plant materials and silage were ground to pass through a 1 mm sieve size (Wiley mill, Standard Model 3, Arthur H. Thomas Co., Philadelphia, PA, USA) for chemical analyses. Acid detergent fiber (ADF) content of fresh V. nilotica plant materials and silage samples were determined using a Fibertec System 1010 (FOSS Analytical AB, Sweden) by boiling samples in an acidic solution followed by filtration (ID 973.18, AOAC, 2016; 2019). Neutral detergent fiber (NDF) content of fresh V. nilotica plant materials and silage samples were determined by using amylase and sodium sulphate (Van Soest et al. 1991).

For mineral analysis, a 0.5 g sub-sample was digested using a technique described by Zasoski et al. (1977). After digestion, an aliquot of the digested solution was used for the determination of calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), sodium (Na), manganese (Mn), iron (Fe), zinc (Zn) and copper (Cu) using an ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometer-Agilent 725 (700 Series), Agilent Technologies, Santa Clara, CA, USA). The ICP-OES can determine the quantity of each element in each sample simultaneously. Before analyses, the instrument was calibrated against a series of standard solutions containing all the elements of interest in alignment with the operating procedures of the manufacturer. Furthermore, 8–12 g of the plant samples were used to determine the total nitrogen (N) concentrations using the dry oxidation method (Timener and Ladha 1993, Majejovic 1995) in a Flash 2000 CHNS-O Analyzer (Thero Scientific, Waltham, MA, USA). For each analysis, the instrument was calibrated against a known standard (Phenylalanine), which contained 8.48% N. Total N was converted to CP by multiplying %N by 6.25 (Meissner 2000).

5.3 RESULTS AND DISCUSSIONS

Browse plants, such as *V. nilotica,* are major sources of livestock feed during the dry season, partially due to their ability to retain their nutritional value during such dry

seasons (Aruwayo and Adeleke, 2020), contrary to grasses. This, along with their rate and extent of encroachment, has the potential to be a good alternative source of feed for livestock.

At the end of the active growing period, the nutritional value of browse plants may not be sufficient to sustain livestock. An example of this is reported by Britz et al. (2022), who indicated that the maturing of browse plants resulted in a decline in the nutritional quality in terms of their mineral nutrients, digestibility, protein and energy content. Thus, the best time to harvest the material for fodder is during the vegetative or early reproductive stages (Ravhuhali et al. 2020; Muzengi et al. 2020; Britz et al. 2022). However, other studies have shown that some of the browse seed pods during the end of the wet season have higher nutritional value and could be used to improve the quality of the fodders created by these encroaching tree species (Mlambo et al. 2004; Uguru et al. 2014; Mokoboki et al. 2019; Ravhuhali et al. 2020; Muzengi et al. 2020). These findings are under the findings of the current study, where results indicated that seed pods generally contained relatively higher quality mineral nutrients, CP and lower amounts of fiber, and, therefore, increased digestibility and energy content compared to the edible shoots. Both seed pods and shoots in the current study contained sufficient concentrations of K, Ca, Mg, Fe, Mn, Zn, Cu and CP to meet the minimum requirements of 5–15 g/kg, 1.8–10 g/kg, 1 g/kg, 0.03–0.1 g/kg, 0.02–0.04 g/kg, 0.02–0.05 g/kg, 0.005–0.1 g/kg and 7–8%, respectively (Table 10), to maintain livestock condition (Meissner, 2000; Meissner et al., 2000).

The fiber content in the shoots of *V. nilotica* had 28% (ADF) and 29% (NDF), and the seed pods had 39% (ADF) and 48% (NDF), which both fall within the adequate range of 19–40% ADF and 25–40% NDF for normal rumen functions (Van Soest et al. 2008; McDonald et al. 2010; Uguru et al. 2014; Spencer, 2018). Small ruminants such as goats and sheep require high concentrations of degradable fiber in their daily diets for rumen function (Spencer, 2018). However, a high level of fiber is often associated with decreased forage intake (Rinehart, 2008; McDonald et al., 2010; Spencer, 2018). Furthermore, forages with a digestible dry matter (DDM) content of greater than 60% are regarded as high-quality forages, as intake will not be impacted (Van Soest et al. 1991; Spencer, 2018).

According to the study results, the *V. nilotica* shoots alone contained 58% DDM while the seed pods had a DDM content of 66%, indicating the importance of the inclusion of the seed pods in livestock diets. The energy content of the *V. nilotica* shoots and seed pods individually was sufficient to sustain the energy requirements for small ruminants (goats/sheep) during the dry season (Meissner, 2000). In addition, both shoots and seed pods had sufficient metabolizable energy (ME) content to meet the energy requirements of lambs up to 20 kg (3.9–10.5 MJ kg–1 DM) as well as those of 40–60 kg dry ewes (7.6–10.2 MJ kg–1 DM). However, neither shoots nor pods were found to have sufficient ME content (14.5–17.7 MJ kg–1 DM) to sustain pregnant and lactating (15.5–19.4 MJ kg–1 DM) ewes. The nutritional value of shoots with the addition of seed pods was found to be higher compared to shoots alone, and it contained sufficient levels of mineral nutrients, CP, digestibility and energy content to maintain livestock conditions during the dry season (Meissner, 2000; Meissner et al., 2000; Rinehart, 2008). Furthermore, the addition of seed pods to the shoots improved the mineral nutrient content of the forages and was found to meet the minimum requirements to maintain small stock conditions. This was true for all mineral nutrients, except for P and Na, which were below the minimum requirements levels of small stock (Meissner, 2000; Meissner et al. 2000). Moreover, the addition of the feed additives to the pure seed pods and pure shoots further increased the nutritional quality of the *V. nilotica* shoots, resulting in a CP content that was suitable for maintaining highly productive livestock herds, which have a minimum requirement of 13–14% CP.

Table 10: Mean (±SEM) mineral nutrient content in experimental diets created from V. nilotica shoots and seed pods with or without the addition of a feed additive (Voermol LS33). Different letters for each variable measured indicate statistically significant differences ($p \geq 0.05$) between different experimental diets within a column. P = probability, F = ratio of statistics

Experimental Diet	N%	K g/kg	Ca g/kg	Mg g/kg	P g/kg	Na g/kg	Fe g/kg	Mn g/kg	Zn g/kg	Cu g/kg
100% seed pods	2.2 ± 0.1^{b}	16.1 ± 0.3^{f}	5.8 ± 0.3^{a}	16.7 ± 0.2^{cd}	1.7 ± 0.1^{f}	0.1 ± 0.003^{a}	0.06 ± 0.003^{a}	0.02 ± 0.001^{a}	0.03 ± 0.001^{b}	0.01 ± 0.0004^{a}
100% shoots	1.1 ± 0.1^{a}	6.7 ± 0.1^{a}	6.4 ± 0.4^{a}	11.6 ± 1.6^{ab}	0.7 ± 0.1^{a}	0.2 ± 0.003^{a}	0.16 ± 0.02^{bc}	0.03 ± 0.005^{bc}	0.03 ± 0.001^{a}	0.01 ± 0.0004^{b}
4:1 (shoots: seed pods)	1.5 ± 0.01^{a}	8.6 ± 0.2^{b}	6.6 ± 0.2^{a}	14.3 ± 1.3^{bc}	0.8 ± 0.03^{b}	0.1 ± 0.004^{a}	0.18 ± 0.02^{bcd}	0.03 ± 0.004^{c}	0.02 ± 0.001^{a}	0.01 ± 0.0011^{b}
4:2 (shoots: seed pods)	1.4 ± 0.02^{a}	10.0 ± 0.2^{c}	6.2 ± 0.03^{a}	12.6 ± 0.1^{ab}	0.9 ± 0.01^{bc}	0.2 ± 0.01^{a}	0.19 ± 0.02^{cd}	0.03 ± 0.001^{bc}	0.03 ± 0.001^{ab}	0.01 ± 0.0003^{b}
4:3 (shoots: seed pods)	1.5 ± 0.03^{b}	10.7 ± 0.03^{cd}	5.8 ± 0.1^{a}	11.8 ± 0.3^{a}	1.0 ± 0.02^{de}	0.2 ± 0.01^{a}	0.16 ± 0.03^{bc}	0.03 ± 0.002^{ab}	0.03 ± 0.0004^{a}	0.01 ± 0.0005^{b}
4:4 (shoots: seed pods)	1.5 ± 0.04^{b}	10.7 ± 0.03^{cd}	5.1 ± 0.2^{a}	12.2 ± 0.5^{ab}	1.1 ± 0.01^{e}	0.2 ± 0.01^{a}	0.15 ± 0.004^{bc}	0.03 ± 0.001^{ab}	0.02 ± 0.001^{a}	0.01 ± 0.0005^{b}
100% seed pods + LS33	2.5 ± 0.04^{c}	17.4 ± 0.3^{g}	5.7 ± 0.3^{a}	20.3 ± 0.2^{f}	1.6 ± 0.1^{f}	1.5 ± 0.2^{b}	0.08 ± 0.002^{a}	0.04 ± 0.001^{c}	0.04 ± 0.002^{c}	0.01 ± 0.0005^{b}
100% shoots + LS33	2.3 ± 0.01^{b}	11.1 ± 0.1^{d}	8.3 ± 0.1^{a}	22.9 ± 1.0^{g}	0.9 ± 0.03^{cde}	2.1 ± 0.1^{c}	0.23 ± 0.01^{cd}	0.07 ± 0.004^{f}	0.05 ± 0.002^{c}	0.02 ± 0.0013^{d}
4:1 (shoots: seed pods) + LS33	2.1 ± 0.18^{b}	13.0 ± 0.6^{e}	6.5 ± 0.1^{a}	19.7 ± 1.2^{ef}	0.9 ± 0.02^{bc}	2.6 ± 0.4^{d}	0.19 ± 0.01^{cd}	0.06 ± 0.003^{e}	0.06 ± 0.004^{d}	0.02 ± 0.0003^{cd}
4:2 (shoots: seed pods) + LS33	1.9 ± 0.03^{b}	13.2 ± 0.3^{e}	5.7 ± 0.2^{a}	18.2 ± 0.3^{def}	1.0 ± 0.1^{e}	1.7 ± 0.1^{bc}	0.16 ± 0.01^{bc}	0.05 ± 0.001^{d}	0.05 ± 0.001^{c}	0.01 ± 0.0006^{c}
4:3 (shoots: seed pods) + LS33	2.0 ± 0.03^{b}	13.9 ± 0.4^{e}	5.7 ± 0.1^{a}	17.3 ± 0.3^{de}	1.1 ± 0.02^{e}	1.9 ± 0.1^{bc}	0.15 ± 0.01^{bc}	0.05 ± 0.001^{d}	0.05 ± 0.003^{c}	0.01 ± 0.0004^{c}
4:4 (shoots: seed pods) + LS33	2.0 ± 0.11^{b}	13.8 ± 0.2^{e}	5.5 ± 0.2^{a}	17.7 ± 0.8^{de}	1.0 ± 0.1^{e}	1.8 ± 0.4^{bc}	0.14 ± 0.01^{b}	0.05 ± 0.003^{d}	0.05 ± 0.004^{c}	0.01 ± 0.0005^{c}

Experimental Diet	N%	K g/kg	Ca g/kg	Mg g/kg	P g/kg	Na g/kg	Fe g/kg	Mn g/kg	Zn g/kg	Cu g/kg
Significance	**$F_{(11,36)}$ =9.5 p ≤ 0.001**	**$F_{(11,36)}$=1 18.2 p ≤ 0.001**	**$F_{(11,36)}$ =1.0 p = 0.474**	**$F_{(11,36)}$ = 21.1 p ≤ 0.001**	**$F_{(11,36)}$= 54.0 p ≤ 0.001**	**$F_{(11,36)}$= 38.1 p ≤ 0.001**	**$F_{(11,36)}$=9. 5 p ≤ 0.001**	**$F_{(11,36)}$=3 2.9 p ≤ 0.001**	**$F_{(11,36)}$=3 2.3 p ≤ 0.001**	**$F_{(11,36)}$=16 .5 p ≤ 0.001**

N = Nitrogen, K = Potassium, Ca = Calcium, Mg = Magnesium, P = Phosphorus, Na = Sodium, Fe = Iron, Mn = Manganese, Zn = Zinc, Cu = Copper

Table 11: Mean (±SEM) crude protein, fiber, digestibility, and energy content in experimental diets created from *V. nilotica* shoots and seed pods with or without the addition of a feed additive (Voermol LS33). Statistically significant differences (p≥0.05) between different experimental diets are indicated by different letters for each variable measured. P = probability, F = ratio of statistics

Experimental Diet	CP%	ADF%	NDF%	DDM%	TDN%	DOM%	DFE Mcal/ kg	ME Mcal/ kg	NE_L Mcal/ kg	NE_M Mcal/ kg	NE_G Mcal/ kg
100% seed pods	13 ± 0.4^{de}	28.3 ± 0.9^{a}	29.3 ± 1.1^{ab}	66.1 ± 2.1^{de}	67.4 ± 0.6^{cd}	64.2 ± 0.6^{cd}	3.0 ± 0.03^{a}	2.6 ± 0.03^{b}	0.7 ± 0.01^{d}	2.3 ± 0.03^{a}	2.1 ± 0.03^{d}
100% shoots	7 ± 0.8^{a}	39.6 ± 2.9^{b}	48.6 ± 3.1^{e}	58.0 ± 2.3^{a}	60.1 ± 2.0^{a}	57.2 ± 1.9^{a}	2.7 ± 0.09^{a}	2.2 ± 0.09^{a}	0.6 ± 0.03^{a}	2.0 ± 0.10^{a}	1.7 ± 0.10^{a}
4:1 (shoots: seed pods)	9 ± 0.1^{b}	35.9 ± 0.8^{b}	39.7 ± 2.7^{d}	60.9 ± 0.6^{ab}	62.7 ± 0.6^{ab}	59.7 ± 0.5^{ab}	2.8 ± 0.02^{a}	2.3 ± 0.03^{a}	0.6 ± 0.01^{ab}	2.1 ± 0.03^{a}	1.8 ± 0.03^{ab}
4:2 (shoots: seed pods)	9 ± 0.1^{b}	36.0 ± 1.1^{b}	39.5 ± 0.4^{d}	60.9 ± 0.9^{ab}	62.7 ± 0.8^{ab}	59.7 ± 0.7^{ab}	2.8 ± 0.03^{a}	2.3 ± 0.03^{a}	0.6 ± 0.01^{ab}	2.1 ± 0.04^{a}	1.8 ± 0.04^{ab}
4:3 (shoots: seed pods)	9 ± 0.2^{b}	31.9 ± 0.4^{b}	35.8 ± 1.6^{abc}	61.0 ± 0.3^{ab}	62.7 ± 0.3^{ab}	59.8 ± 0.3^{ab}	2.8 ± 0.01^{a}	2.3 ± 0.01^{a}	0.6 ± 0.01^{ab}	2.1 ± 0.01^{a}	1.8 ± 0.01^{ab}
4:4 (shoots: seed pods)	10 ± 0.2^{b}	29.3 ± 1.9^{a}	30.0 ± 1.1^{ab}	66.1 ± 1.5^{de}	67.3 ± 1.3^{cd}	64.1 ± 1.3^{cd}	3.0 ± 0.06^{a}	2.6 ± 0.06^{b}	0.7 ± 0.02^{d}	2.3 ± 0.07^{a}	2.0 ± 0.06^{d}
100% seed pods + LS33	16 ± 0.3^{f}	25.6 ± 1.2^{a}	30.0 ± 1.6^{ab}	65.8 ± 0.9^{cde}	67.1 ± 0.8^{cd}	63.9 ± 0.8^{cd}	3.0 ± 0.04^{a}	2.5 ± 0.04^{b}	0.7 ± 0.01^{cd}	2.3 ± 0.04^{a}	2.0 ± 0.04^{cd}
100% shoots + LS33	14 ± 0.1^{e}	30.1 ± 0.7^{a}	32.9 ± 0.9^{bc}	65.5 ± 0.5^{cd}	66.8 ± 0.5^{cd}	63.6 ± 0.5^{cd}	2.9 ± 0.02^{a}	2.5 ± 0.02^{ab}	0.7 ± 0.01^{cd}	2.3 ± 0.02^{a}	2.0 ± 0.02^{cd}
4:1 (shoots: seed pods) + LS33	12 ± 1.1^{c}	34.5 ± 1.4^{b}	48.1 ± 1.4^{bcd}	62.0 ± 1.1^{bc}	63.7 ± 1.0^{bc}	60.7 ± 1.0^{bc}	2.8 ± 0.04^{a}	2.4 ± 0.05^{a}	0.6 ± 0.02^{bc}	2.2 ± 0.05^{a}	1.9 ± 0.05^{bc}
4:2 (shoots: seed pods) + LS33	12 ± 0.2^{c}	29.7 ± 2.7^{a}	30.5 ± 1.0^{ab}	65.8 ± 2.1^{cde}	67.0 ± 1.9^{cd}	63.9 ± 1.8^{cd}	3.0 ± 0.08^{a}	2.5 ± 0.08^{b}	0.7 ± 0.03^{cd}	2.3 ± 0.09^{a}	2.0 ± 0.09^{cd}

Experimental Diet	CP%	ADF%	NDF%	DDM%	TDN%	DOM%	DFE Mcal/ kg	ME Mcal/ kg	NE_L Mcal/ kg	NE_M Mcal/ kg	NE_G Mcal/ kg
4:3 (shoots: seed pods) + LS33	12 ± 0.2^{c}	27.2 ± 1.2^{a}	31.1 ± 1.0^{ab}	67.7 ± 1.0^{de}	68.8 ± 0.9^{d}	65.5 ± 0.8^{d}	3.0 ± 0.04^{a}	2.6 ± 0.04^{b}	0.7 ± 0.01^{d}	2.4 ± 0.04^{a}	2.1 ± 0.04^{d}
4:4 (shoots: seed pods) + LS33	12 ± 0.7^{c}	24.9 ± 1.1^{a}	37.9 ± 4.2^{cd}	69.5 ± 0.9^{e}	70.4 ± 0.8^{d}	67.1 ± 0.8^{d}	3.1 ± 0.03^{a}	2.7 ± 0.04^{b}	0.8 ± 0.01^{d}	2.5 ± 0.04^{a}	2.2 ± 0.04^{d}
Significance	**$F_{(11,36)}=29.0$ $p \leq 0.001$**	**$F_{(11,36)}=8.0$ $p \leq 0.001$**	**$F_{(11,36)}=10.1$ $p \leq 0.001$**	**$F_{(11,36)}=8.1$ $p \leq 0.001$**	**$F_{(11,36)}=7.9$ $p \leq 0.001$**	**$F_{(11,36)}=7.4$ $p \leq 0.001$**	**$F_{(11,36)}=1.0$ $p = 0.474$**	**$F_{(11,36)}=3.6$ $p = 0.004$**	**$F_{(11,36)}=8.3$ $p \leq 0.001$**	**$F_{(11,36)}=1.0$ $p = 0.474$**	**$F_{(11,36)}=8.0$ $p \leq 0.001$**

CP = Crude protein, ADF = Acid detergent fiber, NDF = Neutral detergent fiber, DDM = Digestible dry matter, TDN = Total digestible nutrients, DOM = Digestible organic matter, DFE = Digestible forage energy, ME = Metabolizable energy, NEL = Net energy for lactation, NEM = Net energy for maintenance, NEG = net energy for gain/growth

5.4 TO EXPLORE THE POSSIBILITY OF ENSILING CHIPPED V. NILOTICA SHOOTS MATERIAL

Generally, the recommended DM for good legume silage ranges from 30–40% DM and 45–55% for low and high DM silage, respectively, at ensiling (Kung et al. 2018). The DM content in this study of *V. nilotica* plant material at day 0 of ensiling (Table 12) and after 60 days of ensiling (Table 13) was significantly higher ($p < 0.05$) for the control treatment (shoots only with no molasses) compared to the other treatments (i.e. shoots + seed pods; shoots + molasses; shoots + molasses + seed pods). The DM content of the freshly chopped *V. nilotica* at day 0 of ensiling was 43% (Table 12, which falls within the recommended range for high DM legume silages. Losses in the nutritional quality of silages happen when silage DM is less than 25%, which induces clostridia activities (Wilkinson, 2005).

One of the key criteria in evaluating the quality of silage fermentation is the pH level. Legume forages are known to be rich in protein. However, 10–20% of the buffering effect of plant constituents on pH can be attributed to proteins (McDonald et al. 1991; 2010). A terminal pH level of 4.5 is associated with a reduced amount of water-soluble carbohydrates and increased buffering ability (Nkosi et al. 2016; Kung et al. 2018). A rapid decline of pH to below 5 during the early stages (from day 0 to 21 days) of ensiling is required to ensure good silage quality and inhibit the activity of undesirable microorganisms (McDonald et al. 1991).

Table 12: Mean (±SEM) chemical composition of silage at day 0. Different letters for each variable measured indicate statistically significant differences (p< 0.05) within a column

Treatments	DM%	CP%	Ash%	ADF%	NDF%	WSC g/kg DM	LA g/kg DM
Shoots (Control)	44.04 ± 0.30b	7.2 ± 0.10a	3.8 ± 0.03a	41.6 ± 0.68b	49.8 ± 2.17a	10.4 ± 3.30a	1.22 ± 0.06a
Shoots + seeds	43.05 ± 0.26a	7.6 ± 0.15a	3.9 ± 0.02a	38.9 ± 0.97ab	48.5 ± 2.22a	10.1 ± 0.74a	1.36 ± 0.12ab
Shoots + molasses	42.82 ± 0.11a	7.2 ± 0.15a	4.2 ± 0.03b	38.6 ± 0.49a	49.5 ± 2.02a	19.9 ± 1.37b	1.96±0.35bc
Shoots + molasses + seeds	43.06 ± 0.17a	6.9 ± 0.54a	4.5 ± 0.01c	36.4 ± 1.09a	45.9 ± 0.27a	30.5 ± 4.30c	2.09±0.13c
Significance	$F_{(3.12)}$ =16.00	$F_{(13,12)}$ = 0.96	$F_{(13,12)}$ = 165.6	$F_{(13,12)}$ = 6.37	$F_{(13,12)}$ = 0.95	$F_{(13,12)}$ = 11.72	$F_{(13,12)}$ = 4.84
	p < 0.001	p = 0.459	p < 0.001	p = 0.016	p=0.462	p = 0.003	p = 0.033

DM= dry matter, CP= crude protein, ADF= Acid detergent fiber, NDF= neutral detergent fiber, WSC= water-soluble carbohydrates and LA= Lactic acid

Silages that are undergoing a clostridia fermentation have a relatively high pH as the lactic acid is converted to butyric acid (Kung and Shaver, 2001). The butyric acid content of *V. nilotica* was <0.1 % (Table 13), which was within the recommended level of 0% for legume silages with a DM content of >45%. The acetic acid content of *V. nilotica* ranged between 0.4–0.6%, which falls within the recommended range of 0.5–2% for high DM legume silages (Kung et al. 2018). Furthermore, propionic acid was not detected in this study, and this supports the finding of Kung et al. (2018) for good silage legumes. Volatile fatty acids (VFAs) should be less than 0.1 or not detected at all, because they are not required in high quantities for legume silage. The ammonia-N (NH_3-N) content as a % of total nitrogen in this study ranged from 0.1–0.3% and this value falls within the recommended levels of <12% for high DM legume silages (McDonald et al. 2002). This is also reflected in the high proportion of CP retained in the silage at day 60 (Table 13) in comparison to the fresh forage at day 0 (Table 12).

The pH of *V. nilotica* silage did not change in the aerobic stability test, and this explains the limited carbon dioxide production during the five days of exposure. This resistance to a change in the pH of *V. nilotica* silage can be attributed to the high buffering capacity of *V. nilotica* as a forage legume. The pH value, butyric acid, acetic acid and ammonia-N nitrogen contents are indicative of a well-fermented *V. nilotica* silage.

Table 13: Mean (±SEM) chemical composition, fermentation characteristics and aerobic stability of silage at day 60. Different letters for each variable measured indicate statistically significant differences (p< 0.05) within a column

Treatments	DM %	CP%	Ash %	ADF %	NDF %	WSC (g/kg DM)	Y&M g/kg DM	NH3-N (%total N)	AA (g/kg DM)
Shoots (control)	46.3 ± 0.85c	8.1 ± 0.45b	3.9 ± 0.05a	37.6 ± 6.86a	52.4 ± 0.49b	9.5 ± 0.57a	6.84 ± 0.0a	0.13 ± 0.007a	0.5 ± 0.01a
Shoots + seeds	44.1 ± 0.25b	8.1 ± 0.15b	4.0 ± 0.02a	39.5 ± 0.39a	46.8 ± 0.59a	16.6 ± 2.16a	7.98 ± 0.01b	0.33 ± 0.005d	0.6 ± 0.01b
Shoots + molasses	42.6 ± 0.43a	6.6 ± 0.06a	4.1 ± 0.01b	42.6 ± 0.47a	50.5 ± 0.82b	14.8 ± 1.96a	8.04 ± 0.01d	0.27 ± 0.003c	0.4 ± 0.02a
Shoots +molasses+seeds	43.0 ± 0.49a	7.6 ± 0.17ab	4.4 ± 0.05c	36.0 ± 0.11a	47.2 ± 0.49a	16.6 ± 4.39a	8.02 ± 0.01c	0.19 ± 0.013b	0.4 ± 0.04a
Significance	$F_{(3,12)}$ =17.03	$F_{(3,12)}$ =8.50	$F_{(3,12)}$ =34.78	$F_{(3,12)}$ = 0.68	$F_{(3,12)}$ =19.32	$F_{(3,12)}$ =1.61	$F_{(3,12)}$=7304.6	$F_{(3,12)}$=114.08	$F_{(3,12)}$ =17.63
	p < 0.001	p = 0.007	p < 0.001	p = 0.588	p < 0.001	p = 0.261	p < 0.001	p < 0.001	p = 0.01

DM= dry matter, CP= Crude protein, ADF= acid detergent fiber, NDF= Neutral detergent fiber, WSC= water-soluble carbohydrates, Y&M= Yeast and molds, NH3-N= Ammonia nitrogen, AA= Acetic acid, PA= Propionic acid and BA= Butyric acid

5.5 CONCLUSIONS

Edible *V. nilotica* shoots in this study were found to contain insufficient CP content for maintaining livestock conditions during the dry season. However, adding seed pods to the shoots significantly increased the nutritional quality. Therefore, further research is required to determine whether these seeds passing through the gut of the livestock will survive the dry season to germinate and establish in the next wet season. Secondly, the silage results in this study show that *V. nilotica* can be successfully preserved as silage during the wet seasons for feeding livestock during the dry seasons. It is concluded that *V. nilotica* can be preserved as silage with or without the inclusion of seed pods and molasses. Additional research is required to determine whether adding inoculants will affect the nutritional quality of the silage produced. Additionally, feed intake studies and the impact of silage from woody plants on animal performance should also be included in future work.

CHAPTER 6 - THE USE OF SELECTED PERENNIAL C4 GRASSES

6.1 INTRODUCTION

The livestock sector is critical for both the economic development and food security of South Africa, but the scarcity and poor quality of fodder to meet livestock feed demands reduce ruminant productivity, promote rangeland degradation, and put the most vulnerable population at risk. To address the feed gaps, alternative forages that require less water must be established at a lower cost. Perennial, warm-season/tropical C4-grasses such as *Chloris gayana, Digitaria eriantha, Panicum maximum* and 4 Grazer are alternatives for enhancing the sustainability of the sector. Estimation of aboveground biomass provides information on the primary plant productivity, contribution to fodder banks as well as making decisions such as setting stocking rates. The aim was to assess the potential of selected perennial tropical C4 grasses to contribute to the fodder bank. The objective of the trial was to measure biomass production of selected tropical grasses as influenced by pasture species and harvest day in their first year of growth.

6.2 METHODOLOGY

6.2.1 Description of the study area and agronomic practices

The field experiment was being carried out at the University of Limpopo experimental farm, Syferkuil (23° 53' 10" S, 29° 44' 15" E). A total area of 36 m x 36 m of land was prepared. The soil was ripped, ploughed, and tilled to prepare a fine, weed-free seedbed (Photo 1). Each plot is 5 m x 5 m with an inter-plot spacing of 1.5 m (Photo 2). Grass seeds were planted by hand in rows of 5 m with an inter-row spacing of 15 cm in each plot on 15 February 2023 (Photo 2). Fertilization was adapted to local practice: Phosphorus (20 kg P ha^{-1}) and potassium (12 kg K ha^{-1}). To supplement moisture, 15–20 ml of water is applied once a week through the Rain Bird sprinklers when it does not rain. Weed control was done mechanically with hand hoes and initial weeding was done between the 29th and 03rd of April 2023 (Photo 3).

Photo 1: Final land preparation using a tiller

Photo 2: Plot layout and planted plots – grass species

Photo 3: Plots with weeds and weed-controlled

6.2.2 Experimental design and treatment

The experiment was laid out in a randomised complete block design replicated three times. Treatments included four pasture species: *Chloris gayana, Digitaria eriantha, Panicum maximum,* and 4 Grazer mixtures (*Brachiaria brizantha, Chloris gayana, Panicum maximum*, MG-5, and Mombasa) and three harvest days (63, 77, and 98 days after planting).

6.2.3 Data collection

Biomass production in the form of aboveground phytomass was harvested at 63, 77, and 98 days after planting, representing the vegetative stage, booting stage and 50% flowering, respectively. Biomass was collected using a direct method of harvesting from a 50 cm x 50 cm quadrat (Burns et al, 1989). Harvesting was done at 15 cm from ground level.

6.2.4 Data analysis

Data was analysed using the Grazing Land Management (GLM) procedure of the SAS computer program. Parameters measured were subjected to analysis of variance (ANOVA) and the mean separation was done using Duncan's multiple range test at 5% probability.

6.3 RESULTS

The statistical significance (p-value) of the effect of pasture species, harvest day and their interaction on the biomass production of the four species is presented in Table 14. Pasture species and harvest day had a highly significant effect ($P<0.001$) on biomass production, while the pasture species X harvest day interaction had no significant effect ($P<0.05$).

Table 14: Analysis of Variance (ANOVA) for effects of pasture species (PS), harvest day (HD), and their interaction (PS x HD) on biomass production

Source	DF	Biomass production
Pasture species (PS)	7	***
Harvest day (HD)	3	***
PD x NS	14	ns
LSD		142.2

*** indicate highly significant difference P < 0.001, ns indicate non-significant differences

Significant differences were observed among the different pasture species in biomass production (Figure 16). Biomass production during the first year of growth ranged from 9,300 kg/ha to 5,200kg/ha, with *Panicum maximum* as the significantly highest producer, followed by 4 Grazers, *Chloris gayana, and Digitaria eriantha* as the significantly lowest producers.

Perennial tropical C4 yields are highly variable, depending on genetics, stand age, length of growing season, temperature, solar radiation, precipitation and potential evapotranspiration during the season and soil moisture (Vendramini et al., 2023); hence, the variation in the biomass production of the perennial grass species that were studied.

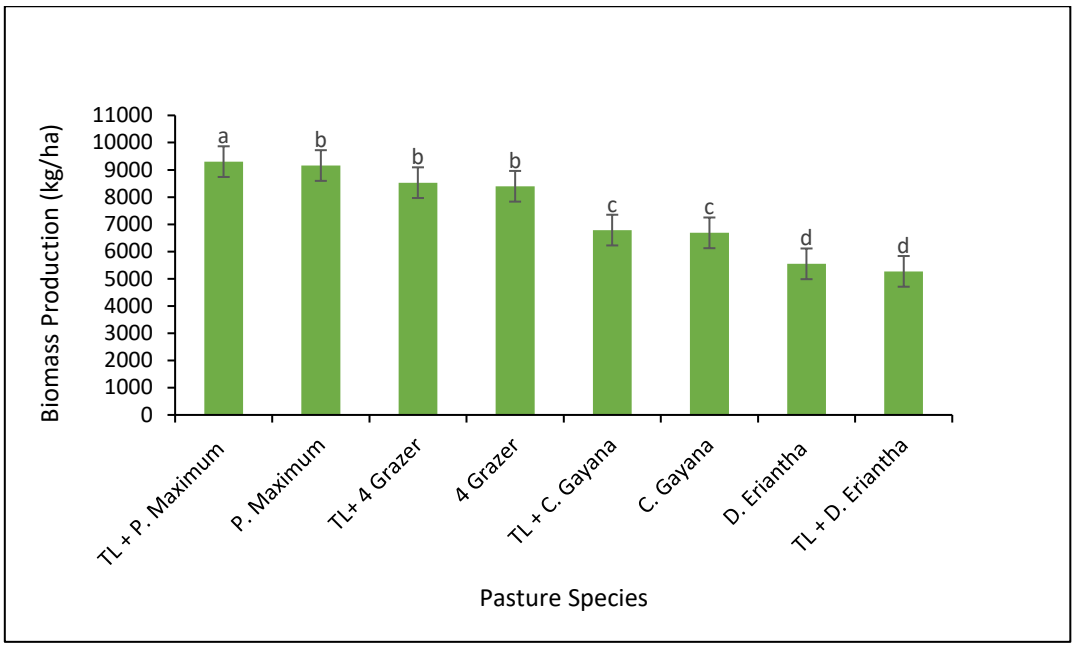

Figure 13: Effect of pasture species on biomass production

Significant differences were observed among the different harvest days in biomass production (Figure 17). The highest dry matter was attained at 77 days after planting, when the pastures were at the booting stage. Significantly lower dry matter production was recorded from pastures harvested 63 days after planting at the vegetative phase. Biomass production at 98 days after planting was significantly lower than at 77 days but higher than at 63 days after planting. Harvesting occurred at 98 days old, while the pastures were in the flowering stage, and it coincided with pastures that had senescent basal leaves. Flowering and seed development generally serve as cues for tiller senescence in cereals and other grasses and could be providing similar cues in C4 perennial grasses (Tubeileh *et al.,* 2016); consequently, 98 days after planting yielded a lower biomass production when compared to 77 days at the booting stage.

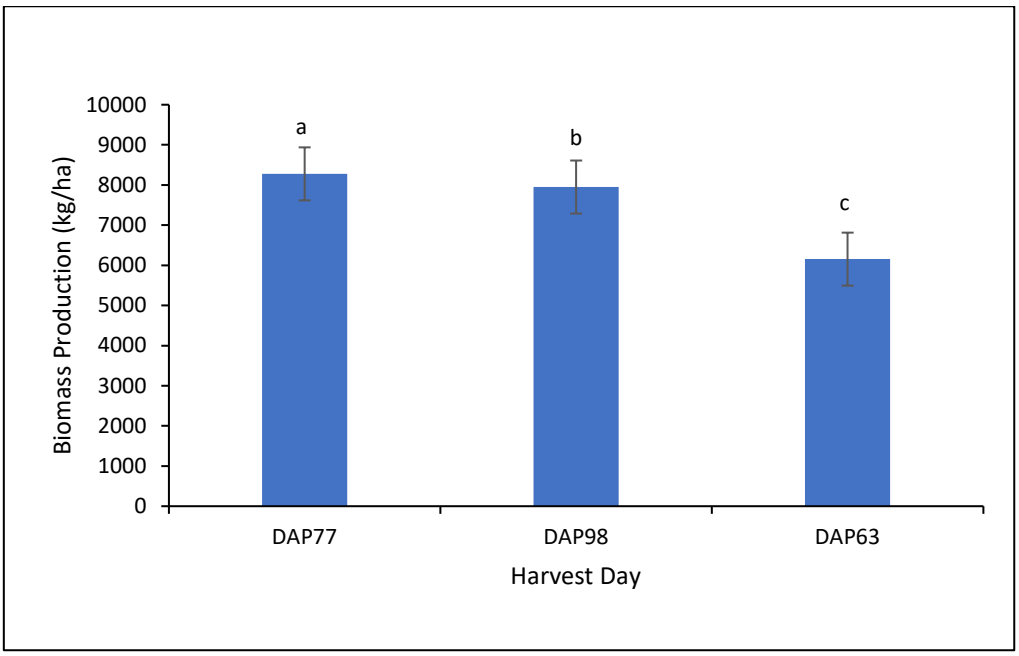

Figure 14: Effect of harvest day on biomass production

6.4 CONCLUSION

Panicum maximum was the leading producer among the four perennial tropical C4 grasses that were studied. 4 Grazer as a grass mixture comprising *Brachiaria brizantha, Chloris gayana, Panicum maximum* and Mombasa has shown a significant biomass production. As a result, *Panicum maximum* and 4 Grazers showed a high potential for contributing more than 8,000 kg/ha of biomass to the fodder bank in their first year of growth.

Regarding the harvest days, harvesting at 98 days when the plot/field had passed 50% flowering resulted in reduced biomass compared to 77 days after planting at the booting stage. Harvesting post-flowering is not recommended to prevent loss of biomass production, due to the increased amount of senescent leaves.

CHAPTER 7 - THE CONTEXT-SPECIFIC DECISION-MAKING TOOL TO ASSIST FARMERS IN ADJUSTING STOCKING RATES WITH WEATHER INFORMATION

7.1 INTRODUCTION

Smallholder livestock farmers mainly depend on natural resources such as rainfall, which are directly affected by climate variability. Besides the shortage of rain, other factors also contribute to the vulnerability of smallholder farmers, such as frequent disasters, poverty, environmental degradation, limited formal safety nets, limited adaptive capacity, limited resources and weak infrastructure (Shiferaw et al., 2014; Myeki and Bahta, 2021).

Smallholder farmers have adopted various drought adaptation and coping strategies over the years. They have done so, for instance, by reducing food sales and food intake, removing children from school and liquidating productive assets such as livestock, land and trees (Mehar and Prasad, 2016). There is no single solution to drought, as it requires an integrated strategy composed of several practices for exchanging knowledge, designing response strategies and implementing solutions (Macon et. al., 2016). Besides, there is limited knowledge of drought-coping strategies (Menghistu et. al., 2018; Hadhu et al., 2015). The coping strategies vary from place to place, based on the community's exposure to drought risk and socio-economic context. Thus, it is incredibly important to analyze how smallholder farmers have responded to drought and its implications. This deliverable aims to study farmers' drought adaptation and coping strategies proactively.

7.2 IMPACT OF CLIMATE VARIABILITY AND EXTREMES

Climate change refers to a long-term (over a decade) change in climate patterns that can be identified by changes in the mean and/or the variability of its properties, whether due to natural variability or human activity. It may involve a gradual change in long-term average climate conditions, greater variability in normal conditions, or changes in extreme events' frequency, magnitude, and distribution (Smit *et al*., 2000). The effects of CC have become an environmental and socio-

economic problem that is increasingly causing global climate-driven hazards (Scholze, Knorr, Arnell, and Prentice, 2006). Climate change is also expected to alter pest and disease outbreaks, increase the frequency and severity of droughts and floods, and increase the likelihood of poor yields, crop failure and livestock mortality (Morton, 2007). Across the tropics, smallholder farmers already face numerous risks to their agricultural production, including pest and disease outbreaks, extreme weather events and market shocks, which often undermine their household food and income security (O'Brien *et al.*, 2004). Climate change impacts livestock production in two ways, directly and indirectly. The most significant direct impact of climate change on livestock production comes from heat stress. (Sejian et. al., 2016), Most production losses are incurred via indirect impacts of climate change, mainly through reductions or non-availability of feed and water resources. It is believed that livestock production and productivity will be among the most susceptible sectors to climate change, due to changes in the hydrological cycle, temperature balance and rainfall patterns, which have a negative impact on livestock production and productivity (Mwiturubani, 2010). Climate change is affecting rainfall, an increase in the frequency of drought and a rise in temperatures, threatening the availability of fresh water for agricultural production and other uses (Kotir, 2010).

Impacts facing the agricultural sector include reduced land suitable for arable and pastoral agriculture, a shortened growing season and a decrease in yields, particularly along the margins of semiarid areas (Turpie et al., 2002). Notenbaert et al. (2010) observed climatic trends that included reduced animal feed productivity, higher disease prevalence and reduced freshwater availability. This was due to the negative effects of lower rainfall, more droughts affecting crops and pasture growth, and the direct effects of high temperatures and solar radiation on animals.

7.2.1 Farmers' awareness of climate change

Farmers' awareness of climate variability and change is central to any decisions that may need to be made to deal with the risk. Climate change is arguably the foremost human and environmental crisis of the 21st century (Tadesse, 2010). This phenomenon adversely impacts livelihood activities, such as agriculture and water provision worldwide through recurring extreme events that include floods, cyclones,

droughts and unpredictable rainfall patterns (Urama and Ozor, 2010). The variations in climatic settings (temperature and rainfall patterns) affect agricultural practices and subsequent production in tropical regions (FAO, 2008). The farmers' exposure to the impacts of climate change is proportionate to the degree of awareness of this subject. If farmers are equipped and capacitated to deal with climate change, their operations are less likely to be exposed to the impacts thereof.

Their awareness and knowledge of climate change underlie an imperative prerequisite in their exposure to the impacts of climate change (Maddison, 2007). Without knowledge, the minor impacts of climate change are stretched beyond their actual extent. Table 15 shows the frequency and percentage of farmers familiar with climate change and different and respective sources of such information (Nesamvuni et. al., 2020). Almost all the farmers (96.17%) have heard about climate change.

According to Maddison (2007), a high proportion of people with some knowledge of climate change is critical for adopting measures to respond to climate challenges. While having heard about climate change will not provide a meaningful basis to rate the farmers' exposure, the relative exposure can only be measured based on the farmers' comprehension of this phenomenon. The farmers who were familiar with climate change provided where they learned about this subject. According to Table 15, multiple stakeholders supplied farmers with climate change information. Unexpectedly, almost all livestock farmers (98.58%) have not heard about this topic from the government. This is unanticipated, as multiple climate change awareness programs exist in different government spheres.

At a more relevant level, the Department of Agriculture initiated the climate change adaptation program for livestock farmers. Yet, the farmers nullified the role of the government in disseminating climate information. On the other end of the spectrum, radio was the most imperative medium for conveying climate change information. Almost all farmers (94.32%) receive climate change-related information through this method. This is because, in rural areas, radios are used for entertainment and the reception of current affairs. Its broader audience base is influenced by its mobility, accessibility, cost efficiency, ease of operation and wide reception coverage.

Newspaper and television were also efficient media in conveying this information, each with an outreach of 16.76% and 32.67%, respectively. Few farmers (6.82%) heard about climate change from their friends. The contribution of the NGOs and churches was minimal; the two contributed a little less than 1% and 1.99%, respectively. A low figure of 4.26% heard this topic at the village meetings. Therefore, it is important to use radio to convey climate information and educate farmers on climate change issues. These concurrently bear the potential to marginalise the farmers' exposure to the impacts of climate change.

Table 15: Frequencies and respective percentages of smallholder farmers and access to climate change information (Nesamvuni et. al., 2020)

Climate change information		Frequency	Percent
Have you heard of climate change?	No	14	3.83
	Yes	352	96.17
	Total	**366**	**100**
From what source of information?			
Government?	No	347	98.58
	Yes	5	1.42
	Total	**352**	**100**
Friend?	No	328	93.18
	Yes	24	6.82
	Total	**352**	**100**
Radio?	No	20	5.68
	Yes	332	94.32
	Total	**352**	**100**

Climate change information		Frequency	Percent
Newspapers?	No	293	83.24
	Yes	59	16.76
	Total	**352**	**100**
NGOs?	No	351	99.72
	Yes	1	0.28
	Total	**352**	**100**
Church group?	No	345	98.01
	Yes	7	1.99
	Total	**352**	**100**
Television?	No	237	67.33
	Yes	115	32.67
	Total	**352**	**100**
Village meetings?	No	337	95.74
	Yes	15	4.26
	Total	**352**	**100**

7.2.2 Observable impacts of climate change

Climate change manifests in different forms, including rising temperatures, changes in water availability, floods, droughts, etc. (Sonwa et al., 2012). However, these outcomes hardly occur concurrently. This section attempts to review the prevalent impacts that are detrimental to smallholder livestock farmers. Table 16 portrays the prevailing climate change impacts affecting their farming.

Most farmers (77.87%) expressed a dip in rainfall quantity and frequency as the major visual evidence of the beginning of climate change. These results align with the remarks of Maluleke and Mokwena (2017) that Limpopo is branded as a drought-prone province. After this, there is a shortage of water resources and pastures (Maluleke & Mokwena, 2017). This is rather unfortunate, because climatic regions of the country are predominated by the intercalations of the arid to semi-arid climatic zone, which is strained with limited water resources (Mpandeli and Maponya, 2014).

Beyond the scope of climate change at a generalized level, the farmers expressed some of the impacts experienced in their communities. Table 16 shows the visual effects of climate change experienced within the localities of the farmers. The majority (80.87%) outlined that drought is the most imperative predicament corresponding to climate change. These findings are in congruence with the findings of Maluleke and Mokwena (2017), which indicate that the Limpopo is prone to drought. Moreover, Kotir (2010) also establishes that climate change affects rainfall, increasing the frequency of drought and rising temperatures. Drought could be easily correlated with the reduction of rainfall.

Table 16: Frequencies and respective percentages of smallholder farmers' beliefs in factors that influence climate change

Factors influencing farmers' beliefs		Frequency	Percent
Low rainfall?	No	81	22.13
	Yes	285	77.87
	Total	**366**	**100**
Does the rainy season start late?	No	300	81.97
	Yes	66	18.03
	Total	**366**	**100**
Heavy rains that bring floods?	No	323	88.25
	Yes	43	11.75
	Total	**366**	**100**
Very hot summer?	No	234	63.93
	Yes	132	36.07
	Total	**366**	**100**

According to Table 17, the farmers did not connect the occurrence of the following climatic phenomena to climate change: tropical cyclones/wind change, land erosion and degradation, destruction of buildings and unpredictable seasons. The following percent of the farmers indicated that each of these factors does not conform to climate change: tropical cyclones 95.63%, land erosion/degradation 93.17%, destruction of buildings 98.91%, and unpredictable seasons (short or long rainy season), 96.17%. These factors are primarily correlated with climate change, especially in South Africa. In addition, Turpie and Visser (2013) reveal that climate change in South Africa manifests in various ways that incorporate higher

temperatures, sporadic rainfall patterns and frequent droughts. Past beyond the point of mere awareness, it all comes down to how equipped the individual is to deal with the impacts of climate change. Table 18 shows the frequencies and percentages of the farmers who have attended a climate change workshop and discussed topics. Unfortunately, almost no farmers (4.11%) had attended any climate change workshop.

Table 17: Frequencies and respective percentages of smallholder farmers and their perceptions on changes that may be due to climate change

Perceived impacts and changes due to climate change		Frequency	Percent
Changes?	No	326	89.07
	Yes	40	10.93
	Total	**366**	**100**
Drought?	No	70	19.13
	Yes	296	80.87
	Total	366	100
Flooding?	No	353	96.45
	Yes	13	3.55
	Total	**366**	**100**
Hurricanes/wind change?	No	350	95.63
	Yes	16	4.37
	Total	**366**	**100**
Soil erosion/ land degradation?	No	341	93.17
	Yes	25	6.83

Perceived impacts and changes due to climate change		Frequency	Percent
	Total	**366**	**100**
Destruction of buildings?	No	362	98.91
	Yes	4	1.09
	Total	**366**	**100**
Unpredictable seasons (short or long rainy season)?	No	352	96.17
	Yes	14	3.83
	Total	**366**	**100**

Workshops are paramount in equipping the attendees with the necessary knowledge on the subject matter. Lack of training is a vital indicator of livestock farming's high exposure to the consequences of climate change. According to Maddison (2007), knowledge of climate change is critical for adapting measures to respond to climate challenges.

Table 18: Frequencies and respective percentages of smallholder farmers who have attended facilitated climate change workshops

Climate change workshop facilitations		Frequency	Percent
Have you ever attended any climate change meeting or training programs?	No	350	95.89
	Yes	15	4.11
	Total	**365**	**100.00**
If yes, where?	At school meetings	3	30.00

Climate change workshop facilitations		Frequency	Percent
	Chief palace	5	50.00
	In the Royal Palace	1	10.00
	Village meetings	1	10.00
What topics were discussed?			
Causes and effects of climate change?	No	10	66.67
	Yes	5	33.33
	Total	**15**	**100.00**
How to adapt to climate change?	No	4	26.67
	Yes	11	73.33
	Total	**15**	**100.00**
Importance of adapting to climate change?	No	13	86.67
	Yes	2	13.33
	Total	**15**	**100.00**
Community participation in climate adaptation?	No	9	60.00
	Yes	6	40.00
	Total	**15**	**100.00**
Awareness?	No	14	93.33
	Yes	1	6.67

Climate change workshop facilitations		Frequency	Percent
	Total	**15**	**100.00**
Ways of mitigation and adaptation?	No	6	40.00
	Yes	9	60.00
	Total	**16**	**106.67**
Have you talked about climate change with your neighbours?	No	155	42.47
	Yes	210	57.53
	Total	**365**	**100.00**

The farmers do not have experience with such gatherings on climate change, making them highly exposed to its impacts. Table 18 shows the frequencies and percentages of farmers who attended a climate change workshop and the topics that were discussed. Almost no farmers (4%) have attended a workshop on climate change; the majority (95.89%). According to Fata and Falazo (2016), a workshop is a great way for someone to learn about a particular subject and how new projects and methods can equip them; thus, without attending workshops, one is deprived of new techniques and new knowledge that are critical for one's operations. Hence, it is unfortunate that farmers do not have the opportunity to attend many prestigious events. Attending them would help them to reduce their exposure to the impacts of climate change.

The few farmers who have attended climate change workshops suggested that these events be held on the following premises: at school meetings (30%), the chief palace (60%) and village meetings (10%). The supremacy of the chief palace as the meeting gathering and information dissemination point reflects how well the rural communities uphold their traditional leaders. The farmers reflected that the following issues were discussed in the meetings: a third (33.33%) indicated the discussions were on the causes of climate change, and the widely covered aspect (73.33%) was on

how to adapt to it. However, 86.67% outlined that the discussions were on the importance of adapting to climate change. More than half (60.00%) indicated no issues of community participation in climate change. The dominance of the topics on adaptation shows that those attending such gatherings are less exposed to the impacts of climate exposure. Unfortunately, those who attend such gatherings are in a minority, which implies that their impact would be marginal.

Surprisingly, the majority (93.33%) were unaware of climate change. This explains why so many are unfamiliar with this phenomenon. However, 60.00% affirm that mitigation and adaptation were prioritised. The minority composition of the farmers has attended the workshops on climate change.

Though the assumption that farmers are blank on this subject matter might not be true, the workshops are ideal for capacity building, especially because they hold the fate of farming in their hands, since the majority of farmers only rely on farming for a livelihood. Given these issues, the sector is highly exposed to the results of climate change.

7.2.3 Feeds resources variability

Smallholder livestock farmers almost entirely rely on the natural feed system. Feeding is an important aspect of livestock farming. Without it, this type of farming is not possible. The type and availability of livestock feed respond directly to the rainfall pattern and amount variations. In view of these, Table 19 shows the frequency and percentage of livestock feed change in response to climate change. It is logical to pre-assume a dip in feed availability in response to the decline in rainfall.

Almost all farmers (90%) confirmed a change in grass availability. Most livestock farmers participate in cattle farming, which is a critical impact as such animals rely mostly on grazing. Grass has a short lifespan and usually picks up after the rainy season. According to Turpie *et al.* (2002), there is a significant reduction in the land for grazing. Notenbaert *et al*. (2010) also observed climatic trends that incorporated reduced productivity of animal feed, higher disease prevalence and reduced freshwater availability. Almost all the respondents deny the emergence of the new grass species.

Table 19: Frequencies and respective percentages of smallholder farmers on the change of feeds available subsequent to the climate change

Change in livestock feeds		Frequency	Percent
Less grass in pastures?	No	34	9.29
	Yes	332	90.71
	Total	**366**	**100**
Less shrubs in pastures?	No	257	70.22
	Yes	109	29.78
	Total	**366**	**100**
New grass species?	No	363	99.18
	Yes	3	0.82
	Total	**366**	**100**
New shrub invasion of pastures?	No	358	97.81
	Yes	8	2.19
	Total	**366**	**100**
Raising of exotic breeds?	No	352	96.17
	Yes	14	3.83
	Total	**366**	**100**

Most respondents (70.22%) also outlined that the shrubs dominate the pasture. This implies that pastures threaten the existence of livestock farming. The pasture available at any given time has specific grazing support for a particular number of livestock. Any excess would deem the pasture insufficient. Smallholder livestock farmers are often unaware of this, as scientific studies are required. Consequently,

livestock fatality is likely to escalate. To sustain their practice, the farmers must supplement feeding with forage and lucerne. However, they may not have the financial muscle to feed their livestock; the strain intensifies if the feeding is prolonged. Consequently, livestock fatality is more likely. Because of these, livestock farmers are highly exposed to the repercussions of climate change.

Ibrahim et al. (2013), in their book with co-authors, indicated that natural pasture degradation leads to a decline of the natural resource base. This includes decreased biodiversity, soil and water quality; more rapid runoff and, hence, higher peak flows and sedimentation of rivers; and lower productivity, increased rural poverty and vulnerability and further land-use pressure. In smallholder setups, it manifests in overgrazing, which is also related to a significant reduction in soil carbon stocks. It is among the main reasons for the large carbon footprint associated with cattle farming worldwide. Therefore, based on studies by Ibrahim (1994), it can be concluded that improved grasses and legume pastures can fix similar amounts of carbon to that of forest systems and that this can improve animal productivity.

7.2.4 Livestock fatality

The profitability of livestock farming is highly affected by the mortality of the animals. Table 20 indicates the frequency and percent of the livestock fatalities corresponding to different causes. Over half of the farmers (55.19%) asserted that the main contributing factor to livestock fatality is the lack of pastures. This view is in accord with Turpie *et al*. (2002) and Notenbaert *et al*. (2010), who established a decline in pastures for livestock. The lack of drinking water follows suit with 39.89%. However, 60.11% do not consider drinking water to be that important. Heat stress/cold, unknown disease and floods accounted for 34.70% and 29.23% and 20.22% out of a hundred, respectively, but 65.30%, 70.77% and 79.18% suggested otherwise.

Table 20: Frequencies and respective percentages of smallholder farmers' livestock fatality

Factors contributing to the loss of livestock		Frequency	Percent
Heat stress/cold?	No	239	65.3
	Yes	127	34.7
	Total	**366**	**100**
Lack of feed?	No	164	44.81
	Yes	202	55.19
	Total	**366**	**100**
Lack of drinking water?	No	220	60.11
	Yes	146	39.89
	Total	**366**	**100**
Unknown diseases?	No	259	70.77
	Yes	107	29.23
	Total	**366**	**100**
Floods?	No	292	79.78
	Yes	74	20.22
	Total	**366**	**100**

DEA (2017a) supports the claim that the temperature increase is affecting livestock, citing the general increase in temperature over the past century. Potential impacts on livestock include changes in the production and quality of feed crops and

forage (Polley et al., 2013). In view of these, smallholder livestock farmers are highly exposed to climate change impacts.

7.3 EARLY WARNING SYSTEM

Wigmore (2019) defined the early warning system as the technology and associated policies and procedures designed to predict and mitigate the harm of natural and anthropogenic disasters and other undesirable events. An early warning system is critical for forecasting a disaster before occurrence. In livestock farming, the authority can trigger the relevant procedures and resources to combat the disaster. It is essential in the marginalisation of the impacts of climate change. Two approaches are generally involved in interpreting the early warning signs: traditional and scientific techniques. The former is often undocumented, passed on from one generation to the next, and is often practised at a family or community level.

Table 21 shows the frequencies and the percent of the availability of the early warning system and operational level to Limpopo and Mpumalanga smallholder farmers. Most smallholder livestock farmers (80.77%) do not have any mode of the early warning system. A further 16.76% are unaware of any early warning system, with only 2.47% being aware. Out of those aware of the early warning system, they classified the system into the key stakeholders responsible. Disaster management was reported as the most well-known early warning system provider, with 57.14%. Secondly, the dryness of streams was also an imperative indicator of the drought by 28.57%. Lastly, 14.29% are reliant on the local radio for weather forecasting. The District Municipality also offers an early warning system through weather forecasting weekly and three-monthly. Only a single respondent reported each of the two initiatives. The inexistence of the early warning system implies that the farmers have to absorb the entire shock of the impacts. In this regard, they are highly exposed to the impacts of climate change.

Table 21: Frequencies and respective percentages of smallholder farmers' perception of the availability of the early warning system

Availability of Early Warning System		Frequency	Percent
Early warning system	No	294	80.77
	Not sure	61	16.76
	Yes	9	2.47
	Total	**364**	**100**
National	Disaster management	4	57.14
	Dryness of streams	2	28.57
	Local FM Radio (weather)	1	14.29
	Total	**7**	**100**
District	Disaster Management	1	1
	Distance Management	1	1
	Total	**2**	**2**
When was the system established?	2016	1	0.66
	2017	2	1.32
	No	2	1.32
	Not sure	146	96.69
	Total	**151**	**100**
Does the early system function effectively?	No	64	43.24
	Not sure	81	54.73

Availability of Early Warning System		Frequency	Percent
	Yes	3	2.03
	Total	**148**	**100**
What functions of early warning should be improved	Drill own borehole	1	10
	Don't know	2	20
	Information Availability	4	40
	Early warning Education	3	30
	Total	**10**	**100**

Ninety-six percent of the respondents were not entirely informed when the early warning systems were installed. Only 2% outlined that the systems were introduced concurrently between 2016 and 2017. However, 43.24% indicated that the existing systems are not effective. A further 54.73% were not sure if the system was informative. Only 2.03% believe that the early warning is an effective tool to prepare them for the rising drought. To curb the dissatisfaction of the farmers with the efficiency of the existing systems, the livestock farmers (30%) require early warning education to stay alert. According to 40%, disseminating the information is also critical for preparation to combat climatic extremes. Also, 20% is not aware of how the system should be improved. The limited information on the early warning system implies that most smallholder farmers are caught off-guard when such events unfold. Subsequently, they have to absorb the total impacts of the extreme event due to their unpreparedness. These, therefore, indicate that smallholder farmers are highly exposed to the results of the climate extremes after climate change.

Based on consultations with key agricultural advisors, the government's early warning system is operational and effective at a level of less than 30 percent. The main challenge is the capacity of the government at provincial level to deliver on the three key areas of the broader Disaster Management function, namely Early

Warning, Risk Assessment and Disaster Recovery. Weather and seasonal forecasts are developed and sent to the provinces for dissemination to the end-user, who is the smallholder farmer. Provinces, in the main, have officials at the provincial level but no dedicated human capacity in districts and local municipalities where the early warning information is supposed to be disseminated. Early warning and disaster-related matters have not been fully assimilated into the provincial organograms of the Department of Agriculture. Agricultural advisors also need to be trained on Early Warning systems whilst being assigned functions of disaster management individually and as a collective.

7.3.1 Contingency

Since livestock smallholder farmers lack a robust early warning system, it is only logical that the impacts of climatic extremes are always in proportion to the phenomenon itself. Therefore, the farmers are usually caught unprepared to deal with such events and have a mountain to climb to deal with them. Table 22 shows the frequencies and percentages of the contingency to curb the impacts of climate change on livestock.

Table 22: Frequencies and respective percentages of smallholder farmers' perception of the availability of climate change contingency plans

Availability of contingency plans	Frequency	Percent
No	308	84.38
Yes	57	15.62
Total	**365**	**100**

Despite the absence of the early warning system, 84.36% of the livestock smallholder farmers indicated that there are no contingency plans to alleviate the consequences of climate change on their farms. Only 15.62% have some plan in place to mitigate these impacts. This implies that the farmers absorb all the results of the disaster when they strike. This translates to financial losses in the form of livestock death when a disaster impedes the serious need for disaster preparedness seminars. The respondents who confirmed the existence of the contingency plan also revealed the intrusive aspects of the plan. Table 23 indicates the evolution that the contingency plan had undergone to deal with the recent challenges, and according to 54 respondents who answered this section (79.63%), the contingency plan in place has transformed within the past 5–10 years. This illustrates an attempt to stay relevant and marginalise the impacts of climate change.

Table 23: Frequencies and respective percentages of smallholder farmers' perception of the dynamism nature of the contingency plans

Contingency to climate change		Frequency	Percent
Has the contingency plan changed in the last 5–10 years?	No	11	20.37
	Yes	43	79.63
	Total	**54**	**100**

Contingency to climate change		Frequency	Percent
How did it change?	Providing feeds	32	71.11
	Plan to drill a communal borehole	1	2.22
	Not sure	9	20
	Water provision	2	4.44
	Building a dam	1	2.22
	Total	**45**	**100**
Describe how the contingency plan has changed	Because of climate change	7	15.56
	Lack of grazing area	31	68.89
	Lack of water	2	4.44
	Others	5	11.11
		45	100
Does the contingency plan include agriculture and food security?	No	345	96.64
	Yes	12	3.36
	Total	**357**	**100**

We are in a global world that is moving very fast; in response, an approach that was established 10 years ago would be outdated today.

However, 20.37% insisted that the contingency plans have not been modified since inception. This would not be ideal to curb recent challenges. Although the study focused on the contingency to address climate change, the respondents leaned their response towards the drought. That improved aspects of the plan should incorporate the provision of the feeds is indicated by 71.11%, while 2.22% are planning to drill a borehole, and 20% are unsure how the improvement should be linked to their existing models. Another 4.44% and 2.22% indicated the provision of water resources and the erection of a dam, respectively.

Four issues were cited for alterations and adjustments of the contingency plans, as answered by 45 respondents. A 15.56% outlined the intensification of climate change, 68.89% revealed a lack of grazing area, 4.44% and 11.11% suggested a lack of water and other reasons for the evolution of the approach. Agriculture and food security were not part of the contingency (96.64%), while 3.36% suggested otherwise.

7.4 USING SEASONAL CLIMATE FORECAST INFORMATION

Since 1994, the SAWS has been actively involved in research around the seasonal time-scale of climate predictions (Klopper *et al*., 1998; Landman and Manson, 1999; Tennant, 1999; O'Brien *et al*., 2000), to provide the best possible information on future climate conditions. This is to reduce the risk in economic and social decisions. Climate information, even if provided in a perfect forecast, has limited value if it cannot be understood and used by the recipient to support the decision-making process (Glantz, 1977; Chagnon, 1992; Osunade, 1994; Mutiso, 1997; Huber and Pedersen, 1998; Eakin, 2002; Roncoli *et al*., 1999; Finan and Nelson, 2001; Roncoli *et al*., 2001a; Roncoli *et al*., 2002a; Luseno *et al*., 2000).

Most studies on the value of the seasonal forecast have been conducted in the developed world (Mjelde *et al*., 1988; Lyakhou, 1994; Mosley, 1994; Mason, 1996; Nicholls, 1996; Mjelde *et al*., 1997; Landman and Mason, 1999; Letson *et al*., 2001; Klopper and Landman, 2003, O'Brien and Vogel., 2003). Various mechanisms have

been used by several organizations to disseminate climate forecast information by distributing fliers, newsletters, electronic and printed media, technical briefs, etc.

Forecasts, moreover, need to be expressed in the language of the users, providing the communities with possible appropriate alternatives to current production methods (Price, 1995; Arctic Council, 1995; Blench, 1999; Stern and Easterling, 1999; Stricherz, 1999; Letson *et al*., 2001; Valdivia and Gillies., 2003; Easton, 2004b; Hansen *et al*., 2004; Ziervogel *et al*., 2004). Blench (1999) and Finan (1999) argue that these forecasts will probably be helpful only to certain types of producers, as not all farmers can equally access or use the information. It also requires trust and communication between users and providers of climate forecasts (Finan, 1999).

Effective use of seasonal forecast information is useful to farmers; however, it is wider than just issuing a forecast and includes examining the current needs, problems and context in which users operate. Furthermore, the use of forecasts provides more than just information. The highly variable nature of rainfall in southern Africa enhances the potential use and value of reliable and dependable seasonal forecasts in the decision-making processes of different sectors. The knowledge that rainfall is so variable imparts considerable inertia in implementing such a process that may often require major shifts in policy and redirection of investments (Mjelde *et al*., 1996; Nicholls, 1996). Using climate forecasts to manage climate-sensitive sectors such as agriculture better is a new frontier in climate-risk management, with potentially very significant implications for farmers (IRI, 2000).

Seasonal climate forecasts also require further integration into agriculture management (Orlove and Tosteson, 1999; Wilbanks and Kates, 1999; Unganai, 2000; McGee, 2004; Ritchie *et al*., 2004). Seasonal climate forecast information in farming communities is increasingly becoming an option to manage risk due to the variable environment in which farmers operate, heightened by the increasing pressure of the cost of inputs such as seeds, fertilizer, and herbicides (Nicholls, 1996). As a result of lower yields, some farmers cannot recover financial costs due to the high cost of inputs. Seasonal climate forecasts may thus help farmers make more informed farm management decisions, based on seasonal climate information. For the seasonal climate forecast to be helpful to farmers, however, the information must be

accurate, reliable and meaningful. The user must be able to understand and interpret the information. Various institutions, such as the SAWS, ARC, Provincial Department of Agriculture (PDA) and various academic institutions disseminate seasonal climate and forecast information through different structures before the season starts in the form of an advisory. It is important to (a) understand how farmers manage climate risks and (b) manage risk and mid-season dry spells.

7.4.1 Practical application of seasonal forecasting

The high rainfall variability in the country has led some farmers to use seasonal forecast information for farm planning and decision-making. Daily weather forecasts allow farmers to plan their daily activities. The SAWS provides the daily weather forecast through print and electronic media and is published online 24 hours a day. Forecasting information useful to farmers is part of a process that includes an examination of the current needs, problems and context in which users operate. Forecasts, moreover, need to be expressed in the users' language. Seasonal climate forecasts are issued as probabilistic outlooks for the future, usually for three months and with a rather broad spatial coverage (Figure 18). Conveying notions of 'probabilistic' information to various users is not easy. Users must understand that all seasonal forecast information or data are probabilities, not deterministic.

A probability forecast outlines how likely an event will occur as a percentage. It can assist farmers in being aware of the risks associated with weather and climate events. Seasonal climate forecasts are grouped into three categories of rainfall probability: (a) above-normal (wet conditions), (b) near-normal (around average) and (c) below-normal (dry conditions), see Figure 18. The first category below normal shows a 50% probability of rainfall being above normal. The second category shows a 30% probability for near-normal rainfall, and the third category shows a 20% probability for below-normal rainfall.

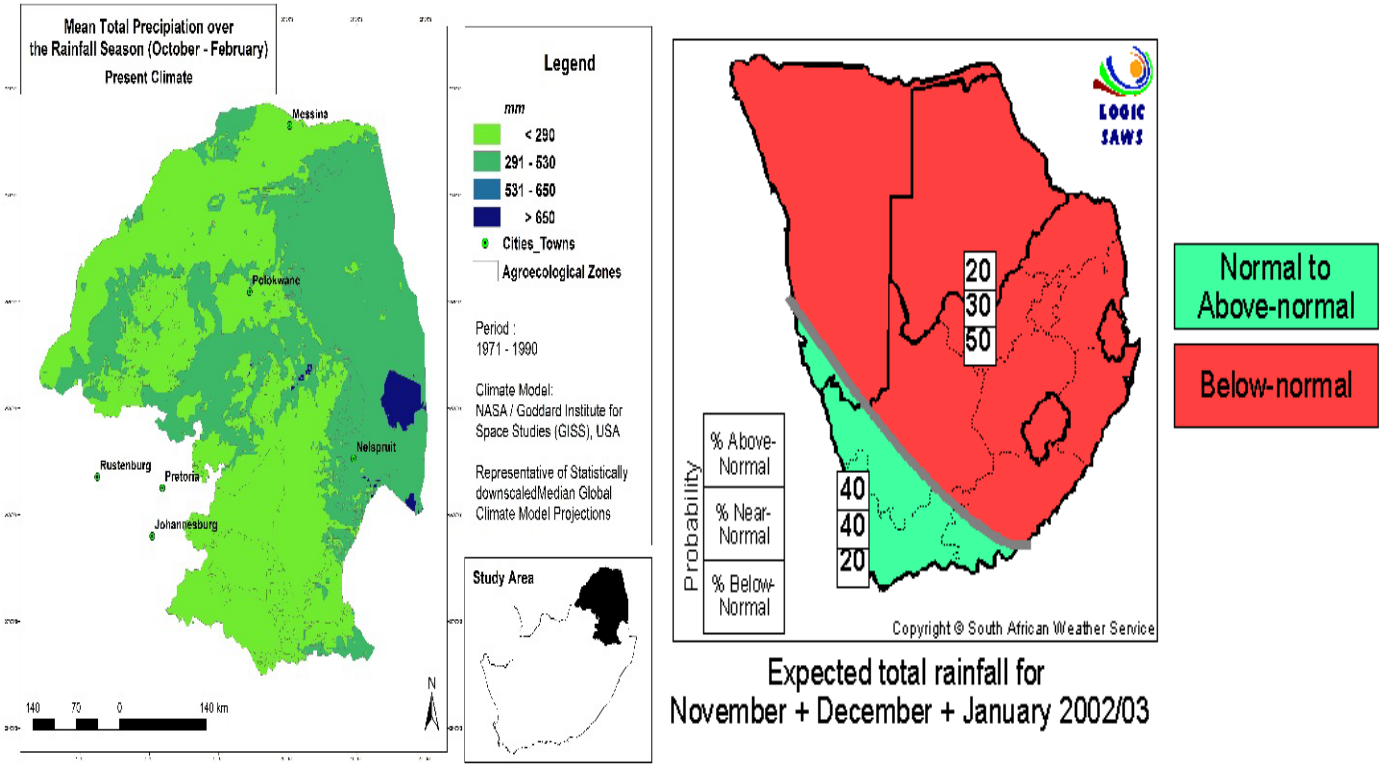

Figure 15: Mean total precipitation over the rainfall season (October–February)

7.5 DESTOCKING AND ITS RATIONALES

Morton and Barton (2002), in their study on destocking as a drought mitigation strategy, comprehensively reviewed the concept of destocking. They helped answer the rationale question while also answering areas of the critiques around the concept of destocking. Destocking is an intervention 'appropriate at the height of a crisis when livestock-keepers are being forced to sell animals at low prices to buy food at high prices' (Oxby, 1989). Some contributions would emphasize the onset of drought and less on the height of the crisis, but the equation of destocking with an intervention in pastoralist purchasing power is clear.

7.5.1 Destocking for positive environmental impact

One good case study in Mali has been documented by Morgan and Barton (2002). The demand for destocking was initiated by meetings of herders, which 'underlined the necessity of destocking their herds as rapidly as possible but at a price that would allow some purchasing power on the cereal market'. The condition set did not compromise the farmers in terms of their aspiration to exchange their livestock for cereal. An external body, which was a cooperative, organised the purchase of

animals to process the animals into dried meat, which was then bought by relief agencies for distribution. This initiative was deemed a great success by the farmer. Toulmin (1995) also combines a discussion of destocking and restocking in the context of a three-phase model of the drought cycle involving fodder availability, livestock numbers and price effects on livestock and grain. In phase one of the drought cycle, 'rainfall failure leads to a fall in pasture production and a collapse in the number of livestock able to be supported' (Toulmin, 1995). At the same time, particularly where the drought extends to cereal-growing areas, grain prices rise because of increased demand from pastoral people. In contrast, livestock prices fall per kilogram of meat because the market is flooded, and per animal, as they lose condition.

Within this context, 'strategies aimed at timely destocking and restocking of livestock numbers have the dual advantage of taking animals off the land sufficiently early in a drought to avoid causing long-term damage to vegetation and soils, and of reconstituting the livestock economy in the post-drought period' (Toulmin, 1995). In phase one of the drought cycle, 'the main imbalance to be addressed is the excess of animal numbers over fodder availability' (Illius et al., 1998). A balanced approach, therefore, will be balancing the positive attribute of destocking on the environment and the welfare or purchasing power of farmers.

Destocking is seen as one of a range of options for overcoming this imbalance, including stock movement, subsidies on fodder and drought-proofing through cultivated fodder reserves or breeding hardiness into animals. In contrast, two options are presented in the discussion of destocking: selling animals still in good condition and selling animals in very poor condition for salvage slaughter. The latter option, of selling animals in poor condition, being on the point of death, can have no environmental rationale. The emphasis should be on maximising pastoralist purchasing power, which may reduce the required famine relief effort while aiding recovery post-drought. To achieve this, market interventions should be implemented early in a drought, before livestock prices decline. This, in turn, demands functional early warning systems and/or seasonal forecasting.

De Haan et al. (1997) support an environmental school of thought in a study of livestock and the environment. In discussing policy options to mitigate environmental impacts in arid-area grazing systems, the authors state that irreversible land degradation in arid zones originates from high stocking rates during droughts. The appropriate drought management strategy is to destock as early and as rapidly as possible, rather than to maintain maximum stock numbers (De Haan et al., 1997). The authors go on to discuss enabling policies for generally increasing voluntary offtake, such as infrastructure investments and grazing fees for communal areas, rather than the time-specific, project-level interventions.

The team also argues for 'pre-emptive livestock sales' in advance of drought, before their condition worsens and value decreases. This argument makes economic sense and makes it easier to nurture the remaining livestock (de Haan et al. 1997). This is, accordingly, the purchasing-power rationale for destocking. In a case study by Aklilu and Wekesa (2001) in Kenya, during the 1999 to 2001 drought, two environmental objectives were achieved, mainly that of seven destocking projects and two 'transport subsidy projects' surveyed, the two report environmental objectives were (a) to reduce environmental stress on the range through destocking of four per cent of cattle at risk' and (b)'to relieve pressure on scarce water and pasture resources' (Aklilu and Wekesa 2001). In the second case, it was noted that 'the impact on saving the scarce water and pasture resources as initially envisaged was negligible'.

7.5.2 Drought-time destocking

There are then two rationales proposed by those who have advocated drought-time destocking: either as an intervention to protect the environment or to boost pastoralist purchasing power and welfare. The two arguments are sometimes mixed unsystematically. One problem with this approach is that the precise nature and force of the argument for supporting purchasing power is obscured when the idea of destocking is criticised on other grounds. One argument against externally assisted destocking is the sheer scale of intervention required to impact the environment. Under any project or policy design that guaranteed the voluntary nature of destocking, it would be difficult to significantly reduce the percentage

change in livestock numbers to mitigate overgrazing. Even with the assistance of NGOs, which are pioneers in this field, they cannot succeed with their limited resources. It can be argued that a far smaller percentage of intake, which represents a considerable organizational task, is sufficient to significantly impact purchasing power.

7.5.3 Tracking, modeling and destocking

The arguments for destocking examined above have been related in varying degrees to the so-called 'new range ecology'. New range ecology, as the name implies, has been a shift in scientific thinking, as exemplified by the scientific papers by Behnke et al. (1993). Scoones (1993) points out that it had roots in a profound shift in pastoral development models led by social scientists who took traditional pastoral institutions and knowledge seriously. One of the publications cited above (Oxby, 1989) can be regarded as part of that shift, one (Toulmin, 1995) appears in a book devoted to the planning and policy implications of the new range ecology, and the two donor publications (Pratt et al., 1997; de Haan et al., 1997) both make positive, though not uncritical, reference to new range ecology. Supporters and critics have summarised the central arguments of new range ecology (Scoones, 1993; Campbell et al., 2000).

To further paraphrase Scoones, there are three central propositions:

(a) Many grazing ecosystems are not at equilibrium and are affected more by rainfall fluctuations than grazing pressure, making opportunistic or tracking strategies environmentally benign and economically efficient
(b) Rangeland's productivity is variable over space and time, necessitating flexible movement
(c) African pastoralist systems have multiple objectives, making simplistic management tools and strategies unlikely.

In the last few years, there have been increasing scientific criticisms of what is seen as the sweeping assertions of the new range ecology (Illius and O'Connor, 1999; Cowling, 2000). As part of this body of work, two studies (Illius et al., 1998; Campbell et al., 2000), based on ecological (and in one case, also economic) modelling, have

criticised what they refer to as 'tracking policies' or 'tracking management scenarios,' which involve drought-time destocking by pastoralists, and by implication, the sort of government or donor assistance to this outlined above.

To address these critiques properly, it is necessary to examine closely how the term 'tracking' and the related term 'opportunism' have been used by the 'new range ecologists', their forerunners and their critics. Sandford (1983) contrasts 'conservative' and 'opportunistic' strategies as ideal types, recognizing that 'pastoralists are unlikely to pursue either of these strategies exactly'. A **conservative strategy** is one 'in which a constant number of livestock graze an area through good and bad years alike' and an **opportunistic strategy** is one 'in which the number of livestock grazing is continuously adjusted to the current availability of forage'. How this adjustment is managed is not made explicit in the definition. Behnke and Scoones (1993) also use the term 'opportunistic management' and its corollary 'opportunistic policy towards range management'. **Opportunistic policy** has three components. One is livestock marketing: 'Livestock sales are one obvious means to achieve rapid destocking, and livestock marketing would play an important role in an opportunistic policy towards rangeland management. Attention would shift to the design of marketing systems which can accommodate massive and unpredictable shifts in levels of throughput (Behnke and Scoones, 1993). The second component, clearly equally important, is herd movement and land tenure, and the authors refer to an 'attempt to foster opportunism by maintaining livestock mobility'. This leads to the third component: the reform and devolution of administration to pastoralists.

The terminology of 'tracking' appears in the new range of ecology literature (Behnke and Kerven,1994; Scoones, 1995; and Toulmin,1995). Within an overall 'opportunistic' approach to rangeland exploitation, Behnke and Kerven (1994) introduce tracking as one of two 'indices' of project success: 'tracking refers to a biological phenomenon, the prompt realignment of livestock forage demands with fluctuating levels of primary production' (the other index, 'buffering', refers to the shielding of pastoral incomes from environmental fluctuations). Scoones (1995) is slightly more specific: 'Tracking involves matching available feed supply with animal numbers at a particular site'.

Scoones lists four ways to achieve effective tracking: (a) pastoral-agricultural links, (b) livestock movement, (c) physiological tracking by low-input animals and (d) livestock marketing. Of livestock movement, he observes that the movement of animals in response to spatial and temporal variation in resource availability is perhaps the most classic of all the tracking strategies. Movement allows herders to track fodder across the landscape, using patchy grass production caused by uneven rainfall or variations in landscape topography (Toulmin,1995). Similarly, Behnke and Kerven (1994) and Toulmin (1995) intend both livestock marketing arrangements and land tenure reform to maintain pastoral mobility when they refer to 'tracking'. On the latter, Behnke and Kerven state that if adjacent grazing areas experience asynchronous productivity flushes and crashes, herd mobility and the nonexclusive tenure arrangements that permit mobility are a cost-effective way for animals to walk away from temporary, local imbalances in stock numbers and feed supply (Behnke and Kerven,1994). Abel (1997) has compared such tracking strategies with conservative strategies and concluded that tracking brings higher economic returns while being no more environmentally damaging.

Illius et al. (1998) and Campbell et al. (2000) use modeling methodologies to criticize these claims. Both models are based on long-run climate, vegetation and animal population, and in the case of Campbell et al., price data was collected in communal areas of Zimbabwe. Illius et al. (1998) compare a relatively high fixed stocking rate achieved by livestock owners selling all stock surplus to that rate once a year with a range of tracking scenarios in which either livestock numbers are adjusted through sales in proportion to annual rainfall or livestock are sold in proportion to livestock mortality. All scenarios used in the analysis include modest restocking by purchase after livestock population crashes. Campbell et al. (2000) compare (a) an 'opportunistic' scenario based on actual cattle numbers in two communal areas, (b) a tight tracking scenario involving sales or purchases to keep cattle numbers at the ecological carrying capacity (as they themselves define it),

(c) a conservative tracking scenario, similar to the last, but where cattle numbers do not go above 80 percent of ecological carrying capacity, and purchases do not exceed 60 percent of the deficit between numbers and ecological carrying capacity and (d) a conservative scenario where numbers are maintained at a fixed

level – 66% of average ecological carrying capacity. Campbell et al. (2000) see 'tracking' as a range of new strategies proposed by the new range of ecologists, which livestock owners could adopt with external support, totally distinct from the 'opportunism' they currently display. However, as we have seen, the two terms are used largely synonymously in the new range of ecology literature.

Distinctions between existing strategies of livestock owners and policy implications are not always clearly made in the new range ecology literature. However, a general policy orientation of supporting existing strategies is evident. In addition, neither set of authors factors livestock mobility into their model. Illius et al. (1998) made the policy implications clear. This is explicit because policies designed to exploit spatial heterogeneity in vegetation conditions were not considered. An underlying reason for both sets of authors is that their models are based on empirical conditions in the communal areas of Zimbabwe, where long-distance movement of livestock in response to environmental variations was massively reduced by colonial policy, placing African farmers and their herds in small, circumscribed reserves, often bounded by commercial farmland or protected areas.

Therefore, empirical or modeled findings from Zimbabwe are of limited relevance to more classically pastoral areas where much of the empirical work underlying new range ecology was done, and many of its policy implications can be promoted. Illius et al. (1998) entered their different scenarios into a detailed mathematical simulation of non-equilibrium rangeland dynamics, including highly variable rainfall and a strong probability of drought, which in turn affected cattle reproduction, live weight gain and mortality, and evaluated them by the long-run sales (in kilogram live weight per hectare).

However, as the authors admit, 'the model does not have an economic component' (Illius et al.,1998) and does not include price changes. They advance three explanations for the failure of tracking policies (including all but the fixed sales option). First, thoroughgoing destocking requires the sale of breeding females, weakening herds' capacity to regenerate in the absence of massive externally assisted restocking post-drought. Secondly, tracking policies lead to sales of more but lower-weight animals. Third, tracking the current season's rainfall does not

mitigate the effect of two-year droughts. The authors conclude that the most rigid variant of the fixed stocking policy is the most rational for pastoralists, at least 'in the absence of an ability to restock heavily after drought' (Illius et al., 1998). This would require huge resources to be deployed. For subsistence pastoralists, the traditional policies of maintaining the maximum number of breeding stock and of hoping most of them will survive drought may be as close as "opportunistic" management can get to dealing with drought (Illius et al., 1998).

This judgement begs the question of how subsistence pastoralism is defined, whether true subsistence pastoralists exist and whether maximum stocking at all times is indeed a 'traditional policy'. Campbell et al. (2000) factor in fluctuating livestock prices and express the results of their simulations in Net Present Values (NPVs). They conclude that strategies based on conservative stocking rates would have higher NPVs than 'opportunistic' stocking rates, except under 'very special and peculiar situations', while 'tracking' scenarios never emerge as having the highest NPVs. This is explicitly linked to a criticism of externally assisted destocking and restocking. '***Some writers have suggested that the government must implement a system to buy and sell cattle to farmers to maintain close tracking.*** Our results suggest that government would have to be willing to provide sizeable subsidies, an unlikely event in these times of dwindling government subsidies' (Campbell et al., 2000).

Essentially, and despite differences in methodologies and the scenarios compared, both Illius et al. (1998) and Campbell et al. (2000) conclude that attempts to track environmental fluctuations, either through marketing strategies pursued by livestock owners or by policies of governments and donors to support those strategies, are not economically feasible. These strategies and policies are compared adversely to the work of Illius et al.1998. The team constantly maximises herd numbers and bears the costs of drought-induced crashes or (in the case of Campbell et al., 2000) maintains relatively lower and fixed stocking rates. As part of larger arguments against 'tracking', these authors, therefore, argue against the sort of externally assisted destocking promoted by Oxby (1989), Toulmin (1995) and recent publications by major donors (de Haan et al., 1997; Pratt et al., 1997). However, none of the models factor in the mobility, even though the new range ecology authors include it as a component of tracking strategy and policy. The comparison is, thus,

made with a truncated and weakened version of tracking. The possibility that external assistance to destocking could be selectively given in more extreme and geographically widespread droughts, while lesser and more geographically restricted droughts are mitigated by measures and policies that enhance livestock mobility, is not considered.

Campbell et al. (2000), in their study in Zimbabwe, factored in livestock price effects but did not make allowance for fluctuations in grain prices during drought. By so doing, they underestimated the greater benefits of sales early in the drought cycle. In areas more arid than Zimbabwe, the increased use of veterinary drugs and diesel boreholes, when resources permit, is a common pastoralist response to drought; providing cash to enable effective use of such inputs early in the drought cycle enhances livestock survival rates. Much of the reason pastoralists do not sell animals early in the drought cycle relates to the physical constraints of often getting weak livestock to market. Fodder and water on stock routes may be in short supply, and only the best animals can make the long journey 'on the hoof' to market. By the time they reach the market, their condition will have deteriorated, and their value will be greatly reduced.

At the same time, market prices are also falling rapidly. Embarking on a long trek to market is an extremely risky undertaking for pastoralists. When given the chance, pastoralists frequently and articulately ask for external intervention to ease the above constraints and are prepared to take collective action to complement such intervention. We believe this represents good practice in externally assisted destocking, designed to intervene in purchasing power, implemented during the onset of drought, using community structures and gaining cost-effectiveness through intelligent use of private traders.

7.6 CONCLUSIONS

Studies of smallholder farmers' perceptions of the impact of climate change have shown that exposure levels affect their daily livelihood choices. Their awareness and knowledge of climate change underlie a crucial prerequisite in their exposure to the impacts of climate change. Though multiple stakeholders capacitated farmers with climate change information, their level of education impedes their understanding

of this phenomenon in their livestock business ventures. Unexpectedly, almost all livestock farmers (98.58%) have not heard about climate change from the government. On the other end of the spectrum, radio was the best medium for conveying climate change information. Almost all farmers (94.32%) receive climate change-related information through the radio. It may also be a consequence of the radio's use of the language, mostly their indigenous languages. The intervention that could empower the farmers will be regular workshops within commodity groups on climate change. Unfortunately, 95.89 % of the farmers have not attended a workshop on climate change.

The manifestation of climate change to smallholder farmers is identified through drought. Most farmers (77.87%) identified a dip in rainfall quantity and frequency as the major visual evidence of the start of climate change. The other evidence is the loss of natural grazing; almost all farmers (90%) confirmed a change in grass availability.

Most livestock farmers participate in cattle farming, so this is a critical impact as animals rely on grazing. Most respondents (70.22%) also reported that shrubs dominate the pasture, a symptom of overgrazing. Consequently, over half of the farmers (55.19%) asserted that the main contributing factor to livestock fatality is the lack of pastures. When smallholder farmers were exposed to extreme weather events, they did not perceive them as part of the climate change phenomenon.

The following percentile of farmers indicated that each of these factors does not conform to climate change: tropical cyclones 95.63%, land erosion/degradation 93.17%, destruction of buildings 98.91% and unpredictable seasons (short or long rainy season) 96.17%. It can be concluded from the study that the government's early warning system is operational and effective at a level of less than 30 percent. The main challenge is the provincial government's capacity to deliver on the three key areas of the broader Disaster Management function: Early Warning, Risk Assessment and Disaster Recovery. Weather and seasonal forecastings are developed and sent to the provinces for dissemination to the end-user, who is the smallholder farmer. Provinces, in the main, have officials at provincial level, but have

no dedicated human capacity in districts and local municipalities where the early warning information is supposed to be communicated.

Early warning and disaster-related matters have not been fully assimilated into the provincial organograms of the Department of Agriculture. Agricultural advisors also need to be trained on Early Warning systems whilst being assigned functions of disaster management individually and as a collective. Based on smallholder farmers' perceptions, the study suggests a need for strategic shifts from natural pastures to small-scale feedlots. The shift should be coupled with the need to establish a dedicated fodder bank as a specialized business. For the farmers to cope and adapt to climate change, an early warning system is needed. The government should intervene by providing facilitated water and small-scale feedlot infrastructure for smallholder farmers.

Smallholder livestock farmers implement various strategies to cope with drought, including increased livestock sales and movement/migration to distant pastures. When faced with crop failure, livestock sales offer an alternative to buffer consumption against income shocks. However, this potential for livestock sales declines in households in certain low-income, high-risk environments that face simultaneous asset and income shocks. Recommendations made in the literature for improving smallholder strategies include diversification in livestock mix, improving livestock marketing and transportation, organizing supplementary feeding, stabilizing livestock prices, destocking, ensuring mobility and establishing slaughterhouses and restocking schemes.

CHAPTER 8 - ADOPTION OF COMMUNITY GRAZING ASSOCIATIONS AND FODDER BANKS INNOVATION

8.1 INTRODUCTION

Pastures, a broad category of land comprising more than 40% of Earth's land area, are characterized by native plant communities and seeded lands managed as rangelands, often associated with grazing (Walker and Hodgkinson 2000). Pasture management constraints, including environmental, managerial, socio-economic and financial factors, are degrading these important natural resources more rapidly (Johnson 1999; Sardar 2000).

In South Africa, the land surface (80%) is classified as semi-arid to arid, of which 82% is used for agricultural activities. Only 14% of the available agricultural land receives sufficient rainfall for arable crop production; the remainder is used for extensive livestock production, forestry and wildlife/nature conservation (DEA 2011). Under semi-arid and arid conditions, the most extensive agricultural activities are livestock farming (sheep, goats, cattle and ostriches) in rangeland settings, where livestock use the natural veld. However, in addition to low annual precipitation, these semi-arid and arid rangelands are often subjected to recurrent droughts, cyclical long-term droughts, extreme temperatures, marginal edaphic conditions and encroaching woody species (DEA 2011).

Therefore, it can be deduced that having suitable pastures and access to conservation fodder banks is of the utmost importance for any livestock farmer. Cassman and Pingali (1995) indicated that the proportion of livestock and pastures, availability of water resources and coverage of pastures are major constraints on livestock production. This leads to many livestock farmers producing below capacity, highlighting the urgent need for conservation technologies for livestock feeds. The reason for livestock farmers' poor adoption of fodder banks worldwide is not fully understood.

Nevertheless, why livestock farmers did not adopt new technologies is complex and requires a comprehensive understanding.

This deliverable focuses on the progress made in adopting community grazing associations and fodder bank innovation. The narrative will be on the preliminary institutional arrangement, the expected development of the grazing/livestock association, adoption of fodder bank Innovation and establishment of fodder banks.

8.2 REGIONAL EXPERIENCES WITH COMMUNITY-BASED RANGELAND MANAGEMENT SCHEMES

This section reviews experiences with community-based grazing schemes in Southern Africa. The intention is to learn from these experiences to build on the food bank approach. Each scheme is concisely described and analyzed through a SWOT analysis, and key lessons are identified. Historically, community-based rangeland management was launched in the 1970s and 1980s and has taken mostly the form of fenced enclosures, except in Lesotho. It has been unfortunate that few have been successful and sustainable. Consequently, community-based rangeland management has not gained the popularity that community-wildlife management schemes have managed to generate since the 1990s.

8.2.1 Zimbabwe's grazing schemes

Zimbabwe's grazing schemes were appraised by Cousins (1988, 1992, 1993 and 1996), Mugabe et al. (2002) and Hamudikuwanda et al (2002). Mugabe et al (2002) indicated that Zimbabwe's livestock control and grazing schemes date back to the colonial era. An attempt to destock was met with great resistance from the communities during the colonial era, and early grazing schemes in the 1970s failed due to population growth and the liberation struggle. The modern grazing schemes were mostly initiated during the 1980s. The objectives of the scheme were to: (a) improve livestock productivity in communal areas, (b) conserve grazing resources and (c) prevent irreversible land degradation. It was assumed that communal livestock productivity was low due to poor management and that high stocking rates caused rangeland degradation. Both assumptions were questioned in the 1990s.

Correct measurement of productivity of rangelands and communal livestock production, including multiple products such as meat, milk, manure, draught power, savings and cultural values.

Rangeland conditions strongly depended on rainfall conditions that prevented ever-increasing stock numbers. The schemes had a 'standard prescription' of fenced rangelands, rotational grazing and resting. The fenced areas were exclusive to scheme members, who selected a Grazing Scheme Committee, which consisted of representatives of traditional authorities. The committee was given the control of grazing management through formal by-laws or informally agreed rules among members. Bylaws also stipulated financial contributions and other membership responsibilities. The schemes then received considerable government support from agricultural extension and donors. Mugabe et al. (2002) reviewed the governance of five grazing schemes in Masvingo province and concluded that most were doing poorly, and one failed. There is no evidence that any grazing scheme led to higher livestock productivity or improved grazing conditions. Mugabe et al. (2002) suggest that the schemes were in decline rather than making progress. In one scheme, labour had to increase again after the fence collapsed. This limited the schemes of their main benefit, as perceived by members. Bylaws were either not developed or enforced with consequence management.

8.2.2 Common problems of the grazing schemes

(a) Limited actual choice for communities due to the prescriptive model
(b) Community conflicts (between members and non-members) and inadequate conflict resolution mechanisms
(c) Boundaries are known but not respected
(d) Interventions are not based on the local conditions
(e) Poor definition of benefits and beneficiaries
(f) Untransparent or unequal benefit distribution
(g) Wealthy cattle owners dominate decision-making due to a lack of procedures and governance
(h) Unclear link with traditional authorities

(i) Top-down approach with a domineering role for donors and agricultural extension. For example, many initial inputs were supplied free of charge and are not perceived as costs by the community.

8.2.3 The SWOT analysis

Table 24: The strengths-weaknesses-opportunities-threats (SWOT) analysis of grazing schemes

STRENGTHS	**WEAKNESSES**
(a) The GC is a shift from the de-stocking focus of past interventions (b) Some local capacity building (GSC)	(a) The model is prescriptive and offers little choice to communities (b) Most interventions are poorly adjusted to local conditions (c) The model has not clearly demonstrated the benefits (d) Dependency on external support (e) Questionable assumptions about productivity and rangeland degradation (f) Appears unsustainable
OPPORTUNITIES	**THREATS**
(a) Link up with the Campfire movement	(a) Political instability (b) Dominant role of District Councils

The grazing scheme model appears to have mostly weaknesses that affect its performance. Continued dependency on external assistance must have further weakened the scheme during years of political turmoil and donor withdrawal. The major opportunity would be to anchor GS in the Campfire approach.

8.2.4 Lessons from Zimbabwe grazing schemes

(a) Top-down, prescriptive grazing interventions do not work well
(b) The benefits of a fenced (community) ranch, other than saving labor, are not proven; community-based projects have no future without clear benefits and benefit distribution mechanisms.
(c) Exclusivity and membership may be necessary but are a source of conflict between members and non-members
(d) While extension and donor support are necessary, they often affect the sustainability of projects
(e) Community-based projects need to determine the position and role of traditional authorities.

8.2.5 Botswana's communal grazing cells

Odell and Odell (1980) reviewed the group ranches planned under the 1975 Village Area Development Program (VADP). The forty planned ranches never materialized due to capacity problems and underestimation of the difficulties in organizing groups to manage cattle. In response, group ranches were abandoned in 1979 and replaced by broad-based support for communal area development, including livestock activities. Despite the above, communal grazing cells were conceived in 1978 through the Livestock Development Project 2 financed by the World Bank. The objectives of the communal grazing cells were to demonstrate improved range conditions and cattle performance through grazing management and control of stock numbers.

A grazing cell is 'a ranching unit that is communally grazed, operated and owned by registered Agricultural Management Association members, aiming to improve range conditions and animal production (Sweet, 1987). The cells were to be located in overgrazed areas around villages.

Rotational grazing, parasite control and better access to grazing, water and other inputs were measures to achieve improved livestock productivity and rangeland conditions. Sweet (1987) observes that the model was taken from commercial

areas, but trials on Animal Production Research Unit (APRU) ranches failed to demonstrate any consistent advantage of rotational over continuous.

Twelve communal grazing cells were planned to spread over three major ecological zones of Botswana. The cell was relatively small (2,340 ha), fenced and hexagon-shaped around a water source meant for 300 head of cattle. The grazing cells were communally owned and stocked with cattle from the community. They were intended for small cattle owners without sufficient cattle to participate in the group ranching scheme. Members would be registered as an Agricultural Management Association (AMA) and select a site (to be approved by the APRU).

8.2.6 The approach was top-down

(a) The government would develop a constitution and annual management plan for the AMA
(b) APRU would provide a ranch manager for five years while the manager appointed by the AMA would be trained
(c) Construction costs for the fence, borehole and handling facilities were funded under the LDP II, while the government paid the interim manager
(d) AMA members were charged a levy of P10 to P12 per head per annum to pay for operational costs other than the manager's (e.g., maintenance, labor wages and purchase of consumables).

8.2.7 Performance

(a) The grazing cell scheme failed as only one was established. This cell had many problems during the first five years and collapsed soon afterwards.
(b) Common problems included the withdrawal of cattle by members (at one point, only 88 cattle were left inside the ranch), fee payment, unwillingness to invest revenues and difficulties meeting the management plan.
(c) Most communities were not interested, partly because they could not identify communal areas that members would use exclusively at the detriment of non-members.
(d) On the positive side, the cell had much better rangeland conditions than outside, at least partly due to the low grazing pressure. The low stocking rates

imply that outside stocking rates have increased, and risks of overgrazing have grown.

(e) Farmers withdrew cattle from the scheme to avoid payments because they realised that cattle weight gains in the cells would quickly disappear after animals were re-introduced into communal areas. In other words, the benefits did not last unless the animals were sold directly from the cell.

According to Bekure and Dyson-Hudson (1982), Sweet (1986, 1987) and Arntzen (1998), a wide range of social, organizational and economic factors have led to the failure of the approach, including:

i. Overgrazing was not perceived as a priority problem by livestock farmers and communities
ii. The cell did not recognise the importance of livestock outputs other than beef
iii. Farmers do not perceive sufficient benefits to warrant reducing stock numbers or paying grazing fees
iv. Communities had difficulties forming effective groups and granting exclusive grazing rights to that group
v. Introduction of too many alien concepts and interference in local grazing systems
vi. Individual farmers were reluctant to hand over cattle management to a group.

8.2.8 The SWOT analysis

Table 25: The strengths-weaknesses-opportunities-threats (SWOT) analysis of grazing schemes

STRENGTH	WEAKNESSES
(a) The scheme was institutionally founded in policies-programs (b) The provision of water through boreholes encouraged farmers to remain in the scheme (c) Training of manager in five years gave the group members enough time to learn	(a) Farmers did not perceive overgrazing as a problem (b) Communities do not recognize grazing land as a finite resource; hence, the unwillingness to limit stock numbers (c) Shortage of extension staff (d) Inexperience of rural people in cooperative ventures and groups (e) People did not wish to pay the cattle levy (f) Few AMA members and insufficient literacy (g) Communities were reluctant to allocate part of overcrowded communal area for the exclusive use of a few members of the community (h) Mostly top-down approach with limited community choices. In essence, the choice was to develop a cell or not. (i) Most costs were borne by LDP 2 and the government. The sustainability of the cells was,

	therefore, doubtful from the start.
OPPORTUNITIES	**THREATS**
(a) Community-based Natural Resource Management (CBNRM) and community-based rural development may offer new opportunities for community-based rangeland management schemes (b) Community ranches can be established under the 1991 NPAD (c) Communities are now more experienced with community-based organizations and projects	(a) The history of failure of community ranches is known to communities, and will hamper any future activity

8.2.9 Lessons from the Botwana grazing cells

(a) Overgrazing is not perceived to be a significant community problem
(b) Community participation is essential
(c) Communal rangeland schemes must address communal livestock farmers' conditions, attitudes and needs
(d) Community participation is not sustainable without net benefits
(e) Membership and exclusion of non-members create problems of benefit distribution.

8.2.10 Swaziland's Grazing Land Management Demonstrations (GLMD)

Range degradation, declining carrying capacity and soil erosion have been concerns since the 1940s in Swaziland. This situation led to the introduction of various grazing schemes, but most of them failed to bring positive results. According to

Critchley (1995), the Grazing Land Management Demonstrations (GLMD) were set up in the 1980s to improve grazing land practices on communal land. Also, it shows that planning for and managing such schemes benefits from guidance from a qualified range of management professionals. The professional's role was to discourage traditional beliefs and practices detrimental to livestock productivity.

The outcome was to demonstrate that with proper range management, the productivity of both range and animals can be significantly enhanced, and rural incomes rose as a consequence.

The GLMD was a government initiative sold by extension staff to the village chiefs, councilors and interested individuals. Subsequently, small parts of grazing areas, ranging between 20 and 125 ha, were identified and fenced for the grazing demonstration. The government provided free fencing material and determined the carrying capacity. The GLMD committee then ascertained how many livestock each member could bring, usually three or fewer.

Members were charged an annual membership and a monthly management fee. Management focused on rotational grazing, breeding, veterinary care and control of stocking densities. The scheme aimed to increase beef production by selling high-quality animals. The GLMD committee was responsible for all management issues while extension staff offered advice. Each committee developed rules and regulations, which were strictly applied and followed. The government would offer technical advice to the GLMD committee. In each case, the committee would be elected from the participating villages to manage a specific fenced ranch. There were fourteen schemes, but five schemes were abandoned due to inter-group rivalry (Critchley, 1995).

8.2.11 Performance

(a) The damaged range has been successfully restored within the fenced and management areas, and the gullied land is generally stabilised and vegetated.

(b) The average basal cover of the veld is said to have increased from less than 50% to 80%. The condition of cattle in the scheme is much better than that outside the scheme.

(c) Calving intervals were shorter, and the calving percentage was raised from 30% to 60%. The GLMDs' success is attributed to the established line of communication and rapport with the land users and chiefs, making institutional successes more important than technical ones (Critchley 1995).

8.2.12 The SWOT Analysis

Table 26: The strengths-weaknesses-opportunities-threats (SWOT) analysis of Grazing Land Management Demonstrations

STRENGTH	WEAKNESSES
(a) The GLMDs have an established line of communication and consultation with the land users and the chief (b) The scheme adopted a bottom–up approach that made it acceptable to members (c) The members had direct benefits from the scheme regarding fence maintenance and veterinary services provided through breeding cow fees (d) The association enjoys technical support from the government (e) The scheme had a good integration of women	(a) The GLMD initiative has never been fully monitored or systematically evaluated (b) The initial cost of fencing material presents a considerable burden to potential associations, who are reluctant to invest their own resources where other groups have received grants (c) Those community members who fall out of the schemes resist the development of further ranches from which they might be excluded, because every new scheme would squeeze the existing livestock onto less and less land

(f) The number of livestock per ranch was decided on the basis of the carrying capacity of the ranch, avoiding overstocking, overgrazing and soil erosion	(d) By reducing the stocking pressure on just one part of the range, the other areas are put under increasing pressure (e) The scheme constitutes a single-purpose commercial beef enterprise instead of a multi-purpose system including milk, draft, and manure-producing herds (f) The scheme is faced with inter-group rivalry
OPPORTUNITIES	**THREATS**
(a) Expansion of the model to include the whole community (less rivalry and resistance) (b) Attraction of donors to expand the scheme into management of other natural resources and forms of livelihood	(a) Response from non-members (b) The absence of formal legislation makes exclusion difficult

8.2.13 Lessons from the Swaziland Grazing Land Management Demonstrations

(a) Communities can take up an external initiative if they have choices, rights and responsibilities

(b) Government/donor support is essential at the initial stages of community-based programs

(c) It is very important to assess an initiative's impact on excluded community members and find ways to make the program acceptable to the whole community

(d) Pilot projects need to integrate into existing policies and programs if they are to go beyond the pilot period.

8.2.14 Lesotho's grazing associations

Grazing associations in Lesotho were established in 1983 by the Government of Lesotho and USAID to solve problems of open-access communal rangelands. The specific goals for establishing Range Management Areas (RMAs) under GAs were to increase the productivity and income of rural livestock producers (Hunter et al., 1991). These were also to facilitate the commercialization of the extensive livestock industry and satisfy the subsistence needs of rural households. They also focused on allowing the management of renewable natural resources to be sustainable and socially acceptable to rural Lesotho. Initially, the program offered **tractor-ploughing services**, **emergency transport and other types of support**. By 1994, nine grazing associations were established covering 10% of the rangelands of Lesotho (Turner, 2003). Membership of the grazing associations in Lesotho is restricted to residents, with a clear distinction between members and non-members. There were two summer grazing areas, each for five villages, with a grazing manager and range rider. In winter, all villages used a common winter grazing area (Buzzard, 1993). The association operated under a constitution and policy, with a management plan based on rotational grazing. The management plan specified details and operational modalities of the rotational grazing program, which covered a subscription fee of M0.50 (US$ 0.15) per animal unit (6 small stock = 1 animal unit).

The management plan was strictly implemented, and farmers who violated it had their livestock impounded until a penalty fee was paid. The penalty fee ranged from M4.00 to M9.00 per bovine and from M0.60 to M1.50 for small stock. The collected fees were used to pay staff salaries. The GAs were initially funded by the USAID donor agency and enjoyed technical support from the government. The executive committee for the GAs comprises two representatives and the chief/headman from each participating village. The committee employed two GA managers and two ranch riders. The Land Husbandry Act confers rangeland management authority upon the GA.

However, the law did not spell out the GA's status. Hence, they become vulnerable to changes in policy direction. This has already led to the loss of communal rangeland in national parks. GAs lack the social authority to enforce controls. Diverse livestock and range management strategies make adopting a communal management scheme problematic.

8.2.15 The SWOT Analysis

Table 27: The strengths-weaknesses-opportunities-threats (SWOT) analysis of Grazing Land Management Demonstrations

STRENGTH	WEAKNESSES
(a) The clear boundaries reduced the conflicts between local and non-resident farmers (b) The associations were legally recognized, thus giving it the authority to discipline those who violate the rules of the association (c) The associations enjoyed the support of the chiefs/headmen (d) The project provides economic incentives to farmers through breeding, animal health and marketing services (e) The association enjoys technical support from the government, though it had been thought that, at one point, the association should be independent	(a) The model assumes that all local residents would be members, but does not take care of those who were not members, due to non-payment of subscriptions or opting not to join the scheme (b) Some farmers may be adhering to the rotational grazing scheme mainly in fear that their livestock will be impounded and not because they saw the program as beneficial to them (c) The nation is very dependent on livestock for livelihood, which makes it difficult to test the effectiveness of the model without alternative sources on which to apply it

(f) Transparent use of collected fees and subscriptions	(d) There is no assurance that the project would be sustainable without government support (e) The committee is made up of holders who have very limited experience in collective decision-making and are subject to factional infighting
OPPORTUNITIES	**THREATS**
(a) Expansion of the model to other resources and sectors (b) Attractive to donors	(a) Non-members' resistance (b) Unsure of government support

8.2.16 Performance of Lesotho's grazing associations

(a) Ivy et al. (1994) reviewed the project and considered the program successful

(b) The reduction of stock numbers through the expulsion of outsiders resulted in an increase in ground cover in RMA from an average of 65.3% to 69.1%. The range conditions improved considerably, increasing plant species diversity by 42%. With vegetation given time to recover for control stock numbers, animal condition improved, small stock reproduction improved by 50%, while mortality declined from 40% to 10%.

(c) Cattle value at auctions in the RMA was higher than non-RMA cattle. There is no data about grazing land productivity. Better, but fewer animals could lead to the same or even lower productivity than before!

8.2.17 Lessons from Lesotho's grazing associations

(a) Fencing is not a necessary condition to improve communal rangeland management

(b) Boundaries need to be defined and respected

(c) Membership is an effective method for exclusion and control over benefits and costs. People will only join and contribute financially if they perceive net benefits
(d) Exclusion can have high costs. It creates social-community conflicts and may adversely impact rangelands elsewhere.
(e) Rotational grazing and herd mobility can effectively improve rangeland conditions
(f) A firm, supportive policy framework is necessary to sustain community-based rangeland management approaches.

8.2.18 Namibia's Northern Regional Livestock Development Project

The Northern Region Livestock Development Project introduced a community-based component in 1997. The project's overall aims were to improve livestock outputs and ensure sustainable use of rangeland resources.

In 1997, the goal of the rangeland component of the project became that communities develop and implement initiatives that improve the sustainability of rangeland resources and, through this, demonstrate methods, techniques and procedures for wider application (Kruger, 2000). Communities would be fully involved in the planning and implementation of sustainable resource management; their management capacity would be strengthened, and their understanding of livestock production systems, their constraints and intervention possibilities would be improved.

The rangeland component of the project had three areas of intervention: water provision, fodder and rangeland management. In his term review, Kruger (2002a) argues that water provision has been most successful despite the technocratic approach. A total of 39 water points were developed, and subsequently, water point committees were established to run them. Some water points did well, and others performed less so.

Some communities were not immediately capable of running their water supply. The siting of water points was not linked to rangeland management issues. According to Kruger's evaluation, rangeland management had made little progress; in part,

livestock owners did not consider rangeland conditions and productivity a major problem. This perception reflects a lack of forward-looking strategies (with illegal fencing, communal rangelands will face increasing pressure in the future), or it could reflect resignation because increased livestock pressure is mostly beyond the control of communities. The component developed a few demonstration plots of grazing, resting and pilot fodder plots. Community-based rangeland management strategies have not been developed and tested.

The lack of legal rights over rangeland resources is a major problem for communities, as they cannot exclude outsiders (to be addressed in the Communal Land Bill).

Key conclusions concerning communities were:

(a) The project has had little impact on social mobilisation and empowerment of local community structures
(b) There has been no increase in livestock production or improvement in rangeland conditions
(c) There has been no direct impact on households' and communities' financial status and food security. Community gardens, developed without consultation to check communities' interests, have had little success.
(d) There was a need to link the implementation of this project closer to mainstream CBNRM approaches.

Recommendations on Livestock Management Measures (Kruger, 2000a):

(a) Testing of additional food sources (crop residues, fodder, rented grazing and hay)
(b) Altering livestock movements, improving animal health, focusing on indigenous livestock breeds, assessing rangeland conditions and marketing needs
(c) Adopting the FIRM approach and establishing a conducive policy/legal environment that guarantees communities exclusive and secure user rights, including grazing resources.

8.2.19 Lesson from Namibia's Regional Livestock Development Project

(a) The absence of a legal framework hampers community management options

(b) Establishing an integrated support service (e.g., FIRM) is useful when it focuses on community needs

(c) Overgrazing is not necessarily perceived as a priority problem for communities. This makes it challenging to design and implement a rangeland/ livestock plan of action.

(d) Water provision is usually a priority. Communities can be charged with water point management, but require training and support.

(e) If projects fail to improve livelihoods and/or food security, attracting and keeping community interest will be challenging.

8.3 OVERVIEW

The nature and scope of livestock projects have significantly changed over time. De Haan (1994) distinguishes four phases in livestock project design:

(a) The ranching phase from the mid-1960s to the early 1980s. The western ranch model was transferred to semi-arid Africa, involving significant capital investments and usually heavy government involvement (LDP and TGLP ranches).

(b) The range/livestock projects from the mid-1970s to the late 1980s focused on communal areas through the development of infrastructure and adjudication of grazing and land rights, sometimes to groups (e.g., SLOCA, grazing cells and schemes)

(c) The pastoral association phase. This overlaps with the previous phase, but there is more emphasis on herders' management services and a less rigid focus on overgrazing and land tenure.

(d) The integrated natural resource management project phase. Examples are the recent phase of NOLIDEP in Namibia. In Botswana, phases 1 to 3 are found, but the trust of agricultural policy has remained in phase 1, i.e., ranching. SLOCA represents phase 2, and IVP could be labelled as a cross between phases 3 and 4.

8.3.1 Some of the attributes of livestock project failure

De Haan (1994) attributes the failure of many livestock projects to several factors. Firstly, governments dominate the livestock support framework, often with a market monopoly and government-controlled prices. Secondly, grazing and land rights are too rigid, following the privatisation and rotational grazing model. There was insufficient attention to the livestock mobility requirement and opportunistic stocking strategies (Sandford, 1990). Thirdly, institutional weaknesses exist in the implementation agencies, notably lacking multi-disciplinary skills. A workshop on rangeland management strategies in semiarid environments added another factor (Ngaido et al., 2002, p. 51): 'Successful local level natural resource management requires better links with other actors in the national system and should be part of an overall development strategy'. Most livestock projects are not integrated in rural development programs. Recognizing that in the early 1990s, the results of phase 4 projects could not yet be assessed; de Haan identifies four issues that require more attention: herder organisation (capability and sustainability assessment is poor), drought contingency measures (e.g. fodder banks, marketing provisions and insurance/drought relief measures), the role of the public sector (e.g. division of responsibilities, top-down attitudes) and cost-recovery/sustainability. The above factors appear to also apply to Southern Africa and to Botswana.

8.3.2 Lessons learned

Some lessons learned indicate the importance of capacity and sustainability assessment of CBOs, partnerships with adjusted roles for stakeholders (e.g., new, less government and more local communities, private sector and NGOs), more flexible resource rights and built-in drought coping measures, a multi-disciplinary approach and integration of livestock activities in rural development programs and planning.

8.4 GOOD PRACTICE

8.4.1 Selection of villages

The project is being implemented in a design that couples a community of farmers with either a demonstration centre, a research station, a university, or a satellite research farm. One of the best practices followed was the weekly, bi-weekly, and monthly meetings and recording of minutes. Project staff trained and facilitated members on fodder from planting and overall management practices as per the project objectives.

Table 28: Indicates the institutions that support the farmers

NAME	ROLE	INFLUENCE
KIS	Lead research organisation	Conduct study
Limpopo Department of Agriculture and Rural Development	Advise, research, fund and support farmers; organize smallholder farmers	Currently, it provides extension services and scientific advisory to support smallholder livestock farmers and personnel with institutional knowledge of livestock projects. The Mbahela Satellite Research Farm is under its management.
Mpumalanga Department of Agriculture, Rural Development and Environment	Advise, research, fund and support farmers; organise smallholder farmers	Currently holds the extension services and scientific advisory that support smallholder livestock farmers and personnel with institutional memories on livestock projects. The department owns the Nooitgedacht Research Station.
SEKHUKHUNE District Office of Agriculture and Rural Development	District offices are implementing arms of the provincial offices. They control the local municipality offices with differentiated roles of value chains, extension services, land reform, disaster, crop production and livestock meant to service local	The Mmakgatle project is based in a Groblersdal village under Elias Motsoaledi Local Municipality. The district's role will determine the support base. The Mmakgatle

	municipalities (agro-ecological zones) that are hubs for extension services through service centres (sub-agro-ecological zones).	Farmers Association participates in the project.
GERT SIBANDE District Office of Agriculture, Rural Development and Environment	District offices are implementing arms of the provincial offices. They control the local municipality offices with differentiated roles of value chains, extension services, land reform, disaster, crop production and livestock meant to service local municipalities (agro-ecological zones) that are hubs for extension services through service centres (sub-agro-ecological zones).	The town of Tjakastad is based in Chief Albert Luthuli Local Municipality. The Tjakastad Farmers Association participates in the projects. However, they are currently passive participants, as no activities have been done on their farms.
University of the Free State	To administer PG students and provide potential support in supervision	Capacity to enhance research rigor and quality in support of the project. Ms Prudence Nenweli has graduated with her Master's in Rural Development at UFS.
Towoomba Research Station Limpopo	The research station/centre is well situated to build farmer support teams of the Mmakgatle Farmers Association	Establish the farmer demonstration sites to directly meet the learning needs of the collaborating Mmakgatle Farmers Association within the geographical regions of the sites and to develop them as project legacy sites under the management of the Limpopo Provincial Departments of Agriculture
The Nooitgedacht Research Station	Situated four km from Ermelo, the Agricultural Department researches crop production and animal husbandry	Establish the farmer demonstration sites to directly meet the learning needs of collaborating Tjakastad Farmers Association participants in the projects within the geographical

		regions of the sites and to develop them as project legacy sites under the management of the Mpumalanga Provincial Departments of Agriculture. However, they are currently passive participants, as no activities have been done on their farms.

8.4.2 Group meetings facilitated by project team

Table 29: The frequency of virtual meetings held, and major decisions made to implement project activities

Dates	Major Decision Taken	Responsible Team Leader
08 November 2022	Inception meeting at Ermelo, project introduction at Vhembe, drought-coping strategy, community grazing associations, potential partnership with Sakata Seed producers	Prof A.E. Nesamvuni Dr N.B. Nengovhela Dr T.P. Madzivhandila Mr Oupa Keromecwe Ms Kedi Chueu Ms Nomusa Mashile Ms Mboni Mulaudzi
16 November 2022	Finalisation of grass species mixture, communication with nurseries in Vhembe and Gert Sibande Municipalities, and engagement with Sekhukhune District Municipality	Prof A.E. Nesamvuni Dr N. B. Nengovhela Dr Julius Tjelele Dr Lesego Motshekga Mr George Xaba

		Ms Lethabo Mashamaite
22 November 2022	Supply chain processes to procure the grass mixture, report back from the supply of lucerne tree, Leah Armstrong, reports on nurseries at Vhembe and Gert Sibande	Dr N.B. Nengovhela Prof A.E. Nesamvuni Dr T.P. Madzivhandila Ms Kedi Chueu Ms Brenda Tlhabane Ms Lethabo Mashamaite
26 November 2022	Grass mixture and land preparation, development of Tree Lucerne User Guide, development of water-smart approaches and development of entrepreneurial support to farmers and nurseries	Dr N.B. Nengovhela Prof A.E. Nesamvuni Dr T.P. Madzivhandila Mr Ntuwiseni Mmbi Mr Oupa Keromecwe Ms Kedi Chueu
06 December 2022	Development of land preparation protocols, finalization of the User Guide by 10 December 2022, alignment of the activities with water-smart approaches and entrepreneurship and drought-coping questionnaire	Dr N.B. Nengovhela Prof A.E. Nesamvuni Dr T.P. Madzivhandila Mr Ntuwiseni Mmbi Mr Oupa Keromecwe Ms Kedi Chueu Ms Mboni Mulaudzi

17 January 2023	State of readiness to plant grass mixture, all teams received grass mixture packs, and training in land preparation by tractor operators for limited till. Tree Lucerne User Guide to be circulated to all teams electronically. Kedibone to set up a Gmail account so that all documents and photos from the project could be deposited onto the Google Drive.	Dr N.B. Nengovhela Prof A.E. Nesamvuni Dr T.P. Madzivhandila Mr Ntuwiseni Mmbi Mr Oupa Keromecwe Ms Kedi Chueu Ms Mboni Mulaudzi
24 January 2023	The teams to document and report on the minimum tillage approach used after planting. Teams agreed to plant before end of January to early February. The use of irrigation and herbicides was not recommended as the idea was to mimic the case of resource-poor farmers. Mechanical weeding is preferred, and irrigation can be used if there is notable water stress. If it is possible, measure the amount of water-use efficiency, which might be	Dr N.B. Nengovhela Prof A.E. Nesamvuni Dr T.P. Madzivhandila Mr Ntuwiseni Mmbi Mr Oupa Keromecwe Ms Kedi Chueu Ms Mboni Mulaudzi

	possible for the scope of this study.	
14 March 2023	At Towoomba, planting was done on 30 January 2023. Pictures were sent. Germination is currently at 70%. At Mmagatle, planting was done on 8 February 2023, and farmers were involved. By 15 February, sorghum had already germinated, and grasses had also germinated. At Nooitgedacht, planting was done on 28 February 2023 due to the rains received in early February. The seed has germinated. At Mbahela-Tshiombo, the land has been prepared, but planting has not been done. There were no activities on the experimental sites of the ARC or the University of Limpopo.	Prof A.E. Nesamvuni Dr N.B. Nengovhela Dr T.P. Madzivhandila Ms Kedi Chueu Mr Ntuwiseni Mmbi Mr Oupa Keromecwe Ms Lerato Nenweli Dr Lesego Motshekga Dr Julius Tjelele

On 2 November, 2022, a major visit was made to mobilise Team Mpumalanga to participate and set roles and responsibilities at Ermelo-Nooitgedacht Research Station.

A visit was also made to the commercial farmer, Thabane, to set up a plot to plant his grass and trees. The Mbahela–Tshiombo site was visited over eight times to set up

a nursery and meet with farmer groups. Similarly, the Mmakgatle farmers were visited over six times for planning, plowing, planting and fencing activities. Farmer Association Members were instructed on the project's activities and the process of fodder plantations. Meetings were also conducted to explain the concept and sensitize them to mobilize resources for the proposed fodder plantations.

8.4.3 Selection of site

8.4.3.1 Mbahela

The farmer association chose the site at Mbahela for testing the grass mixer at the experimental plot. The experimental plot is situated close to the farmer association plot, which is, on average, one hectare. In agreement with farmer associations, the project intends to adopt the best grass mixer for the open lands around farmers' homesteads, such as wastelands and uncultivated portions.

8.4.3.2 Mmakgatle

Farmers made selections based on proximity to the dipping tank. The site was also near the homestead for ease of monitoring and possible weeding. The government later funded the site for fencing using poles and barbed wire. Since the plot was on common land and wastelands, protecting the area from cattle grazing, theft or other damage is extremely important. Planting was conducted in the rainy season as climatic conditions are better suited for adaptation and growth.

8.4.4 Land preparations

Towoomba Land Preparation

Pegging of planted land at Towoomba

8.4.4.1 Fencing

Only the Mmakgathle Farmers Association received the fencing material during the course of the project.

Photo 4: Mmakgatle Farmers receiving fencing materials

8.4.4.2 Mix of grass planted

Tropical perennial grasses (Digitaria eriantha, Chloris gayana, Panicum maximum and 4 Grazer mixture (Brachiaria brizantha, Chloris gayana, Panicum maximum, MG-5 and Mombasa) were selected.

Photo 5: Planted grass species in blocks being surveyed by the lead farmer Mr Mphaphuli

8.4.4.3 Protection and land management

Protection and management of fodder plots are crucial for the success of this entire intervention. Each production plot was assigned to the farmer association's leadership to protect it from cattle grazing, damage to plants and fences and theft of grass. Each group's members are responsible for weeding, intercultural operations and manuring their portion of the plot. Ideally, during the harvest, every member will get the grass from their part of the plot.

8.4.4.4 Establishing village fodder nurseries and promotion of fodder cultivation

The grass mixer was outsourced from a private company. Several meetings were held to establish nurseries that were supposed to be focused on the lucerne tree.

8.4.4.5 Challenges faced

(a) Aftercare practices in community fodder banks

As reported in the literature, the main challenge has been encouraging beneficiaries to adopt aftercare practices such as weed management and fertilization/manuring of the community fodder banks. This challenge also affected the experimental stations and the university-based research and demonstration sites. The project funds have been used to hire service workers and tractors to clear the weeds.

Literature reports citing similar challenges with no sustainable solutions corroborate this. Weed growth was observed in one of the fodder banks, which required aftercare. Though the farmers were made aware of the problem, aftercare remained a challenge. One of the proposed solutions has been to demarcate the sub-areas for each member for aftercare. In one village area, the work on land on a plantation had to be abandoned due to local-level politics.

(b) Non-availability of fodder trees

The non-availability of sufficient fodder trees has remained a severe constraint, as there are no fodder nurseries in the area. The project supplied seeds to all demonstration and experimental sites for germination. The success was in the grass planting at the university experimental site. There has been less success in growing the lucerne tree at the farm level, demonstration site, and university. Studies have shown that, in many instances, the government becomes the sole provider of fodder, challenging the notion of self-sustainability. Secondly, the project attempted to utilize established nurseries to grow lucerne trees and provide planting material for the next year. These nurseries were chosen based on proximity to the villages. This attempt was unsuccessful due to the lack of skill to germinate and plant the lucerne tree.

8.5 PROFILE OF FARMERS' ASSOCIATION

8.5.1 Mmakgatle Diphiri farmers

Established on January 26, 1996. The original number of members was 56 farmers—both male and female. Currently, 68 farmer members are managing 900 cattle (see Photo 6).

Photo 6: Mmakgatle Diphiri farmers

Initially, the main motivation for the group's formation was to address the massive issue of stock theft. Farmers formed a group to protect animals, but the group progressed to include aspects on how to improve cattle production and marketing. The group decided to increase the number of cattle sold through an auction company. As a group, they negotiated with the cattle buyer for better marketing arrangements, but continued to explore other market opportunities. Hence, members are thrilled about the contracted marketing arrangement. Some members have indicated that they will need training and continued support from the government and research team. The group management structure includes a leader, treasurer and secretary. The decision-making process is through a central committee but follows a thorough consultative process among members.

8.5.2 Main constraints

Aside from stock theft, the main problem was with animal marketing, including a lack of market information, accessibility, low prices and lack of training.

8.5.3 Key achievements

The key achievements were improved market access through the assistance and training provided by the government and other programs. An auction market was brought to the village. The group believed that the price they received was still an issue, but this was better than selling in other long-distance markets. There was also an improved marketing decision-making process. Farmers are now able to decide when and what to sell.

Additionally, there was improved knowledge of production practices, including better herd management (including a better understanding of carrying capacity and stocking rates; better bull and breeding management; ear tagging and stock identification and record-keeping). Better succession planning through more involvement of young farmers also resulted.

8.5.4 Main challenges and opportunities

- Improvement of pasture management, including growing and producing own feed
- Proper and improved breeding management
- Excitement about the prospects of the new initiative in marketing their animals. They are committed to making the project a successful venture, but have acknowledged that they will need support and assistance.

8.6 Mbahela Farmers' Association

8.6.1 Gender profile

The group has 26 livestock farmers, constituting 22 males and only four women.

8.6.2 Age profile

The association has three members under the age of 35, 16 between 36 and 60, and eight over 60.

8.6.3 Livestock numbers

The association has 165 cattle, 481 goats and 146 sheep.

8.7 CONCLUSIONS

The early generation of grazing schemes and cells largely failed due to a variety of factors. For community grazing associations to succeed, grazing lands in communal areas should be a priority both to the communities and government. Grazing schemes should be established with extra benefits to communities such as veterinary access and support, inputs, marketing links, processing and transport.

CHAPTER 9 - ENABLING POLICY ENVIRONMENT

9.1 INTRODUCTION

9.1.1 The geophysical profile of Limpopo and Mpumalanga

The country's geophysical profile, particularly in Limpopo and Mpumalanga, indicates that 85% of the land is classified as semi-arid, of which 82% is designated for agricultural use. Only 14% of the available agricultural land receives sufficient rainfall for arable crop production. The remainder is used for extensive livestock production, forestry and wildlife/nature conservation (Jordaan et al. 2013). Under semi-arid and arid conditions, the most extensive agricultural activities are livestock farming (sheep, goats, cattle and ostriches) in rangeland settings, where livestock use the natural veld. However, in addition to low annual precipitation, these semi-arid and arid rangelands are often subjected to recurrent droughts, cyclical long-term droughts, extreme temperatures, marginal edaphic conditions and encroaching woody species (Jordaan et al. 2013). The impacts of drought remain devastating for vulnerable rural communities, particularly those heavily reliant on livestock for livelihoods. Some of the worst droughts in the country occurred between 2012 and 2018, with the 2015/16 drought regarded as the worst since 1992.

9.2 EXISTING POLICY FRAMEWORK

The Department of Agriculture, Land Affairs, and Rural Development (DALRRD) has long recognized the need to promote sustainable rangeland management as an essential part of drought management strategies for the livestock sector from as far back as 1922/23 (Drought Investigation Commission Report). A new body of knowledge now supports this; for example, some of the recent documents include the draft National Drought Management Plan (2005), draft Climate Change Sector Plan for Agriculture, Forestry and Fisheries (Notice 38851 of 2015, Government Gazette), and draft Climate-Smart Strategic Framework (Notice 41811 of 2018). In efforts to assist farmers in managing the effects of drought, the DALRRD disseminates drought-coping strategies on a quarterly basis through the National Agro-meteorological Committee (NAC) Advisory bulletin to provide early warning information and strategy for drought preparedness, coping and recovery measures

in line with climate and weather conditions. The NAC advisory report contains information on interventions implemented by the DALRRD through the Drought Relief Scheme, which is implemented in line with the Disaster Management Act (Act 57 of 2002).

The implementation framework for the Drought Relief Scheme states that relief assistance should only be granted to farms that adhere to the correct stocking rate with no signs of overgrazing, as guided by the National Grazing Capacity Norms (Conservation of Agricultural Resources Management Act 43 of 1983). However, most drought preparedness and coping strategies do not distinguish between rangeland users.

The strategies are largely applicable to commercial individually-owned farms (large commercial farmers) and not suitably aligned with the realities of communally managed rangelands (small-scale and emerging farmers), which have complex governance issues related to land and water security, i.e., "tragedy of the commons". The resilience of their agro-ecosystems influences the capacity of land users to cope with drought, the diversity of livelihood options, access to resources and institutional support (Vetter, 2009). Therefore, there is a need to develop drought-coping strategies that apply to communally-managed rangelands for government efforts for drought relief to have a meaningful impact on rural livelihoods.

9.2.1 Expectations of the drought relief schemes

Effective implementation of drought relief schemes should ideally seek to prevent livestock herds from starving to death, due to lack of grazing and water. Farmers have expressed concerns over the turnaround time for implementing the drought relief scheme, as the relief efforts were provided long after the disaster (Ngaka, 2012). Rural livestock farmers require more appropriate and timely drought relief support to practice sound rangeland management. A study conducted in high rainfall districts in the Eastern Cape showed that climate is not necessarily linked to ecological vulnerability to drought, poor planning and management of water supply, poor grazing practices and land management lead to severe land degradation. Therefore, drought relief efforts should provide a long-term proactive

strategy that strengthens rural communities to practice sustainable rangeland management within constraints imposed by changing and variable climates. Rangelands in many communal areas of South Africa are severely affected. Consequently, it is essential to rehabilitate degraded rangelands to enhance soil water retention and establish climate-smart fodder banks using drought-tolerant pasture species. Thus, farmers must develop a culture of establishing fodder banks (within their farms) that will be used strategically during periods of limited feed supply to promote all-year-round fodder flow within the limitations imposed by climate (erratic rainfall) and sustainable utilisation of natural resources (soil and veld). This will further help reduce farmers' dependence on government fodder-provision subsidies. A fodder bank is an integral component of sound veld management practices, as the availability of such a unit on a farm helps to alleviate pressure on the valuable, yet vulnerable, veld resources. It represents the only reliable counter to the disruption of the fodder flow caused by drought and other calamities. Another added benefit of a fodder bank is that it reduces reliance on expensive concentrates.

This section emphasizes creating a conducive policy environment to enable climate-smart fodder banks in selected rural communities. This is to relieve pressure on vulnerable and yet valuable communal rangeland resources, thus enhancing the resilience of communal livestock farmers to drought. Central to such an enabling policy environment is developing a National Drought Plan focused on an agricultural mix of crop, pasture and livestock. The rationale of such a plan will be motivated by the fact that most droughts are particularly evident in the agricultural sector and in vulnerable communities in the country. Food insecurity and the livelihood of farmers are the most significant associated impacts of drought, as the level of food is usually reduced during drought disasters, thereby increasing people's vulnerability.

9.3 CURRENT POLICY ANALYSIS

The problem statement of the Drought Management Plan establishes the objective of a comprehensive drought policy, particularly one focused on agriculture and the mixed farming of crops and livestock. Most rural households rely on agriculture for

their food and income, which plays a vital role in the stability of rural communities. When drought occurs, these communities often find themselves without their livelihoods and the investments they have made in agriculture.

Historically, responses to drought have been reactive, following inconsistent patterns. The shortcomings of past and current policies can be attributed to poor coordination among governmental structures, resulting in slow and ineffective responses to drought, especially in farming communities with limited resources. While government policies have improved over the years, particularly since the implementation of the Disaster Management Act of 2002 (Act No. 57 of 2002) and the Drought Management Plan of 2005, there remains a need for a more focused approach to drought management in agriculture, both for crops and livestock.

This new policy should complement existing frameworks and will be enhanced by approved policies, including a practical and accessible early warning system. Given its developed commercial farming sector alongside a significant subsistence farming sector, South Africa requires a more comprehensive plan to protect its rural communities and their economies from the devastating effects of drought. The main focus of the policy will be on making smallholder farmers and agro-pasture-based red meat producers more resilient to drought. This would include policies promoting general good practice in communal and commercial rangeland development, promoting reduced vulnerability, and encouraging participation. Table 30 presents a summary of the current policies in use, along with an analysis.

9.3.1 Drought Management Plan (2005)

The plan was meant to develop an effective, integrated risk and disaster management system for plant and animal husbandry and price and income systems to minimise the impact of droughts.

9.3.2 Draft Climate Change Sector Plan (2013)

The sector plan was developed to establish vulnerability assessments, mitigation strategies and adaptation strategies to minimise the adverse effects of climate change.

9.3.3 Draft Climate Change Sector Plan (2015)

The Draft Climate Change Sector Plan for Agriculture, Forestry and Fisheries contributes to the livestock and drought debate through its focus on community grazing, mainly (a) the degraded state of rangelands (veld), loss of and low herbage yields, (b) change in veld composition, alien invasive grass species and weed infestations in grasslands, (c) grassland/woody species dynamics, C3 and C4 grassland dynamics and C3 and C4 grasslands and fire dynamics, (d) reductions in grazing areas and reduction in resilience to extremes; also, on vulnerabilities and challenges facing small-scale subsistence farmers in South Africa. Small-scale livestock farmers are vulnerable to fluctuations in river flow because their domestic animals become stressed or die when flows are low, unreliable or streams dry up. Furthermore, at low flows, the water quality is poor. Conversely, livestock and wildlife tend to become diseased if flooding occurs.

9.3.4 Draft Climate Smart Agriculture Strategic Framework for Agriculture, Forestry and Fisheries (2018)

This strategic framework was developed to provide an enabling and coordinated policy environment focusing on (a) reducing the vulnerability and risk related to climate variability and change, (b) enhancing adaptation capacity and promoting research communication and extension services.

9.3.5 National Climate Change Adaptation Strategy (2019)

The strategy was developed to build resilience and adaptive capacity to respond to climate change risks and vulnerability. It promotes integrating climate change adaptation response into development objectives, policy, planning and implementation.

9.3.6 The Climate Change Act (2024)

This act was formulated to provide for effectively managing inevitable climate change impacts by enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change. This includes building social, economic

and environmental resilience and an adequate national adaptation response in the global climate change response context.

9.3.7 National Policy on Comprehensive Producer Development Support (2024)

The main objective of the policy is to regulate and guide the provision of support measures for various categories of producers, thereby contributing to the restoration of natural resources and to a sustainable, transformed and competitive agricultural sector. It emphasizes promoting disaster risk reduction measures, including post-disaster recovery and rehabilitation.

Table 30: Analysis of main acts, plans and strategies in relation to drought and community grazing

LEGISLATION	KEY OBJECTIVES	ISSUES
1. Draft Climate Change Sector Plan for Agriculture, Forestry and Fisheries, NOTICE 500 OF 2015	A sector-related climate change strategy and scenario to promote climate change awareness and knowledge, advocate sustainable terrestrial and aquatic ecosystems-based production practices that minimize emissions of greenhouse gases, conserve the sector's natural environments, promote adaptation, and mitigate the effects of climate change as far as possible	1. Section 2.5.6, Livestock-related aspects on community grazing—mainly (a) the degraded state of rangelands (veld), loss of and low herbage yields, (b) change in veld composition, alien invasive grass species and weed infestations in grasslands, (c) grassland/woody species dynamics, C3 and C4 grassland dynamics and C3 and C4 grasslands and fire dynamics, (d) reductions in grazing areas and reduction in resilience to extremes 2. Section 2.6.4 on Vulnerabilities and challenges facing small-scale subsistence farmers in South Africa. Small-scale livestock farmers are vulnerable to river flow levels because their domestic animals become stressed or die if flows are low, unreliable, or streams dry up. Furthermore, at low flows, the water quality is poor. Conversely, livestock and

LEGISLATION	KEY OBJECTIVES	ISSUES
		wildlife tend to become diseased if flooding occurs. 3. Section 3.3, Projected changes related to components of the agriculture sector, addressed explicitly in 3.3.3 Rangelands and planted pastures. Climate change (including the effects of increased atmospheric carbon) may complicate the existing problems of bush encroachment and invasive alien species in rangelands. 4. Section 4.4 on adaptation to climate change in South Africa: agriculture and livestock-related, specifically addressing 4.4.5, Dryland crop-related: Other adaptations as it relates to new suitability areas of major grass species such as Eragrostis Curvula and Kikuyu 5. Section 4.4.8, Rangeland and livestock-related, this relates to adaptation to changes in veld composition, loss of herbage yields, alien invasive species, fodder banks and supplementary feeding 6. Section 4.4.10 addresses the subsistence farmer, specifically overcoming farmers' constraints and the poverty trap, namely, poor commercialization, poor infrastructure, and low farm productivity; factors that largely result in poverty.
2. Draft Climate Change Sector Plan 2013, NOTICE 7 OF 2013	The objective of the Draft Climate Change Sector Plan is (a) to ensure compliance with international obligations on climate change, (b) to	1. Section 4.2, A vulnerability assessment of climate change should be conducted for the sector. 2. Section 4.3 on mitigation and adaptation,

LEGISLATION	KEY OBJECTIVES	ISSUES
	minimize or reduce the negative impacts and risks associated with climate change to increase and improve food, fiber, timber and energy production.	appropriate mitigation and adaptation strategies must be identified to minimise the adverse effects of climate change. 3. Section 4.4 on response and recovery to minimise the adverse effects of climate change.
3. No. 22 of 2024: Climate Change Act, 2024	To enable the development of an effective climate change response and a long-term transition to a low-carbon and climate-resilient economy and society for South Africa in the context of sustainable development and to provide for matters connected to that.	1. Objectives of the Act, section (b), provide for the effective management of inevitable climate change impacts by enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change, building social, economic and environmental resilience and adequate national adaptation response in the context of the global climate change response. 2. Chapter 4, section 20 on the Adaptation scenarios section, subsection (2) (a) to (d). The adaptation scenarios must(a) be based on the best available science, evidence and information, (b) include climate monitoring infrastructure for the climate system and early warning system, (c) include a consideration of the potential impacts of climate change on the environment of the Republic and associated vulnerabilities, and (d) contain available adaptation response options to reduce identified vulnerabilities by

LEGISLATION	KEY OBJECTIVES	ISSUES
		building adaptive capacity and resilience, in the context of actual or anticipated social, economic and environmental costs. 3. 21,on the purpose (4) (a) to (b) namely, (a) achieve a reduction in the vulnerability of society, the economy and the environment to the effects of climate change, strengthen the resilience of the socio-economic and environmental system and enhance the adaptive capacity of society, the environment and economy to the impacts of climate change, (b) reduce the risk and vulnerabilities from current and future climate scenarios. 4. Section 21 (5) (d) of the National Adaptation Strategy and planning must include available adaptation response options to reduce identified vulnerabilities by building adaptive capacity and resilience in the context of the actual or anticipated social environment. 5. Section 22 on the Sector Adaptation Strategy and Plan (1) (a) (i) that identifies and spatially maps risks and vulnerabilities that will arise in areas, ecosystems and communities which are vulnerable to the impacts of climate change.

LEGISLATION	KEY OBJECTIVES	ISSUES
4. Draft Climate-Smart Agriculture Strategic Framework for Agriculture, Forestry and Fisheries -NOTICE 428 OF 2018	The five core objectives of the framework are: (a) to guide actions at all levels of government, investors and development partners on mainstreaming CSA into agriculture, forestry and fisheries plans, programs and projects (b) contribute to increasing productivity and growth of agricultural, forestry and fisheries-related value chains with nutrition and gender considerations (c) enhance resilience to climatic and weather shocks on the social, environmental, and economic aspects of agriculture, forestry, fisheries production, and food systems (d) contribute to low carbon development by efficiently using agricultural, agribusiness, forestry and fisheries resources to reduce national emission intensity in the AFF production and food systems (e) strengthen governance and institutional coordination to effectively implement the Climate-Smart Agriculture Framework Program at national, provincial and local levels.	1. Chapter 6, section 6.1, Output, An Enabling and Coordinated Policy Environment. With a focus on (a) reducing vulnerability of the Agriculture, Forestry and Fisheries systems, (b) reducing and managing risks related to climate variability and change by promoting the implementation of specific adaptation options, (c) enhancing elements of adaptive capacity and (d) promoting research, communication, institutional development and extension agencies 2. In its Chapter 6 and section 6.4.3 on (a) improve nutrition through supplementation, forage and fodder conservation.

LEGISLATION	KEY OBJECTIVES	ISSUES
5. Drought Management Plan of 2005	The DMP's vision is to develop an effective, integrated risk and disaster management system for plant and animal husbandry and price and income systems to minimize the impact of droughts.	1. Section 3, Item 3.1.4 Any assistance to farming communities will be under the **Disaster Management Framework.** To qualify for this assistance, farming communities should have applied prevention and mitigation strategies, e.g., planting drought-tolerant crops, de-stocking and using available insurance products, following good farming practices, and utilising early warning information in their planning.
6. National Climate Change Adaptation Strategy 2019. The Republic of South Africa Version UE10. Department of Forestry, Fisheries and Environment	The strategic objectives of the policy are (a) Objective 1: build climate resilience and adaptive capacity to respond to climate change risks and vulnerability, (b) Objective 2: promote the integration of climate change adaptation response into development objectives, policy, planning and implementation, (c) Objective 3: improve understanding of climate change impacts and capacity to respond to these impacts, (d) Objective 4: ensure resources and systems are in place to enable implementation of climate change responses.	1. Section 3.4. on the Strategic Interventions Intervention 3: develop a vulnerability and resilience methodology framework that integrates biophysical and socio-economic aspects of vulnerability and resilience. 2. Section 5, develop a coordinated climate services system that provides products and services for key climate-vulnerable sectors and geographic areas. 3. Section 6, Climate Risk and Vulnerability Assessment Framework, develop vulnerability and resilience methodology framework that integrates biophysical and socio-economic aspects of vulnerability and resilience.
7. National Policy on Comprehensive Producer	The main objective is to regulate and guide the provision of support measures to the various categories of producers,	1. Section 8.2.3.2. emphasises promoting disaster risk reduction measures, including post-disaster recovery and

LEGISLATION	KEY OBJECTIVES	ISSUES
Development Support	thereby contributing to the restoration of natural resources and a sustainable, transformed, and competitive agricultural sector.	rehabilitation. Three subsections, (ii), (iii) and (iv), address issues relating to drought and its impacts on livestock. These are: (a) design and implement a soil health, rangeland health and farming resilience evaluation, monitoring and reporting system for each of the categories of farmers and prioritise farmers who comply during post-disaster recovery, (b) maintenance of an early warning system to ensure timely provision of appropriate information, (c) timely provision of the post-disaster recovery and rehabilitation measures.

9.4 THE CONTEXT OF DROUGHT MANAGEMENT FOR COMMUNITY-BASED RANGELAND LIVESTOCK PRODUCTION

Morton and de Haan (1995) wrote a comprehensive policy paper addressing drought management, focusing on community rangeland livestock production. Severe droughts frequently occur in our country and sub-Saharan Africa. These droughts cause significant human suffering and hinder pro-poor livestock development, especially in rangeland systems. They lead to the death of millions of animals and leave many people destitute, forcing them to rely on food relief. Furthermore, droughts undermine the reliability of livestock supply to markets, discourage investments in livestock improvement, exacerbate conflicts, and may contribute to environmental degradation. There are multiple reasons for investing in drought management, some of which are indicated below:

9.4.1 Drought causes major losses in livestock

Drought affects rangeland and agro-rangeland livestock systems by reducing the available forage, leading to livestock deaths. It may also directly kill livestock through a lack of drinking water. By weakening livestock, drought may also increase their vulnerability to a range of animal diseases, both during the dry phase and a succeeding recovery phase when internal parasites may flourish in newly rainy conditions (Toulmin, 1995).

9.4.2 Drought reduces the purchasing power of livestock farmers

Livestock farmers generally depend for their staple food and, in particular, their energy requirements, on cereals purchased with the proceeds from sales of livestock and livestock products (crop-livestock, by definition, grow some, perhaps most, of their food, which makes them vulnerable to drought in very different ways). During droughts, several things may happen: a) pasture-based red meat producers lose stock through mortality and thus cannot sell them, b) the stock that pasture-based red meat producers do sell is in poor condition and so fetch lower prices, c) pasture-based red meat producers sell more stock, and accordingly, market prices, even per unit live weight, decline sharply and d) grain prices go up, if drought has also affected the grain-supplying regions. The combined result will be a sharp decline in pasture-based red meat producers' ability to purchase food and, thus, a risk of famine. Of these points, many authorities have assumed systematic selling of stock on rangelands as part of pasture-based red meat producers' response to "track" rainfall Toulmin (1995), if not hampered by lack of transport and market infrastructure as reported by Mouton and Bason (2002).

9.4.3 Drought makes flows to market unpredictable

Suppose there is a lack of response to drought in the sales of stock. In that case, this is probably not because of an irrational attachment of pasture-based red meat producers to their stock, but for a combination of reasons, such as the knowledge that restocking after drought will be difficult (as there will be few female animals on the market), the intention to ride out the situation in the hope that full drought will not materialize, and physical difficulties in getting livestock to markets. But whatever

the pasture-based red meat producers' response to selling during drought (and it is likely to vary among rangeland communities and between them and agro-pasture-based red meat producers and mixed farmers), drought is still expected to disrupt flows of animals to both domestic and export markets, probably due to scarcities during drought and post-drought phases. This will make the physical and financial planning of livestock marketing more complex, both for government authorities and for the private sector. Drought may also decrease the quality of livestock presented to the market and increase the disease risk.

9.4.4 Drought discourages or prevents investment in livestock

In addition to the concern about discouraging government and private sector investment, recurrent drought may make it difficult for pasture-based red meat producers to invest in improving animal health. Over recent years, the failure of government veterinary services to provide for rangeland areas has become apparent. There has, therefore, been increased interest in alternative models of animal health care involving Community-based Animal Health Workers (CAHWs) and other sorts of para-veterinarians based on cost recovery from pasture-based red-meat producers. The concern is that in periods of drought, pasture-based red-meat producers may find it challenging to continue to pay for animal health services. This will mean a risk of disease outbreaks and diminish the viability of the CAHWs' businesses. The CAHWs should be well designed lest they undermine the long-term viability of CAHW systems based on cost recovery.

9.4.5 Drought contributes to desertification

As with the relationship between drought and livestock sales, the links between drought and desertification are controversial. Some claim that desertification is too broad a concept, used excessively and unscientifically, and in a way that fits governments and donors' preconceptions about pasture-based red-meat producers (Swift 1996). They also draw support from scientific views known as the "new range ecology" that suggest that the productivity of African rangelands is defined more by rainfall than by grazing and that "overgrazing" is a seriously problematic concept (Behnke 1993). Against this, many argue that gross environmental degradation occurs in rural rangelands, which can be considered

desertification and is at least triggered by drought episodes, even if socio-economic factors influence both (Dregne 2000). Some would also point to the importance of trees in African rangelands, their absence from the new range ecology literature, and their vulnerability to prolonged over-browsing or overcutting (Illius and O'Connor 1999). Others would focus on the effects of drought-driven sedentarization in small towns or relief centres and the resulting localised degradation and deforestation (McPeak 2003)

9.4.6 Public sector involvement in managing drought is justified

As can be seen, many of the benefits of managing drought are, in principle, open to all, and no one's enjoyment of them subtracts from anyone else's: i.e., they are "public goods" in economic terminology. A natural environment free from degradation, a social environment free from violent conflict and with adequate protection for its citizens from mass death and destitution, and an enabling environment for livestock trade based on consistent throughput and a high reputation in export markets, benefits all, and no private individual can capture the benefits exclusively for himself or herself. While some responsibility for providing them can and should be taken by local communities or traders' associations, the government's role is to facilitate and guarantee them.

9.4.7 Increased vulnerability to drought of livestock producers

It is almost certain that the vulnerability of livestock producers to drought is increasing, and thus, drought impacts are worsening. There are many reasons for increasing vulnerability, and some of them form vicious circles of causality:

(a) Drought impacts are cumulative, as affected households are less able to cope with the next drought.
(b) Sedentarisation by pasture-based red meat producers, undertaken because of their inability to practice rangeland migration, the attraction of access to goods and services found in small towns, and their dependence on food aid distribution, can result in localised land degradation around settlements and can further increase vulnerability.

9.5 BENCHMARKING WITH EXPERIENCES FROM THE SADC COMMUNITY-BASED RANGELANDS MANAGEMENT SCHEMES AND NATURAL RESOURCE MANAGEMENT

This section reviews experiences with community-based grazing schemes in Southern Africa. The intention is to learn from these experiences to benchmark policy imperatives. The SADC schemes have been aggregated and analyzed through a SWOT analysis, and key lessons have been identified.

Historically, community-based rangeland management was launched in the 1970s and 1980s and has mostly taken the form of fenced enclosures, except in Lesotho. Unfortunately, only some have been successful and sustainable. Lessons learned from the SADC can assist in crafting better policies for Drought Management Plans and Strategies. Several authors reported the SWOT analysis and the lessons learned in studies done in different countries (Cousins, 1993 & Mugabe et al., 2002 for Zimbabwe; Critchley, 1995 for Swaziland; Ivy and Turner, 1994 for Lesotho and Sweet, 1987 for Botswana).

9.5.1 Common problems of the grazing schemes

(a) The prescriptive model limits communities' actual choices. Communities should be given space to participate in the new policies
(b) Community conflicts (between members and non-members) and inadequate conflict resolution mechanisms. The formation of local committees should be prioritized
(c) Boundaries are known but need to be respected. Only self-managed structures at local level can achieve this.
(d) Interventions are not based on the local conditions
(e) Poor definition of benefits and beneficiaries
(f) Untransparent or unequal benefit distribution
(g) Wealthy cattle owners dominate decision-making due to a lack of procedures and governance
(h) Unclear link with traditional authorities

(i) Top-down approach with a domineering role for donors and agricultural extension. For example, many initial inputs were supplied free of charge and were not perceived as costs by the community.

9.5.2 The SWOT analysis

Table 31: The strengths-weaknesses-opportunities-threats (SWOT) analysis of grazing schemes

STRENGTH	WEAKNESSES
(a) The schemes should be institutionally founded in policies and programs (b) The provision of water through boreholes, fence maintenance and veterinary services provided through breeding cow fees encouraged farmers to remain in the schemes (c) Training of managers gave the group members enough time to learn (d) The schemes must have an established line of communication and consultation with the land users and the traditional leaders (headmen and chiefs) (e) The schemes should adopt a bottom-up approach that makes it acceptable to members	(a) Farmers did not perceive overgrazing as a problem (b) Communities who did not recognize grazing land as a finite resource; hence, the unwillingness to limit stock numbers (c) Shortage of extension staff (d) Inexperience of rural people in cooperative ventures and groups (e) Members who did not wish to pay the cattle levy and membership dues (f) Communities who were reluctant to allocate part of overcrowded communal area for the exclusive use of a few members of the community (g) Most of the schemes employed a top-down approach with limited community choices

(f) The schemes should foster support from government, NGOs, private sector and traditional leaders (g) The schemes should also have a good program for integrating women, youth, and disabled groups (h) The number of livestock per scheme should align with the ranch's carrying capacity, avoiding overstocking, overgrazing and soil erosion (i) The schemes and/or livestock associations should be legally recognized, thus giving them the authority to discipline those violating the schemes and/or association's rules. Also, to account for both technical and financial matters of the scheme.	(h) The initial cost of fencing material presented a considerable burden to potential schemes, where members were reluctant to invest their own resources, whereas other groups had received grants as members of the scheme (i) Those community members who fall out of the schemes resisted the development of further ranches from which they might be excluded because every new scheme would squeeze the existing livestock onto less and less land (j) By reducing the stocking pressure on just one part of the range, the other areas are put under increasing pressure (k) The schemes constituted a single-purpose commercial beef enterprise instead of a multi-purpose system that included milk, draft and manure-producing herds. This led to an inter-group rivalry.

	(l) The model assumed that all residents would be members but did not take care of those who were not members, due to non-payment of subscriptions or opting not to join the scheme (m) Some farmers adhered to the rotational grazing scheme mainly in fear that their livestock would be impounded and not because they saw the program as beneficial to them (n) There is no assurance that the project would be sustainable without government support (o) The committees comprised holders with limited experience in collective decision-making and were subject to factional infighting.
OPPORTUNITIES	**THREATS**
(a) The schemes and community-based rural development may offer new opportunities for community-	(a) The history of failure of community schemes is known to communities and will hamper any future activity

based rangeland management schemes (b) Communities have gained more experience with community-based organizations and projects (c) Expansion of the scheme model should include the whole community (less rivalry and resistance) (d) Attracting donors to expand the scheme to manage other natural resources and forms of livelihood	(b) Political instability (c) District councils and traditional leaders have dominant roles (d) There is an absence of formal legislation to control the exclusion and inclusion of members. (e) Non-members resistance (f) Uncertainty in government support

The grazing scheme model primarily appears to have weaknesses that affect its performance. Continued dependency on external assistance must have further weakened the schemes during years of political turmoil and donor withdrawal. The major opportunity would be to anchor the schemes' integrated incentive program to the farmers. Such an approach should include support from the government, NGOs and private sector, as well as their contribution to providing water through boreholes, fence maintenance and veterinary services provided through breeding cow fees.

9.5.3 Lessons from the South African Development Community Countries (SADC) grazing schemes

(a) Top-down, prescriptive grazing interventions do not work well. Communities can take an external initiative if they have choices, rights and responsibilities.

(b) The benefits of a fenced (community) ranch, other than saving labor, are not proven; community-based projects have no future without clear

benefits and benefit distribution mechanisms. Fencing is not a necessary condition to improve communal rangeland management.

(c) Exclusivity and membership may be necessary but can cause conflicts between members and non-members. Therefore, assessing an initiative's impact on excluded community members and finding ways to make the program acceptable to the whole community is very important. Preference should be established for cohesion with all members.

(d) While extension and donor support are necessary, they often affect the sustainability of projects; the approach should be to build a self-sustaining scheme with one's own contribution and support from donors.

(e) Community-based projects must determine the position and role of traditional leaders and local government authorities

(f) Overgrazing is not necessarily perceived as a priority problem for communities. This makes it challenging to design and implement a rangeland/ livestock plan of action.

(g) Community participation is essential and can be enhanced by sustainable and equitable net benefits to all members

(h) Communal rangeland schemes must address communal livestock farmers' conditions, attitudes and needs

(i) Fencing is not a necessary condition to improve communal rangeland management

(j) A firm, supportive policy framework is necessary to sustain community-based rangeland management approaches

(k) The absence of a legal framework hampers community management options

(l) If projects fail to improve livelihoods and/or food security, attracting and keeping community interest will be challenging.

9.6 POLICY RECOMMENDATIONS

Public policy in drought management needs to focus on making pasture-based and agro-pasture-based red-meat producers more resilient to drought. This would include policies that promote good practice in rangeland development, reduce vulnerability and promote participation.

9.6.1 Policies promoting general good practice in rangeland development

Because drought is such an important feature of rangeland livelihoods, many of these interventions will, in any case, be part of general good practice in rangeland development:

(a) Protecting rangelands and most critically dry-season grazing areas from further encroachment, and establishing or strengthening land tenure and natural resource management systems that allow collective management of resources and facilitate rangeland mobility

(b) Establishing or strengthening institutions for pasture-based red meat producers to manage their own affairs as much as is feasible, to represent their concerns effectively to higher authorities, and to manage conflicts between themselves, or between pasture-based red meat producers and farmers

(c) Improving rangeland marketing opportunities: removal of unnecessary constraints on marketing, such as inappropriate veterinary policies, investments in infrastructure, and provision of market information

(d) Improving animal health, particularly enabling the development of sustainable delivery systems

(e) Providing the enabling institutional environment for the integration of drought management activities along the drought cycle of planning-mitigation-relief rehabilitation across the levels of community, district (or appropriate local government unit) and nation, and between investment and policy

(f) Supporting livelihood diversification directly by stimulating non-rangeland employment opportunities and indirectly through education.

9.6.2 Policies promoting institution-building to reduce vulnerability

Other policies may involve building institutions that are more explicitly concerned with reducing drought vulnerability. There has been much recent discussion of three sorts of intervention, which must all still be considered speculative or in a pilot phase:

a) Promoting banking and other forms of savings (in forms other than livestock) among pasture-based red meat producers, mainly to save the value

represented by surplus male livestock in some rangeland systems (Coppock 1994, Swift 2002).

b) Promoting new types of livestock insurance, particularly index-based systems which pay out based on large-scale patterns of mortality that are beyond the control of individual livestock owners (Swift 2002)

c) Disseminating weather forecasts derived from climate modeling and remote sensing directly to pasture-based red meat producers: recent work shows that pasture-based red meat producers can understand and are ready to listen to "scientific" weather forecasts, but that lack of information is not a limiting factor, the problem lies with their ability to act on that information (Luseno et al. 2003)

9.6.3 Policies promoting participation

Drought management among pasture-based red meat producers and agro-pasture-based red meat producers has to involve the participation of communities. This is true for two main reasons: a) the participation of communities will maximise the chances of interventions, particularly mitigation and rehabilitation interventions, being appropriate to their needs, their perceptions of what constitutes a drought, and how they already manage drought. (b) Farmer's knowledge of what constitutes a severe drought and what the signs of such a drought are during its onset will be a necessary part of early warning systems.

Much has also been written about how pasture-based red meat producers themselves respond to drought, using terms like coping strategies: the essential strategies include migration, herd accumulation with (debatably) sales of livestock during drought onset and supplementation with purchased feed, and non-rangeland employment. As part of drought contingency planning, the successful design of mitigation and rehabilitation interventions needs to be founded upon these strategies that pasture-based red meat producers already adopt. While some knowledge of these strategies can be provided by outside researchers gathering information and reporting back to governments and donors, a better foundation will be provided by a truly participatory dialogue on the design of interventions between the communities and the agencies.

9.7 INVESTMENT TASK AT LOCAL COMMUNITY LEVEL

9.7.1 Early warning

Those managing drought must, to the extent that is practical, equip themselves with the best available knowledge of the likelihood of future drought and its significant impacts. This knowledge can come from various sources. Increasingly, international technological capacity in remote sensing and climate modelling can provide helpful seasonal drought forecasts. Large-scale quantitative surveys of the availability and price of food in markets can pick up the economic impacts of drought at an early stage. Livestock keepers' knowledge of their environment and past experiences coping with drought will be invaluable in designing and implementing systems to detect severe drought at its onset phase. Such knowledge will be locality-specific and needs thoroughgoing participation of livestock keepers in early warning systems by the use of "participatory rural appraisal methods, including semi-structured interviews, social mapping, food ranking and seasonal calendars, to elicit mainly qualitative information." (Swift, 2001). Early warning systems must also meet two other criteria.

Firstly, they must be cost-effective to maximise their chances of financial sustainability. Generally speaking, a high degree of participation supports this, as community labor can be substituted for paid enumerators. There are dangers, though, if community participation results in pressures for collecting unfeasibly large amounts of information or information that is mainly qualitative and difficult to aggregate and analyze.

Secondly, early warning systems must generate information that, to some extent, can be standardized across geographical areas, as it will be used in government and donor decisions to commit resources to relief and subsidised mitigation programs. A system that relies too heavily on the participation of livestock keepers and, therefore, unduly favors locally identified indicators and qualitative information, jeopardises such standardisation. It can lead to manipulation by politicians and present a "moral hazard" if beneficiaries and their representatives slant responses to exaggerate drought severity and claim relief resources.

9.7.2 Contingency planning

Knowing about an oncoming drought is of little use if the participants in the drought management system are not able to act upon it, either because they do not have plans or because they do not have resources. Making sure those plans and resources are in place is the task of contingency planning. Contingency planning can cover any or all of the responses to drought now outlined, especially considering livestock keepers' traditional and existing coping strategies, including mechanisms of mutual assistance, which they should take care not to erode. However, they should also recognize the limitations of such coping strategies in the face of deeper and more widespread vulnerability to drought, as described above.

Contingency plans prepared locally should be "on the shelf" for activation when the early warning system signals the appropriate drought stage. The final decisions should be made using traditional decision-making bodies or by creating new "community drought committees". In either case, attention must be paid to capacity building and avoiding problems of gender, age, livestock holding or social stratum inequity.

9.7.3 Responding to drought

Governments, donors and NGOs across Africa and elsewhere in the world have responded to droughts among pastoralists and agro-pastoralists in various ways. These responses have varied by when they were made (or should have been made) in the drought cycle and whether they were aimed at saving lives or preserving or rebuilding livelihoods. There is no single standard terminology for classifying these responses, but the following terms have been found useful:

9.7.4 Mitigation

Mitigation activities are aimed at preserving livelihoods and are typically planned for the early stages of the onset of drought. However, mitigation activities are generally still practiced only on a pilot scale and primarily by NGOs. This is because of the high transaction costs required for careful planning and in-depth knowledge of local conditions. If mitigation activities are successful, they are preferable to food

relief because they are more cost-effective, strategically provide inputs to livelihoods, let people feed themselves, and take place early in the drought cycle before people are destitute. In principle, mitigation activities should involve low subsidy levels, at least an explicit subsidy, benefiting the household. They provide a better basis for sustainable livelihoods post-drought, and they are generally regarded as preferable, morally and in terms of human dignity, to the mass distribution of free food.

De-stocking involves purchasing animals from pastoralists during the onset of drought and distributing the meat to those or neighbouring poor communities as relief food. A smaller number of experiences have involved subsidising private traders to buy livestock in areas where typical market linkages were not functioning for various reasons. Both forms salvage value from animals that might otherwise die and boost pastoralist purchasing power; de-stocking to redistribute also has important nutritional benefits.

Both forms of intervention can be highly successful given their objectives, although it is crucial to be transparent about them. De-stocking to redistribute meat is costly, though not necessarily more expensive than the relief operations it partially replaces, and the barriers to scaling it up are chiefly logistical. De-stocking through subsidy is potentially a more sustainable intervention; it may be possible to finance it through levies on sales in good years or insurance-like mechanisms, but its ultimate success depends on our understanding more about why and in what circumstances pastoralists are prepared to sell animals during droughts (Morton and Barton 2002).

Veterinary Interventions involving emergency provision of free or subsidised veterinary drugs and vaccination services can be highly cost-effective regarding livestock losses. However, it is also essential that such measures do not erode the sustainability of emerging community-based animal health schemes, which practice cost recovery through a markup on drugs sold.

Water Provision, involving emergency drilling of boreholes and repair and maintenance of existing boreholes, appears to be highly cost-effective in preventing livestock losses and mitigating the hidden costs of the labor, particularly women's labor, used in water collection. There is an issue of financial sustainability,

but the institution of cost recovery arrangements up to and including contributions to depreciation has been successful. There is also an issue of environmental sustainability, such as preventing boreholes from becoming perennial and contributing to localised overgrazing. Still, there is evidence that local management arrangements linked to using grazing resources, including the capacity to shut boreholes in "normal" years, can work.

Supplementary feeding of livestock, mainly selected breeding stock, has some appeal to pastoralists, and there is some evidence of its cost-effectiveness. However, importing feed on a large scale is a massive logistical task, unless there are specially favored areas that can be set aside as "cow-calf camps", which is likely to depend on the availability, formal or informal, of commercial ranch land or protected areas. Large-scale feed distribution also raises the issue of overgrazing and environmental degradation, arguably resulting in North Africa and the Middle East. However, few sub-Saharan African countries are likely to scale up feed distribution to that extent.

9.7.5 Rehabilitation

Rehabilitation activities should occur at the end of the drought cycle as rainfall returns. They aim to restore people to their "normal" livelihoods or, as is increasingly realized, to improved and less vulnerable livelihoods. They are:

Restocking is the gifting or subsidised sale of large numbers of animals. Many restocking experiences have been had, mainly on a pilot scale and implemented by NGOs, and there is now substantial literature on the subject, as indicated by Heffernan et al. (2004).

Range rehabilitation. While technical solutions can only be successful in the context of understanding and working with local collective resource management structures, there are positive experiences of using physical soil conservation measures and reseeding carefully chosen annual and perennial species.

9.7.6 Promoting long-term drought resilience

As discussed above, there is no clear boundary between promoting drought resilience and general good practice in pastoral development. But certain investments can be recommended under a banner of long-term drought management:

a) Reaching an agreement on the conservation of some regions of rangeland as drought-time grazing reserves (Hendy and Morton 2001)
b) Developing sustainable animal health services (Catley, Blakeway and Leyland 2002)
c) Under certain conditions, encouraging feed storage
d) Where it is an issue, promoting the maintenance of Indigenous livestock breeds against the unplanned importation of exotic and less drought-resistant genes.

9.7.7 Building an evidence base

Finally, drought management for pastoralists and other poor livestock keepers remains a relatively new form of development. Little is known about what works, especially in mitigation. Governments must continue to invest in pilot activities, research, and the development of frameworks that enable objective, comparative evaluation of different experiences.

9.8 CONCLUSIONS

This policy deliverable aims to inform policymakers and decision-makers on how to manage droughts in the livestock sector, particularly in community-based rural rangeland and agro-rangeland systems. It summarizes the current policies and their shortfalls in addressing drought management for community-based rangeland livestock production. The deliverable gives the rationale for involvement, stressing the public good elements, and provides an overview of the current policy and expected trends, which point to an increased vulnerability of rural rangeland livestock farmers. The paper recommends a comprehensive policy focused on the

livestock–rangeland sector and stresses the need for community involvement in drought management.

CHAPTER 10 - GENERAL CONCLUSIONS AND RECOMMENDATIONS

This section presents the study's conclusions and recommendations.

10.1 Conclusions

10.1.1 Reviewing the literature

The lack of significant growth in forage production remains a serious issue despite notable advances in livestock production. Simply expanding the area dedicated to fodder may not be a practical solution; we need to develop strategies to address the substantial gap. Given the challenges faced by rainfed farmers, establishing a community fodder bank could be a viable option. Challenges to be considered include: (a) establishing a strong relationship with farmers, (b) locating a shared piece of land that is collectively owned, (c) recognising underutilised or marginal land that can be developed, and (d) choosing appropriate fodder crops for cultivation on less productive farms. Feed accounts for nearly 60% of the expenses in livestock raising and is a crucial factor in profitability. Therefore, the primary focus should be on developing diverse forage production systems that are suited to rainfed areas.

10.1.1.1 The development of cultivated pasture crop models incorporating underground water

The geospatial modeling of the geo-climatological variables that comprise rainfall, soil type, soil drainage, soil pH, soil depth and water level is instrumental in the establishment of the prospective potential of the tree lucerne. About 30% of the land surface is optimally suitable, and another 60% is deemed suitable for the plantation of the tree lucerne in the study area. Only a mere 5% is considered non-ideal. The development of the tree lucerne as a fodder bank crop will significantly reduce the smallholder livestock farmers' vulnerability to the impacts of climate change.

A fodder bank will improve the sustainability and profitability of smallholder operations. It will also increase the rangelands' grazing capacity.

Given the climatic setting, groundwater is key to the sustainable management of tree lucerne.

10.1.1.2 The use of agro-meteorology and climate information as drought-coping strategies

Limpopo and Mpumalanga exhibit a diverse array of climatic conditions that may not be ideal for livestock farming. The cause of climate change is leading to the increasing frequency of dry spells and erratic rainfall patterns. Smallholder farmers require alternative grazing to sustain their livestock under current conditions. The adoption of climatological information has the potential to reduce smallholder farmers' exposure to climate change impacts and to help them manage their practices more accurately, given the information available to them. The climate information also reduces the losses associated with improper practices that expose farmers to the impacts of climate change. Farmers have a better chance of commercializing their operations by adopting appropriate preparedness plans and mitigation strategies.

10.1.1.3 The use of selected perennial tropical C4 grasses

Panicum maximum was found to be the leading producer among the four perennial tropical C4 grasses that were studied. Four (4) Grazer as a grass mixture comprising *Brachiaria brizantha, Chloris gayana, Panicum maximum,* and Mombasa has shown a significant biomass production. As a result, *Panicum maximum* and 4 Grazers showed a high potential for contributing more than 8,000 kg/ha of biomass to the fodder bank in their first year of growth. Harvesting at 98 days, when the plot/field had passed 50% flowering, resulted in reduced biomass compared to 77 days after planting at the booting stage. Harvesting post-flowering is not recommended to prevent loss of biomass production due to the increased amount of senescent leaves.

10.1.1.4 The context-specific decision-making tool to assist farmers in adjusting stocking rates with weather information

Studies of smallholder farmers' perceptions of the impact of climate change have shown that exposure levels affect their daily livelihood choices. Their awareness and knowledge of climate change were prerequisites for their exposure to its impacts. Although multiple stakeholders provided farmers with climate change information, their level of education impedes their understanding of this phenomenon in their livestock enterprises. Unexpectedly, almost all livestock farmers (98.58%) have not heard about climate change from the government. At the other end of the spectrum, radio was the most essential medium for conveying information about climate change. Almost all farmers (94.32%) receive climate change-related information through the radio. It may also be a consequence of the radio's use of the language, mostly their indigenous languages. The intervention that could empower the farmers will be regular workshops within commodity groups on climate change. Unfortunately, 95.89 % of the farmers have not attended a workshop on climate change.

10.1.2 Early warning system

It can be concluded from the study that the government's early warning system is operational and effective at a level of less than 30%. The main challenge is the provincial government's capacity to deliver on the three key areas of the broader Disaster Management function: Early Warning, Risk Assessment and Disaster Recovery. Weather and seasonal forecasts are developed and sent to the provinces for dissemination to the end-user, who is the smallholder farmer. Provinces, in the main, have officials at the provincial level but no dedicated human capacity in districts and local municipalities where the early warning information is supposed to be disseminated.

Early warning and disaster-related matters have not been fully assimilated into the provincial organograms of the Department of Agriculture. Agricultural advisors also need to be trained on Early Warning systems whilst being assigned functions of disaster management individually and as a collective. Based on smallholder farmers' perceptions, the study suggests a need for strategic shifts from natural

pastures to small-scale feedlots. The shift should be coupled with the need to establish a dedicated fodder bank as a specialized business. For the farmers to cope and adapt to climate change, an early warning system is needed. The government should intervene by providing facilitated water and small-scale feedlot infrastructure for smallholder farmers.

Smallholder livestock farmers implement various strategies to cope with drought, including increased livestock sales and movement/migration to distant pastures. When faced with crop failure, livestock sales offer an alternative to buffer consumption against income shocks. However, this potential for livestock sales declines in households in certain low-income, high-risk environments that face simultaneous asset and income shocks. Recommendations in the literature for improving smallholder strategies include diversifying the livestock mix, improving livestock marketing and transportation, organizing supplementary feeding, stabilizing livestock prices, destocking, ensuring mobility and establishing slaughterhouses and restocking schemes.

10.1.2.1 Adoption of community grazing associations and fodder banks innovation

The early generation of grazing schemes and cells largely failed due to a variety of factors. For community grazing associations to succeed, grazing lands in communal areas should be a priority for both the communities and government. Grazing schemes should be established with extra benefits to communities, such as veterinary access and support, inputs, marketing links, processing and transport.

10.2 RECOMMENDATIONS

10.2.1 Type of fodder

Hay presents the greatest opportunity to bridge the feed gap due to the seasonal variability in feed quality and availability in smallholder livestock systems. Under such conditions, it will be fundamental to address the hotspots of overgrazing, bush encroachment and reduction in grazing lands. Adoption of forage conservation methods among smallholder farmers, who produce most livestock in the country, remains very low. This is due to resource, knowledge, labour and skill limitations, as

well as gender constraints, systemic issues and a lack of sufficient land or conserved forage. Ultimately, haymaking in smallholder livestock production systems is poor in quality, with frequent use of crop residues.

Major investments are needed to increase awareness of the need, benefits and best strategies for growing and conserving improved forages across the two provinces. A paradigm shift in the objective of livestock production from sustaining large numbers of low-productivity herds to maintaining a smaller number of well-fed, high-productivity animals is needed. This requires a move away from feeding unimproved crop residues, which are typically poor in quality. The focus should be on feeding balanced rations containing upgraded crop residues with improved harvested or conserved forages and other ingredients that can sustainably optimize livestock productivity and profitability. Market-oriented farmers and cooperatives need to be established that specialize in forage conservation with profitable practices with well-conserved forages, rather than crop residues or native forages.

Government must establish sustained extension support that provides technical knowledge to optimize forage production, conservation and quality, including forage-breeding programs that currently focus on developing high-yielding and quality forages for which the whole plant will be fed to optimize livestock productivity by progressive farmers. In addition, appropriate, accessible and affordable equipment is a fundamental need, such as choppers, balers and compressors for making densified feed blocks, various silo options, silage additives, etc. A paradigm shift is also required to include smallholders as buyers, rather than makers of conserved forages, because many lack time and other resources to make high-quality conserved forage.

10.2.1.1 The development of cultivated pasture crops (grasses and tree lucerne) models incorporating underground water

Governments should formally adopt the tree lucerne as a supplementary crop to livestock feeding, particularly in the arid and semi-arid regions of the country. The national agricultural ministry should play an integral role in supporting smallholder operations by providing seedlings of this crop to improve their resilience to climate change. Moreover, extension officers should be thoroughly trained in this

commodity to ensure high-quality support services for smallholder farmers. With a well-coordinated support system, smallholder livestock operators will finally operate economically and sustainably. This study developed a manual to support the training of farmers and extension officers.

CHAPTER 11 - CAPACITY BUILDING AND PUBLICATIONS

11.1 CAPACITY BUILDING

Two postdoctoral students, Dr Jutas Mavhungu and Dr Khuthadzo Ndwambi, were supported through the project. The project further managed to recruit the following students who are registered at a university.

11.1.1 Ogabegi Ruth Bosede

Her project is on using geoengineering to mitigate climate change impacts and implications for livestock production in Southern Africa. She has contributed to an international conference through a presentation abstract. She has been delayed in doing her final write-up due to the revision of her data analysis. At the time of writing, she was doing her final write-up on her results and discussions, and preparing papers.

11.1.2 Ranwendzi Ndivhuho Emmanuel

Doctoral: His work will contribute to the understanding of religion (mainly African Independent Churches) and culture in smallholder farmers' development. The title of his thesis is "African Initiated Churches (AIC) as Empowering Conduit for Sustainable Community Development". He published a paper based on the contribution of indigenous leadership to a local community. At the time of writing, he was busy with phase 2 of his research work, and his data had been collected, transcribed and analysed. He had started with the write-up of chapters and papers.

11.1.3 Netshithotholwe Rialivhuwa Tertia

Master's**:** A recipient of the EWSETA Bursary and the Green Matter Nedbank Scholarship. She has completed her studies and graduated with her degree in 2025.

11.1.4 Nenweli Lerato Prudence

Master's in Sustainable Agriculture, Graduated.

11.1.5 Takata Siphelele:

Master's of Science: His project is looking at characterising drought-tolerant mechanisms in tree lucerne seedlings, subjected to varying moisture stress levels. At the time of writing, he was on the last lap of his work. The submission of his thesis was expected in May 2025 and graduation in September 2025.

11.1.6 Komane Maduubu Thabiso

B. Sc. Agric. Hons: Graduated.

11.1.7 Mathebula Rito

B. Sc. Agric. Hons: Graduated.

11.2 PUBLICATIONS

1) USER MANUAL: A guide to establishing a tagasaste nursery, https://bit.ly/4uUHXwS
2) Bosede R. Olagbegi, Edward Nesamvuni, Gabriel R. Lekalakala, Babatunde J. Abiodun and Ashleigh Ho. Effects of geoengineering intervention on livestock production in Southern Africa. World Climate Research Program. Open Science Conference 2023. 23–27 October, Rwanda
3) Mulaudzi M., Mashiloane M.L., Netshipale A.J., and Raphulu T. 2023. Analysis of drought adaptation strategies for improving Vhembe District farmers' livestock survival in Limpopo province, South Africa: Preliminary results. All Africa Conference on Animal Agriculture, Gaborone, Botswana. 26–29 September 2023
4) Takata S., Madakadze C., Müller. F., and Tjelele J. 2024. Growth and adaptive characteristics of tagasaste (Chamaecystisus palmensis) tree seedlings in response to varying water availability. Proc. 59th Annual Congress Grassland Soc. of South Africa. Gariep Forever Resort, Gariep, South Africa.
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9) Van Loon A.F., Matanó A., Tirivarombo S., Artur L., Day R., Rohse M., Mustafa S., Geris J., Taylor S., Bharucha Z.P., Chirindja F., Nesamvuni A.E., Huhn A.L., Nomquphu W., Ebrahim G., Comte J-C. 2024. Towards more connection in drought and flood management in the transboundary Limpopo basin. Jamba
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11) *Syed Md Touhidul Mustafa1, Oluwaseun Franklin Olabode1, Luis Artur2, Zareen Bharucha3, Annatoria Chinyama4, Farisse Chirindja2, Rosie Day5, Fulvio Franchi6, Josie Geris1, Stephen Hussey7, Edward Nesamvuni8, Alcino Nhacume9, Alfred Petros10, Hanne Roden11, Melanie Rohse3, Sithabile Tirivarombo6, Anne Van Loon12, and Jean-Christophe Comte1. Increasing resilience to floods and droughts in the Limpopo River Basin: development of

a basin scale hydrological model to support sustainable groundwater management

12) Anne F. van Loon, Alessia Matanó, Sithabile Tirivarombo, Luis Artur, Rosie Day, Melanie Rohse, Syed M.T. Mustafa, Josie Geris, Simon Taylor, Zareen P. Bharucha, Farisse Chirindja, Azwihangwisi E. Nesamvuni, Anna L. Huhn, Wandile Nomquphu, Girma Ebrahim, Jean-Christophe Comte. 2025. Towards more connection in drought and flood management in the transboundary Limpopo basin. Jàmbá: Journal of Disaster Risk Studies, Vol.17 (1) DOI: https://doi.org/10.4102/jamba.v17i1.1798 |

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2) Ntsiapane A.D., Swanepoel J.W., Nesamvuni A.E. & Ojo, T.O. 2023. Assessing the efficiency of smallholder wool farmers in the changing paradigms of the Free State province of South Africa. South African Journal of Animal Science, 53(1): 125–132. https://doi.org/10.4314/sajas.v53i1.14).
3) Mavhungu T.J., A. E. Nesamvuni, K. A. Tshikolomo, N. S. Mpandeli and J. van Niekerk. 2023. Perception on Irrigated Smallholder Agricultural Enterprises led by Women and Youth (ISHAEs W-Y) towards climate extreme events variability for the selected field crop suitability potential at Vhembe District Municipality in Limpopo Province of South Africa. International Journal of Phytology Research 2023; 3(3):21-28
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6) Mavhungu T.J., Nesamvuni A.E., Tshikolomo K.A., Mpandeli N.S. and van Niekerk, J.A. 2024. Demography and Socio-Economic Aspects on Irrigated Smallholder Agricultural Enterprises and Their Association with the Cultivation of Maize (Zea mays L.) as a Selected Field Crop. Agricultural Sciences, 15: 729-741. https://doi.org/10.4236/as.2024.157040
7) Mavhungu T. J., Nesamvuni A. E., Tshikolomo K. A., and van Niekerk J.A. 2024. Correlation of demographic factors with the cultivation of sweet potatoes (ipomoea batatas l.) at irrigated smallholder agricultural enterprises in Vhembe district, RSA. International Journal of Agriculture and Plant Science, Volume 6 (4): 18-24
8) Ntsipane A., Swanepoel J., and Nesamvuni A.E. 2024. PESTEL Analysis of Smallholder Wool Producers for Improved Efficiency and Rural Livelihoods: A Case Study of The South African Wool Value Chain. Agraris Journal of Agribusiness and Rural Development Research 10(2):279-295. DOI: 10.18196/agraris.v10i2.667
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16) Nesamvuni A.E., Ndwambi K.A., Tshikolomo K.A., Mavhungu T.J., Mpandeli N.S. 2025. The Use of Agro-Meteorology and Climate Information as Drought-Coping Strategies. International Journal of Ecology and Environmental Sciences. 7(3): 42-53
17) Mahopo T.C., Nesamvuni C.N., Nesamvuni A.E., and van Niekerk J.A. 2025. Perceptions of Street Food Vendors on the Determinants of Competitiveness of their Enterprises in Vhembe District, Limpopo Province. S. Afr. J. Agric. Ext. Vol. 53 No. 5, 2025: 183-206.

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CHAPTER 12 - REFERENCES

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CHAPTER 13 - APPENDIX 1

Farmer-Based Knowledge to Generate Compelling Stories About Extension–Farmer Relationships and Engagement

1. Introduction

Agricultural extension remains one of the most critical pillars in strengthening smallholder farming systems, particularly within South Africa's semi-arid environments, where climate variability, land degradation, and resource constraints pose persistent challenges. Within such contexts, the relationship between farmers and extension practitioners becomes far more than a service mechanism—it transforms into a dynamic partnership grounded in trust, shared learning, and co-creation of viable solutions. The Water Research Commission (WRC) project on Sustainable Community Grazing and Climate-Smart Fodder Banks has provided a unique opportunity to witness and document these relationships in action across rural communities in Limpopo and Mpumalanga.

As the project unfolded, it became increasingly clear that farmer-based knowledge, the insights, practices, innovations, and lived experiences of the farmers themselves, plays an indispensable role in shaping meaningful agricultural development. While scientific models, climate data, and technical guidelines form important foundations, the everyday decisions farmers make based on local observations, generational wisdom, and adaptive creativity often determine whether interventions succeed or fail. This document seeks to capture that knowledge and elevate it into compelling stories that showcase how farmers and extension practitioners learn with and from each other. Across project sites, ranging from the communal fields of Mmakgatle to the irrigated plots of Mbahela–Tshiombo, to the research-linked environments of Toowoomba, Nooitgedacht, and the University of Limpopo, farmers engaged deeply with project activities. They participated in land preparation, planted fodder species under minimum till

conditions, monitored germination patterns, experimented with feed innovations, established nurseries, and assessed climate-linked planting decisions.

These activities reinforced that farmer experience is not only complementary to scientific inputs, but it is also foundational.

Extension officers, in turn, played a crucial facilitating role. They provided technical guidance, validated farmer innovations, helped refine locally born ideas, and ensured that farmers remained central to decision-making. Instead of the traditional top-down extension model, the project demonstrated a participatory, grassroots-driven approach in which farmers and extension practitioners stood side-by-side, literally and figuratively, during planting, monitoring, and problem-solving. This approach fostered trust, strengthened collective ownership, and encouraged farmers to adopt new technologies, such as establishing fodder banks, developing drought-resilient forage mixtures, and implementing low-cost nursery systems. Capturing these moments through stories helps bridge the gap between technical reporting and human experience. Stories illuminate how farmers interpret new information, why they adapt certain practices, and what extension support means to them in real time. They reveal the emotional, social, and cultural dimensions of farming, dimensions often overlooked in policy documents yet essential for long-term adoption and sustainability.

The stories documented in this chapter, ranging from improvised sweet-potato-vine feedlots to revived nursery innovations, to youth-led climate data collection, reflect the creativity, resilience, and aspirations of rural farmers. They also demonstrate the evolution of extension as a collaborative practice rooted in mutual respect and shared effort. Together, these narratives offer valuable insights for researchers, policymakers, extension managers, and development stakeholders seeking to strengthen farmer engagement, enhance climate adaptation strategies, and promote sustainable livestock production across communal landscapes. In essence, this introduction sets the stage for exploring how farmer-based knowledge and extension engagement intersect to produce transformative, context-appropriate innovations, captured not through statistics alone but through the voices and lived experiences of the farmers themselves.

2. Purpose of the Document

The purpose of this document is to:

a) Capture and synthesise farmer-based knowledge that emerged through the project.
b) Develop compelling, evidence-based stories showcasing extension–farmer engagement.
c) Present narratives that demonstrate human capital development, empowerment, innovation adoption, and experiential learning.
d) Provide communication material for final project reporting, WRC knowledge dissemination, and future policy advocacy.

3. Methodology for Collecting Farmer-Based Stories

The development of the stories draws on:

3.1 Site Visits and Participatory Observation

Field interactions at Mmakgatle village, Mbahela–Tshiombo village, Armasfort farm, and Mpumalanga/ Limpopo research stations, where farmers co-planted demonstration sites, monitored germination, controlled weeds, and participated in fodder bank establishment.

3.2 Farmer Narratives and Reflective Accounts

Discussions with lead farmers (e.g., Mr. Mphaphuli in Mbahela), women-led groups in Vhembe, and youth participants involved in planting, compost preparation, and fodder harvesting.

3.3 Extension Team Reflections

Experiences documented from district extension officers, nursery managers, grazing association coordinators, and project team members who supported farmers.

3.4 Integration of Project Monitoring Data

Progress reports from demonstration sites, germination rates, fodder bank performance, and student-led knowledge outputs.

4. Emerging Themes from Farmer-Based Knowledge

4.1 Trust-Building Through Co-Learning

Farmers expressed that planting fodder species with the extension officers, rather than being instructed, built trust. Hands-on planting at Mmakgatle (Feb/March 2023) where farmers, tractor operators, and extension officers worked jointly, strengthened perceptions of partnership.

4.2 Empowerment Through Practical Innovation

Key examples include:

- Using sweet potato vines as emergency feed under zero-grazing systems at Mbahela.
- Reviving abandoned nurseries to produce Tree Lucerne seedlings using household materials such as baskets and plastic bags.
- Developing small feedlot structures from locally available materials.

These innovations emerged directly from farmer experimentation supported by extension advice.

4.3 Climate-Smart Awareness and Local Decision-Making

Farmers increasingly made decisions on planting dates, irrigation timing under water stress, and mechanical weeding to mimic low-resource conditions, reflecting improved climate adaptation literacy.

4.4 Strengthened Collective Action

The formation and strengthening of farmer groups through district-level consultations enabled shared learning and encouraged group ownership of grazing associations and fodder bank sites.

4.5 Youth and Women Leadership in Agricultural Innovation

Women-led groups in Vhembe and youth farmers at Mmakgatle played central roles in nursery establishment, measuring seedling progress, and managing small irrigation pits.

5. Compelling Farmer–Extension Stories

Story 1: "Turning Vines into Life"—The Mbahela Farmer Innovation

At the Mbahela–Tshiombo irrigation scheme, farmers faced recurring feed shortages during dry spells. Livestock were visibly losing condition, and despite the presence of irrigated plots, farmers had limited options for fodder preservation.

During one of the extension–farmer site visits, lead farmer Mr. Mphaphuli demonstrated an improvisation that would later become one of the most celebrated innovations in the project. The farmers had begun collecting sweet potato vines, a normally under-utilised crop residue, and combining them with available grasses to feed their cattle. Extension officers were initially surprised by the simplicity and effectiveness of the method. They conducted on-site evaluations and confirmed that the mixture provided sufficient palatability and energy to maintain the cattle's body condition.

Encouraged, the extension team helped the farmers refine the process by introducing basic guidelines on drying vines, reducing spoilage, and establishing small household feedlots using readily available materials. The transformation was remarkable. Livestock that had previously been at risk of weight loss under zero-grazing conditions began to show visibly improved body condition.

Farmer Quotes:

"We were tired of watching our cattle suffer every winter. These vines were always here—but we never knew they could save our animals." — Mr. Mphaphuli

"Extension officers did not come to tell us we were wrong. They came to help us improve what we had started. That gave us confidence."

"Now our neighbours ask, 'How did your cattle survive the drought?' And we tell them: the answer is in the vines."

This story reflects the powerful blend of farmer creativity and technical refinement, showing how innovations born from necessity can evolve into climate-smart practices when supported by extension.

Story 2: "From Bare Fields to Green Blocks"—The Mmakgatle Transformation**

The Mmakgatle community demonstration site stands as a testament to what can happen when extension officers and farmers engage as equal partners. When the grass mixture was first delivered in early 2023, tensions were high, farmers had experienced previous interventions that lacked follow-through, and many were sceptical that the new fodder bank approach would make any difference in their drought-prone environment. Everything changed on 8 February 2023, when extension officers, tractor operators, and farmers came together to plant the grass mixtures under a minimum-tillage system. Farmers actively participated in land preparation, pegging, block layout, and seed broadcasting. The planting process became a communal event, with women, men, and youth all contributing.

Just two weeks later, the first signs of sorghum germination appeared. Photos were shared across the project's communication channels, creating excitement and restoring public confidence. The demonstration blocks became a learning environment where farmers could physically observe germination patterns, weed pressure, and moisture retention under their own soil and rainfall conditions.

The shared sense of achievement forged a strong bond between farmers and extension personnel. For many farmers, this was the first time they had seen a collaborative effort produce such tangible results. The story of Mmakgatle became a symbol of hope, illustrating that the adoption of fodder banks is not merely technical—it is relational, trust-driven, and anchored in joint action.

Farmer Quotes:

"When we planted together, it felt like we were on the same team—not just being told what to do."

"The day we saw the first green shoots, we celebrated like we had harvested already. It gave us hope again."

"For the first time, extension was not about reports and meetings. It was about doing the work with us."

The Mmakgatle story demonstrates that technical success often begins with relational success.

Story 3: "The Basket Nursery"—Innovation from Limited Resources**

In the Tshiombo farming community, where Tree Lucerne seedlings initially struggled to grow in plastic bags due to heat stress and poor aeration, women farmers led the way in creating an unexpected solution. Without access to conventional seedling trays or shade structures, they repurposed old household storage baskets to create makeshift nurseries. The baskets provided natural aeration and drainage, and farmers covered them with street-mesh wire to protect the seedlings from chickens and birds. Extension officers, upon visiting, recognised the ingenuity of the system and helped the women refine the setup by advising on watering schedules, soil mixture proportions, and proper seed depth.

What began as an act of necessity soon evolved into a local innovation hub. The basket nurseries produced healthier, more uniform seedlings than many of the conventional bags previously used. The method was later shared with the other demonstration sites, becoming a low-cost, farmer-led technology promoted across the project. The Basket Nursery story illustrates the critical role of women's creativity in advancing climate-smart agriculture. It also highlights how extension systems can amplify local innovations when they recognise and validate farmer-led adaptations.

Story 4: "Data in Our Hands"—Youth Farmers and Weather-Based Decisions**

At Nooitgedacht Research Station and surrounding farmer groups, rainfall variability had long been a barrier to successful planting. Youth farmers, often more technologically inclined, played a central role in bridging this gap. Through extension training on agro-meteorology, they began recording local rainfall using simple rain gauges installed as part of the trial. This process transformed how planting

decisions were made. Youth farmers correlated rainfall data with germination success, weed emergence, and soil moisture patterns across trial blocks.

They documented these observations and shared them with extension officers during weekly discussions. For the first time, farmers could justify delaying or advancing planting based on real data rather than guesswork. The youth, often overlooked in communal farming systems, emerged as knowledge leaders. Their weather insights shaped block management, influenced discussions about seed viability, and helped align planting calendars across villages. This story demonstrates how empowering youth with basic scientific tools can transform traditional farming into a data-informed system, while strengthening intergenerational learning between elders, youth, and extension advisors.

Story 5: "We Plant Together, We Learn Together" – The Power of Joint Action

One of the most profound examples of extension–farmer engagement emerged during the very first collaborative planting at Toowoomba Research Station. Unlike previous extension activities where farmers were passive recipients, this event brought together farmers, researchers, postgraduates, extension officers, and tractor operators to plant side-by-side. The collaborative planting did more than establish demonstration blocks, it reshaped relationships. Farmers felt valued as co-creators, not as beneficiaries. Students gained firsthand experience interacting with smallholder realities. Extension officers gained insights into the practical constraints farmers face when trying to implement climate-smart practices without herbicides, fertilisers, or irrigation. The collective labour of pegging, broadcasting seed, monitoring germination, and discussing field challenges created a shared sense of ownership. This site later evolved into a legacy learning hub, where farmers and extension teams returned for follow-up assessments, measurements, and reflections. The story demonstrates that sustainable agricultural interventions are built on shared work, shared learning, and shared responsibility, the foundation of strong extension–farmer relationships.

6. Influence of Extension–Farmer Engagement

Farmer experiences indicate that high-quality engagement:

a) Improved farmers' confidence in their farming decisions.
b) Increased adoption of fodder bank technologies.
c) Enhanced community mobilisation for drought preparedness.
d) Strengthened relationships, making extension visible and trusted.
e) Supported human capital development through student involvement and knowledge exchange.

7. Recommendations for Sustaining Farmer-Based Knowledge Systems

a) Create Community Knowledge Hubs at demonstration sites for continuous learning and peer teaching.
b) Digitally document stories (audio, video, photo essays) for WRC platforms.
c) Formalise farmer–extension learning cycles (seasonal reflection workshops).
d) Integrate youth and women innovators into local training modules.
e) Develop policy-ready case studies based on documented stories.

8. Conclusion

Farmer-based knowledge is a powerful driver of innovation, ownership, and sustainability. The compelling stories emerging from this project reflect not only the technical achievements but also the profound relationships built through shared labour, mutual respect, and co-creation of climate-smart solutions. These narratives should feed directly into the final project report, WRC communication products, and broader stakeholder engagement as the project approaches completion in February.

CHAPTER 14 - APPENDIX 2

NETSHITHOTHOLE RIALIVHUWA TERTIA: HER STUDY EXPERIENCE AS A POSTGRADUATE STUDENT – MASTER'S IN GENDER STUDIES

Water Research Commission Funding and Green-Matter Fellowship

In 2019, I made a pivotal decision to return to school, driven by my desire to expand my knowledge and skills. I enrolled in a Bachelor of Arts in Development Studies at the University of Venda at the age of 27. Walking into that first class, I acutely felt the 10-year gap between myself and my younger classmates, as well as the 6 years I had spent away from academia. The room buzzed with the energy of students who were actively engaged and well-versed in contemporary issues, while I was grappling to readjust to the academic environment. To my surprise, I scored the highest mark on the very first test I took. The feeling of accomplishment was exciting, but along with that achievement came unwanted attention, which I found overwhelming. The first year of my studies proved to be a formidable challenge. Lacking financial support, I endured the daily ordeal of bus travel, often returning home late after evening classes. Despite these hardships, my passion for education fuelled my determination, and I persevered through it all.

As 2020 rolled in, the world was thrown into disarray with the onset of COVID-19, forcing a sudden shift from traditional in-person teaching to online learning. This transition was not easy for anyone, and I found myself navigating many obstacles. My only means of connectivity was an unreliable cell phone, which barely sufficed for attending online lectures and gathering resources for notes, assignments, and presentations. Nevertheless, through sheer grit and resilience, I passed all my modules and proudly completed my undergraduate degree in 2021.

In 2022, my academic journey continued as I registered for an Honours degree in Gender Studies at the University of Venda. During this period, I successfully applied to the MenTut programme, which enabled me to step into a tutoring role. This experience not only sharpened my understanding but also gave me valuable lecturing experience as I guided other students. By 2023, I had reached a significant milestone: graduating with my honours degree, and I immediately set my sights on furthering my studies.

I eagerly registered for my first year of Master's in Gender Studies that same year, excited to delve deeper into the complexities of the subject I was so passionate about. As I approached 2024, I found myself grappling with the daunting decision of potentially giving up my master's degree at the University of Venda. The weight of financial strain was pressing heavily on my shoulders, compounded by the rigorous academic demands that seemed increasingly overwhelming. Just when I felt ready to throw in the towel, a glimmer of hope emerged in the form of the Water Research Commission and the GreenMatter fellowship, which stepped in to support me during that challenging time. Their assistance not only alleviated some of my financial burdens but also reignited my passion for my studies.

In 2023, I was selected for the GreenMatter Water Fellows Programme, a professional and leadership development initiative that supports the growth of postgraduate students. The fellowship, sponsored by the Nedbank Eyethu Community Trust, ran from April 2023 to February 2024. It included only funded programmatic activities; however, it did not provide a financial bursary.

Throughout the programme, I participated in a comprehensive professional development programme comprising webinars and in-person workshops. These activities were designed to enhance leadership skills, emotional intelligence, and readiness for a career in the social and environmental sectors. This prestigious fellowship offered valuable opportunities to build a professional network and strengthen my capacity to contribute as a transformative leader in South Africa's social and environmental field. I gained access to the *GreenMatter* Fellowship Programme through a project funded by the Water Research Commission, led by Prof Azwihangwisi Edward Nesamvuni, titled *Development of Sustainable Community Grazing and Climate Smart Fodder Banks for Smallholder Livestock Enterprises in Limpopo and Mpumalanga Provinces of South Africa,* Contract Number: C2022/2023-00770. In 2024, I was fortunate enough to receive a postgraduate funding award of R160,000 through the student support funding associated with the same project, which covered both the 2024 and 2025 academic years. This generous funding not only alleviates financial pressures but also qualified me for the prestigious GreenMatter Fellowship for a second time.

Participation in this fellowship is a requirement for all funded students, and I was excited to engage with such a vibrant community focused on environmental sustainability and innovation. Through this fellowship, I had the privilege of engaging with a diverse group of accomplished fellows from various institutions. This experience not only alleviated my financial concerns but also fostered valuable connections and insights, which significantly enhanced my academic, professional, and personal journey.

On 12-16 May 2025, the GreenMatter Fellowship conducted an in-person induction workshop at Rosemary Hills, Pretoria. It was a highly productive workshop because I had the chance to connect and interact with other fellows and the funders of the GreenMatter fellowship. I had the incredible opportunity to engage myself in the vibrant atmosphere of Sandton City while attending the insightful Nedbank workshop on 15 July 2024. Surrounded by the bustling energy of the city, I found it to be a fertile ground for inspiration.

Following that, I participated in a transformative writing retreat at the breath taking Kruger National Park from 20 to 24 October 2025. The peaceful environment was a perfect backdrop, allowing me to focus on refining my data collection tool. The peacefulness of nature around me enhanced my creativity and productivity, making the entire experience truly rewarding. One of the highlights of the trip was the unforgettable game drive. It was my first time exploring the wild, and the experience was nothing short of breathtaking. Witnessing the impressive wildlife in their natural habitat felt refreshing.

Moreover, the Greenmatter fellowship presented me not only with the chance to explore the diverse landscapes of South Africa, a luxury I seldom afford but also gifted me with the friendship of companions like Keatumetse and Simiso. I will always treasure these experiences and bonds that have enriched my life. Since I became a Greenmatter fellow, I have experienced significant growth in my communication skills. My ability to present ideas clearly and effectively has improved markedly, allowing me to engage with others more confidently. I've also honed my interactive skills, fostering deeper connections and discussions with my peers.

Additionally, I have developed a strong capacity for active listening, which has enhanced my understanding and responsiveness in conversations. Overall, the

fellowship has been a transformative experience in my personal and professional development.

The online sessions on mastering interview techniques have been an incredibly valuable experience for me. I am now serving as an intern in the Faculty of Humanities, Social Sciences, and Education, working in the office of the Executive Dean at the University of Venda. I accomplished this because of the skills I developed during these sessions. I have developed effective strategies for managing the pressures of office life, thanks to the valuable skills I gained from attending engaging webinars and hands-on workshops led by experienced professionals at GreenMatter. These sessions not only enhanced my knowledge but also equipped me with practical tools to navigate challenges in my work environment. Throughout my first and second years in the master's program, I encountered significant challenges with supervision, which ultimately hindered my initial goal of completing the degree within two years. After much anticipation, I finally presented my research proposal in late 2024. The moment I received approval felt like a breath of fresh air, and I was eager to move forward.

In 2025, I achieved a crucial milestone by obtaining ethical clearance, which enabled me to begin data collection for my research. With the funding I secured, I hired two dedicated data collection assistants, a decision that enabled me to expedite my work.

The experience of being in the field and interacting with participants was nothing short of amazing. Engaging with them allowed me to hear their stories and understand their experiences from their unique perspectives, enriching my research in ways I hadn't anticipated. However, data analysis posed its own set of challenges. Balancing the demands of my day job with late-night and early-morning work sessions proved to be taxing. Despite this, my determination to complete the research kept me motivated every day. By April 2025, after countless hours of hard work and revision, I finalised my document and submitted it to external examiners, setting my sights on graduating in September 2025.

Unfortunately, I faced another setback when one of the external examiners delayed the submission of their report, causing me to miss the graduation deadline. By the end of September 2025, I received my results, and I was overwhelmed with joy to

learn that I had passed with distinction. Now, I eagerly anticipate the graduation ceremony scheduled for May 2026, marking the culmination of my journey.

In my spare time, I enthusiastically dedicate myself to running the Women's Intervention Programme. Through this organisation, I provide invaluable support to grade 12 learners as they navigate the complexities of applying to universities, colleges, and securing bursaries. I engage with students directly by visiting secondary schools, delivering motivational talks that inspire and prepare them for the challenges and excitement of university life.

In addition to my work with young learners, I collaborate with the University of Venda Housing Unit on critical campaigns addressing gender-based violence and substance abuse across all university residences. Although my organisation is not yet formally registered, my passion for making a positive impact drives me to run it online. This endeavour not only allows me to assist others but also helps me to develop and refine my leadership and innovative skills in meaningful ways.

I am confident that the skills I have acquired will serve as a strong foundation for advancing my academic and professional journey. I am proud to share that I have successfully completed my Master's degree with the distinction of cum laude, and I am eagerly looking forward to celebrating my graduation at the University of Venda Graduation Ceremony in May 2026. Additionally, I am excited to announce that I presented my first research paper at the prestigious SAHUDA 2025 Conference, held at Walter Sisulu University from October 22 to 24, 2025. This opportunity marked a significant milestone in my career. At present, I am officially enrolled and navigating the registration process for a PhD in Gender Studies at the University of Venda. This marks an exciting new chapter in my academic journey, one that I eagerly anticipate as I delve into the complexities of gender issues and contribute to meaningful discourse in this field.

I am especially grateful to the Water Research Commission and the GreenMatter Fellowship for enabling me to achieve my goals. I am also committed to helping others who share a passion for education but have limited access to resources.

Netshithothole Rialivhuwa Tertia