

**EVALUATION OF CACTUS (*Opuntia ficus-indica*) AND *Prosopis juliflora* AS
POTENTIAL SUPPLEMENTARY FEED RESOURCES FOR LIVESTOCK IN
DROUGHT-PRONE AREAS OF KENYA**

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**A Thesis Submitted to the Board of Postgraduate Studies in Partial Fulfilment of the
Requirements for the Doctor of Philosophy Degree in Natural Resources Management
of Egerton University**

EGERTON UNIVERSITY

NOVEMBER 2021

DECLARATION AND RECOMMENDATION

Declaration

I declare that this thesis is my own work and has not been submitted to any other institution of higher learning for the award of an academic degree.

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DEDICATION

To the Most High God, Jehovah Ebenezer; for this far He Has brought me!

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ABSTRACT

The purpose of this study was to determine plausible pathways to combat feed scarcity and quality in dry lands using locally available and under-utilized feed resources. Baringo, Laikipia and Nyeri counties were purposefully selected for this study due to the prevalence of Cactus (*Opuntia ficus indica*) and *Prosopis juliflora* as potential drought-tolerant forage species. Structured questionnaires were administered to 317 households using multi-stage sampling techniques to quantify the vulnerability of pastoral livestock production systems to climate change and their coping strategies. Proximate analytical techniques were used in evaluation of nutrient content of Cactus (*O. ficus indica*) and *P. juliflora* using on-farm forage sampling and randomized block design feeding trials. Red Maasai weaner lambs were blocked on the basis of body weight and physiological condition. The treatment diets were proportionally determined combinations of under-utilized potential forage resources as follows: (T₁) 100% *Cenchrus ciliaris* grass hay as basal diet (control), (T₂) 80% *C. ciliaris* hay + 20% wilted Cactus (*Opuntia ficus indica*) fodder (T₃) 50% *C. ciliaris* hay + 20% Cactus (*O. ficus indica*) + 30% *Prosopis juliflora* leaf meal (T₄) 50% *C. ciliaris* hay + 20% Cactus (*O. ficus indica*) fodder + 30% *P. juliflora* pods meal. Analysis of variance (ANOVA) methods were used to isolate significant treatment effects on Cactus (*O. ficus indica*) and *P. juliflora* forage samples and rations. The influence of socio-economic factors on adoption of improved climate change adaptation technologies were assessed by means of Chi-square analysis. Results of this study indicated that change of livestock species was a widely adopted technology of reducing vulnerability of livestock production enterprises to climate risks (46%). The most preferred coping strategies in the event of floods or droughts were migration (37%), purchase of conserved feeds (17%) and livestock off-take (14%). Gender segregated, age and education level ($p < 0.001$) influenced the adoption of improved climate change adaptation technologies. Significant ($p < 0.001$) crude protein (CP) content (14.9%) was observed in young spiny and spineless Cactus cladodes. Highest CP content (26%) was associated with young shoots of *P. juliflora*. Ripe fruits of Cactus (*O. ficus indica*) had ($p < 0.001$) higher nitrogen free extracts (NFE) (39.6%) content as compared to other plant parts. Sheep that received T₄ rations recorded the highest *in vivo* and *in vitro* nutrient digestibility (78 and 63% respectively). Faecal output was positively correlated to DM intake ($r^2 = 0.88$, $p < 0.001$), *in vivo* ($r^2 = 0.87$, $p < 0.001$) and *in vitro* feed degradability ($r^2 = 0.87$, $p < 0.001$). Faecal Nitrogen was negatively correlated ($r^2 = -0.64$, $p < 0.001$) to these values. Research evidence from this study points to the need for tailoring livestock feeding practices in dry areas to take into consideration socio-economic factors (literacy levels, gender and age) to enhance the capacity of the farmers to benefit from the existing improved forage varieties and livestock feed supplementation options. The high CP levels of Cactus (*O. ficus indica*) young cladodes and fruits, and *P. juliflora* young shoots and pods authenticate their value as under-utilized drought-tolerant supplementary forages for livestock in the truncated landscapes of Kenya.

TABLE OF CONTENTS

DECLARATION AND RECOMMENDATION	ii
COPYRIGHT	iii
DEDICATION.....	iv
ACKNOWLEDGEMENTS	v
ABSTRACT.....	vi
LIST OF TABLES	xi
LIST OF FIGURES	xii
LIST OF ABBREVIATIONS AND ACRONYMS	xiii
CHAPTER ONE	1
INTRODUCTION.....	1
1.1 Background to the Study.....	1
1.2 Statement of the Problem.....	3
1.3 Broad Objective	4
1.3.1 Specific Objectives	4
1.4 Research Hypotheses	4
1.5 Justification of the Study	5
1.6 Scope of the Study	7
1.7 Limitations and Assumption of the Study	8
1.8 Definition of Terms.....	9
CHAPTER TWO	11
LITERATURE REVIEW	11
2.1 The Link between Environmental Aspects and Livestock Feed Resources	11
2.2 Global Climate Change Risks and Vulnerability to Livestock Sector.....	12
2.3 Africa’s Risks of Climatic Change and Associated Vulnerability.....	14
2.4 Risks Associated with Climatic Changes and Vulnerability in Kenya.....	19
2.5 Adaptation of Agricultural Production Systems to Climate Change	22
2.6 Contribution of Agriculture to Climate Change	24
2.7 Mitigation Strategies to Livestock-Caused Negative Environmental Impacts	26
2.8 The Role of Drought-Tolerant Plant Species in Adapting Livestock Systems to Climate Change	29
2.8.1 Description and Geographical Characteristics of <i>Cacti species</i>	30
2.8.2 Origin and Distribution of <i>Cacti species</i> in Kenya.....	31

2.8.3 Physiological Adaptations of <i>Cacti species</i>	31
2.8.4 <i>Cactus species</i> as Fodder for a Changing Climate.....	34
2.8.5 Environmental Role of Cactus (<i>Opuntia ficus indica</i>) Invasion in Soil and Water Conservation	37
2.8.6 Ecosystem Goods and Services Provided by Cactus (<i>Opuntia ficus indica</i>) species	38
2.8.7 Description, Origin and Distribution of <i>Prosopis juliflora</i> species in Kenya.....	40
2.8.8 Environmental Role of <i>Prosopis juliflora</i> in Sustainable Soil and Water Conservation	41
2.8.9 Pastoralists' Experiences with <i>Prosopis juliflora</i> in Kenya	43
2.9 Knowledge Gaps	44
2.10 Conceptual Framework.....	46
CHAPTER THREE.....	49
METHODOLOGY	49
3.1 Baseline Survey Sites.....	49
3.1.1 Baringo County Study Site	49
3.1.2 Laikipia County Study Site.....	50
3.1.3 Nyeri County Study Site	50
3.2 Research Instruments	53
3.3 Sampling Techniques and Sample Size Determination	53
3.3.1. Method of Sampling	56
3.4 Data Collection on Climate Change Vulnerability to Livestock Systems.....	56
3.5 Baseline Survey Data Analysis	57
3.6 On-farm Sampling of Forage Materials for Proximate Analysis.....	57
3.6.1 Laboratory Analysis of Forage Samples	58
3.6.2 Statistical Analysis of Forage Samples	58
3.7 On-Station Feeding Experimentation	59
3.7.1 Location of the Study.....	59
3.7.2 Research Design and Dietary Treatments.....	59
3.7.3 The feeding Trial.....	61
3.7.4 <i>In vivo</i> Digestibility Trial.....	61
3.7.5 Chemical Analysis	62
3.7.6 <i>In vitro</i> Dry Matter Digestibility.....	63
3.7.7 Statistical Analysis.....	63

CHAPTER FOUR.....	66
RESULTS AND DISCUSSION	66
4.1 Demographic Profiles of the Respondents.....	66
4.2 Land Tenure and Ownership.....	70
4.3 Main Livestock Production Systems and Ownership	70
4.4 Main Constraints Associated with Livestock Keeping in the Study Areas	72
4.5 Local Climate Change Coping Mechanisms.....	74
4.6 Available Feed Resources and Strategies for adjusting to Poor Quality Feeds.....	78
4.7 Adoption Status (%) of Improved Climate Change Adaptation Technologies.....	80
4.7.1 Main Reasons for Not Adopting Climate Smart Adaptation Strategies	81
4.7.2 Adoption Level (%) of various Improved Climate Change Adaptation Technologies	83
4.8 Perceptions and Utilization of Cactus and <i>Prosopis juliflora</i> (% respondents).....	85
4.9 Sources, Access, and Utilization of Agricultural Information by Gender.....	89
4.10 Membership to Agricultural groups.....	92
4.11 Nutritional Characterization of Cactus (<i>Opuntia ficus indica</i>) and <i>Prosopis juliflora</i>	93
4.12 Effects of Cactus (<i>Opuntia ficus indica</i>) and <i>Prosopis juliflora</i> -based Diets on Performance of Red Masai weaner lambs	100
4.13 <i>In vivo</i> and <i>in vitro</i> Nutrient Degradability Coefficients	101
CHAPTER FIVE	110
CONCLUSIONS AND RECOMMENDATIONS.....	110
5.1 Conclusions.....	110
5.2 Recommendation for Management Action	110
5.3 Recommendation for Further Study.....	111
REFERENCES.....	112
APPENDICES	135
Appendix 1: Household Baseline Survey Questionnaire.....	135
Appendix 2: Checklist for Key Informants Interview	145
Appendix 3: Plates 3.1-3.6: <i>Opuntia ficus indica</i> and <i>Prosopis juliflora</i> as Potential Drought Tolerant Forages Species.....	146
Appendix 4: ANOVA Table for Nutrient Composition of Cactus (<i>Opuntia Ficus Indica</i>)	147
Appendix 5: ANOVA Table for Nutrient Composition of <i>Prosopis Juliflora</i>	148

Appendix 6: Correlation Analysis on the Nutritional Quality of Cactus (<i>Opuntia ficus indica</i> and <i>Prosopis juliflora</i>	149
Appendix 7: ANOVA Table for Treatment Rations.....	150
Appendix 8: Correlations Analysis for Dependent Variables.....	151
Appendix 9: Major Areas covered with Cactus (<i>Opuntia ficus indica</i>) and <i>Prosopis juliflora</i> Invasions in Kenya.....	152
Appendix 10: Research Permit from NACOSTI	153
Appendix 11: Letter from the University.....	154
Appendix 12: List of Publications	155
Appendix 12.1 Publication 1 - Journal paper.....	155
Appendix 12.2: Publication 2 - Book	157
Appendix 12.3: Publication 3 - Journal paper	158
Appendix 12.4: Publication 4 - Journal paper	160
Appendix 12.5: Publication 5 – Book Chapter	162

LIST OF TABLES

Table 3.1 Chemical Composition of Experimental diets (% DM).....	60
Table 3.2: Summary of Data Analysis	65
Table 4.1: Demographic Characteristics of the Respondents (%)	66
Table 4.2: Livestock Ownership and Ranking in Households.....	71
Table 4.3: Local Coping Mechanisms to Effects of Climate Change on Livestock Production Systems (% Respondents).....	74
Table 4.4: Available Feed Resources (% Respondents)	78
Table 4.5: Adoption Level (%) of various Improved Climate Change Adaptation Technologies	83
Table 4.6: Association between Demographic Characteristics of Respondents and Adoption of Improved Climate Change Adaptation Technologies	84
Table 4.7: Sources, Access and Utilization of Agricultural Information by Gender (% respondents)	90
Table 4.8: Mean Percent (%) of Respondents who Attended various Agricultural Trainings and Seminars.....	92
Table 4.9: Proximate Composition of Different parts of <i>Opuntia ficus indica</i> and <i>Prosopis juliflora</i> (%DM).....	94
Table 4.10: Effects of spineless Cactus (<i>Opuntia ficus Indica</i>) - <i>Prosopis juliflora</i> - based Rations on Dry Matter Intake and Nutrient Digestibility of Red Maasai Weaner.....	101

LIST OF FIGURES

Figure 2.1: Conceptual Framework	48
Figure 3.1 : Map of Kenya showing the Study Locations (Loboi, Mukogondo and Gatarakwa in Baringo, Laikipia and Nyeri Counties respectively).	52
Figure 4.1: Main Sources of Livelihood (%) of Respondents	67
Figure 4.2: Land Tenure and Ownership	70
Figure 4.3: Main Livestock Production Systems	71
Figure 4.4: Main Constraints to Livestock Production	73
Figure 4.5: Household Mobility by Gender	75
Figure 4.6: Coping Strategies to Poor Quality Feed Resources (% Respondents)	79
Figure 4.7: Adoption Status of (%) of Climate Smart Adaptation Technologies	81
Figure 4.8: Main Reasons for not Adopting Climate Smart Adaptation Strategies.....	82
Figure 4.9: Social-cultural Perceptions regarding Cactus species	86
Figure 4.10: Uses of Cactus species	86
Figure 4.11 Social-cultural Perceptions regarding <i>Prosopis juliflora</i>	88
Figure 4.12: Uses of <i>Prosopis juliflora</i>	89
Figure 4.13 Percentage of Respondents with Membership to Agricultural Groups	92

LIST OF ABBREVIATIONS AND ACRONYMS

AfDB	African Development Bank
APP	African Progress Panel
ARC	Agricultural Research Council
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
APP	African Progress Panel
APSK	Animal Production Society of Kenya
ASALs	Arid and Semi-Arid Lands
AU-IBAR	African Union Inter-African Bureau for Animal Resources
CAWMA	Comprehensive Assessment of Water Management in Agriculture
CAM	Crassulacean Acid Metabolism
CF	Crude Fibre
CP	Crude Protein
DE	Digestible Energy
DHP	3,4-Dihydroxy pyridine
DFID	Department for International Development
DM	Dry Matter
EE	Ether Extract
DMD	Dry Matter Digestibility
EMP	Efficiency of Microbial Production
FAO	Food Agricultural Organization of United Nations
FAO-ICARDA	Food and Agricultural Organization of United the Nations-The International Center for Agricultural Research in the Dry Areas
FAO-ICARDA-ISHS	Food and Agricultural Organization of United Nations-The International Center for Agricultural Research in the Dry Areas-The International Society for Horticultural Science
GDP	Gross Domestic Production
GHGs	Greenhouse Gases
GLM	General Linear Model
GoK	Government of Kenya
HH	Household

HIV/AIDS	Human Immune-Deficiency Virus/Acquired Immune-Deficiency Syndrome
IITA	International Institute of Tropical Agriculture
IFPRI	International Food Policy Research Institute
ILRI	International Livestock Research Institute
IPCC	Inter-governmental Panel on Climate Change
ITK	Indigenous Traditional Knowledge
IUCN	International Union for Conservation of Nature
IVDMD	<i>In-vitro</i> Dry Matter Digestibility
KALRO	Kenya Agricultural and Livestock Research Organization
KARI	Kenya Agricultural Research Institute
KNBS	Kenya National Bureau of Statistics
LEAP	Livestock environmental assessment and performance partnership
LSD	Least Significant Difference
MBP	Microbial Biomass Production
MDG	Millennium Development Goals
ME	Metabolizable Energy
MEA	Millennium Ecosystem Assessment
MoA	Ministry of Agriculture
MtCO ₂ eq	Metric tons of CO ₂ equivalent
NAPA	National Adaptation Programmes of Action
NDF	Neutral Detergent Fibre
NFE	Nitrogen Free Extract
NGO	Non-Governmental Organization
NRC	National Research Council
OECD	Organization for Economic Cooperation and Development
RAE	Rehabilitation of Arid Environments
RoK	Republic of Kenya
RUE	Rain Use Efficiency
SAS	Statistical Analysis System
SCFAs	Short Chain Fatty Acids
SEM	Standard Error of a Means
SNV	Netherlands Development Organization
SPSS	Statistical Package for Social Sciences

SSA	Sub-Sahara Africa
TDN	Total Digestible Nutrient
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Program
UNFCCC	United Nations Framework Convention on Climate change
UNHABITAT	United Nations Human Settlement Program
USEPA	United States Environmental Protection Agency
WANA	West Asia and North Africa
WMO	World Meteorological Organization
WRI	World Resources Institute
WUE	Water Use Efficiency

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Plant materials that constitute the nutritional diet of an animal are closely related to the nature and quantity of greenhouse gases (GHGs) emitted to the environment (Adhikari et al., 2015). This makes nutritional strategies an important way of reducing livestock greenhouse gas emissions, which has adverse effects to the environment and global climate change (Valadez et al., 2015). Therefore, manipulation of diet composition to inculcate related change in enteric fermentation characteristics in ruminants is still a practicable approach in lowering methane production. Formulation of low-environmental impact balanced feeds using locally available and under-utilized feed resources such as Cactus (*Opuntia ficus indica*) and *Prosopis juliflora* constitutes a plausible pathway for enhancing environmental health and reducing the related global climatic changes risks.

Most importantly, it has been noted that the livelihood of individuals in the arid and semi-arid areas heavily depends on the livestock products as the major source of their income (Government of Kenya [GoK], 2018). However, livestock industry is faced with challenges that range from seasonal fluctuations of feed quality as well as scarcity of feeds during periods of drought. Pastureland productivity has been recorded to be lower at less than 5 tonnes DM (dry matter) per hectare per year and lower yields of consumed biomass of less than one tonne per hectare per annum. Therefore, it means that for an adult cow to be fed, it will need about 12-15 hectares of land to be sustained (Giridhar & Samireddypalle, 2015). Current report indicates that coordinated action to address climate change is urgently needed to enhance food nutrition and security, land fertility and reduce on hunger simultaneously (Inter-governmental Panel on Climate Change [IPCC], 2019). As highlighted by the report, climate change detrimentally affect food in terms of production and yields, accessibility in terms of ability to obtain the food, the cost and utility of the same food in terms of cooking and nutrition quality. Other factors such food stability, disruption and availability are major areas that are negatively affected by the climate change. As predicted, food insecurity will be a major problem in the future due to the increased climatic changes that will negatively affect the crop yields and the land productivity. Most arable areas in the tropics are at a major risk of climate change impacts. The global climatic changes have with no doubt impacted negatively on the livestock productivity and rangeland degradation (IPCC, 2018), and Kenya is not an exception. For the

past few years, Kenya has been experiencing the negative effects of climatic changes that have led to encroached and increased arid and semi-arid areas crippling agriculture and the economy (GoK, 2015a, 2015b, 2018). According to Ben Salem and Louhaichi (2014), adaptability of perennial plant and drought resistant species provides possibilities of improving animal feeds (forage) availability in the arid and semi-arid areas.

In some countries like Brazil, Mexico, South Africa, Tunisia and India, Cactus (*Opuntia ficus indica*) has been incorporated and utilized as animal feed (Dubeux et al., 2015), complementing the farmers' income. *Prosopis juliflora* agroforestry on the other hand has been reported in Argentina (Kyuma, 2013). However, in general, the forage potential of *Prosopis juliflora* and *Opuntia ficus indica* based livestock diets innovation has not been evaluated in dryland ecosystems of Kenya. Additionally, there are many voices from the local communities advocating for eradication of these drought tolerant plant species in Baringo, Laikipia and Nyeri (North) counties (Githae, 2018). On the other hand, there are tremendous ventures in development of Cactus-Prosopis species animal-based feed systems, which will in turn enhance livelihood, animal production and hence reduce the pressure and over encroachment of the natural pasturelands. The main challenge that needs to be addressed in the drylands and desert-like regions in Kenya and the environs encompasses enhancements of the community adaptability to climate change as their daily living depends on climate-sensitive and scarce resources (Adhikari et al., 2015; Huang et al., 2016; International Livestock Research Institute [ILRI], 2015). Response, adaptability and resilience by the rural and arid communities requires technologies and innovations that will aid and/or support their response emerging hazards either environmentally or naturally. Like other developing countries, Kenya has also been on the brim and facing climatic change challenges, and adverse effects on livestock and other agricultural sectors of the economy (GoK, 2018).

Prosopis juliflora has many uses such as feed for livestock, bio-fuels, source of bee pollen and herbal medicine, and can be a solution to most of these climate change related challenges (Harding & Bate, 1991). However, its utilization as source of livestock feed and in environmental control has been limited in Kenya due to its weedy nature, aggressive colonizing ability, presence of thorns and lack of management system and/or technologies (King'ori et al., 2011). As a result, although *Prosopis juliflora* has been shown to be a potential feed resource in drought-prone areas of Kenya, the rural communities in these regions perceive *P. juliflora* as a noxious weed (King'ori et al., 2011; Koech et al., 2011). They have put pressure on the

Government of Kenya to initiate eradication programs for this plant (Choge et al., 2002; Ministry of Agriculture [MoA], 2007).

Previous research findings indicate that many species of Cactus (*Opuntia ficus indica*) have been widely cultivated in many dry areas of the world for forage and as a tool to combat desertification (Valadez et al., 2015). Such livestock feeding and agronomic data with regards to its domestication and utilization as source of livestock feed is lacking in Kenya (Kang'ara & Gitari, 2010). The current study is designed to assess the effect of climate change risks on livestock production systems, and also evaluate the feed potential of *Prosopis juliflora* and Cactus species (*Opuntia ficus indica*) in selected drought-prone areas of Kenya. This information could be useful for informing the relevant authorities, database creation and advising the policy to empower marginalized rural communities in the fight against hunger, poverty, food and feed insecurity as exacerbated by climate change using available natural resources and ecosystems.

1.2 Statement of the Problem

Livestocks being a major source of livelihood takes care of approximately 13 million Kenyans who are mainly pastoralists and agro-pastoralists in most of the desert-like regions (ASALs). However, climate change has resulted in floods and frequent droughts with subsequent unpredictable low feed quantities and quality, a factor that has led to large livestock mortalities in rangelands. Climate change impacts have also led to low productivity of animals in Kenya mainly due to inadequate feeds occasioned by seasonal fluctuations of quality supply consistently in a given year. Feed quantity and quality are functionally linked to the pulsations in the water cycle (seasonality of water availability). Decline in the productivity of the livestock, reduced forage quantities, seasonal feed scarcity, decline in feed quality, reduced pastureland and grazing lands, water inaccessibility and frequent fights and conflicts related to strained and unavailability of natural resources provides the evidence of the detrimental effects of climatic changes in Kenya. With high dependence on the highly sensitive climatic dependent resources, the pastoralists are more vulnerable to variability caused by the climatic changes than other agricultural-based livelihoods in other ecosystems. The energy and protein requirements of livestock in rangelands can be ameliorated by exploiting the un-tapped feed potential from drought-tolerant plants such as Cactus (*Opuntia ficus indica*) and *Prosopis juliflora*.

Promotion of the efficiency in utilization of these aggressive, drought tolerant plants species would offer a solution to pastoral communities in rangelands. On the other hand, rapid lignification of plant-forage materials due to extreme temperatures also contributes to the low quality of available feed resources in marginal areas. This prompts for supplementary feeding that may not be affordable to the resource constrained rural communities. Therefore, assessment of locally available, under-exploited invasive drought-tolerant forage plant resources would offer a climate smart agricultural solution that would enhance resilience of systems used in livestock production to reduce climatic change risks. This formed the background of this research work.

1.3 Broad Objective

To study the vulnerability of livestock climate-induced production risks and evaluate the potential usefulness of drought-tolerant *Cactus-Prosopis* plant materials as supplementary feed resources to improve livestock feed security in rangelands.

1.3.1 Specific Objectives

- i. To quantify the vulnerability of pastoral and agro-pastoral livestock production systems to climatic change risks and the local adaptability mechanisms employed by the rural communities as influenced by demographic characteristics of respondents (age, gender and literacy levels) in Baringo, Laikipia and Nyeri Counties.
- ii. To determine the nutritional composition of *Prosopis juliflora* and Cactus (*Opuntia ficus indica*) as influenced by various plant parts (young and mature shoots, barks, ripe and un-ripe fruits) and plant species (spiny and spineless Cactus (*Opuntia ficus indica*)) in selected arid and semi-arid lands (ASALs) in Kenya.
- iii. To determine the effects of *Prosopis juliflora* and Cactus (*Opuntia ficus indica*) species-based feed rations on feed intake, faecal nitrogen, faecal output and nutrient digestibility (*in vivo* and *in vitro*) in Red Maasai weaner lambs.

1.4 Research Hypotheses

The following null hypothesis from the research objectives were formulated and tested at significance level of $p>0.05$:

- i. **H₀₁:** There is no significant correlation between demographic characteristics of respondents (age, gender and literacy levels) as measures of vulnerability to climate change in the study areas and various improved climate change adaptation technologies in livestock production systems.
- ii. **H₀₂:** There is no difference between the nutrient composition of *Prosopis juliflora* and spiny and spineless Cactus (*Opuntia ficus indica*) as influenced by plant parts and species.
- iii. **H₀₃:** There is no significant difference between *Prosopis juliflora* and spineless Cactus (*Opuntia ficus indica*) species-based feed rations on feed intake, faecal nitrogen, faecal output and nutrient digestibility (*in vivo* and *in vitro*) in Red Maasai weaner lambs as compared to the control diets.

1.5 Justification of the Study

Pastoralism as the main stay of the rural communities living in the Kenya's drylands is impacted negatively by climate change variability (GoK, 2018). However, despite the effect of environmental factors such as soil degradation and drought among other factors, pastoralism has essential roles in improving the economic status and employment of the pastoral communities, which accounts for almost 95% of their livelihood and income generation (GoK, 2015, 2017, 2018). Hitherto, with the effect of increased temperature extremities, higher rates of evapotranspiration and prolonged droughts, increased encroachment of arid lands, lack of portable water and decreased agricultural productivity, forage and livestock yields has resulted to increased insecurity in terms of food and malnutrition (Azocar, 2007; ILRI, 2015; Thornton & Lipper, 2014).

Therefore, the need for adaptability, and sustainability together with pragmatic solutions are essential to curb the effect of droughts and climatic changes that leads to encroachment of arid lands by invasive plant species. Prior and proper preparation for future catastrophe due to climatic changes in the range land is also necessary for enhancing the adaptive capacity of rural pastoral communities (Felkener et al., 1997; Food and Agricultural Organization of United the Nations [FAO], 2018; Kibria et al., 2015; Thornton & Lipper, 2014). However, the current aggressive invasion of encroacher bush species such as *Prosopis juliflora* and the Cactus (*Opuntia ficus indica*) species in most of the livestock grazing lands which in turn eliminates the grazing pastures is a threatening condition to livestock productivity and the pastoral community livelihoods (Choge et al., 2002; Opiyo et al., 2014). Reports by Kyuma (2013)

documented that an approximate area of 12000 Km² is invaded by *Prosopis juliflora* in Kenya. The approximate total *Prosopis juliflora* biomass yield is 3,000,000 tons per year, enough to sustain 2055 mature cattle in rangelands per annum. The estimated rate of spread of *Prosopis juliflora* is 55% per annum, implying an ecological threat in the near future (Kyuma, 2013).

However, there is little knowledge on sustainable utilization and management of these invasive tree species in Kenya, while people are still languishing in poverty and food insecurity (Aboud et al., 2005; Aboud et al., 2012; Choge et al., 2002). For sustainable food production from livestock, adapted perennial plant species such as the Cactus (*Opuntia ficus indica*) and *Prosopis juliflora* offer opportunities for improving forage availability in dry areas (Food and Agricultural Organization of United the Nations- International Center for Agricultural Research in the Dry Areas [FAO-ICARDA], 2017). Research findings by Ben Salem and Louhaichi (2014) showed that lambs fed on straw supplemented with spineless Cactus (*Opuntia ficus indica*) and salt bush (*Atriplex numularia*) grew at a rate of 80g per day. Similarly, dairy cattle receiving a complete mixed diet composting of 60% ground Cactus (*Opuntia ficus indica*) cladodes, 20% chopped hay and 20% protein-rich concentrate yielded about 25 litres of milk per day (Dubeux, 2016; Kibria et al., 2017).

Ben Salem and Louhaichi (2014) concluded that Cactus species can survive in arid and dry climates where nothing else could grow, and for this reason it can be an important forage crop for livestock feed security. However, livestock performance data on Cactus (*Opuntia ficus indica*) is missing in a Kenyan context and it should be validated for adoption and policy makers. Studies by Koech et al. (2011) demonstrated that *Prosopis juliflora* could be used as goats feed up to 200 g/goat/day giving highest feed intake (0.26 kgd⁻¹) and daily weight gain (0.061kg d⁻¹), with no adverse effects on digestibility.

Although *Prosopis juliflora* pods are palatable (Plate 3.5 (Appendix 3) and nutritious for livestock, rural pastoral communities have reported loss of teeth by livestock with subsequent death due to starvation (Choge et al., 2002; King'ori et al., 2011). Scientifically, this can be proven pragmatically that there is higher amount of sugars that are soluble in the outer pod parts and seeds that contain more nutrients (having almost up to 39% crude proteins) pass undigested through in the alimentary system causing the poor utilization of nutrients by the animal (Koech et al., 2011). Presence of the sugar in the outer parts of the pods causes the livestock teeth decay as it sticks on the surface of the the teeth causing microbial growth. After defecation, there is scarification of the seeds that are not digested, triggering and enhancing the

prolific germination process, thus aggravating the colonization process of *Prosopis juliflora* (Choge et al., 2002).

The current study targeted these two invasive tree species Cactus (*Opuntia ficus indica*) and *Prosopis juliflora* for value-addition and formulation of balanced livestock feed supplements to provide strategic nutrients (proteins and energy) that are limiting in dry lands. Use of the *Prosopis juliflora* pods and seeds by crushing them to avoid re-germination and processing as feed would give animals more balanced nutritious rations. This would subsequently slow its invasiveness in the long run, while reducing rural communities' vulnerability to climate change in livestock production systems and environmental conservation. The main outcome of adding value to *Prosopis juliflora* and *Opuntia ficus indica* (Cactus species) as balanced rations for livestock in rangelands is expected to have long term impacts on enhancing economic status in rural livelihoods and food and nutrition security. This formed the basis for this study.

1.6 Scope of the Study

The study focus was mainly in dry lands, and specifically Baringo and Laikipia Counties as representatives of pastoral system of livelihood, and Nyeri County (Northern region) representing an agro-system of livestock production. Agro-pastoral communities and the pastoral people are vulnerable and sensitive to climate change risks in their livestock production. This was assessed and documented in the study using various measures (Socio-economic characteristics of the respondents (gender, age and literacy levels), level of adoption of various improved technologies on climatic changes adaptation, constraints to livestock production, local coping mechanisms to adjust to adverse impacts of climate change, available feed resources, coping strategies for poor quality feeds, membership to agricultural groups, capacity building workshops, main sources of agricultural information, access and utilization of this information.

It was assumed that livestock production coping strategies in dry areas with considerable climatic risks is a function of socio-economic, socio-cultural as well as demographic factors. It was also assumed that the local climate change coping mechanisms adopted by these marginal communities were not sustainable to enhance their adaptive capacities to climate change effects on livestock production as their main source of livelihood. In the study, the feed potential of *Prosopis juliflora* and *Opuntia ficus indica* (Cactus species) in terms of nutrient composition and performance when included in livestock rations as a step to combat nutrient deficiencies in feeds and feed scarcity was also evaluated. The influence of plant species and various parts

of the potential forage plants on their feed quality was documented for possible database development, promotion of its use in livestock ration formulations and development of policy document on their conservation and utilization.

1.7 Limitations and Assumption of the Study

Limitations of the research was to the following areas which included to Baringo, Laikipia and Nyeri counties in Kenya. To obtain elaborative and insight findings, all the pastoral and agro-pastoral systems of livestock production in Kenya may need to be studied which was not possible due to constraints such as cost of the study, distance, terrain and accessibility. However, only a representative sample of these systems was used in the study, purposefully selected due to the prevalence of *Prosopis juliflora* and Cactus (*Opuntia ficus indica*) in these counties. The study sites were also chosen due to the previous experiences with these invasive tree species problems which elicited many reactions between the local communities and the Government (Githae, 2018). The study assumed that the potential utility of drought-resilient and under-utilized Cactus (*Opuntia ficus indica*) and *Prosopis juliflora* as livestock forage supplement formulations has not been fully exploited, a factor that would increase pastoral communities' vulnerability to climate change risks. It was also assumed in the study that the livestock feeding practices used by pastoral and agro-pastoral farmers as climatic changes adaptability strategy in arid lands and areas in Kenya are not clearly understood, a factor that make them difficulty to move out of poverty.

The practical implications of the findings of the study would provide baseline information on potential usefulness of these invasive tree species as feed for enhancing the adaptive capacity of pastoral communities in rangelands, and to inform the policy makers to conserve and manage these invasive tree species by utilization as livestock feed in rangelands, with the aim of eliminating the “slush and burn” slogan and adopt “slush and feed” as the new slogan. Some *Prosopis species* have been reported to have condensed tannins that have high protein precipitating capacity higher than tannins from other tree browses. There was a need to analyse for condensed tannins in *Prosopis juliflora* to ascertain their levels for future recommendations. However, laboratory analysis for tannins is expensive, and thus was not done in this study due to financial constraints.

1.8 Definition of Terms

Adaptive Capacity: can be defined as the potential or the ability of given system to adapt well with a problem to different climatic changes that might be extreme or unpredictable, having capability to be affected moderately or not, and it is able to survive and adapt to the consequences resulting from the variabilities. Some of the adjustment can be behavioural, technological or in terms of the resources (Pettengell, 2010).

Climate Change Adaptation: This is defined as the ability to adjust to natural or artificial changes that result to altered or changed environment conditions. Climate change adaptability is the adjustment to human or natural system to the expected or actual stimuli, moderating the related adverse effect and the utilize the available or created fortunes (Ben Salem, 1996; Pettengell, 2010).

Climate Change Impact: This can be defined as the as the consequences either positive or negative resulting from long term climatic patterns variability or changes on the environs, and the population inhabiting the area. Manifestation of the effects can be through droughts, melting of icebergs, glaciers and snows, floods and the rise in the sea levels in the coastal regions (IPCC, 2007, 2014).

Climate Change Mitigation: It is the amelioration or enhancement of sinking the greenhouse gases (GHGs) through anthropogenic intervention methods (FAO, 2007, 2009a, 2011). Mitigations are the measures put in place to ameliorate causative agents of a certain phenomenon (in our case, the climatic changes through reduction of gases that trap and emit heat into the atmosphere).

Climate Change: It is the change in the climatic patterns for a long period of time that is over a decade, and can be measured as changes in the variability and means of the related properties resulting from human related activities, and/or natural causing agents/variables (IPCC, 2014).

Climate Smart Agriculture: It is defined as sustainability increase in agricultural activities in terms of adaptation and resilience, productivity, reduction and mitigation of the greenhouse gases, and enhancement in the food and nutritional security in a given country in relation to the developmental goals to reduce risks (FAO, 2011).

Climate Variability: This can be defined as the changes (rather fluctuations) in the parameters that constitute climate of a certain region as a result of the impact of long-term impacts (IPCC, 2007, 2014).

Coping Strategies: they are methods employed by individuals to adapt, tolerate, minimize, or reduce the effects of a certain new phenomenon they are not used to, as in our case effects due to adverse climatic changes on the life of the people (FAO, 2011).

Drought Resistance: It is the ability to which a plant maintains its biomass production during arid or drought conditions.

Drought Tolerant: This refers to the ability of a plant to sustain and keep the balance and turgidity of water during the exposure to harsh conditions and stresses such as drought therefore, evading the stresses and the related repercussions.

Livelihood: it is the support of an individual's existence or having ability to secure the necessities of life

Pastoralism: This is defined as the living behaviour where individuals' rare livestock and they are in constant movement to search for animal water and pasture, a process also called nomadism.

Resilience: This is the persistence a system can have without changing its state under pressure or change due to external or internal factors. This involves the capability of coping up with certain stressful situations resulting from political disturbances, environmental stress, external pressures, and social distress (Terry & Geraldine, 2009).

Risk: This is the combination of impact and the magnitude of a calamity or something that is a nuisance occurring, and it entails the uncertainties that occur or controlled by the exposures, sensitivity, adaptation and the changes in the climatic conditions (IPCC, 2007).

Coping Strategies: It is the endurance of the coping mechanism, and usage of the same mechanism for a period of time without causing injuries to the livelihoods of peoples and the environment or resources

Vulnerability: It is the degree of susceptibility of a system, or inability of the system to cope up with adversity either due to climatic changes or related calamities and other extremisms (IPCC, 2007, 2014).

CHAPTER TWO

LITERATURE REVIEW

2.1 The Link between Environmental Aspects and Livestock Feed Resources

Livestock is a key asset among the rural communities living in the arid and semi arid lands (ASALs) of Kenya. Livestock ascertain major roles in fulfilling social, management and economic function among the ASALs inhabitants in these dry lands agro-ecosystems. Due to challenges related to the environment, for instance higher temperatures, low amounts of rainfall and poor rainfall distribution, livestock production as a source livelihood has been challenged (Hidosa & Guyo, 2017). In addition, environmental related aspects such as global warming with the associated climatic changes have affected productivity of the livestock system where there is less feed for the livestock, affected metabolism rate and less metabolic activities. This leads to poor livestock productivity, with negative impacts on rural communities' livelihoods, a factor that can lead to hunger and chronic poverty. Moreover, climatic changes have been predicted to increase vulnerability of livestock keepers living in rangelands. This is through reduction in livestock productivity due to reduced herbage yields, and increased lignification in the tissues of the plant and subsequent decrease in forage digestibility and intake (Leng, 2005). Additionally, environmental aspects such as climate change has been reported to increase invasive shrub invasions in grasslands (Hidosa & Guyo, 2017). According to Rao et al. (2014), such shrubs infestation has a significant effect in the reduction of the quality and quantity of forages for various species of livestock, such as the grazers, mainly the cattle and sheep.

On the other hand, climatic changes and truncated landscapes in rangelands have escalated the reduction of feed quantity and quality among the pastoral communities (Ochieng et al., 2017; Opiyo et al., 2013). The hot and dry seasons have induced significant reduction in forage biomass yields growing in lowland environments. Hidosa and Guyo (2017) stated that increased environmental temperatures, higher nitrogen and carbon dioxide levels decreases the productivity of pastures. Conversely, many semi-arid areas are predicted to experience lower rainfall due to climatic changes and variability (Rao et al., 2014). The length of the pasture growing period is expected to decrease in many parts of the tropics. This may be accompanied by greater variability in rainfall patterns with more frequent droughts (Hidosa & Guyo, 2017). The study made by Tubiello et al. (2007) on evaluation of climate change impact on quality of forage species revealed that high temperature tends to increase lignification in plant tissues and

hence decrease the intake and digestibility of forages. Concurrently these high temperatures have been reported to induce a shift from C3 grass species to C4 grasses which has direct implications on forage supply and demand (Tubiello et al., 2007).

Rangelands are an important asset for pastoral communities' livelihoods. This is supported by Hidosa and Guyo (2017) who studied rangeland productivity to assess the environmental effects and concluded that climatic change had negative effect on the vegetation in the dry land ecosystems, which led to depressed productivity of pastures for livestock. It was also reported in these studies that the changes in the seasonality affected the pasture availability and quality that escalated the rangeland management and the grazing patterns (Oxfam International, 2010; Tubiello et al., 2007). Similarly, as the climate changes and becomes drier and hotter, the composition of the pasture changes and is more likely unsuitable for grazing purposes. In conjunction with that, the chemical composition of the rangeland pasture grasses and browse species is affected by the climatic changes as they adapt to the harsh environment, with subsequent risks of biodiversity alteration. Moreover, previous research findings have shown that hot and dry environment negatively affect the quality and the quantity of pastures in dry and the arid areas. Water scarcity is also a major challenge affecting livestock production due to climatic changes (Tubiello et al., 2007). According to Hidosa and Guyo (2017), the forage species diversity, optimal growth rates and the growth dynamics change as the levels of carbon dioxide and temperatures varies. Environmental related aspects have also been implicated in the infestation of invasive plant species such as *Prosopis juliflora* which has been reported to have adverse effects on loss of forage species diversity (Maundu et al., 2009).

2.2 Global Climate Change Risks and Vulnerability to Livestock Sector

Rao et al. (2014) defines rangelands as un-improved grasslands, savannas, shrub-lands, hot and cold deserts and tundras. They cover approximately one-fifth of the world's land surface and provide feed for approximately 50% of the world's ruminant livestock and countless numbers of wild herbivores (Madzwamuse, 2010, 2011; Walker, 1994). Billions of people around the world either directly or indirectly derive food or income from livestock that graze or browse on these lands. Rangeland and livestock ecosystems are complex, with myriad interactions among the biotic and abiotic components of the system as well as the economic and social components (Rao et al., 2014). However, the effects of a changing climate have direct and indirect impacts on rangeland ecosystem at many different spatial and temporal scales. Delgado et al. (1998) listed these climate change impacts on rangelands as follows; changes in forage

yield, changes in livestock productivity, changes in ecological processes, alterations in farm level profitability, changes in regional farm incomes and possibly modification of regional and national food production and incomes. This will have adverse effects on rural communities' livelihoods, food and nutrition security.

Additionally, increased carbon dioxide (CO₂) in atmosphere affects plant species productivity and leads to change in precipitation, wind patterns, solar radiation and temperature, that would have essential effects, either negative or positive on plants and livestock productivity in rangeland ecosystem (MacLeod et al., 2013; Ochieng et al., 2017; Opio et al., 2013). As a result, the productivity that is driven by the changes in the climatic conditions affects regionally, locally and nationally the food availability and supply for the human population together with the having economical impact that in a lot of nations worldwide, mostly in the developing countries that lack resources to aid in the adaptability process.

Climate change has direct effects on livestock productivity as well as indirectly through changes on the availability and quality of pasture grasses and browse plants (Mganga et al., 2013). They determine the adaptable livestock type in differentiated ecological zones and resulting to livestock that can succinctly support and sustain communities in the rural areas. On the other hand, green house gas (GHG) emissions from livestock along the the livestock product-chain attribute to 9% of the emitted anthropogenic CO₂, 65% of nitrous oxide and 37% of methane (IPCC, 1996). There are several pragmatic approaches that are available to aid in the mitigation against emissions from these sectors for instance agroforestry to do aid in carbon and organic carbon sequestration and restoration, livestock diet improvement and proper manure and nutrient management system.

At least a billion of the world's poorest people depend on animals for food, fibre, income, social status, security, and companionship. According to IPCC (2018) and United Nations Framework Convention on Climate Change [UNFCCC], (2018), all climate change related hazards and their related disasters have a negative impact on livestock and livelihoods. Climate change is expected to cause an increase in weather-related disasters and extreme weather events, such as prolonged droughts, heat waves, storms, desertification, and increases in insect infestations (IPCC, 2007; World Resources Institute [WRI], 2005). Changes that have been seen to be long-term have been associated with jeopardizing with the animals' future for instance those on the homes, wilderness, forest, farm, ocean, and even in the zoos. Considering livestock agriculture, rearing of animals for clothing, food, and animal-based energy sources

have been seen to be a great source of climatic changes, contributing to the emission of almost 18% of greenhouse gas (GHG) emissions (9 % CO₂, 37 % CH₄ and 65 % N₂O) (IPCC, 2014; Thornton et al., 2002, 2008; World Meteorological Organization [WMO], 2011). Although changes in the climatic conditions have been seen to have detrimental effect on all animals, ruminant animals have metabolic activities such as ruminal enteric fermentation and manure production that directly contributes to climatic change by emitting greenhouse gases (GHG) for instance nitrous oxide (N₂O) and methane (CH₄). The production of biogas is one way to reduce GHG emissions from manure while increasing farm profit, and providing environmental benefits (National Research Council [NRC], 1981; Thornton et al., 2008; Walker, 1994). Research findings by Thomas and Ranganekar (2004) concluded that during development of the climatic change mitigation and adaptation programs and policies, livestock husbandry and good agricultural practices and their welfare should be considered.

2.3 Africa's Risks of Climatic Change and Associated Vulnerability

Reports by IPCC (2018) indicates that vulnerability to climatic change affect mostly the Africa continent mainly due to limited resources. According to Thornton et al. (2008), this situation is escalated by a combination of various stressful factors caused by environmental changes, with lower adaptation capability by the forage feeds. Reports by IPCC (2019) indicated that climatic changes and environmental related factors largely affect the Africa as a continent and it is vulnerable to the effects of global warming, being in the tropics. This has led to increased economic crippling, that has increased the rate of poverty levels, infringed access to technologies, capital and good infrastructure. Environmentally, Africa has been facing challenges related to conflicts and constant wars in some regions, rapid ecosystem degradation and, continued problems of soil fertility due to over-utilization of the arable land. With this kind of factors and other unpredicted calamities for instance fire outbreaks, the adaptive capacity of livestock keepers has been a major challenge (IPCC, 2007, 2018). Projections given by the Inter-governmental Panel on Climatic Changes about Africa show that more than 250 million individuals up to 2020, could be facing problems related to water depression and food insecurity (IPCC, 2007, 2015).

Other reports from the IPCC (2018) indicate that in the 21st century, climate related risks globally possess the greatest challenge exerting pressure on food and feeds. The rate at which the global warming is happening and changes in the climatic conditions, is evidently seen to be overwhelming and threatening, and may be irreversible and detrimental. Encroachment of

the arid and the semi-arid areas with increased water stress in the pasturelands and areas inhabited by the pastoralists is evident of the climatic change adverse impacts, which is reported to affect almost two thirds of African continent (Adhikari et al., 2015; Huang et al., 2016). Varying rainfall patterns, extremities in temperatures, soil infertility, extended droughts, heavy storms, and occasional floods negatively impacted the arid and semi-arid areas too (IPCC, 2007, 2013; ILRI, 2015). It is important to note that these areas are inhabited with more than 380 million people who subsist on available resource for a living including the pastoralists who depend heavily on livestock (IPCC, 2015; Thornton et al., 2007).

Douglas et al. (2008) documented those climatic changes have led to adverse weather changes and related diseases, adversely impacting on the agriculture as a whole (livestock and crop farming) with reduced water catchment areas. This translates to increased environmental vulnerability and livelihood of people being at risk. Impacts related to climate changes are catastrophic sometimes, chronic, persistent and long term. This might be encompassed with declined productivity, catastrophic floods and death of livestock (Douglas et al., 2008; Gill & Smith, 2008). A good example is the African Sahel region that has been experiencing extreme drought spells for more than three decades becoming the immense climatic effect ever recorded by the researches in the world (IPCC, 2014, 2019; Nandi-Ndaitwah, 2011). African Sahel is inhabited by millions of people who are agro-pastoralist, pastoralists and nomads engaging in livestock rearing, and do small-scale farming for survival. Reports from the United Nations Environment Program [UNEP] (2011) indicated that Sahel's climate has become drier in the past few decades, causing encroachment of dry lands (deserts) and prolonged droughts. An example of a country in Africa experiencing the Sahelian adverse effects is Sudan.

Further researches have shown that climatic changes are a threat to the rangeland ecosystems causing their shrinkage in turn affecting the livestock rearing among the pastoral communities. This can result to continued conflicts between the pastoralists and other communities engaging in farming activities. Taking an example of Tanzanians, there has been a conflict over years over grazing lands, water and grass in areas such as Kilimanjaro, Mara and Morogoro (Tanzania National Adaptation Programmes of Action [NAPA], 2007). The National Adaptation Program of Action (NAPA) a subset of the UNFCCC (2018) claimed that extremities in climatic changes involving floods, drought and extremely hot temperatures in African ASALs has negatively affected pastoral communities' economic status (Sierra Leone NAPA, 2007; Sudan NAPA, 2007; Tanzania NAPA, 2007; Uganda NAPA, 2007; Zambia

NAPA, 2007). Due to these negative impacts associated with climate change, most of the communities have been forced to migrate in such of arable lands, water and pasture, most of them having deteriorated livelihood and languishing in poverty due to frequent tribal and communal wars.

In the period 1950 to 2004, the IPCC (2007) recorded that due to urbanization, the urban population grew averagely by 4.3% causing an immediate increase of people from thirty-three (33) million to three hundred and fifty-three (353) million. Complexity involved in immigration and immigration patterns, that aid in the distribution of income inform of remittance as a result of response to movement and related stresses emanating from resource constraints and conflicts, have been exacerbated by socio-economic and environmental factors (IPCC, 2018). Droughts outbreaks have been experienced all over the world but its impact and severity has been seen more in Africa compared to other continents and Sahel has been majorly affected. With the repeated occurrence of the droughts, loss of property, livestock deaths and many lives lost due to hunger and lack of water with related malnutrition cases has been experienced with unplanned migration rates. Anticipation by the IPCC (2007) indicated that Sahel was at risk of becoming drier by the year 2100, with a likelihood of 25 percent decline in the rainfall and with extreme increase in temperatures. With that and related cases in other regions of the world, it is forecasted that the rate of migration might increase, new settlements experienced which will put pressure on the resources and infrastructure in the new settled areas. As the climatic changes occur, leading to droughts or an expected flood, it affects the migration patterns including short-termed migration due to response in the climatic changes and continued migration from persistent drought.

Most of the African countries experiencing climatic changes have claimed that the affected communities adjust to the adverse climate changes through traditional mechanisms such as a shift in the crops being farmed and livestock kept, utilization of wild foods, reduced meals intake, harvesting of water traditionally, use of loans and inter-house transfer, warning systems and dwelling in merchants and those people who can lend them money (Sudan NAPA, 2007; Ethiopia NAPA, 2007). These countries also stated that migration (both permanent and temporal) is the most mechanism used by the inhabitants for coping with the changes in the climate (Gambia NAPA, 2007; Sudan NAPA, 2007; Ethiopia NAPA, 2007). Lack of ways for income diversification in the ASALs and rural areas, escalated cost of living, less job opportunities and extreme poverty rate have contributed to the increased migration in the

regions, and to urban areas in search of greener pastures (Gambia NAPA, 2007). Studies have argued that when people are unable to adapt and lack the capability to cope with the changes in the environment and climate, they tend to migrate. However, many researches are underway to aid in the adaptability and survival of the affected communities (Scott, 2008; United Nations Environmental Program [UNEP], 2007).

Isohyets causing a shift in rainfall have been reported to be a concern also in some of the countries and are responsible for shifts in the agro-ecological zones and spontaneous displacement. They also affect the norms and traditions of people, and tribal systems and patterns (Sudan NAPA, 2007). Displacement of people by climatic changes or floods or calamities has been accompanied by great environmental damage and, related suffering of mankind. Degradation of land and poor livelihood has been experienced largely in most of the large refugee camps in Africa. As a result of the environmental degradation, it becomes more frustrating to curb problems related to poverty and malnutrition. It has been experienced in Sudan where due to environmental degradation, many Sudanese have been displaced, and therefore posing a challenge in resettling the displaced persons. To halt unnecessary displacements, a call for environmental degradation control is evitable, which is a double cost to many governments (United Nations [UN], 2008; UNEP, 2011). Great concerns have also been raised concerning the rising of HIV/AIDS and other diseases such as malnutrition and under-nutrition associated with migration of people.

There has been a pressure exerted on resources due to increased human and livestock population. With expansion of agriculture in the marginalized areas has been reported to increase, and consequently exacerbate failures in crops, conflicts, and compromised biodiversity and degraded environment (IPCC, 2007). Conflicts have been caused by several factors which constitutes management of resources, inequalities in the structural set up, distribution of available land and limited land resources. Such wars and conflicts have been associated with degradation of the available natural resources. Those individuals that are marginalized also feel segregated exacerbating the conflicts. However, other reports documented that variation in changes in the climate play a major part in conflicts especially those in the areas with scarcity of water and pasture land (Scott, 2008). Encroachment of deserts and arid land leads to migrations and related conflicts over the limited resources (IPCC, 2007). Prolonged droughts, frequency in higher abnormal temperatures and soil infertility are major effects expected as a result of climatic changes and variability that impact negatively on rural

pastoral communities (Boko et al., 2007). Migration and conflicts in most of the rural areas has been caused by prolonged drought causing individuals to move mostly in urban areas amounting to pressure on available resources, infrastructure and social amenities (Ramin, 2009). Lack of enough rain causes reduced productivity in farm foods and livestock related food leads to pressure on the locally available food, therefore, causing starvation and malnutrition among the people, especially the children, pregnant women, the elderly and the people living with disabilities.

Poverty and urbanization in Africa are two inseparable things (Ramin, 2009). This is because of increased slums in the major urban areas in Africa. Slums are defined by the United Nations Human Settlements Program [UNHABITAT] 2010) as areas in the urban centres without satisfactorily social amenities such water, electricity, and sanitation services, having substandard houses, dirty environment, overcrowded, being insecure and socially excluded. Almost 72% of those dwelling in urban centers in Africa, are slum dwellers and constitutes the largest world's proportion (UNHABITAT, 2010). People in slums are exposed to a lot of vulnerability such environmental pollution, diseases, floods, or inaccessible to proper social amenities as the slums are located close to factories, major highways and in restricted land (Ramin, 2009).

Slums dwellings are made of weak materials sometimes in areas prone to floods or land slides (Boko et al., 2007). It is predicted that in over ten years to come, climatic changes effects will progressively be experienced all over the continent of Africa. The effects due to climatic changes and as a result of urbanization is unpredictable and the interaction of the two on the environmental vulnerability cannot be well underestimated (IPCC (2018). Other Reports indicated that synergetic interaction between the climatic changes and the urbanization process has and will greatly influence the burdens of diseases in the world (IPCC, 2018). Almost half of the population in African urban centers (45% of the population) faced the challenge of access to proper and sufficient social amenities (such as sanitation) by the year 2000 causing many to have poor lifestyle (UNHABITAT, 2010). Africa's Eastern areas inhabitants had a challenge of defaecating in the open by over 33% of the inhabitants by the year 2006 (UNHABITAT, 2010). Such practices lead to outbreak of foodborne related diseases (cholera, Typhoid etc), water contamination and outbreaks in slums located in these areas (Ramin, 2009). As studied by Douglas et al. (2008), increased temperature and higher precipitation have led to rise in the sea levels, indicating that there is a hazard of frequent flooding in most of the African towns and

cities. There are key reservoirs that perpetuate calamities such as cholera, malaria, dengue and yellow fever in urban areas, all of which are linked to flooded areas, ditches, latrines and septic tanks.

2.4 Risks Associated with Climatic Changes and Vulnerability in Kenya

Management of the unreliable and insufficient rainfall by the pastoral and agro-pastoral communities has been the major challenge affecting their livelihoods. Regular drought occurrences in Kenyan dryland lands (Arid and Semi-arid areas) have affected approximately 3 million and more individuals living in these dryland ecosystems. This has been reported to exert an economic burden of almost \$12.1 billion in the year 2008-2011 (GoK, 2015; ILRI, 2014). Associated risks include increased cost of agricultural production in the ASALs elevated by the high costs in the entire commodity value chain. The unpredictable rainfall patterns, unreliable feed production and higher variability in the climatic changes, negatively affect livestock and farm productivity (GoK, 2018). Hitherto, increased climatic changes, and variability in the climate conditions has increased the vulnerability of the pastoralists, and even the other agricultural communities. Weather variations and unpredictability and frequency in the drought occurrence (occurring closely than before), possess a concern to the near future as it is a great concern to the Kenyan economy and related environmental concerns (GoK, 2015).

Reports by IPCC (2018) indicated that climatic changes have led to increased global warming that has in turn caused rise in the sea levels leading to related floods, disruptions in some economies and posing environmental hazard. Kenya has for a period of time been experiencing stresses posed by drought, elevated heat and floods that are a risk to humanity health and livelihoods. It is of importance to note that Kenyan economy being greatly dependent on agriculture which is the backbone of the gross domestic product (GDP), it is at high risk and vulnerable to the drastic changes and shifts in the climate. Other sectors of importance in Kenya that are largely affected by the climate change and vulnerability include wildlife, health, energy, tourism and water catchment areas (GoK, 2016). Disasters and calamities associated with weather-related impacts has alleviated the conflicts among the communities due to strained natural resources which has been a major contributor to increased threats and insecurity issues (GoK, 2010; Oulu, 2011). Impacts such as loss of life, livestock death and biodiversity interference are as a result of extremities in climatic changes negatively affecting the economy. For instance, Kenya as a country, had a GDP loss of 0.36% yearly and an average

of 58% death per annum in the period ranging 1997-2016 alluded to weather related calamities and catastrophes (GoK, 2015, 2017, 2018).

Human associated losses due to flood cannot be underestimated and many lives have been lost in Kenya due to the same (GoK, 2018). In the year 2018, it was approximated that over 183 lives were lost because of floods. Also, more than 220,000 people were displaced and over 700 schools closed affecting children (over 145,000 children) (GoK, 2018). As a result of the floods also food related illnesses outbreak such as cholera, were experienced in more than six counties with tremendous increase in dengue and malaria infections. An approximation of 43 flood disasters have been reported in Kenya since 1990 to 2015, and with global warming this seems to worsen. This is because it is predicted that by 2030, almost 270,000 of individuals in the coastal communities will be at risk of floods due to the rising sea levels. Notably Kenyan coastal area is the largest East African seaport with great tourism opportunities and increased fishing activities which are also highly impacted by climatic changes.

Other reports by GoK (2018) indicated that Kenyan droughts have negatively impacted approximately 4.8 million individuals whose livelihoods have been affected, and similarly, triggering some conflicts locally on the resource that are scarce leading to incapability of the communities to adapt and easily adjust to the climatic changes. The 2014-2018 drought was declared a national emergency in February 2017 and it affected 23 of 47 counties in the ASALs (GoK, 2018). More reports by GoK (2018) indicated that almost half a million Kenyans had a problem of accessibility to water since 2014-2018 and issues of food insecurity had been a major problem for around 3.4 million Kenyans. This was escalated by the problems associated with drought and changes in the climatic conditions. It is also estimated that malnutrition related diseases have been a quagmire to most of the children living in the ASALs (over 23 counties totalling to 482,882 children). Some of them have dropped out of school and others not being able to join schools due to poverty and impacts of severe prolonged droughts (GoK, 2017).

With the effects of the drought, a significant change in the migration patterns has been experienced in the ASAL areas both for wild animals, humans and livestock, and human-animal conflicts experienced during these migration process. Meteorologist predict that most of the Kenyan ASALs are vulnerable to environmental climatic changes and are likely to expand due to increased urbanization and GHGs. Poverty incidences are high in the ASALs with higher competition over the scarce available resources due to increased population density

and migration to urban centres. There is also lowered access to proper infrastructure in this region and demised social amenities to meet the needs of the ASAL communities. Presence of portable water in the regions has been a problem and other utilities such as telecommunication services and electricity being a major problem to them.

Communities in the ASALs are highly dependent on the livestock and subsistence agriculture that are vulnerable to changes in the climate and these activities support almost 70% of the population that nationally depends on the livestock. Conflicts and wars between counties and communities have been escalated by the changes resulting from the climate (GoK, 2015a, 2018). With the unpredictable rainfall patterns and the changes that leads to rise in temperatures, it has been seen that some areas become less conducive, and unproductive for both crops and livestock for instance cattle and shoats, and hence reduced herds. Due to the unfavourable environmental conditions, the pastoralist is forced to migrate to better areas with resources resulting to conflicts with the cohabiters of the favourable areas. For instance, Taita Taveta has been in constant conflicts with the pastoralists from Garissa County who migrate to neighbouring counties in search of pastures and water. This can also be an incidence with other countries for instance Kenya and Tanzania, Ethiopia and Somalia where there is much migration and the communities close to each other compete for water, pasture, natural resources and food.

Concrete evidences have shown that climatic changes are linked to the most of migrations experienced in Kenya for the communities that heavily relied on livestock and agro-pastoralist (Oulu, 2011). Reduction in the agricultural productivity, castigates the rural-urban movement and migration causing increased slums and over-population in the urban centres. On the other hand, scarcity of the available resources and related land disagreements contribute to the conflicts and wars in the pastoral communities resulting to displacement of people and losses of lives. According to Oulu (2011), droughts, floods, and landslides have greatly contributed to propel changing their areas of settlement and others being displaced among the Kenyan communities. Communities that are vulnerable include the pastoralist and the marginalized groups, gatherers and the hunters, and those people who depend on fishing as the source of livelihood. These economic activities heavily depend on the climatic changes that lead to environmental degradation with competitiveness on the land resources. Another group of people with vulnerability include the elderly, children and people with disabilities as their vulnerability involves issues with health and mobility. Those communities heavily depending

on fishing are highly affected by heavy rainfall, severe storms, sea tidings, and overfishing resulting to severe poverty among these people. Taking an example, in 2013 since May to July, many people in the fishing communities were unable to fish due to climatic effects and those who did, were risking their lives from drowning and boat capsizing (GoK, 2013).

2.5 Adaptation of Agricultural Production Systems to Climate Change

Scarcity of water globally is a big problem and has been persistent for the past four decades becoming a major concern for over 2 billion people all over the world (African Development Bank [AfBD], 2010, 2011; Millennium Ecosystem Assessment [MEA], 2005). There is foreseen future crisis on water, food and feed productivity due to climatic changes and variability, with the changes that are being seen now as reported by the Comprehensive Assessment of Water Management in Agriculture [CAWMA], 2007) report. Therefore, there is need for pulled together efforts by different countries to improve on different aspect that affect water catchment areas (especially fresh water) and food productivity to curb the upcoming challenges in the future years (African Union Inter-African Bureau for Animal Resources [AU-IBAR], 2013). Localization in the impacts of water shortages have started to raise eyebrows to many which is caused by negative impact on the water resources (African Progress Panel [APP], 2010). An increase in temperatures lead to more demand in water requirement by livestock, other animals and plants also for compensation of respiration and transpiration respectively. For instance, *Bos indicus* water intake is approximatd to rise from approximately 3kg per dry matter intake at 10°C (ambient temperature) to approximated 5kg per dry matter at 30°C, and an approximation of 10kg of water per dry matter at 35°C (NRC, 1981; Rao et al., 2014).

Ground water is seen to the solution for future crisis of water due to the effect of climatic changes and the global warming. However, with increased higher temperatures water tables are predicted to go lower (Masike, 2007). With regards to livestock, climatic changes have been seen to negatively affect the feed resources that leads to lower productivity and it is evidently seen in the reduced pasture grasses and browse trees and shrubs available. Effect on the animal feeds indirectly affect what the animals produce and reproduce, the capacity the rangelands can accommodate and capability of the ecosystem to buffer its own sustainability. Furthermore, agribusinesses in the animal feed value chain are affected by increased prices in the stovers, and ASAL encroachment to rangelands and other arable lands.

Previous research findings by Masike (2007) concluded that there is change in the niche of the generic species in different locations as there is increase or reduction in rainfall and temperatures and a lot of variability is seen in the grass and crop species. In some parts of the East African countries, for instance, crops such as maize is being substituted with millet and sorghum as they are more resistant to environmental changes compared to maize (Thornton et al., 2002, 2008). With the change in the land use results in a changed animal diet and available food and feed to curb food insecurity during drought seasons. Therefore, with the changes in feed and food insecurity issues, there is likelihood of animal productivity being affected and challenges in maintaining the available livestock numbers.

Ruminant feed availability is threatened by climatic change related risks. It is important to note that the climate change impact on the feeds and animal productivity vary with different areas, systems of production and the species of the pasture and forage crops. For instance, productivity of C4 kind of plants increase with increase in temperatures ranging from 30-35°C and it encompasses most of the pastures and fodders. This is implicated on the fact that the rate of evapo-transpiration does not affect the normal growth of the plants. In C3 plants such as rice and wheat, temperature effects cause increase in CO₂ levels with significant positive impacts on the productivity of these types of crops (IPCC, 2007; Thornton et al., 2015). The biomass of feed and food crops changes with time since harvest which also affect significantly the livestock productivity due to the changes in the quantity and quality in given grains and hence less available metabolizable energy (ME) mostly in stovers from maize utilized in the dry season.

Livestock productivity is highly determined by the composition of different forage feed species, different grasslands and rangelands. With the change in the temperatures and the carbon dioxide levels, it is noted that there is change in the optimal growth by different species. Composition of different grasslands change with change in the environmental conditions and the different species dynamics is altered by these changes (Thornton et al., 2008). There is significant alteration of the livestock productivity resulting from a slight change in the temperature variation. Browse plant species in the rangelands are foreseen to enlarge in the near future as a result elevated amount of carbon dioxide and increased competition by the same browse plants (Morgan et al., 2007). Lignification of plant tissues is increased by higher temperatures which results into poor digestibility and intake of the feed material (Jones & Thornton, 2003; Manson, 1990). Therefore, high temperature related effects on forage quality

and/or lignification, there is significant reduction in the available nutrients from the animal feed which impacts the livestock productivity. To a larger extent, it affects the amount of forage supply, leading to problems associated with food insecurities for the subsistence farmers and the pastoral communities.

2.6 Contribution of Agriculture to Climate Change

An estimation of the agricultural activities' contribution on emissions globally (for GHG) is at 10 to 14% compared to all emissions made (Baumert et al., 2005; FAO, 2009a; Smith et al., 2007b). Agriculture has been reported by other researchers as the major emitter of the non-carbon dioxide greenhouse gases, contributing to about 52 and 84% of total methane in the environment and emitted nitrous oxide respectively (Verchot, 2007). When organic materials are decomposing in areas limited with oxygen, Methane (CH₄) is emitted and conditions that escalate such processes include fields having rice and are under irrigation. On the other hand, Nitrous oxide is emitted as a consequence of excess nitrogen that supersede the plants requirement (Smith, 2008). Carbon dioxide (CO₂) comes from microbial decay, burning of plant litter, and burning of soil organic matter. However, the net flux of this gas in agriculture is thought to be small (Smith et al., 2008; United States Environmental Protection Agency [USEPA], 2006). It has been reported that the emissions from agricultural materials had been on the rise and in the next coming years it is expected to increasing significantly.

A study done by USEPA (2006) approximated that the emissions from agricultural materials were expected to increase to about 6,000 metric tons of CO₂ equivalent (MtCO₂eq) in the year 2005 to around 7,000 MtCO₂eq in the years 2020. Enteric fermentation and the soils used for agricultural purposes are the major sources of GHGs (Thornton et al., 2008). An increase in the amount of Nitrous oxide (N₂O) that is emitted from the cultivated lands was predicted to escalate by 37% by the last year (year 2020), N₂O emitted by 24%, and the CH₄ from the enteric livestock to have increases by 30%, while CH₄ from manure and that from cultivated rice by almost 22 percent (USEPA, 2006). As shown by these estimations, it is predicted that most of the emissions will be majorly from the enteric fermentation process and the fields that are cultivated, mainly with rice (Verchot, 2007).

Studies have shown that there is minimal increase in the emitted gases in most of the developed countries. Emissions from the Organization for Economic Co-operation and Development (OECD) countries was approximated to increase by a percentage of 10 from the year 2005 to 2020 (USEPA, 2006). The rise in the income, the population growth, per capita caloric intake,

and the change in the preferences of diets in many of the developing countries have been attributed to the increased emission rates among the countries (USEPA, 2006). Research conducted by Rosegrant et al. (2009) supported there is predicted increase in the quantity of cereals produced globally and it was estimated to grow by almost 0.9 percent annually in the period 2000-2005. The growth is expected to be faster by 2025, followed by a slow growth rate. Other research findings by Sandenbergh et al. (2015) indicated that demand for meat products (beef, mutton, chevon, pork, and poultry) is likely grow even faster. However, the demand for cereals is estimated to increase to around 1.048 billion metric tons (an approximation increase of 56%). Out of the increase, maize demand is expected to increase by 45%, wheat is expected to increase by 26% and rice by 8%. The remaining percentage is for coarse grains such as the sorghum, millet among others (USEPA, 2006).

Previous reports by Rosegrant et al. (2009) projected that with the growth in demand of proteinous foods for instance milk and meat in most of the developing countries, it is predicted that similar pressure will also be exerted on the coarse grains in general and maize used for making the feeds and food for animals. Similarly, around the globe it is estimated that the demand for cereals for livestock feeding will increase by almost 430 million metric tons in the period 2000 to 2050, causing an unstable demand of cereals averaging at 41% increase. Rosegrant et al. (2009) indicated that around 16 percent of the total maize would be used for biofuels and over 60 percent of maize produced will be utilized in formulating feeds for livestock. Most of the demands for feeds and biofuel will be accounted for by China around 12 percent and India around 10 percent (USEPA, 2006). On the other hand, some of the practical methods used in climatic changes mitigation include the land management process which has gained more concentration in recent years. Therefore, with increased carbon sink strategies including using of land management approaches for reducing emissions, this method provides pragmatic methods of regaining soil fertility (UNFCCC, 2018). Despite the fact that agriculture has been seen to be a contributor of emissions of GHGs, one need to know that it plays crucial and essential responsibility in the mitigation process and reduction of factors that lead to changes in the climate worldwide.

Smith et al. (2008) looked into the importance of agriculture as a potential in the mitigation greenhouse gases emission, based mainly on the livestock and cropland-based categories. In their research they claimed that almost 5,500 to 6,000 MtCO₂eq per annum of the GHGs could be mitigated by the agricultural products by the years 2030. The mitigation measures by

agriculture are attributed to the soil carbon that sequesters the GHGs, and it is mostly attained by management of the grass lands, crop lands and cultivated and degraded land restoration processes, despite the less carbon dioxide net flux obtained from agriculture (Smith et al., 2008). Reduction of methane can be highly attributed to the process of managing rice and livestock production practices.

2.7 Mitigation Strategies to Livestock-Caused Negative Environmental Impacts

Research findings by Martin et al. (2008) confirmed a significant contribution of livestock to climate change in diverse ways. Emissions from the livestock value chain amount to approximately 9 percent of the emitted total anthropogenic Carbon-dioxide, 65% of Nitrous oxide and 37% of methane (Gill & Smith, 2008; Martin et al., 2008). According to Steinfeld et al. (2006), some mitigation measures (technical measures) are in place to reduce emissions in the agricultural sector. For instance, the sequestering process by use of agro-forestry, improved livestock diet, restoration of organic carbon and improved management of livestock and manure. Biogas usage has been effective in the reduction of emissions of methane, and hence being environmentally friendly, it enhances profits at the farm gate level (Martin et al., 2008).

Globally, GHGs emitted by agriculture sector are approximated to be around 10-12% (or roughly 5.0 to 6.1 gigatons of carbon dioxide equivalents) as compared to the ones induced by the human anthropogenic activities (Gill & Smith, 2008). Methane from ruminal fermentation was approximated to be 1.9 Gt of CO₂ equivalents, which was amounting to approximately 37% of the GHGs produced by the agricultural sector. The estimates given above, despite giving the values for agricultural effect, they did not include the GHGs from fossil fuel utilized during animal husbandry, crop planting and the changes in the usage of the land. Putting into consideration the whole agricultural value chain, livestock contribution to emissions amount to approximately 18% as stipulated by Steinfeld et al. (2006) and hence increased impact on the global warming. With such effects and production of GHGs, pragmatic approaches are required as it is urgent and requires critical approaches.

The conversion ratio of feeds is reduced by the loss of carbon by the same feed to the environment, with reduced feed quality, and subsequent reduction in feed intake and weight gain (Bonifacio et al., 2017). The emission of carbon dioxide from ruminal fermentation is simple and well elaborated. During the digestion process in the ruminants, feeds through fermentation process are converted to short chain fatty acids including the propionic acid, acetic acid and the butyric acid with other 2-4 carbon containing fatty acids. The small chain

fatty acids provide energy for the microbes in the rumen and in turn the microorganisms produce protein for the animal, and during the process of metabolization the microbes generate carbon dioxide and methane. The two gases are the metabolic wastes produced by the microbes during the digestion process and they pose environmental challenges resulting to global warming (Bonifacio et al., 2017). The process of microbial conversion of feed to important nutritional component for the animal is essential, and therefore the need to look into ways to reduce the emissions that result from the same through doing more research and coming up with new ways and strategies in livestock feeds and feeding (Bell et al., 2016; Van Soest, 1994).

The efficiency of microbial production to produce essential nutrients depends on the conversion of feed into microbial biomass. The conversion produces short chain fatty acids which in turn reduces the carbon lost in to the environment. Therefore, the microbes will reduce the emissions intended to be emitted to the environment. A study conducted by Blummel et al. (2001) stated that there are higher losses of feed into gases and water from fermentation with higher efficiency microbial biomass production. Also, higher amounts of produced propionate in a kilogram of digested feed by ruminants is about 193g as compared to larger amount of acetate produced (which amounts to approximately 338g). Scientifically proven, increased propionate content and the efficiency of microbial protein production (EMP), simultaneously has a higher significant effect on the amount of carbon emission by the ruminants.

Amount of methane emitted to the environment during digestion of the feed is reduced by higher amounts of propionate produced in the rumen. When there is higher amount of acetate produced during the digestion process, the amount of methane emitted ranges from approximately 45 to 70 litres per kilogram of feed digested, and when there is high propionate production an approximation of only 20-30 litres of produced methane is experienced, implying a reduction by half of the amount of methane emitted to the environment during the ruminal fermentation in ruminant animals (Martin et al., 2008). Further research reports by Martin et al. (2008) showed that with increase in the amount of feed concentrates, there can be increased amount of propionate produced in turn reducing the methane emissions.

According to Bell et al. (2016), utilization of concentrates as a means to reduce the amount of methane emitted to the environment can be the best strategy in agricultural practices to mitigate GHGs emission to the environment. However, there are a lot of challenges in developing countries mostly associated with increased usage of concentrates as animal feed.

To commence with, are issues associated with food insecurity and hence jeopardizing with the prices of the food, becoming a great burden to the poor due to increased food prices and competition between man and his animals. Secondly, utilization of the natural resources for instance biomass, water and land can only be efficient in areas where the livestock feed production is from the crop by-products and residues that are not edible by humans. Similarly, if the biomass used for the ruminant feeding are planted, it can only be effective in areas that are not arable (Livestock environmental assessment and performance partnership [LEAP], 2015).

Different other interventions have been incorporated to enhance the minimization of carbon losses to the environment, in addition to the use of the process of shifting ruminal acetate production to propionate through the use of concentrates as supplementary feeds for ruminants. Some of these interventions include the use of natural and synthetic feeds, and feed additives to reduce the carbon loss (Martin et al., 2008). Another approach is the introduction of anaerobic species of microbes that can be able to breakdown fibre, to produce less or no methane during the complex metabolic processes. These kinds of microbes and the associated metabolic pathways require more research and the way they can be introduced in the digestive system of most ruminant animals.

Previous research findings by Ellis et al. (2007) concurred with the same mechanisms for adding value to *Leucaena leucocephala* species to minimize effects of anti-nutritional factors mainly the mimosine. According to Bell et al (2016), ruminal microbial microorganisms such as the anaerobic bacteria found in some ruminants has the potential to de-activate the anti-nutritional factors found in these forage shrubs. These bacterial populations were screened and isolated for subsequent inoculation in the digestive system of ruminant animals (Bell et al., 2016).

As livestock persists to be the main well-spring of livelihood, especially in the rural areas among the pastoral communities, it necessitates to look for pragmatic ways in which the sector can be made more economic and income-earning having in mind how the reduction of its impact on the environment can be reduced. Similarly, viability of the sector should be looked into for its own and livelihood sustainability (Bhatt et al., 2006). With regards to environmental change, livestock is both part of the problem, and also part of the solution where crop-livestock integration systems pose adverse effects to these systems. However, livestock will serve as an important tool for risk mitigation and diversification (LEAP, 2015). Increasing the efficiency

of livestock production, for instance by enhancing higher productivity from fewer numbers of livestock will play a key role in mitigating environmentally adverse effects from livestock (LEAP, 2015). There are, however ceilings to this approach mainly defined by feed resources. Feeding of livestock should not lead to competition for human food sources with livestock. Instead, it should be based on converting non-human edible feed sources, such as crop residues and agro-industrial by-products into human edible food. Some trade-offs between positive and negative effects of livestock have to be put into consideration (Bonifacio et al., 2017).

2.8 The Role of Drought-Tolerant Plant Species in Adapting Livestock Systems to Climate Change

Due to chronic land degradation and sub-divisions, coupled by an un-usual global population growth in a warming and drying world, it is expected that there will be rise in the need for many of the cash crops especially in the dryland regions, and mostly those that can adapt to the harsh conditions (Dubeux, 2016; Nobel, 1994). However, drought tolerant plant species have special characteristics that enables them to produce well under stressful environment and dryland in a sustainable manner especially in the soils that have less nutrients and where nothing else can grow (FAO-ICARDA, 2017). With the requirement for the drought resisiant varieties and crops mostly in the drylands, and areas with unpredictable weather conditions that are approximated to occupy almost 40% of the arable land on the earth, more researches need to be in place for a pragmatic solution (Nobel, 1989).

The above-mentioned areas have a problem of low rainfall, high temperatures, soils with poor nutrient contents and the high evapo-transpiration that do not allow proper agricultural practices and physiological growth of some of the crops grown in the regions. Agricultural economic activities are halted by these factors. Over the past several million years, drought tolerant plant species such as *Prosopis juliflora* and Cactus (*Opuntia ficus indica*) have had an evolution in their anatomical characteristics and the physiological properties that have aided them in production process in as much as their growth is in unfavourable conditions, that is, lack of nutrients and water in the regions (FAO-ICARDA-ISHS, 2017; Nobel, 2009). On the other hand, the CAM pathway of Cactus species enables them to colonize semi-arid environments where water is scarce and soil surface temperatures often exceed 55°C (Nobel, 1989, 1991; Nobel & Hartsock, 1983).

2.8 1 Description and Geographical Characteristics of Cacti species

Cacti are perennial plant species which is xerophytic, adapted and capable of surviving in hot and dry environments. Cacti are classified in the plant family Cactaceae. They belong to the order Caryophyllales with four sub-families namely *Pereskioideae*, *Maihuenioideae*, *Opuntioideae* and *Cactoideae* (Kang'ara & Gitari, 2010; Omweri, 2018). Cactae family plants exhibit characteristics of adaptability to desert like conditions by having thick cuticles, succulent tissues (for water storage), Craculacean Acid Metabolism (CAM), and shallow roots to tap any water from any shallow rainfall and asynchronous reproduction system (Omweri, 2018). Biologically, the Cacti family are epigynous (having inferior flowers) in nature, however some of them constitutes superior flowers. Another important characteristic of Cacti is that they are entomophilous. Such plants do the pollination process by use of organism such as bats, insects, birds and the bees (Omweri, 2018).

Similarly, Cacti have a common place dicot and other major tissues for their adaptability together with the aerosols that grow into spines (Kang'ara & Gitari, 2010). Other species of the Cactae family have sharp spines with length approximating to 5 cm and having clustered barbed stickers known as glochids (Kang'ara & Gitari, 2010). What uniquely differentiate Cacti from other plants is the aerosols that are reduced branches, and hence less water loses through transpiration (Omweri, 2018). Cacti enlarged stems, spines instead of leaves that reduce evapotranspiration, presence of shallow roots and the plant being green in almost all parts enhances the process of photosynthesis and aid the plant to easily adapt to the desert environment (Kang'ara & Gitari, 2010; Omweri, 2018).

Some of the Cacti species have been seen to grow to a height of 20-25m and are tree-like (arborescent) for instance the genus *Pereskia*, with a race of *Brasili Opuntia*, and they form the tallest freestanding Cacti species (Omweri, 2018). *Stenocereus thurberi* Cacti species grow shrubby while others grow columnar for instance the *Cephalocereus senile*. Globuse Cacti include Fero Cacti *latispinus* whereas epiphytic forms are seen in *Rhipsalis paradoxa* and *Pfeiffera iantothele*. Some Cacti species develop barreliform (*Denmoza rodacantha*), or articulated like the *Opuntia quimilo* (Kang'ara & Gitari, 2010). *Opuntia* species are characterized by having cladodes, modified photosynthetic stems and areioles (Omweri, 2018). Different types of Cacti species have different anatomical characteristics and they exhibit different morphological characteristics and different growth stages a phenomenon called dimorphic (Omweri, 2018).

2.8.2 Origin and Distribution of Cacti species in Kenya

Cactus is not native to Kenya. Cacti species present in Kenya were introduced by the white-settlers in 1940's to 1960's (Omweri, 2018). Their origin is postulated to be from Bolivia, Peru, Argentina in the Northwest and the northern parts of Chile (Central Andean region), (Kang'ara & Gitari, 2010), and the new world (Nobel, 1990). As documented by Omweri (2018), Cacti species, only *Opuntia ficus-indica* can be found in all the continents on earth with an exception in the Antarctica. Most of the species are found in drylands, semi-arid and arid regions of different countries in different continents for instance Mexico, Tunisia, Algeria, Argentina, Chile and Kenya. Narrowing to Kenya, regions where the Cactus species have grown include Mukogoda and Lamuria in Laikipia East, around Lake Baringo where they have grown as hedges, Laikipia North and Nyeri North (Kang'ara & Gitari, 2010). Introduction of the Cacti species in some parts of Laikipia was through a colonial settler who did the fencing of his home using the Cacti species to prevent invasion of predators to his home (Kang'ara & Gitari, 2010). The other reason for their growth was to prevent land degradation, prevent erosion of soil and enhance the process of restoring vegetation in the given ecosystem (Omweri, 2018). From various studies, it has been deduced that different cacti in different regions contain phenolic compounds that are specific for a given region. The highest cacti diversity is found in Mexico (Omweri, 2018).

2.8.3 Physiological Adaptations of Cacti Plant Species

Crassulacean Acid Metabolism (CAM) is the pathway that Cactus (*Opuntia ficus indica*) uses to derive the initial products of photosynthesis process. The CAM pathway take place when there is lower water availability and higher temperatures (Schweig, 2017). Crassulacean Acid Metabolism (CAM) plants produces organic matter mostly during the night as they utilize CO₂ and in the presence of enzymes to make the organic compounds. The CAM plants in the presence of light (daytime) uses the C₃ metabolism process to produce carbohydrates by utilization of CO₂ and keep the same sugars for the dark metabolic process (Schweig, 2017; Winter & Holtum, 2014). Many research studies show that Cacti have a high-Water Use Efficiency (WUE) as compared to other rangeland forage vegetation. Water use efficiency (WUE) is a concept that shows a relationship between plant productivity and water use. It is a measure of the amount of biomass produced per unit of water used by a plant (Winter & Holtum, 2014).

Study by Schweig (2017) indicated that succulent plants and cactus plants (*Opuntia species*) possess stems that are succulent and swollen used for storage of water, contain thick cuticle

covered with wax (prevent water loss), and contain thick epidermis for water storage. They (cactus species) possess root system that are extensive, that are shallow and spread over the surface to tap any light rainfall water on the surface, any moisture in the soil and on the surface and even in the air during cold nights with condensed moist air. The cactus plants have also been reported to contain stems with fluted ribs which aid the stems for easy expansion and contraction without damaging the tissues on the surface (Francis, 2013).

Due to these specific phenological, physiological and structural adaptations of Cacti species, they are considered to be in a good condition to be adaptable to the predicted variabilities in the climate for the come days (Novara et al., 2014; Novoa et al., 2015; Obiri, 2011). Cactus (*Opuntia ficus-indica*) has been reported to sequester carbon by a capacity of 20 tonnes of dry matter (equivalent to 30 tonnes of CO₂) per hectare per annum when the growth conditions are suboptimal being likened to the ones in the drylands (Walther et al., 2002; Winter & Holtum, 2014).

According to Winter and Holtum (2014), an increase in the carbon dioxide resulting from the fossil fuel utilization resulted in elevated variability in the climate. Therefore, with the variability in the climate, matters of environmental global warming arises with modification in the precipitation processes in the different continents that in the process affect the distribution of the plant species (Root et al., 2003; Walther et al., 2002). Previous studies have concentrated on understanding the sequestration process of carbon dioxide by the biological agents as in different plant types. Cacti plants use water more efficiently as compared to C₃ and C₄ plants and their carbon dioxide intake is more more efficient leading to much more productivity compared to the latter two (Cornelis, 2006; Nobel, 2009; Root et al., 2003). The biomass generated by the cacti is approximated to be 5-10 times more compared to that produced by the C₄ and C₃ plants species (Borland et al., 2002; Doran, 2002; Francis, 2013).

The capability of the CAM systems for accumulation of higher amounts of biomass highly rely on the ability of the plants to utilize more of the carbohydrates to aid in the growth process rather in the process of nocturnal acid metabolic activities (Borland & Dodd, 2002). Of importance, are the roles played by the cacti species in the arid and semi arid areas in the carbon cycle. Cacti aid in the metabolic processes that lead to development of nutrients present in the plant and removal of the CO₂ from the environment aiding in curbing global warming (Doran, 2002; Nobel, 1994). The processes are essential in the soil regeneration too through decomposition a process catapulted by the presence of microorganism in the soils. Some

studies have been conducted in different areas to see the sequestration effect of cacti (*Opuntia ficus indica*) in the utilization of carbon. Nobel and Hartsock (1983) documented the rate of exchange of gases by the *O. ficus-indica* where carbon dioxide uptake was measured per cladodes by the use of infrared gas analysers with cuvettes adapted in fitting cladode's morphological characteristics were quantified.

Cacti (*Opuntia ficus indica*) species as compared to the C3 and C4 species, are more efficient in the utilization of the carbon dioxide and water to form plant nutrients (Han & Felker, 1997; Nobel, 1991, 2009). Nobel (2009) claimed that temperatures greatly affect the amount of nocturnal gas exchange and the related consequences. When temperatures are low (especially at night), the vapour concentration in the internal parts of CAM is lower which results in leads efficiency in the utilization of the water. Therefore, this make the CAM species the most adaptable species in desert like areas and can be suitable in the semi-arid and arid areas. Essentiality of the stomata diurnal closure and nocturnal opening in CAM species as a way to conserve water should therefore be exploited maximally more so in the current changes in the climatic conditions due to global warming.

Opuntia plants have also an advantage of easily growing and regenerating apart from them being CAM species. These plants can be grown easily in regions where the precipitation process is unreliable and inadequate as they sink carbon. Similarly, they grow in areas where the evaporation process is much higher for normal plants and the amount of rain insufficient to support plant growth (Nefzaoui et al., 2011, 2014; Osmond et al., 2008). For the C3 and the C4 plants, it has been recorded that when they lose more than 30% of the water content they undergo a damage in the tissues that can not be repaired. With Cacti species their tolerance level to water losses is high and many have been seen to remain viable after even losing more than 80-90% of the water content in their tissues (Nobel, 1994).

The reason for their tolerance is the ability of the cacti plants to reserve more water in their succulent tissues and allocation of the water to different cells depending on the stress available and concentrating on the essential metabolic process for survival with the ability to tolerate higher dehydration rate (Nefzaoui & El Mourid, 2010; Nobel, 2009). Some of other properties cactus species that make them adaptable to the drylands include daytime stomatal closing, presence of mucilage and the cuticles are thicker which aid in water retention reducing the loss of water. Moreover, Cacti species remain viable even in extreme conditions because of its asynchronous development nature in some of its organs. Cacti have been seen to grow in

extreme areas where rainfall is insufficient, and temperatures are extremely high during the day and low during the nights. Different studies (Han & Felker, 1997; Hartzell et al., 2015, 2018; Nobel, 2009) have reported that the tolerance of many Cacti (*Opuntia ficus indica*) species on high temperatures is amazing and can withstand upto 60-70° C, which many other plant species cannot survive.

2.8.4 Cactus species as Fodder for a Changing Climate

Cacti are exceptionally tolerant to extreme drought having Crassulacean acid metabolism (CAM), a significant benefit for dryland agriculture. Cactus species can be classified into two types viz the spiny and the spineless (*Opuntia ficus indica*). There are some challenges associated with the spiny types where they can damage the alimentary system of the livestock feeding on them. Other reports in Kenya (Laikipia and Nyeri (North) counties, Cactus has been reported to kill livestock and children (Githae, 2018). The spiny type of cactus therefore requires to be scrapped or be burned before being used as feed for the animals. Generally, Cactus species have low fibre (16-17%) and protein content (4-5%) and has to be supplemented with rich source of fibre and nitrogen in order to enhance animal performance (Nefzaoui & Ben Salem, 2001). However, fertilization with organic or inorganic fertilizers has been shown to improve its crude protein content (Ochoa et al., 2014; Osmond et al., 2008).

Cactus, being a Crassulacean Acid Metabolism (CAM) plant, its potential as the source of forage in large amount for all livestock can not be underestimated especially in the arid and semi-arid (Ochoa et al., 2014). In other countries of Africa such as in Tunisia, spineless Cactus yields 20t/ha/year of fresh cladodes as reported in areas with 150mm/year rainfall and 100t/year in areas with 400mm/year of rainfall under rain-fed conditions (Nefzaoui & Ben Salem, 2001; Samah et al., 2015). Spineless cactus has a capability to carry more DM as compared to other types of forages found in the dry lands. They are always greener and succulent during the dry seasons and therefore, a good source of alternative nutrients such as water, energy and vitamin for livestock in the extreme drought seasons.

Reports by Zemon (2015) found out that Cactus has ability of withstanding severe defoliation, keep more water in the succulent tissues and can easily regenerate. Cactus maintenance cost is manageable, cheaper and easier to establish. Due to its anatomy and physiology, Cacti species perform well in various climatic conditions, extremities and in different ranges of soil types (Azocar, 2001; FAO, 2017). With all these properties, it is essential for the pastoral communities to embrace cacti in the feed system putting in mind that it also aids in the process

of conserving soils, and enhancing the rehabilitation of desert lands (Ben Salem Salem, 1996; Ben Salem et al., 2010; Monteiro et al., 2014; Ochoa et al., 2014).

Cactus utilizes the concept of tolerance to drought together with the water use efficiency (WUE) to make forage in large amount that is green, succulent and with higher dry matter in the drought season (Abidi et al., 2009). Cactus species is also cheap to maintain and hence the best animal feed to be invested in all harsh climatic conditions (Delgado et al., 1999, 2008; Nefzaoui & Ben Salem, 2001). Research findings by Mganga et al. (2013) authenticated the fact that drought tolerant plant species can be a solution in forming part of 'Famine Feed Banks' for successful livestock production programmes for small-scale and subsistence farmers in semi-arid and arid lands. This in turn can aid in mitigating against the prevailing chronic feed scarcity aggravated by the recurring frequent floods and droughts due to climate change. In increasing and stabilizing fodder reserves, drought resistant forages such as Cactus species have been shown to effectively mitigate against the effects of drought on resource-constrained livestock keepers in West Asia and North Africa (WANA) regions and reduce the risks faced by these farmers which are attributed to climate change (Ben Salem et al., 1996; Reynolds & Arias, 2001).

There are various benefits both to livestock and to men that can be accrued from Cactus. For instance, Cactus species can survive harsh climatic conditions and in areas where there is limited rainfall. They grow in areas where other plants or crops cannot thrive. In developing countries such as Ethiopia, most of the fodders and other livestock feeds are provided mostly by the Cactus plantations and at the same time acting in the environmental conservation. The plant contains up to 90% water when fresh, and research has shown that, when fed to livestock, water requirements for livestock can be reduced by 40 to 100% in arid and semi-arid regions (New Agriculturalist, 2008).

The Cactus plant (*Opuntia ficus indica*) is grow freely in most parts of the Kenyan arid and semi arid areas. Abidi et al. (2009) indicated that the tolerance of some of cacti species to extreme environmental conditions is attributed to their anatomical and physiological characteristics that aid them to adapt. The anatomical flat oval shape of the stem, referred to as cladodes remain green and succulent throughout the year and contain about 90% moisture. As an excellent livestock feed, Cactus not only produces large tonnages of green forage throughout the year if agronomically is well managed, but also can be a good source of vitamins, energy and water that is deficient in dry seasons (FAO, 2017).

Nefzaoui and Ben Salem (2001) in their research work found out that Cactus (*Opuntia ficus indica*) had low fibre (16-17%) and protein (4-5%) content and therefore, they recommended a need for biofortification with other sources that are rich in nitrogen and fiber for better nutritional value. According to Dubeux (2016), one to three years old Cactus cladodes contain higher amount of water in winter and spring (85 percent -90 percent), implying a dry matter (DM) of 10-15%), low in CP (3-5%), ash content ranging from 10-25%, Calcium (2.9-4.2%) and Phosphorus (0.3-0.4%). Cactus cladodes are high in carbohydrates (approximately 60%, starch levels of approximately 7.5% and β -carotene of approximately 6.5 mg kg⁻¹ DM (Vásquez et al., 2011; Zemon, 2015). With their succulence, Cactus cladodes contain lower amount of fiber (NDF) ranging from 18-20%, Lignocellulose (acid detergent fibre (ADF) 12-20% and lignin (ADL) 1.5-4%.

Cactus, though having a great potential of fodder production, it remains under-utilized as a result of inadequate information on how it can be utilized as a source of excellent fodder and other uses in many of the East African countries, with Kenya included (Kang'ara, 2009). In Baringo, Laikipia and Nyeri (Northern region) counties, the communities in these regions regard Cactus as a weed and noxious plant (Kang'ara, 2009). Therefore, information on their fodder potential need to be collated and disseminated to pastoralists and other stakeholders in order to promote and exploit Cactus as livestock feed. According to Kang'ara (2009), it can be concluded that utilization of Cactus in the drought encroached areas as the main source of fodder offer the great opportunities in the areas with unpredictable climatic conditions. In Kenya all the species of cactus constituting the spineless and the spiny are found and grow well. With this potential and availability of the cactus in the Kenyan arid and semi-arid areas, it calls for researches in understanding the different species and varieties of cactus present in Kenya and creation of their databases. Determination of their agronomical needs and more understanding on their effect on the livestock when used as feed for the different varieties need to be considered.

With the available literature, the use of cactus as animal feed is highly recommended especially in the marginalized areas, arid and semi-arid areas. Usage of large quantities of spineless species as the main feed source should be encouraged, as they have reduced so much and are posing extinction risks in the coming days. The need to conserve and preserve cactus species both *in situ* and *ex situ* is of essence for further studies and future utilization of the same. Joined efforts between different government ministries, parastatals and NGOs for instance the

ministries of Livestock, Agriculture and fisheries, Rehabilitation of Arid Lands (RAE) and Universities is required to promote, develop and and in commercialization of Cactus species in livestock feed production (Kangara, 2009).

2.8.5 Environmental Role of Cactus (*Opuntia ficus indica*) Invasion in Soil and Water Conservation

The rangelands work as a multi-functional system and cactus can play an important role in these rangeland ecosystems. The biomass that is above the ground does sequestration of carbon present in the atmosphere sinking it in the soils directly. Invaders such as Cactus (*Opuntia ficus indica*) have been reported to have positive effects on arid- and semi-arid ecosystems, as they increased soil organic matter and soil N with subsequent increase in soil carbon sequestration (Han & Felker, 1997; Walther et al., 2002). Some of the positive factors attributed by the *Opuntia species* invasion include the carbon sequestering characteristics, soil coverage property and OM sequestration. Looking at the vegetation growth in most of the arid and semi-arid areas, it is scarce and therefore making those regions vulnerable and fragile to problems associated with soil erosion, heavy winds and occasional floods.

Despite the severity of extreme climatic conditions in the desert-like areas, drought resistant vegetation such as Cactus species (*O. ficus indica*) play crucial role in the mitigation and regulation of water losses and catchment in the areas (Vasquez et al., 2011). Susceptibility of the soils found in desert-like areas include low organic matter, erosion of soils, and low water holding capacity. All this are as result of scarcity in vegetation and the crops in the arid and semi-arid areas (Cornelis, 2006; Doran, 2002). In such scenerios, Cactus pear (*Opuntia species*) buffers the effect of erosion by controlling it in arid and semi-arid regions as it grows quickly and has small roots that regrow each year from the main root during rainy seasons. In dry periods, the small roots die, adding organic matter to the soil. With an increased organic matter content, it is easier for the soil to absorb rain water. Cactus (*Opuntia spp*) have been used in environmental conservation as they are excellent in controlling soil erosion processes and aid in the reduction of the desertification process (Nefzaoui et al., 2011).

Cactus adapt easily to any changes in the climatic conditions, and they can grow in soils with low fertility and have tolerance to increased carbon dioxide levels. It is an essential cover crop in most of the desert-like regions and its utilization can be immense as a livestock feed especially in the sense that it easily grows and adapt well to the arid conditions (Reynolds & Arias, 2001). Taking example of Algeria and Tunisia, marginalized lands rehabilitation

processes have been embraced and cactus is the main crop grown in contours (Nefzaoui et al., 2011).

2.8.6 Ecosystem Goods and Services Provided by Cactus (*Opuntia ficus indica*) species

According to FAO-ICARDA-ISHS (2017), cultivation of Cactus (*Opuntia ficus indica*) has been done for many years purposing to improve rangeland in North Africa. Further research findings indicated that soil erosion can be controlled by cactus mostly when used in contour planting (Dubeux, 2016). This is supported by previous research findings by Mustafa et al. (2017) which proved that water and soil conservation processes are much efficient when cactus agroforestry is used in the affected areas. Some of the advantages of cactus (*Opuntia species*) in the ecosystem include; conservation of the biodiversity, water and soil erosion prevention, and increased moisture that promote growth of other vegetation and micro-biome development (macro-environment development).

Also, the cactus vegetation provides habitat for some of the world animals in the arid and the semi arid areas, aid in the sequestering of carbon and also promotes the beauty and anaesthetic value of the desert-like regions (FAO-ICARDA, 2017). According to FAO-ICARDA-ISHS (2017), pragmatic approaches are required to combine socio-economic factors, farming and conservation of the environment using Cactus in the ASALs, a real possible solution to predicaments in the arid areas. Apart from usage of Cactus fruits and the cladodes as livestock feed, *Opuntia species* have a number of other uses as medicinal, nutraceutical and food industry applications (FAO-ICARDA-ISHS, 2017; FAO-ICARDA, 2017). For instance, fresh Cactus cladodes and its fruits have been used in Mexico for its nutritional and healing properties (FAO-ICARDA, 2017). Further reports by FAO-ICARDA-ISHS (2017) indicated that the Cactus species (*O. ficus-indica*) fruits, flowers and cladodes contain medicinal value and have used for in different countries to cure different diseases.

Cactus fruits contain antioxidants such betalin and flavonoids and are also excellent sources of different nutrients such as carbohydrates and vitamins. Similarly, the flowers are also good sources of betalins and flavonoids. Some of these compounds in the flowers and the fruit (betalin) have a potential to be used as food additives in different products. On the the other hand, the cladodes have chlorophyll pigments and mucilage, and the cactus seed can be used for oil extraction. The oil contains more of the unsaturated fatty acids composed of the phytosterols and the linoleic acid (FAO-ICARDA, 2017). Cladodes have antiviral and anti-

ulcer potential, and they prevent problems associated with anti-inflammatory activities and offers protection against gastric lesion (FAO-ICARDA-ISHS, 2017).

Use of Cactus extracts from fruits as supplements in different foods exhibit healthy properties by reducing the oxidative stresses and increasing the antioxidant capacity of the food. The fruits reduce and prevent cancer-causing agent especially the cervical, bladder and the ovarian cancer. Inclusion of cladodes from young Cactus in daily human food has shown to reduce the triglyceride and cholesterol levels in the the blood. The same cladodes have a positive effect on patients with diabetes that does not depend on insulin production (mellitus) causing the hypoglycemic effect. Further reports documentation by FAO-ICARDA-ISHS (2017) indicated that blood glucose and obesity is also reduced by cladodes from the young cadodes.

Infusions made from cactus flowers also play important role in the prevention of the prostate related cancers. They also have depurative and diuretic effect which aids in the process exclusion of kidney stones in the kidney. Additionally, the cactus seeds contain a lot of phytosterls, tocopherols and the unsaturated fatty acids for instance linoleic acids. Cladodes posses wound curing properties together with the extracted oils (FAO-ICARDA, 2017). Marmalades, syrups, Juices, liquors and candies extactions from the fruits of the cactus also provide and avenue for food and product development (FAO, 2017). According to FAO-ICARDA-ISHS (2017), many products derived from Cactus (*Opuntia ficus indica*) such as nutraceuticals, cosmetics, feed and food products can be found readily in shops and markets across the world. Cactus flowers, seed oils and pads can be utilized in the processes of soap production, cosmetics and the shampoos.

The oil from the seeds has also been used in various cosmetics products for anti-aging properties ans anti-wrinkles. A mixture of livestock manure and the cladodes can be an excellent source of biogas which is environmentally friendly. Some of the insects that lives in the cactus for instance the cochineal insects are a good source of food colours (carminic acid), fabric, cosmetics and drugs. If cactus is given an appropriate concentration, it is a source industrial development in rural areas and offers opportunity for industrial growth and manufacture in production of value-added products that have higher demand in the world market (FAO-ICARDA-ISHS, 2017).

2.8.7 Description, Origin and Distribution of *Prosopis juliflora* species in Kenya

Prosopis juliflora is classified under the family Fabaceae (Leguminosae), subfamily Mimosoideae and genus *Prosopis*. It is a well-adopted shrub to harsh environmental conditions of many arid zones. *Prosopis juliflora* originated from South America, the Caribbean, and Central America. The species is distributed in the lowlands of Americas, Africa and Asia (Damasceno et al., 2018). *Prosopis juliflora* is known in Kenya by its Swahili name, “*Mathenge*”, or more popularly as Mesquite, which is a general term used for many of the 44 species belonging to the genus *Prosopis*. All *Prosopis species* are part of the family Fabaceae, also called Leguminosae (Harding & Bate, 1991). It has multiple stems which tend to grow in a jagged fashion, with thick thorns that can reach up to 5 cm length. The bark is grey-green in colour and becomes rougher and scallier with maturity.

An additional adaptation that allows *Prosopis juliflora* to quickly invade and dominate an ecosystem is the ability to release allelochemicals from its roots, leaves and fruits (Pasiiecznik et al., 2001). Allelochemicals are substances produced by organisms to react to abiotic and biotic factors in their environment. This in turn allows *Prosopis juliflora* to inhibit seed germination or growth of surrounding plants, while it is unaffected by other plants allelochemicals (Damasceno et al., 2018).

Today, *Prosopis juliflora* is invasive in many countries away from its original distribution areas in Mexico and North and Central South America. *Prosopis juliflora* has already spread throughout the arid and semi-arid regions of North, West, East and Southern Africa, the West of the Arabian peninsula, South East Asia, South West Australia, Southern USA and the South of Brazil and Uruguay (Maundu et al., 2009). In the year 2014, *Prosopis juliflora* was documented in 129 countries (Shackleton et al., 2014). In Kenya, the rapid spread began in the regions of the first large-scale plantations in Baringo County, Bura (Taita-Taveta County) and Turkana County where the dense thickets are found today (Kyuma, 2013; Maundu et al., 2009). Generally, the Kenyan drylands and arid regions have been documented to have the largest infestations.

In Kenya, the largest infestations are found in the Eastern and North Eastern counties, as well as in the Rift Valley and Coastal regions. In drier areas, *Prosopis juliflora* benefits from lakes (Lake Baringo), river systems (Tana and Turkwel) and seasonally flooded areas like the Lotikipi plains and disturbed areas such as farms and urban areas (Maundu et al., 2009). The rivers Turkwel and Tana, including Tana River Primate National Reserve and Arawale

National Reserve, and the Lotikipi plains are particularly sensitive ecosystems that are now threatened by *Prosopis juliflora*. The plains which form an important grazing area for the local Turkana people are now at risk of *Prosopis juliflora* infestation. Other conservation areas affected include the Lake Bogoria National Reserve, Shaba National Reserve, Samburu National Reserve and Marsabit National Reserve as well as Mount Kulal Biosphere Reserve and the Tsavo National Parks (Maundu et al., 2009).

2.8.8 Environmental Role of *Prosopis juliflora* in Sustainable Soil and Water Conservation

Regaining of a certain area in terms of ecosystem and biodiversity, restoring of the degraded and the marginal land is essential and this aids in the achievement of the UN-Sustainable Development Goals (UN-SDGs). Introduction of the fast-growing trees, has been done in many of the countries globally for the past few decades to ensure that land and degraded ecosystem are restored and marginal lands regain stability for more production in terms of agriculture (Sheikh et al., 2020). Degraded lands are less productive and many terms are used to describe these lands such as contaminated lands, abandoned lands, degraded lands, marginal lands and/or wastelands. Sustainable management of the land resources is therefore an important aspect of environmental sustainability. Much work has been done globally aimed at assessing the effects of *Prosopis juliflora* on the abundance composition, and activity of soil microbial and pathogenic communities, and their effects on soil and beneficiary plant species (Wakshum, 2019).

Prosopis juliflora is one of the most economically and ecologically important tree species in arid and semi-arid zones of the world. It is an important species because of its high nitrogen-fixing potential in very dry areas and drought seasons (Mosbah et al., 2017). Moreover, *P. juliflora* is effective in increasing the total mycorrhizal colonization of roots and reducing heavy metals such as Cadmium (Cd) levels in plants. This is affected by coir pith that is a byproduct of the coir industry and *P. juliflora* charcoal prepared by burning *P. juliflora* plant wood (Senthilkumar et al., 2015).

Prosopis juliflora is a salt and drought tolerant tree/shrub species. According to Dave and Bhandari (2013), it is an excellent Nitrogen-fixing plant, with deep-reaching roots and tolerates dry as well as waterlogged soils. *Prosopis juliflora* is found in areas where water and poor soil fertility are the principal agents limiting plant growth and can survive and even flourish on some of the poorest land, unsuitable for any other tree species (Wakshum, 2019).

Preliminary analysis of the soils under *P. juliflora* canopy revealed that the areas that had higher infestation were having high means in terms of soil moisture content ($10.5 \pm 1.35\%$) and mean pH value approximating to 8.7 ± 1.03 . While the means for the areas that were lowly infested had a pH of approximately 9.4 (Shitanda et al., 2013). *Prosopis juliflora* has been reported to have positive effects on soils, where significant reduction in terms of salinity and alkalinity has been reported in the areas underneath the canopies of this plant (Senthilkumar et al., 2015). Shitanda et al. (2013) also reported lower soil pH and sodium levels under the *Prosopis juliflora* canopies in comparison with the regions that were open. Areas that were occupied by the canopies had amelioration effect in which additional micro and macro elements are present in the area. A lot of minerals were seen from soil samples taken under the canopies and some of the elements present include Potassium, Magnesium macro elements. Iron, Manganese and Copper were the recorded micro-elements important for normal growth of the plants. The *P. juliflora* leaves contributes to high levels of organic matter under their canopy.

Additionally, *P. juliflora* trees aid in the process of nitrogen fixation and contributes to the increased amount of nitrogen in the soils in areas where they have grown (Shitanda et al., 2013). High levels of macro and trace elements underneath the *P. juliflora* infested areas have increased biomass from the decomposing leaves that fall on the ground and are also associated with an increase in leaf litter deposition and the plants mycorrhizal associated with the soil.

According to Pasiacknic et al. (2001), the large quantities of leaves shed annually are a potential source of nutrients in the soils under the *P. juliflora* canopies. This micro and macro-elements in the soil aid in improving the the chemical and the physical properties of the soils in these areas. Increased biomass in the soils highly influences the processes of controlling rain water run-off and the rate of water infiltration, and hence reduction in erosion of soils (Shitanda et al., 2013). There is increased humidity to the ground and the area covered by the canopy, the thickets acting as wind breakers reducing soil erosion, evapo-transpiration reduction and creation of a micro-climatic conditions. The micro-climate conditions created is essential for growth and survival of fauna and flora. *Prosopis juliflora* plant has been shown to affect the soil structure and both the macro and micro-mineral nutrients, therefore, enhancing the environmental characteristics. Furthermore, the plant affects the nitrogen, organic carbon and the calcium-related minerals in their canopies.

2.8.9 Pastoralists' Experiences with *Prosopis juliflora* in Kenya

Prosopis juliflora was introduced in Kenya by the joint effort of the Kenya Forest Research Institute (KEFRI), the Government of the People of Finland and the National Irrigations board of Kenya in the late 1970's (GoK, 2013; MoA, 2007). Global concern about deforestation caused by fuelwood shortages, prompted introduction of *Prosopis juliflora* to drylands of Baringo, Tana River and Turkana Counties (MoA, 2007). *Prosopis juliflora* is in the International Union for Conservation of Nature (IUCN) new list of the top 100 world's worst invasive alien species. Unlike some other parts of the world where it has been introduced, *Prosopis juliflora* potential benefits have not been tapped in Kenya. Sustainable utilization is therefore required in the development of new commercial low-cost livestock feed supplements.

Additionally, *Prosopis juliflora* problem has stirred different reactions from the habitats of Baringo County, indicating that the plant is responsible for livestock teeth decay and dysfunction, leading to starvation and death (Kyuma, 2013). A lot of concerns have been raised about elimination of the *Prosopis juliflora* aimed at reducing the spread of the the species and be replaced with other crops that are more desirable. Research findings by Kyuma (2013) indicated that *Prosopis juliflora* is a good source of low-cost livestock feed for pastoral communities living in dry lands, only if there is expanded utilization and knowledge on how they can be utilized. Livestock feeding trials in India where they used rations having about 45% of *Prosopis juliflora* produced acceptable cattle live weight gains of 1.5 kg per day (Tewari et al., 2000).

Other literature from Peru indicated that utilization of *Prosopis juliflora* pods can be a great income source, that can amount to almost US\$ 50 daily and 150 kgs per individual daily (Kyuma, 2013). Previous research results from Khobondo et al. (2019) depicted that addition of pods of *Prosopis juliflora* in in layers' diets at the level of 10%, increased weight gain and significant egg production ($p < 0.05$) without affecting egg production and weight gain. This was supported by King'ori et al. (2011) who indicated that *Prosopis juliflora* pods can be included at levels of upto 10% in layer diets without affecting egg production and weight gain.

Research findings by Kyuma (2013) indicated that the average chemical composition of *Prosopis juliflora* pods is comparable to other commercial concentrates available in the market like the dairy meal. The reported nutrient composition of *Prosopis juliflora* pods is as follows; dry matter (88%), crude protein (28%), and ash (5%), neutral detergent fibre (51% and acid detergent fibre (29%) (Choge et al., 2002; Koech et al., 2011). However, despite the good

profile of principle nutrients such the high crude protein, twigs, leaves and pods of *P. juliflora* contain high levels of anti-nutritinal factors (condensed tannins and alkaloids) which make these feeds lethal to rumen microflora and annihilated fermentation (Damasceno et al., 2018).

Harding and Bate (1991) reported that in the presence of enough rainfall *Prosopis juliflora* colonizes at a high rate three times more than when there is inadequate rain. When the arid and semi-arid areas are flooded with rains the *Prosopis juliflora* form thick thickets that are impenetratable like then ones experienced in Kenyan desert-like areas (Aboud et al., 2005, 2012). In other areas such as Baringo, those staying their have claimed and asked for compensation for the invasion and introduction of the *Prosopis juliflora* species that have occupied most of their productive land and replaced most of feed crops, as they see it as a noxious weed plant. Due to the overhead cost involved in the the eradacation process of *Prosopis juliflora*, it cannot be the best solution to be taken. With this challenge, there is a need for construction of *Prosopis juliflora*-based small scale feed industries in the region that would offer a candidate solution for the utilization of the noxious weeds as feed and as an income generating avenue (Pasiiecznik et al., 2001). *Prosopis juliflora* seeds are un-digested by the livestock, and therefore, this makes them to easily grow in the drylands, as these conditions favour germination process. Therefore, mitigation menasures and efforts put across to manage the weed can be a big enhancement and relief for those living in these affected areas.

2.9 Knowledge Gaps

Supply of adequate quantity and quality of feed for livestock is a major challenge throughout the world (Koech et al., 2011; Nefzaoui et al., 2013) This constraint of feed supply has led to low livestock productivity in most developing Countries, including Kenya. However, *Prosopis juliflora* has been reported to supply a cheaper feed supplement for livestock in the arid and semi-arid lands of Kenya as compared to the commercial concentrates (Koech et al., 2011). *Prosopis juliflora* has potential to provide emergency forage feeds for livestock in pastoral communities in dry lands if knowledge on its utilization is expanded (Tewari et al., 2009). Livestock feeding trials in India that used feed rations with upto 45% of *Prosopis juliflora* gave acceptable cattle live weight gains of 1.5 kg per day (Tewari et al., 2000). Some of the sources of income include collecting of the *Prosopis species* pods that can bring earnings of about US\$ 50 daily, with about 150kgs being collected by each individual on daily basis (Tewari et al., 2009).

On the other hand, both spiny and spineless Cactus (*Opuntia ficus indica*) generate a high biomass of green forage ranging from 30 to 250 tons/ha in semi-arid areas that can sustain livestock through the driest seasons (Nefzaoui & Mourid, 2009). Previous research findings by Nefzaoui et al. (2013) indicated that *Cactus species* have the capability to lower the need for other conventional high energy feeds such as maize and barley. Unlike the conventional crops, if cactus is consumed excessively, they do not cause acidosis as they contain high mucilage levels that aid in the salivation reducing the effect of pH reduction in ruminants. *Cactus species* will not cause acidosis in ruminants as a result of high levels of mucilage, which enhance salivation and avoid serious decreases in pH (Dubeux, 2016; Nefzaoui et al., 2013). Dried Cactus cladodes have been reported to partially replace maize germ in a feeding trial for weaner lambs (Ben Salem & Louhaichi, 2014).

According to Ben Salem et al. (2004), the consumption of Cactus (*Opuntia ficus indica*) cladodes increases the amount of omega 3 (CLA) in lambs and kids' meat, a factor of high importance and meets the ultimate goal of human health concern. On the other hand, lambs fed on straw supplemented with spineless Cactus (*Opuntia ficus indica*) and saltbush (*Atriplex numularia*) grew at a rate of 80g per day, comparable to conventional feed resources such as Lucerne hay (FAO-ICARDA, 2017; FAO-ICARDA-ISHS, 2017). The potential of Cactus as a feed in semi-arid areas is under-utilized. To enhance Cactus utilization as animal feed in Kenya, it is imperative to disseminate knowledge on multi-functionality of this crop as supplementary feed for livestock in dryland areas, and develop it as a sustainable crop in the wake of climate change.

However, despite the potential of *Prosopis juliflora* and cactus (*Opuntia ficus indica*) as livestock feed, problems associated with these trees have arisen different reactions among the rural inhabitants of Baringo, Laikipia and Nyeri counties. The rural communities in these counties have been requesting for external support to eliminate these crops for killing their animals (Choge et al., 2002; Githae, 2018). For instance, the local communities in Baringo sued the Government for introducing *Prosopis juliflora* in the country, which was responsible for uprooting their goats' teeth, with subsequent death due to starvation (Choge et al., 2002). Furthermore, the spiny Cactus (*Opuntia ficus indica*) issue in Laikipia County and Nyeri (North) has been reported as a killer of livestock in the County (Kangara, 2009). However, residents in Nyeri County (Northern region) had a good report of feeding spineless (*Opuntia*

ficus indica) Cactus to livestock, with observed increase in milk yields of upto 40,000 litres per month in Nyala Dairy Cooperatives (Kangara & Gitari, 2010).

The current study conducted demand-driven research to authenticate the importance of the two invasive tree species Cactus (*Opuntia ficus indica*) and *Prosopis juliflora*, and generate a data that can be used to inform the local communities and the policy about the usefulness of these trees currently regarded as noxious weeds. The generated data will advocate for conservation and controlling the invasiveness of these tree species by management and utilization, and not by destructive eradication. Therefore, the current study assessed the vulnerability, constraints to livestock production systems as impacted by climatic changes and the local coping strategies, and the level of adoption improved climatic changes adaptation technologies. Data documented in this study can be used to inform the farmers and policy makers to make more sustainable, strategic and efficient use of a natural resources that are under-utilized and taken for granted, such as Cactus and *Prosopis juliflora*. Considering this utilization, there will be an improvement in the livelihoods, Nutrition and food security for marginalized people living in rangelands.

2.10 Conceptual Framework

This study was based on a framework that considers crop and livestock raising as one of the most climate-sensitive economic activity. Resource-constrained rural communities have been realized to be vulnerable to the impacts of climatic changes as they have low endowment of resources, knowledge, extension services and technology development and adoption. The hypotheses tested revolved around the premise that livestock production coping strategies in dry areas with considerable climatic risks is a function of socio-economic, socio-cultural as well as demographic factors. Changes in the nutritional qualitative content of the Cactus (*Opuntia ficus indica*) and *Prosopis juliflora* are theoritcal seen to be associated with the physiological conditions, phonological stages and the anatomical charactersitics of the species or the plants studied.

The quality and availability of feed resources have a direct impact on livestock productivity, which is the main livelihood support system in marginal areas. In order to inform the policy on locally available and cost-effective options for adapting livestock systems to climate change, there is need for assessing the vulnerabilities of the rural communities to climate change risks as bench marks, and test options available for adapation and mitigation of climate change impacts in livestock production systems. The ability to use improved climate change adaptation

strategies would be limited by different factors including literacy level, gender, available extension services and the age of the pastoralists/nomads. The importance of scientifically improved adaptation mechanisms can not be of importance if the the affected individuals in the dryland can not utilize it or their views about the mechanism is not taken into consideration. The available options will include adoption of improved feed crop varieties, fodder conservation, improved livestock species, water harvesting and manure management, among others as implicated in the conceptual framework (Fig. 2.1). Identification of the mentioned options will aid in the process of understanding different pragmatic phenomenon that can be used by the farmers to adapt to different climatic changes and most applicable strategies.

For the process of enhancing agricultural productivity, the farmers might need to have easy accesbilty and effective usage of improved climatic change adaptation strategies through identification, solving and reducing issues that realy affect the utilization and accessibility of these strategies. The process can apply factors such as demographic charactersitics, socio-economic and local coping strategies that could positively affect the utilization of improved livestock adaptation strategies to enhance their adaptive capacity to climate change phenomenon. These risks include natural disasters such as droughts, floods, heat waves, and soil salinity. As depicted by the conceptual framework, the study is anchored on the concept that the utilization and access of improved livestock adaptation strategies is influenced by a number of psychological, socioeconomic and demographicfactors of the pastoral individuals. Figure 2.1 indicates variables hypothesized to influence livelihood resilience to climatic changes among pastoral and agro-pastoral farmers in the study areas.

Reports by ILRI (2015) indicated that one of the most important effects of climate change on livestock production is mediated through variation in quality and quantity of feed resources. This results in lose of livestock, leading to chronic poverty in pastoral systems. However, the pastoral communities have evolved indigenou traditional knowledge as a way of coping with climate variability aimed at saving their livelihood resources. These local mechanisms need to be building upon and/or mainstreamed into the scientifically proven technologies developed for mitigating climate change negative impacts on livelihood resources (Fig. 2.1). Interactions between climate change negative impacts and adoption of improved technologies to mitigate these negative impacts will enhance pastoral communities' adaptive capacity and resilience to climate change-related impacts, thus leading to food security and poverty eradication in dry land ecosystems (Fig. 2.1).

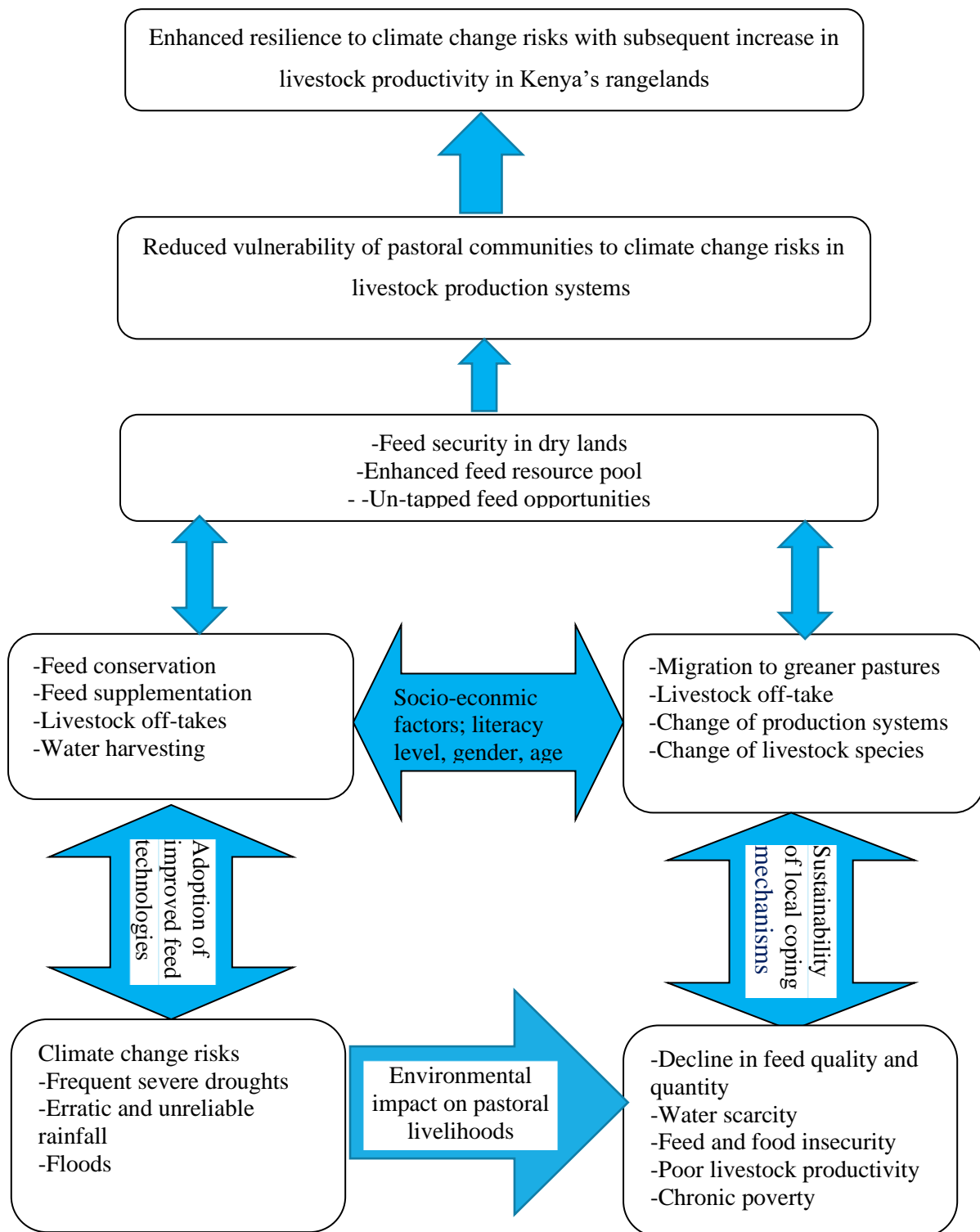


Figure 2.1: Conceptual Framework

CHAPTER THREE

METHODOLOGY

3.1 Baseline Survey Sites

The study sites were located in Baringo, Laikipia and Nyeri counties. The study areas were purposefully chosen because they were largely pastoral and agro-pastoral counties with large areas covered by the invasive *Prosopis juliflora* and spiny and spineless Cactus (*Opuntia ficus indica*). These invasive tree species had elicited many problems between the local communities and the Government of Kenya, who demanded their eradication and compensation of their animals that had died from consuming the plants (Appendix 9; Choge et al., 2002; Githae, 2018). Nyeri County (Northern region bordering Laikipia County) is semi-arid and is infested by extensive colonization of spiny Cactus (*Opuntia ficus indica*) which had also faced many complains from the rural communities who claimed that livestock and children suffered lethal effects by interacting with *Opuntia ficus indica*. (Appendix 9; Githae, 2018).

The study sites were purposefully selected as study areas mainly to address issues of the potential utility of *Prosopis juliflora* and Cactus (*Opuntia ficus indica*) as invasive tree species through innovative feed technology development for sustainable livestock production in the ASALs. The vulnerability of the pastoral and agro-pastoral systems to changes in the climatic condition and the associated risks in the study sites were assessed to ascertain their status, with respect to the readily available invasive tree species' sustainable exploitation.

3.1.1 Baringo County Study Site

Baringo County is situated in the dryland areas (ASALs) of Kenya. Although some areas of Baringo County are of good agricultural potential, greater part of it is located in Agro-ecological Zone IV and V (GoK, 2015). The region has temperatures having a range of 10°C to 35°C both for minimum and maximum respectively experienced across the County. Mean rainfall in Baringo County is approximated to 1,500mm with a mean minimum of 600 mm per annum in the lowlands (FAO, 1996). It covers an area of 11,015 Km², with population density of 50 people per Km², and approximately 110,649 households. The soils in this region are volcanic rocks and alluvials (FAO, 1996, 2018).

Pastoralism land use systems are dominant, with irrigated agriculture around Perkerra irrigation scheme. Main livestock species found here are the local zebu (*Bos indica*), sahiwals and their

crosses and shoats. Low trees and shrubs found here include *Acacia mellifera*, *Acacia tortilis*, *Acacia horrida*, *Acacia reficiens*, *Acacia nubica*, *Acacia paslii*, *Acacia Zanzibarica*, *Acacia hockii*, *Adansonia digitata*, *Terminalia prunioides*, *Dobea spp.* *Dioppspyros spp.* and *Commiphora spp.* Massive *Prosopis juliflora* (Mathenge) and *Cactus species* (*Opuntia ficus indica*) colonization is also found in this County (Appendix 9; Githae, 2018; Kyuma, 2013). Common grasses are *Eragrostis superba*, *Cenchrus ciliaris*, *Cymbopogon spp.*, *Bothriochloa spp.* and *Heteropogon contortus*.

3.1.2 Laikipia County Study Site

This County borders Samburu County to the North, Isiolo County to the North East, Meru County to the East, Nyeri County to the South, Nyandarua County to the South West and Baringo County to the West. It is located in Agro-ecological zone IV, with an average maximum and a minimum annual rainfall of 750mm and 400mm respectively. The region has an annual mean minimum temperature of 16°C and maximum annual temperature of 26°C. The County has a population density of about 42 people per Km² and approximately 103,114 households. The soils are loam, sandy and red soils (FAO, 1996, 2018). It is the home of most *Acacia* trees and shrubs including *Acacia seyal*, *Acacia seneyal*, *Acacia brevispica*, *Acacia drepanolobium* and *Acacia gerrardii*. *Euphorbia* trees occur in some drier parts of this zone. *Cactus* colonization is a main problem in this County (Appendix 9; Githae, 2018).

Grasses found in this region include *Themeda triandra*, *Pennisetum mezianum*, *Pennisetum stramineum*, *Pennisetum massaiense*, *Eragrostis superba*, *Hyperenia spp.* *Setaria spp.*, *Digitaria milanjana*, *Bothriochloa insculpta*, and *Cenchrus ciliaris*. Other grasses include *Chloris roxburghiana* and *Cynodon spp.* Besides *Acacia spp.*, other important legume *spp.* includes *Indigoferra* and *Crotolaria spp.* Pastoralism is the principal land use system in this County. Main livestock species in this County are the local Zebus, shoats and some grade cows (Friesians and Ayshires) and their crosses around the foot of Mt. Kenya.

3.1.3 Nyeri County Study Site

Nyeri County is found in the central part of Kenya. Its neighboring counties include Meru in the North East, in Northern part is Laikipia, in the Eastern part in Kirinyaga, Western part in Nyandarua and on the Southern part is Murang'a County. It is in Agro-ecological Zone II and III, representing a high potential area, with Northern region that borders Laikipia County being semi-Arid (FAO, 2018). Temperatures range from a mean annual minimum of 12°C to a mean maximum of 27°C, with rainfall of mean minimum of 550mm and mean maximum of 1,500mm

per annum (FAO, 1996). It covers an area of 3,337.1 Km², with population density of about 208 people per Km² and about 201,703 households. Soils are mainly ferrasols and vertisols.

The main grasses are *Pennisetum clandestinum* (Kikuyu grass), *Themeda triandra* (Red oats), *Andropogon chrysostachyus*, *Andropogon pralonsia*, *Exothea abyssinica*, *Digitaria scalaram*, *Eragrostis lascantha*, *Setaria sphacelata*, *Pennisetum catabasis* and *Sporobolus filipes*. Large tracks of Cactus species (*Opuntia ficus indica*) colonization are found in the Northern region of Nyeri bordering Laikipia County (Githae, 2018; Kang'ara, 2010). The main legumes include *Medicago sativa* (Alfalfa or Lucerne), *Trifolium johnstonii*, *Sesbania sesban* and *Leucaena leucocephala*. Mixed crop-livestock systems are dominant in this county. Livestock species common in these regions are grade animals (*Bos taurus*) mainly Ayshires, Friesians and their crosses.

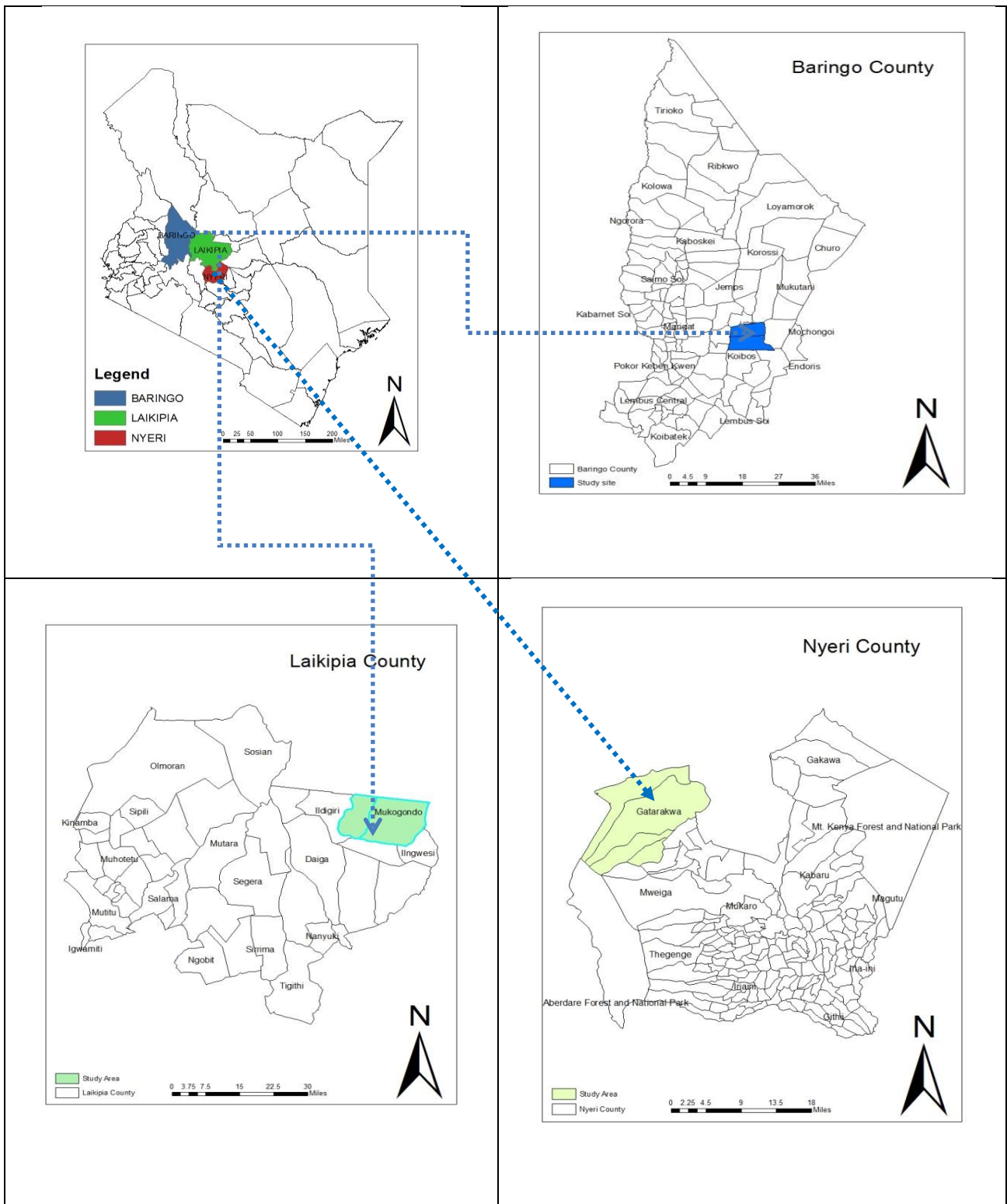


Figure 3.1: Map of Kenya showing the study locations (Loboi, Mukogondo and Gatarakwa in Baringo, Laikipia and Nyeri Counties respectively).

Source: Mwangi, P. (2014). Department of Land Resource Management and Agricultural Technology (LARMAT). University of Nairobi.

3.2 Research Instruments

The main tool employed in gathering information and opinions of the interviewees (pastoral and agro-pastoral communities) was a structured questionnaire. A checklist with important and key information on the practices done was applied to collect relevant information from the farmer groups and Government officials (extension officers). The baseline survey was carried out during the dry season between the month of January and March, 2014. The study followed a cross-sectional design, covering three Counties as representatives of pastoral and agro-pastoral system of livestock production namely; Baringo, Laikipia and Nyeri counties, and three sub-counties (Marigat, Mukongodo and Gatarakwa respectively). Pre-tested structured questionnaires were used to obtain quantitative (means and percentages) data from households, while key informant interviews were used to obtain in depth information about the study area.

Both quantitative (percentages and mean) and qualitative/non-numerical data (observations and dichotomous variations) was employed in an exploratory cross-sectional survey approach study. The major focus in this baseline study was to assess how pastoral and agro-pastoral livestock production systems were vulnerable to climate change risks, including the nature of coping strategies they employed to adjust to the adverse impacts of climate change in livestock production systems and the adoption level of improved climatic changes adaptation technologies. The generated information from the study was important and could be used to recommend for further research and/or advice policy on sustainable utilization of noxious invasive tree species such as *Prosopis juliflora* and *Cactus species (Opuntia ficus indica)*.

Nyala Dairy Cooperative in Nyandarua County was selected for questionnaire piloting, with about 15 dairy farmers as sample size that was determined following the method that was used by Mugenda and Mugenda (2003) that is used in sampling for a population size that is lower than 10,000. In the main questionnaire administration, a total of 317 households were interviewed (Baringo; 170 households, Laikipia; 82 households and Nyeri 65 households), out of which 252 households were pastoralists and 65 were agro-pastoralists.

3.3 Sampling Techniques and Sample Size Determination

The study used techniques of multi-stage sampling procedures. Purposive sampling was used in the initial stage in selecting Nyeri, Laikipia and Baringo counties in Kenya to represent the ASALs, and desert-like areas having unpredictable climatic conditions, frequent occurrence of droughts and no or little rainfalls. On the other hand, the rural communities in these regions

had put pressure on the government of Kenya to initiate eradication programs of *Opuntia ficus-indica* (Choge et al., 2002; MoA, 2007). Therefore, sustainability pathways were sought by this project to manage these invasive plants by utilization and not by eradication which would pose negative environmental impacts such as increase in greenhouse gasses (GHGs) emission. For stage two, similarly, purposive sampling was used in selecting of constituencies in the study regions namely; Nyeri North, Laikipia North and Baringo Central. At the third stage, one sub-county in each constituency was randomly selected and the following sub-counties were taken; Gataragwa, Mukogodo and Marigat using purposive sampling as a result of the area having unpredictable climatic changes and falling under the category of the ASALs with the agro-pastoral and the pastoral communities. There was random selection of different Wards in each of the selected sub-counties at the fourth stage and the wards included Lamuria ward in Gataragwa, Ilmotiok ward in Mukogodo and Loboï ward in Marigat. Ilmotiok and Loboï wards in Laikipia North and Baringo Central constituencies respectively practiced pastoral system of livestock production, with approximated 473 and 979 respondents (household heads) respectively, while Lamuria ward in Nyeri North constituency practiced agro-pastoralism with approximately 375 households (Kenya National Bureau of Statistics [KNBS], 2010).

Government documents and/or reports helped in the getting of the number of the respondents (households) in the three locations selected from the study counties (KNBS, 2010). All of the names in the obtained list of households were given a specific identification number for traceability. A sample size of 317 households was obtained by use of a formula described by Mugenda and Mugenda (2003) as follows;

$$n = \frac{Z^2 pq}{d^2} \dots\dots\dots i$$

Where:

P= the proportion in the target population estimated to have the desired characteristics being measured

Z= the standard normal deviate at the required confidence interval
n = the desired sample size
if the target population is greater than 10,000

d = the level of statistical significance

q= 1-p

The actual overall sample size interviewed in the three selected counties was 317 households. Sample size distribution per County was as follows; 170, 82 and 65 households for Baringo, Laikipia and Nyeri counties respectively. For such cases as the above, there was no pilot study that had been carried so far to determine the population proportions that had desired characteristics, such households with access and adopted climate smart strategies used for adaptability in the feeding and production of animal feeds for instance the fodder conservation process, fodder plant varieties and the improved varieties of pasture. In such scenario, 50 percent was suggested to be used as described by Mugenda and Mugenda (2003). The population that was targeted was the one that had accessibility and used improved adaptability strategies and it was taken to be 0.5 and the statistical level of significance of 0.05 was given leading to a z-value of 1.96.

Sample size for population greater than 10 000 was thus calculated as follows:

$$n = \frac{(1.96)^2(0.5)(0.5)}{(0.05)^2} = 384 \dots\dots\dots \text{ii}$$

From the study, since the population size of the selected areas was below 10 000, the formula suggested by Mugenda and Mugenda (2003) was applied as below;

$$n_f = \frac{n}{1 + n/N} \dots\dots\dots \text{iii}$$

Where; n_f = the desired sample size (when the population is less than 10,000)
 n = the desired sample size (when the population is more than 10,000)
 N = Total population in the three study counties

Total calculated sample size was $n_f = \frac{384}{1+384/1827} = 317 \dots\dots\dots \text{iv}$

Final sample size; Nyeri County: $375/1827 * 317 = 65$

Final sample size; Laikipia County: $473/1827 * 317 = 82$

Final sample size; Baringo County: $979/1827 * 317 = 170$

3.3.1. Method of Sampling

A systematic random sampling procedures were adopted in the study as described by Nassiuma and Mwangi (2004). This kind of sampling procedures was selected because it ensured that there was equity in the probability. It is also advantageous in the sense that each unit sample had equal chances of being selected as per the strata as compared to the simple random sampling which poses a challenge of missing out some areas (Nassiuma & Mwangi, 2004). The sampling method involved taking a sample from the population N , a sample size of n in a way that starting with a unit corresponding to a number r chosen at random from the numbers $1, 2, \dots, k$ every k^{th} unit is selected. The number k is taken as the nearest integer N/n and is called the random interval. The number r picked at random is called the random start. In the event that the selected household will not be available on the day of the interview, the next household on the list was used.

For Baringo County $k = 979/170 = 5$

For Nyeri County $k = 375/65 = 5$

For Laikipia County $k = 473/82 = 5$

In order to obtain the random number to commence with, random selection of numericals from 1 to 5 were selected randomly from a given container. For this research the number 4 was chosen as the start number and at getting the households, from the given list, every 5th number (HH) was selected from the list until a total of 82, 65 and 170 households were obtained from the list for Laikipia, Nyeri and Baringo counties respectively.

3.4 Data Collection on Climate Change Vulnerability to Livestock Systems

The interviews were aimed at collecting socio-economic data on aspects relating to climate change vulnerability and the local coping mechanisms in the targeted farming systems *viz*, demographic profiles of the respondents (gender, age and literacy levels) and socio-economic aspects (livestock asset ownership, adoption level of improved climatic changes adaptation technologies, gender, constraints to livestock production in relation to climate change risks, management of poor quality of feeds, local coping mechanisms to adjust to climate change risks, household mobility by gender, sources, access and utilization of agricultural information, agricultural related capacity building and membership to agricultural groups.

3.5 Baseline Survey Data Analysis

The questionnaire for socio-economic data on aspects relating to climate change vulnerability and the local coping mechanisms in the targeted farming systems was coded, tabulated and analyzed using Statistical Package for Social Sciences [SPSS], 2011) version 20.0. Computation of descriptive statistics (mean, percentages) was done to establish the level of responses. The coefficient of correlation was calculated to assess whether there was any relationship between demographic characteristics of the respondents and the adoption of improved climate change adaptation technologies. Chi-square method was applied to analyse the process of rejecting or not rejecting the null hypothesis at 0.05 level of significance for the categorical data (Correlation between demographic characteristics of respondents (age, gender and literacy levels) in the study areas and various improved climate change adaptation technologies in livestock production). The results of the analyses were presented using bar graphs mainly, and cross-tabulation tables.

3.6 On-farm Sampling of Forage Materials for Proximate Analysis

An investigation on the qualitative aspects of Cactus (*Opuntia ficus indica*) and *Prosopis juliflora* was done during the dry season (July and August, 2014). Different parts (ripe and unripe fruits, young and mature cladodes) of cactus (*Opuntia ficus indica*) and *Prosopis juliflora* (green and dry leaves, bark, green and dry pods) were sampled for nutritional evaluation.

A systematic plot sampling design approach was employed to collect forage samples for nutritional characterization from the three counties. Four micro-sites were randomly selected in each study site/Wards viz Loboï (Baringo), Ilmotiok (Laikipia) and Lamuria (Nyeri) Counties. The selection criteria for these micro-sites were based on the invasive trees' infestations and availability.

In each sampling site, two bottom-top extended parallel transect lines of 50 m in length each and spaced at distance of 10 m were designated. Transects were laid out parallel to one another. Eight 5 m x 5 m plots were laid at equal distance of 20 m interval. In each 5 m x 5 m plot, one 4 m² sub-plot was laid out randomly for forage sampling. The inner 4 m² sub-plots were identified for forage sampling in order to avoid any form of contamination of forage samples in the periphery which served as a guard row. Forages were sampled by picking 8 to 10 hand-fulls of the preferred forage parts in each of the 4 m² sub-plots at random. The sampled forage phenological parts included mature and young cladodes/shoots, unripe and ripe fruits (*O. ficus indica*), and leaves (both green and dry), pods (both dry and green) and barks (from young and

mature trees stems) of *P. juliflora*). Duplicate samples weighing 500g were taken and drying done in an oven at 60°C for 48 hours. They were thereafter ground and passed through a 1-mm sieve size to obtain fine particles, then storage was done in plastic bottles at room temperature awaiting further analysis (chemical). A total of 93 samples were collected for laboratory analysis. (Twenty *Prosopis juliflora* samples (Baringo County) and 73 cacti (*Opuntia ficus indica*) from Baringo, Laikipai and Nyeri (North) counties).

3.6.1 Laboratory Analysis of Forage Samples

For forage sampling, sub-samples were cut into pieces of 5cm, and the samples were first oven dried at 60°C for 48 hours to determine the dry matter (DM) and thereafter preserved. The forage samples were then ground using a Wiley mill (Type: WRB80C/2Q) to pass through 1 mm screen size and stored in labelled sample bottles for laboratory analysis. The dry matter (DM), ash and crude protein (CP) content of the feeds were determined by drying the samples in an oven set at 105°C for 12 hours, and ashing in muffle furnace at 500°C. The Nitrogen content was estimated using the Kjeldahl procedures as described by Association of Official Analytical Chemists (AOAC, 1999), and Crude protein (CP) content calculated by multiplying the N content by 6.25. The ether extract (EE) content in the forage samples was obtained by Soxhlet extraction method (AOAC, 1999). Crude fibre (CF) was determined according to AOAC (1999). Nitrogen free extract (NFE) was determined mathematically by subtracting the sum of percentages of all the nutrients already determined from 100 calculated according to Van Soest (1994) as follows;

$$\text{NFE (\%)} = 100 - (\text{Moisture} + \text{CP (\%)} + \text{EE (\%)} + \text{ash (\%)} + \text{CF (\%)}).$$

3.6.2 Statistical Analysis of Forage Samples

In the forage quality analysis, the data was subjected to Analysis of Variance (ANOVA) using the General Linear Model (GLM) procedure of Statistical Analysis System (SAS, 2002). Differences among treatment means were tested using least significance difference (LSD). Coefficient of correlation was computed to assess whether there was any relationship between independent variables (Plant parts and plant species) and dependent variables (chemical composition of forage samples (DM, CP, CF, EE, ash and NFE)).

The model used for chemical composition statistical data analysis of Cactus (*Opuntia ficus indica*) and *Prosopis juliflora* was;

$$Y_{ijk} = \mu + S_i + R_j + e_{ijk} \dots \dots \dots v.$$

Where;

Y_{ijk} = Response variables (DM, CP, CF, EE, ash and NFE)

μ = Overall mean

S_i = Plant parts effect

R_j = Plant species effect

e_{ijk} = Random error

3.7 On-Station Feeding Experimentation

3.7.1 Location of the Study

Experimental investigation on the qualitative aspects of Cactus (*Opuntia ficus indica*) and *Prosopis juliflora* were carried out between the months of June to August, 2014. Digestibility of dry matter (DM (*in vitro*)) was done and analysed at the University of Nairobi, at the Department of Animal Production laboratory. Digestibility of nutrients (*in vivo*) was carried out at Kenya Agricultural and Livestock Research Organization (KALRO), Perkerra Research Station. The animals for this study were purchased from the surrounding pastoral communities in Marigat sub-county.

3.7.2 Research Design and Dietary Treatments

Sixteen male Red Maasai weaner lambs aged 3-4 months with an average initial body weight of $13.3 \text{ kg} \pm 2.4$ (mean \pm standard deviation (SD)) were used in the feeding trial for dry matter (DM) intake of the test rations. The experimental animals were grouped into four blocks of four animals per treatment, and each animal was randomly assigned to one of the four dietary treatment feeds in a randomized block design (RBD). The experimental weaner lambs were blocked based on their initial body weight and body condition. The experimental animals were neck-tagged for identification, and allowed 14 days adaptation period to allow the sheep accustom to the experimental diets and pen environment. During the adaptation period, animals were dewormed for internal parasites using Albendazole, and sprayed for external parasites using Dominex. The experimental animals were also vaccinated against sheep pox and blue tongue based on recommendation of a veterinarian.

The treatment diets included pure rations of *Cenchrus ciliaris* hay (used as control) and proportionally determined combinations of *Prosopis juliflora* pod meal, *Prosopis juliflora* leaf meal, spineless (*Opuntia ficus indica*) Cactus leaf meal and *Cenchrus ciliaris* hay. Four test diets were formulated. For every block of animals, one of the following four types of test diets were received; (T₁) 100% *Cenchrus ciliaris* grass hay as basal diet (control); (T₂) 80% *C. ciliaris* hay + 20% wilted Cactus (*Opuntia ficus- indica*) fodder; (T₃) 50% *C. ciliaris* hay + 20% Cactus (*Opuntia ficus indica*) + 30% *Prosopis juliflora* leaf meal; (T₄) 50% *C. ciliaris* hay + 20% Cactus (*O. ficus indica*) fodder + 30% *Prosopis juliflora* pods meal (Table 3.1).

Table 3.1: Chemical composition of experimental diets (% DM)

Treatments	DM	CP	NDF	Ash
TRT ₁ (C 100) (control)	87.3	6.3	75.6	13.9
TRT ₂ (C80, CT20)	80.0	8.2	73.8	13.3
TRT ₃ (C50, CT20, PL 30)	72.0	12.5	70.4	13.0
TRT ₄ (C50, CT20, 30 PP)	70.0	18.8	66.3	9.6

Abbreviations: C: Cenchrus ciliaris hay, *CT: Spineless Cactus*, *PL: Prosopis juliflora* leaf meal, *PP: Prosopis juliflora* pods meal *DM: Dry matter*, *CP: Crude protein*, *NDF: Neutral detergent fibre*

T₁: *C. ciliaris* (100% (control),

T₂: *C. ciliaris* (80%) + Spineless cactus (20%),

T₃: (*C. ciliaris* (50%) +Spineless cactus (20%) +*Prosopis juliflora* leaf meal (30%),

T₄: (*C. ciliaris* (50%) +Spineless cactus (20%) +*Prosopis juliflora* pods meal (30%)

Ratio combinations of the test diets were based on the principle of 3:1 energy to protein ratio of inclusion level according to Leng (2005) as follows; (T₁) 1:0:0 (Grass forage (as control) (100%); (T₂) 1:0:0 (Grass hay: Cactus (*Opuntia ficus indica*)) (80%, 20% respectively); (T₃) 5:2:3 (Grass hay: Cactus (*Opuntia ficus indica*): *Prosopis juliflora* leaf meal (50%, 20%, 30% respectively); (T₄) 5:2:3 (Grass hay: Cactus (*Opuntia ficus indica*): *Prosopis juliflora* pods meal (50%, 20%, 30% respectively).

According to Leng (2005), feed resources containing less than 7% CP generally do not support optimum rumen fermentation. Feed intake and digestibility in ruminants are not optimum when forages contain low CP and high fibre. Thus, an energy to protein ratio of 3:1 is recommended in grass-legumes mixtures for livestock feeding. This would supply the required CP and energy levels required for microbial cell synthesis. Additionally, optimal energy and protein inclusions in the ruminant diets can control other nutritional and/or metabolic-related disorders such as acidosis and bloat (Leng, 2005). Therefore, the treatment diets included proportionally determined combinations of *P. juliflora* pod meal meal, spineless cactus (*Opuntia ficus indica*) leaf meal and *C. ciliaris* hay. Data was collected on dry matter intake (DMI (g/d). The test rations were processed into about 2 cm chop-length using a forage chopper, and mixed thoroughly to minimize feed selection by the experimental animals.

3.7.3 The feeding Trial

After the acclimatization period of the 14 days to the experimental diets and pens, the feeding trial was conducted for 90 days. The experimental sheep were offered the test diets in two equal portions at 08.00 and 16. 00 h daily throughout the feeding trial. The test feeds were offered at the rate of 2% of their average body weights, after an adjustment of refusals of 20 percent (Leng, 2005). Feed refusals were weighed and recorded for each animal and the difference between daily offer and refusal was calculated to determine the daily feed intake in each experimental sheep. Samples taken from batches of feed offered and refusals were collected per animal over the experimental period and pooled on treatment basis pending laboratory analysis for dry matter (DM), crude protein (CP), Neutral Detergent Fibre (NDF) and Ash.

A total of 576 experimental feed samples were obtained (3 samples bulked per week per animal x 12 weeks' trial x 16 experimental animals), from which 80 composite sub-samples were obtained for laboratory analysis. The eighty composite sub-samples were obtained by bulking 5 samples per animal (16 sheep) collected during the entire feeding period of twelve weeks. Initial and final body weights of the experimental sheep were measured using suspended weighing balance of 100 kg weighing capacity at the beginning and at the end of the experiment for two consecutive measurements after overnight fasting.

3.7.4 *In vivo* Digestibility Experimentation

At the end of the feeding trial, the animals were transferred to metabolism cages for nutrient balance trials for further 14 days. During this experiment, a quantitative collection of samples

of the experimental feeds offered, refusals and faeces was conducted to determine the following variables; apparent *in vivo* NDFD (%), faecal output (g/d) and faecal-N (g/d) (AOAC, 1999). The animals were acclimatized to the metabolism cages and pen environment for 7 days, prior to the 8-day collection period. All the experimental sheep were harnessed with a faecal collecting bag to collect faeces for the determination of apparent digestibility of the test diets. Sheep were allowed to acclimatize to the faecal collection bags and metabolism cages for 7 days. This was followed by collection of faeces for seven more days, which was done every morning before provision of feed and water. Faeces collected were weighed daily and 20% of the daily faeces voided by each animal was sampled and pooled over the collection period for each sheep separately and placed in airtight polyethylene plastic bags and stored in a deep freezer (-4°C) until the digestibility trial was completed. At the end of the digestibility trial, faecal samples collected from each animal were thoroughly mixed, and 10% of the total sample collected from each animal were sub-sampled, weighed and partially dried at 60°C for 72 hours.

The partial dried samples of the faeces were ground to pass through a 1 mm sieve and stored in airtight polyethylene plastic bags pending further chemical analysis for Nitrogen balance. During the digestibility period, feed offered and refusals were collected daily and feed samples from each feed offered and refusals from each animal were taken daily to make a composite sample. A total of 5 composite feed offered samples and 5 refusal samples were collected from each animal separately and pooled per treatment. The apparent digestibility coefficient (DC) was calculated as follows;

$$\text{DC \%} = \frac{\text{Total amount of nutrients in feed offered} - \text{Total amount of nutrients in faeces}}{\text{Total amount of nutrients in feed offered}} \times 100$$

Representative samples of test diets, refusals and faeces were collected daily and dried at 105°C to determine the daily intake of Neutral Detergent Fibre (NDF) for each animal. Other representative samples of each feed material, by animal for refusals and faeces were collected daily over the 5-day collection period, bulked, mixed, sub-sampled and ground to pass a 1 mm sieve for subsequent laboratory analysis.

3.7.5 Chemical Analysis

All the representative samples of daily feeds offered and refusals during the feeding and digestibility trials, and faecal samples from the digestibility trial were analysed for Neutral

Detergent Fibre (NDF) according to the procedures described by Van Soest and Robertson (1985), and Nitrogen according to AOAC (1999).

3.7.6 *In vitro* Dry Matter Digestibility

In-vitro digestibility was determined according to Jouany and Thivend (1986). The four experimental diets that were used in the feeding trial (above) were subjected to dry matter digestibility (IVDMD) *in vitro*, where the test diets were incubated separately in an artificial rumen. The test rations were; (T₁) 100% *Cenchrus ciliaris* grass hay as basal diet (as control without supplementation), (T₂) 80% *C. ciliaris* hay + 20% wilted *Cactus (Opuntia ficus indica)* fodder, (T₃) 50% *C. ciliaris* hay + 20% *Cactus (Opuntia ficus indica)* + 30% *Prosopis juliflora* leaf meal, (T₄) 50% *C. ciliaris* hay + 20% *Cactus (Opuntia ficus indica)* + 30% *Prosopis juliflora* pods meal.

A 13g DM sample of each experimental substrate was incubated in pairs in flasks of one litre that contained 100 ml of rumen liquor, 100 ml of solid rumen content, 300 ml of artificial saliva and 187 mg of soluble nitrogen which was provided as ammonium sulphate solution, and subsequently shaken in a water bath at 39°C for 96 hours. Rumen fluid was collected before the morning feeding from one rumen cannulated boran steer, receiving chopped *C. ciliaris* grass hay *ad libitum* as basal diet and supplemented with Lucerne hay. Liquid samples of 9 ml were taken from the flasks at the beginning of incubation (t_0) and then after 96 hours according to the procedures described by Jouany and Thived (1986). Rumen fluid which had no test ration samples was put in each flask aimed at correcting for possible effect of rumen fluid on fermentation process, provided as a duplicate blank. Determination of dry matter residues was determined after 96 hours of *in vitro* digestion.

3.7.7 Statistical Analysis

Data on DMI, *in vivo* NDFD, faecal nitrogen, faecal output and IVDMD was subjected to Analysis of Variance (ANOVA) using the General Linear Model (GLM) procedure of Statistical Analysis System (SAS, 2002). Differences among treatment means were tested using least significance difference (LSD) test. Coefficient of correlation was computed to assess whether there was any relationship between the experimental diets and DMI, *in vivo* NDFD, faecal nitrogen, faecal output and IVDMD.

The model used for data analysis was as follows:

$$Y_{ijk} = \mu + t_i + e_{ijk}, \dots \dots \dots \text{vi}$$

Where;

Y_{ijk} = Response variables (DMI, *in vivo* NDFD, faecal nitrogen, faecal output and IVDMD),

μ = Overall mean,

t_i = Treatment effect (T₁, T₂, T₃, T₄.)

e_{ijk} = Random error

Table 3.2: Summary of Data Analysis

Objectives	Hypotheses	Dependent Variables	Independent Variables	Statistics
1. To assess the vulnerability of pastoral and agro-pastoral livestock production systems to climate change risks and the coping mechanisms employed by local communities to adjust to climate change in Baringo, Laikipia and Nyeri Counties	There is no significant association between socio-economic characteristics of respondents in the study area and various improved climate change adaptation strategies in livestock production	Level of adoption of improved climate change adaptation strategies	Age Education Gender (HH)	Descriptive statistics (Percentages, means), (Chi-square (correlations)) (SPSS, 2011 version 20.0)
2. To evaluate the feed quality potential of Cactus (<i>O. ficus indica</i>) and <i>P. juliflora</i> species fodder as influenced by plant species and plant parts in selected ASALs of Kenya.	There is no significant difference between the nutritive quality of Cactus (<i>O. ficus indica</i>) and <i>P. juliflora</i> as influenced by various plant parts and plant species.	DM, CP, CF, EE, ash and NFE	Plant species Plant parts (mature or young leaves/cladodes, fruits (ripe, unripe), bark, seeds, pods)	F-test ($p < 0.05$) (ANOVA) (SAS, 2002). Correlations, logistic regression
3. To evaluate the effects of Cactus (<i>O. ficus indica</i>) and <i>P. juliflora</i> species - based feed rations on performance of red Maasai weaner lambs.	There is no significant difference between Cactus (<i>O. ficus indica</i>) and <i>P. juliflora</i> species-based feed rations on performance of red Maasai weaner lambs as compared to the control diets.	DMI (g/d) <i>In vitro</i> DMD (%) <i>In vivo</i> NDFD (%) Faecal-N (g/d) Faecal output (g/d)	Test ration types (T ₁ , T ₂ , T ₃ , & T ₄ (Treatments))	F-test ($p < 0.05$) (ANOVA) (SAS, 2002) Correlations, logistic regression

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter describes the results based on the specific objectives and research hypothesis posed in chapter one. The results presented are the demographic and socio-economic characterization of the sampled population, main constraints associated with livestock production adaptation mechanisms, and adoption of potential climate change adaptation technologies. The chemical composition, *in vivo* and *in vitro* nutrient digestibility of selected drought resilient plants *viz* Cactus (*Opuntia ficus indica*) and *Prosopis juliflora* also forms an integral part in this chapter. In summary, the results presented here quantifies the vulnerability and possible interventions of pastoral livestock production systems in the selected dryland counties. Demographic profiles of the studied pastoral and agro-pastoral communities contain important socio-cultural and socio-economic data which is critical in explanations of behavioural responses such as gender of the respondent, age, education, formal or non-formal employment etc in relation to land use practices and innovation diffusion and adoption patterns. Subsequently this determines the vulnerability and possible scientific and/or policy intervention measures in such livestock production systems.

4.1 Demographic Profiles of the Respondents

Demographic characteristics of respondents are summarized in Table 4.1.

Table 4.1: Demographic Characteristics of the Respondents (%)

Demographic profiles		Baringo	Laikipia	Nyeri	Overall
		n= 170	n=82	n=65	N=317
Gender	Male	55	53.9	54.7	54.7
	Female	45	46.1	45.3	45.3
Age (Years)	18-35	33.9	46.7	16	32.7
	36-45	38	24	28	32.4
	46-55	18.1	14.7	20	17.8
	56-65	7.6	9.3	18.7	10.6
	66-75	2.3	4	12	5
	>76	0	1.3	5.3	1.6
Education	None	22.8	64	2.7	29.8
	Primary	20.2	11.3	27.4	19.6
	Secondary	18.1	9.3	34.7	20.7
	University	2.9	1.3	2.7	2.5

Results as depicted by the research indicated that those who responded to the questionnaires mostly were male (55%) compared to female (45%). These results also revealed that most of the respondents interviewed were below 45 years (Table 4.1). However, Nyeri County reported an old generation of respondents (55-75 years old) that was involved in agriculture. Laikipia County had the highest number of youths (aged 18-35 years) involved in farming (Table 4.1). Overall, the level of education in all the study Counties was low (primary (20%) and secondary education (21%). Laikipia County had the greatest percentage of respondent who did not attend school (60%). Both crops and livestock production were the main sources of livelihood in Nyeri County (98%), while pastoralism was the main source of livelihood (56%) in Laikipia County (Figure 4.1). Overall, mixed crop and livestock production system (52%) was most preferred in the study Counties (Figure 4.1).

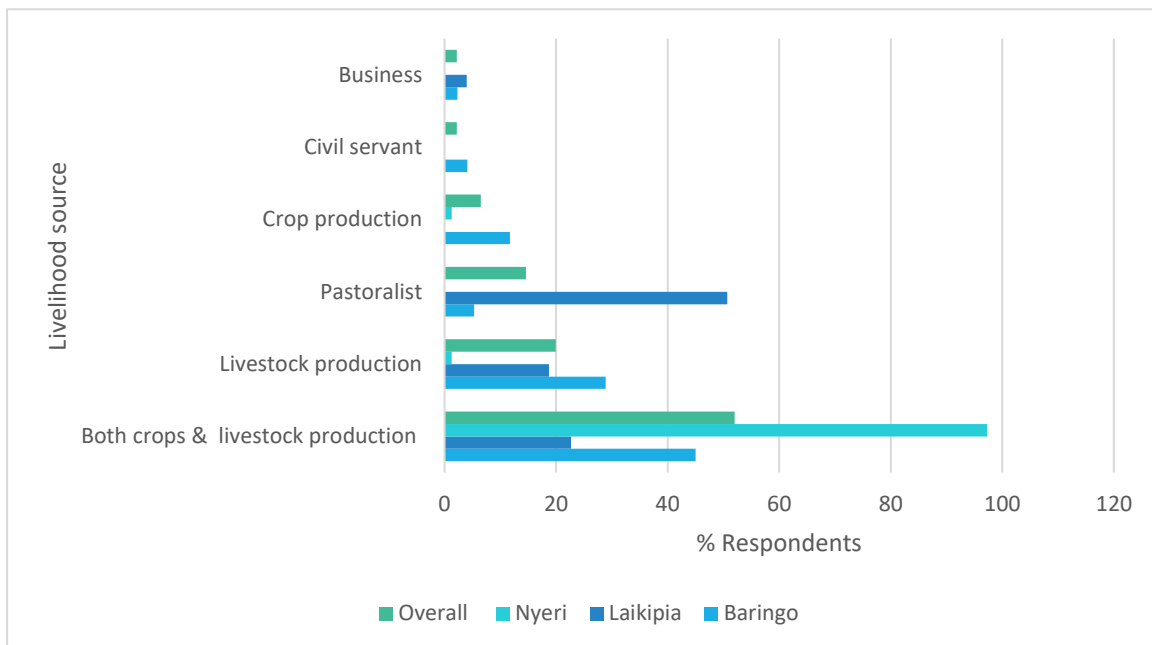


Figure 4.1: Main Sources of Livelihood (%) of Respondents

With regards to demographic profiles of the respondents, there was overall gender disparity in the proportion of male being 55% and female 45% of the household heads in the entire study area. These findings reflect that generally there was unequal participation of males and female's household heads in farming. This can be linked to cultural norms in African context where men are generally the leaders and decision makers in most farming communities (Chenyambuga et al., 2014; Rota & Sperandini, 2010). This implies a need to boost efforts aimed at gender mainstreaming in livestock production in the study sites.

Research findings by Bitende et al. (2001) reported a gender disparity where women are disadvantaged in most cases, when it comes to ownership of family resources, and are mostly considered as inferior, in the class of children. These findings are consistent with those of Chenyambuga et al. (2014) who reported a strong ethnic bias against women with regards to access and control of resources in pastoral communities in Tanzania. There is a need to put into consideration the household gender composition in order to understand the possible options available to adjust to adverse effects of climate change and variability. The fact that more male respondents were recorded (55%) than the females (45%) is an indicator of gender biasness. This may be linked to cultural norms of many pastoral communities in Africa where women have no say in family matters, where they should keep quiet in presence of men.

According to Chenyambuga et al. (2014), cultural norms and traditions in some communities in East Africa do not recognize economic role of women and youth in the society, and are usually put in lower social positions. However, women play a unique role in stewardship of natural resources and support to household such as care for children, the sick, the old and the disabled (Bitende et al., 2001). It is therefore vital these marginalized people are empowered to gain technological skills to move them out of poverty. Since food security and nutrition is not possible without income, there is need for capacity building on how to utilize available natural resources such as Cactus and *Prosopis species* to improve their sustainable livelihoods.

The current study revealed that greater number of the respondents were below 45 years old. This finding indicates that mainly a young generation was involved in livestock production. On average, household heads were relatively old in Nyeri county (>75 years old), suggesting possible advantages in farming owing to the experience and skills they may perhaps have accumulated over time. However, the implication of largely aging household heads is that weariness of the main decision makers could slow down agricultural production that could cause them not to embrace new agricultural innovations and technologies in livestock production (Joseph & Kaswamila, 2017). This can be linked to the higher levels of education reported in this County, which is normally associated with employment. These elderly respondents could be retirees from the civil service, as evidenced by their higher education levels. Comparatively young household heads were found in Laikipia County (47%), a reflection of improving attractiveness of agriculture to the younger generation in this county. However, this had bearing to the high illiteracy levels observed in this County, an implication that most of the youths that were less educated or not educated might have engaged themselves in other economic activities such as pastoralism.

Overall, about 30% of all household heads had not acquired any formal education in the study Counties. It was observed that 21% of the household heads had secondary level of education, while 20% had primary education. This trend was not similar across all the study counties, where the proportion of the respondents who had attained secondary school education was varying with the different counties. Highest illiteracy levels of households' heads were observed in Laikipia County (64%), while most learned household heads were found in Nyeri County (35%). These results imply that some Counties were more vulnerable to climate change impacts on livestock production than others. High literacy levels enhance relevant capacity to understand and effectively implement improved feed production, management and utilization technologies to generate the desired productivity impacts. Zendera (2010) reported that illiteracy levels could be as a result of poor or inadequate accessibility to relevant or required information and slow adaptability to the improved climate smart technologies.

The main livelihood source of most household heads was mixed crops and livestock production (52%). Nyeri County had benefited from this crop livestock system of production (98%). Mixed crop livestock production system has many advantages namely; allows diversification of risks, more efficient use of labour, recycling of farm wastes thus preventing nutrient losses with subsequent increase in crop and forage yields for increased cash incomes (Ryschawy et al., 2012). The system is responsive to market development. This could be one of the underlying reasons why mobility was limited in Nyeri County, where the farmers could have benefited from this system for surplus feeds. The highest proportion of household heads involved in pastoralism was reported in Laikipia County (51%). These findings are in agreement with GoK (2018) which documented pastoralism as the back-bone of rural household economies in the ASALs. This implies that policy and technical interventions aimed at improving rural livelihoods should be targeted at commercializing crop and livestock production in the study Counties.

4.2 Land Tenure and Ownership

The land tenure and ownership in the study areas is presented in Figure 4.2.

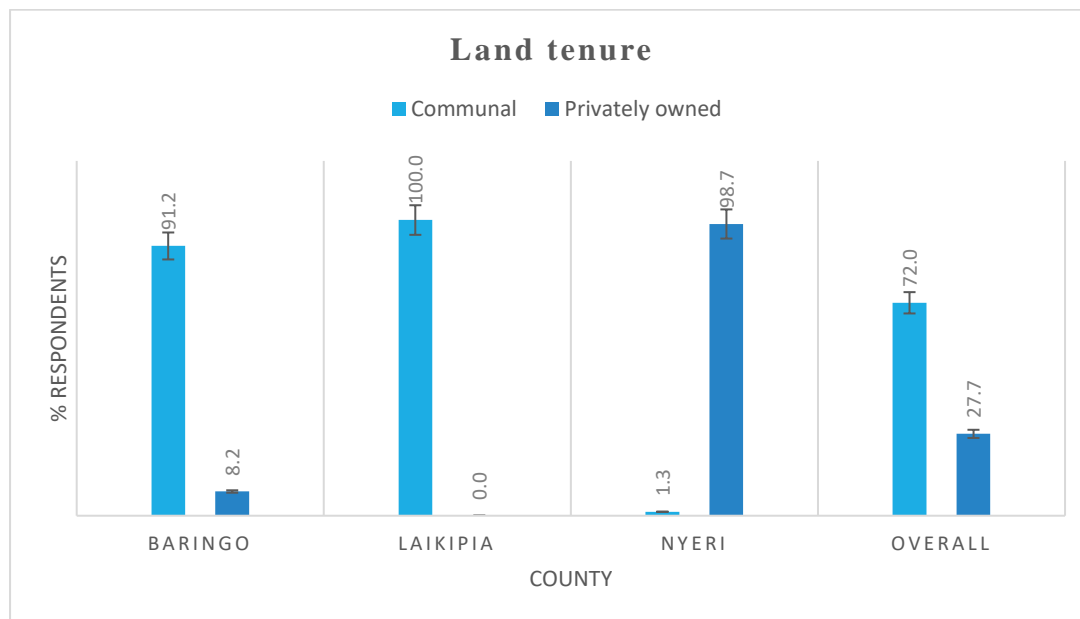


Figure 4.2: Land Tenure and Ownership

Communal form of land ownership was more practiced in Baringo (91%) and Laikipia (100%) counties. More of private land ownership (98%) was reported in Nyeri County (Figure 4.2).

According to Opiyo et al. (2016), with regards to land tenure and land use, private ownership is advantageous in the sense that the owner can be able to manage farm resources effectively and secure rights to reduce conflicts. This can enhance agricultural intensification, reduce land disputes, access to development credits and increase investment on land and land market. Communal land tenure is found mainly in the ASALs. Since the land is communally owned, development tend to be minimal since no one wants more of his or her investments to benefit the whole community who are not contributing in terms of finances, time, and/or professionalism. This has adverse impact on dragging community development.

4.3 Main Livestock Production Systems and Ownership

Overall, extensive system of livestock production (41%) was the most preferred method of production system by the respondents in all the study sites (Figure 4.3).

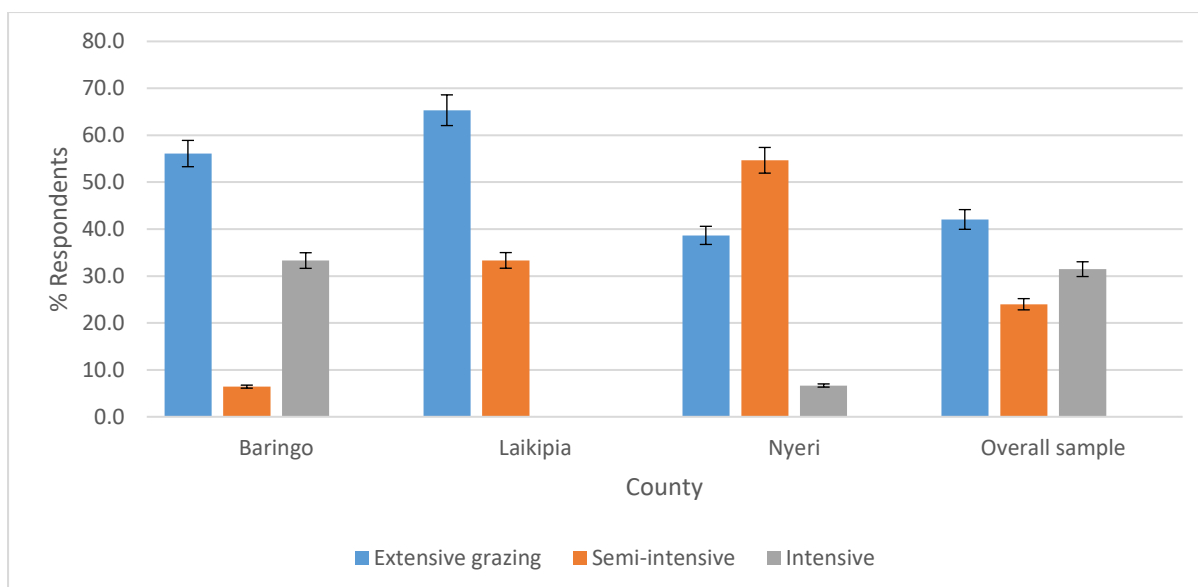


Figure 4.3: Main Livestock Production Systems

Laikipia (67%) and Baringo (58%) had the highest number of respondents who practiced extensive system of livestock production. Semi-intensive system of production was most practiced in Nyeri County (54%). It is evident from this study that cattle were the most important livestock in all the study areas (83%), followed by sheep (64%) Table 4.2). Poultry production, mainly indigenous chicken (57%), scored higher than goats (10%) in Nyeri County.

While cattle were mainly owned by men (Table 4.2), poultry production (indigenous chicken) was more of the women business in all the study areas. Rabbit production was dominated by children in all the study counties (36%). Extensive grazing system was more practiced in Laikipia (65%) and Baringo (58%) Counties. This scenario could be attributed to the large and communal land holdings in these Counties. This agrees to the research findings by Saitabau (2014) who reported that livestock production systems were in part influenced by land tenure.

Table 4.2: Livestock Ownership and Ranking in Households

Livestock spp	Baringo			Laikipia			Nyeri			Overall
	%	Rank	Owner	%	Rank	Owner	%	Rank	Owner	
Cattle	85	1	M	92	1	M	73	1	M	83.3
Sheep	69	2	M	76	2	M	48	2	M	64.3
Goat	50	3	M	70	3	M	10	4	M	43.1
I-Chicks	40	4	F	54	4	F	57	3	F	50.2
Rabbits	32	5	C	25	5	C	50	5	C	35.6

Abbreviations: M= male, F= female, C= children, I-chicken= indigenous chicken

On the other hand, higher levels of semi-zero grazing systems (54%) were recorded in Nyeri County, a factor that is also attributed to small land holdings and individual tenure systems. In extensive production, grazing of livestock is without boundaries due to availability of large pieces of land that are communal. This could be influenced by several factors mainly the environmental aspect of the study sites which are in the ASALs.

Farming and livelihood activities in the ASALs is hampered by the harsh environment, characterised by low precipitation, soils of high salinity with low fertility, and high temperatures (Magita & Sangeda, 2017). Extensive grazing has limitations due to livestock disease transmission risks and conflicts over limited resources such as water and pastures. Lack of quality and quantity feeds for livestock continues to be the main challenges associated with livestock production in the dry land ecosystems. The severe effects of inadequate quality feed supply call for approaches of introducing and promoting feed improvement technologies in the ASALs. The feed ration innovation of *Opuntia* and *Prosopis* species-based feed supplements developed in this study would be a break through to the pastoral farmers in the ASALs.

From the study it was clear that there were disparities in livestock ownership, where livestock of higher value such as cattle were owned by men, while poultry production was a dominant activity by women. These findings are consistent with previous baseline survey results by Bitende et al. (2001) who reported that women are in most cases disadvantaged when it comes to family resources ownership, where in most cases they are classified together with children. Similar observation by Chenyambuga et al. (2014) reported a strong ethnic background biased against women in livestock keeping communities. Poultry production scored higher than goats in Nyeri County, a factor that may have been due to the close proximity of markets in the major towns of Nyeri and Nairobi.

4.4 Main Constraints Associated with Livestock Keeping in the Study Areas

Results of the survey on challenges facing livestock production in the pastoral and agro-pastoral areas are presented in figure 4.3.

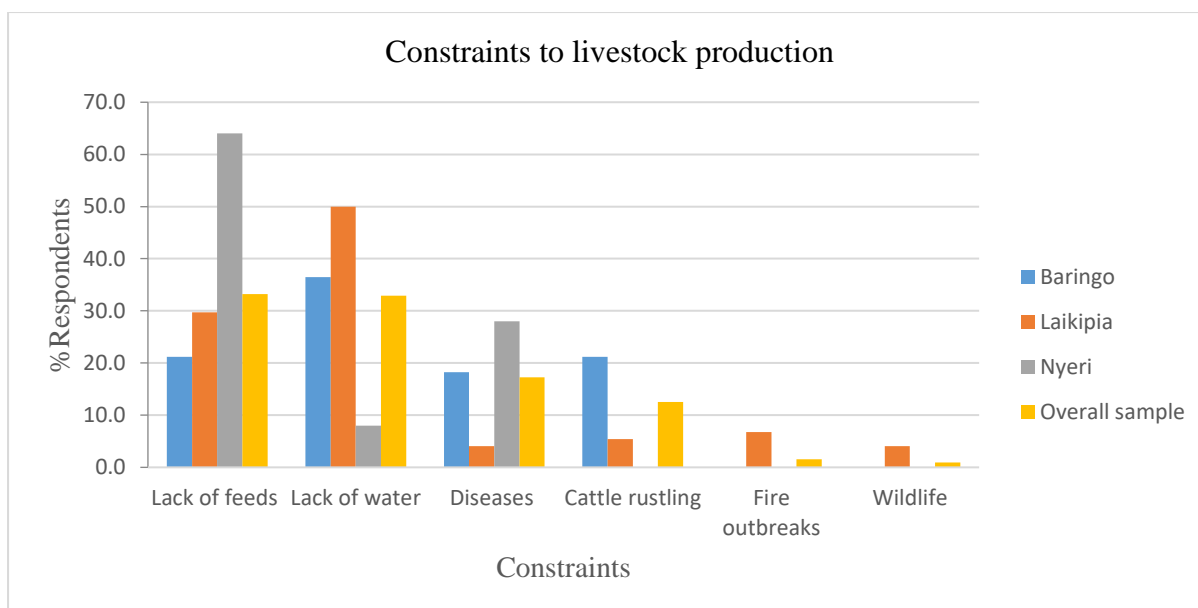


Figure 4.4: Constraints associated with Livestock Production

Overall, lack of feeds and water (33%) was the main constraint recorded by most respondents in all the study counties. However, Nyeri County was most affected by feed scarcity (64%) than other study counties. Water problems was highly recorded by most respondents in Laikipia (50%) and Baringo (37%) counties. Cattle rustling (21%) was common in Baringo County (Figure 4.4). Previous research findings showed that frequent droughts are a serious challenge for rural communities who depend wholly on natural resources for their livelihoods (Nicholson, 2014). Overall, lack of feeds and water were the main constraints cited by most respondents that were hindering livestock productivity in the studied regions. However, the severity of the constraints varied across the counties. The scarcity of feeds (64%) was listed as an impediment and a major challenge facing the production in livestock in Nyeri County. Notably, an observation was made by the study that lack of both feed resources and water for livestock were the critical threat pastoral communities in Laikipia and Baringo County (Figure 4.4).

As it was anticipated in Nyeri County, small household land holding ranging from 0.2 to 0.4 ha per was linked to feed scarcity in this County (Staal et al., 2001). High valued crops like coffee and tea are given priority at the expense of planted fodders and forages which are usually purchased off-farm (Table 4.3). Lack of water and feeds was expected in Baringo and Laikipia counties since these regions are arid and semi-arid regions (ASALs) located in zone IV-VI (FAO, 1996, 2018), with annual rainfall ranging from 300-1800 mm. However, according to the report of the Intergovernmental Panel on Climate Change [IPCC], 2018), there is a projected increase in drought risk in most parts of Eastern Africa by the 2050s, which is feared to threaten climate sensitive livelihoods such as livestock keeping. In such scenario, there is

need to formulate policies as development interventions in order to reduce risks, enhance the adaptive capacity and livelihood resilience for reduced household vulnerability to climate change and variability in the ASALs. Livestock diseases were more common in Nyeri County (28%). This can be attributed to the exotic livestock breeds that are less resistant to diseases.

4.5 Local Climate Change Coping Mechanisms

Overall, migration (37%) to greener pastures was the most preferred coping strategy against drought (Table 4.3).

Table 4.3: Local Coping Mechanisms to Effects of Climate Change on Livestock Production Systems (% Respondents)

Phenomena	Coping Mechanism (%)	Baringo n= 170	Laikipia n=82	Nyeri n=65	Overall N=317
Drought	Migration	48.5	59.5	4	37.3
	Purchase conserved feeds	0.6	0	50.7	17.1
	Livestock off-take	1.8	2.7	38.7	14.4
	Use own conserved feeds	8.2	1.4	14.7	8.1
	Take no action	8.2	1.4	1.2	7.2
	Take to friends	5.3	2.7	8.0	5.3
	Collect and store pods and leaves	3.5	1.4	6.7	3.9
Floods	Take no action	41.5	40.5	49.3	43.8
	Conserve feeds-hay	12.3	0	34.7	15.7
	Donate feeds	3.5	0	4	4.8
	Conserve feeds-silage	3.5	1.4	5.3	3.4
	Sale of feeds	0.6	0	5.3	1.9

However, this coping strategy (migration) was more prevalent in Laikipia (60%) and Baringo (49%) than in Nyeri County (4%). Purchasing of conserved feeds (51%), livestock off take (39%) and use of own conserved feed (15%) were the main coping strategies to drought in Nyeri County. It was observed in the study that majority of respondent were taking no action against floods (44%). Nyeri County was leading in feed conservation in form of hay (35%), followed by Baringo County (12%), while in Laikipia county there were no feed conservation practices reported (Table 4.3). Overall, only men and animals were moving away during

droughts (16%) with the intention of searching for water and pasture or food for both the livestock and men (Figure 4.5).

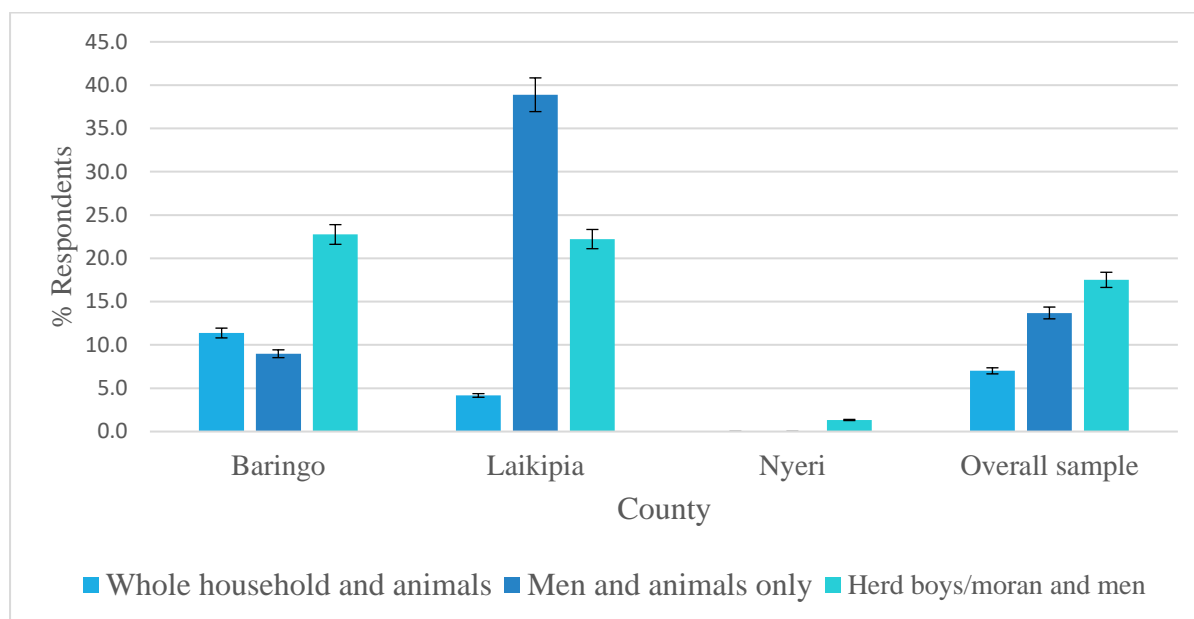


Figure 4.5: Household Mobility by Gender

Household mobility as a local coping strategy to climate change was limited (0.4%) in Nyeri County (Figure 4.5). Higher household mobility of men and animals was observed in Laikipia County (31%). Overall, whole household mobility (with women and children inclusive) was limited (7%) in all the study sites (Figure 4.5).

In order to enhance their adaptability potential to climatic change risks, the results from this study showed that respondents developed various coping mechanisms against drought and floods. Overall, greater percentage (44%) of respondents did not take action against droughts and floods, an indicator of high vulnerability to climate change impacts. Overall, the top most preferable coping priorities against droughts and floods were migration (37%), feed conservation and use of conserved feeds (17%) and livestock off-take (14%). However, the magnitude of these coping strategies varied across the Counties. Migration emerged as the most preferred method of adjusting to adverse effects of climate change in Baringo County (49%) and Laikipia (60%). This migration was mainly aimed searching for pastures and water for their livestock. It was observed in the study that migration as a coping strategy was minimal Nyeri County (4%).

The lack of migration in Nyeri County can be attributed to the small and privately owned lands with documents such as Title deeds, contrarily to Laikipia and Baringo counties where land

sizes are large with communal tenure system. With communal land tenure ownership, livestock movement is not restricted, whereas in privately owned lands there is livestock confinement and limited movement. This can be advantageous when it comes to livestock disease control. Additionally, higher levels of mixed crop-livestock system of farming were reported in Nyeri County in this study (Figure 4.1).

According to Ryschawy et al. (2012), mixed crop-livestock system is responsive to market development as a result of the many under-lying benefits that are associated with this system, namely; allows diversification of risks, more efficient use of labour, recycling of farm wastes thus preventing nutrient losses with subsequent increase in crop and forage yields for increased cash incomes (Ryschawy et al., 2012). The system provides a variety of feed resource pool from the extra crop residues from crops for dry season feeding, thus less mobility in search for green pastures as observed in Neri County.

The results obtained from the study concur with those given by Opiyo et al. (2014) in which they concluded that resilience and coping strategies of pastoral communities to different climate change-related risks vary from within different communities households and geographical areas based on existing climate change adaptation technologies that enhance the resilience of pastoral communities. On the other hand, Lopondo (2017) indicated that some coping strategies are not effective and thus could negatively impact the adaptive capacity of the targeted rural livelihoods, which would subsequently affect the economic status of the targeted community. For instance, migration would cause families to live far from each other, the couples and children separate as others migrate with the animals in search of good pastures and water.

Poor accessibility of livestock products (milk, meat, ghee) by the members who are prone and vulnerable among the pastoral and agro-pastoral societies (children, women and the disabled) when the animals move away can result into chronic malnutrition and death. Thus, this kind of social distancing is not healthy in terms of family cohesion. This agrees with research findings by Opiyo et al. (2016) who documented that some strategies applied by pastoral livelihoods were not sustainable, as they could be harmful to the environment. This can be supported by research findings by Lopondo (2017) who indicated that settlement around water points can cause degradation that would lead to enhancing the vulnerability of their livelihood to climate variability.

In Nyeri County, migration to greener pastures was limited. However, in Baringo and Laikipia counties, household migration was higher for men and animals. The findings can be supported by the fact that the individuals were owning small portions of land with fewer animals, and a permanent form of land tenure, unlike in the other counties where sedentary and nomadic form of livestock production system was still practiced (Staal et al., 2001). Fewer animals can be managed by off-farm purchase of conserved feeds as evidenced in this study (Table 4.3), unlike large numbers of animals in extensive grazing whose sustainability through purchase of feeds off farm could be unaffordable and uneconomical. The study revealed that women and children had limited mobility in the study areas, a factor which would increase their vulnerability to various climate change adverse effects. Mobility enhances social networks of household members that can enhance their scientific understanding and new ways of doing business to enhance food security, unlike when there is home confinement leading to poor exposure to the outside world. Mobility can thus be an effective way of building social networks to exchange good farming ideas and friendship (Zendera, 2010).

However, research findings in Darfur reported that climate change has adverse consequences of enhancing forced migrations which may result in triggering conflicts over limited natural resources such as land, water and pastures. The environmental pressure increases the chances of conflicts when rules regarding traditional boundaries are broken (Scott, 2008). Climate change related impacts such as droughts and desertification have many dangers of altering the rural livelihoods of pastoral communities, such as the migration aspects of rural pastoral communities into new grazing regions. Reports by Scott (2008) reported a high rate of migration, and livelihood alteration in North Darfur led to conflicts which led to loss of lives and livestock. Many livestock keepers have been reported to migrate from Northern Central and Southern parts of the state due to droughts and peoples displacement. The reported migration of the rural communities was as a result of lack of drinking water and good fertile lands for farming (Scott, 2008).

On the other hand, mobility is reported to be an effective mechanism adopted by pastoral communities in rangelands to reduce risk associated with droughts (Opiyo et al., 2015). Reports from the current study showed that 14% of the respondents viewed movement as an adaptation strategy to reduce livestock risks associated with climate variability. However, the level of mobility differed between the surveyed locations, a factor that can be linked mainly to land sizes and tenure systems. Outcomes of the key informants' discussion confirmed that herd

mobility was effective in allowing opportunistic use of resources and minimization of the negative effects of droughts, livestock disease outbreaks and livestock losses due to raids.

However according to Musembi and Kameri-Mbote (2013), these movements oftenly results in violent conflicts over limited resources like feeds and water. It was observed in the study that overall, 14% of the respondents were using livestock offtake as a strategy to combat droughts. This practice was more practiced in Nyeri County (39%) as compared to other study Counties (2% in Baringo and 3% in Laikipia). Research findings by Lopondo (2017) suggested that livestock offtake due to drought can be one of the successful mechanisms of adapting livestock systems to climate change, where increased off-take is practiced to meet the household's demand for food and cash in times of drought and food shortage.

4.6 Available Feed Resources and Strategies for adjusting to Poor Quality Feeds

Overall, native pasture grasses were cited as the most abundant forage feeds (81%) in the study sites (Table 4.4).

Table 4.4 Available Feed Resources (% Respondents)

Available feed resources	Baringo n=170	Laikipia n=82	Nyeri n=65	Overall sample N=317
Native pasture grasses	81.9	65.8	92	80.6
Fodder trees and shrubs	7	11	0	6.3
Planted pasture grasses	0.6	5.5	2.7	2.2
Planted forages/fodder	0.6	0	5.3	1.6
Crop residues	1.2	0	0	0.6

Fodder trees and shrubs and planted pasture grasses for livestock feeding were limited in the study areas (6 and 2% respectively). The most popular method of improving poor quality of feeds across all the study counties was collection and conservation of forage supplements (27%). However, greater number of households that were interviewed in Laikipia (50%) and Baringo (49%) counties weren't offering supplementary feeds to their livestock (Figure 4.6).

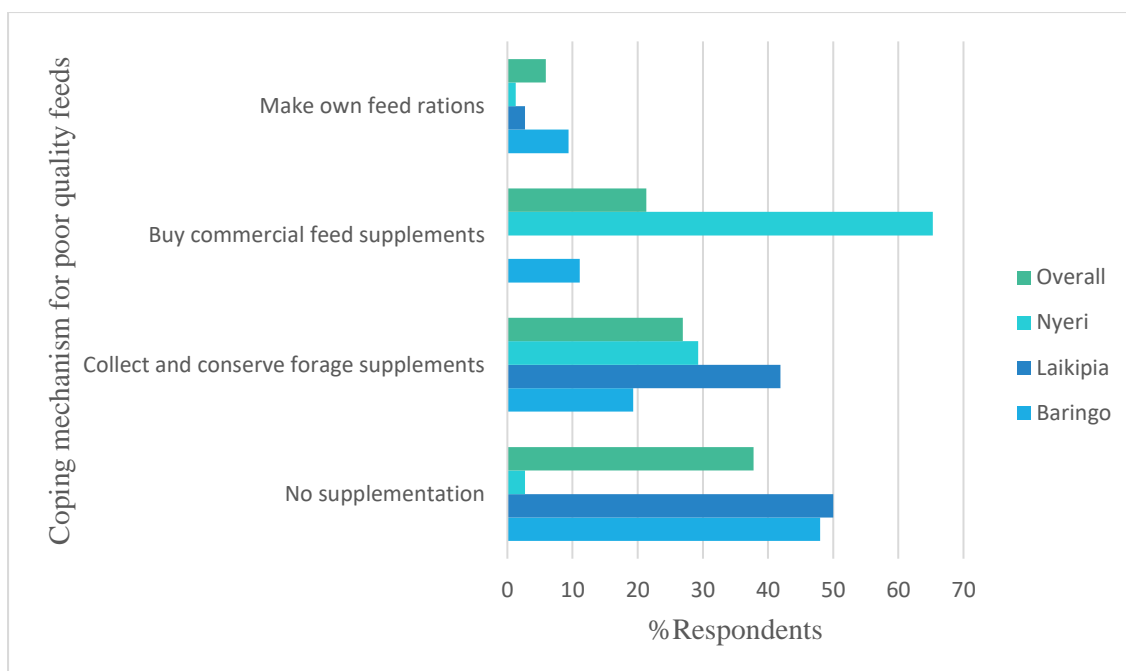


Figure 4.6: Coping Strategies to Poor Quality Feed Resources (% Respondents)

Nyeri County was leading in utilization of commercial feed supplements (65%) for their livestock (Figure 4.6). Overall, home-made ration formulation was limited in all the study areas (6%). The availability of only one type of forage resource (native grasses) implies a future threat in the livestock sector. This is supported by the Inter-Governmental Panel on Climate Change (IPCC, 2018), which documented a projected global increase of temperature to 2.5 °C that will result to major losses of biodiversity, one of them being a high risk of extinction of 20-30% of all plant and animal species. According to Lopondo (2017), drought has remained one of the major disasters that contribute to a higher vulnerability among the pastoral communities who are the endemic population to drought effects. High temperatures due to climate change has been linked to rapid lignification of plant tissues, with subsequent reduction in digestibility, feed conversion ratio and feed intake. There is a need to adopt drought tolerant forage species as a means of forage feed diversification in order to reduce vulnerability of livestock systems to climate change in the ASALs.

With regards to coping with poor quality of forage feeds due to adverse effects climate change and variability, the greatest percentage of respondents (38%) reported non-supplementation of their livestock. This was an implication of poor performance of livestock in the pastoral communities, owing to the effects of high temperatures to pastures. The findings were consistently in line with the results of Giridhar and Samireddypalle (2015) that recorded that, climatic changes have a potential to negatively affect both plant and animal productivity,

Variability in the different species of forage production, quality and composition, and the adverse effect on the ecological imbalances as a result of the distortion of the forage/fodder species. The study revealed that livestock supplementation was poorly practiced in Laikipia and Baringo. Conserving fodder during the times of plenty, for utilization during the periods of scarcity allows an even, year-round supply of livestock feeds that can reduce livestock mortalities and loss of livelihood. The study report from this study showed that collection and conservation of leguminous fodder trees and shrubs such as *Prosopis juliflora* pods was not preferred by the livestock keeping communities in Baringo. This was due to allegations that these trees species were responsible for the loss of animal teeth, with subsequent death due to starvation. According to Kyuma (2013), this could be scientifically true due to the concept that outside part of the *Prosopis juliflora* pods contain higher amount of the sugars that are soluble. It was also noted that the seeds had more of the nutrients having higher amount of the crude proteins of upto 30%. These seeds which are more nutritious with high crude 20-30% were not digested in the alimentary canal therefore, passing in the system and shed to the environment via the dung. This made the nutrients un-available to the livestock, causing a major disadvantage. Similarly, another challenge is in the sugars present in the pods which stick on the animals' teeth resulting in the teeth decay.

When the animal defaecate, the seeds that are not digested become scarified (after being pre-digested in the gut), and germinate more readily and grow prolifically, thereby enhancing the invasiveness of the *Prosopis juliflora*. According to Tewari et al. (2000), elimination of the invasive *Prosopis juliflora* by deforestation is not economical. If these seeds could be harvested, together with value-addition and/or processing in form of total mixed rations (TMR) as supplementary feed to livestock could increase livestock productivity and reduce the aggressive regeneration and colonization of *P. juliflora*. This would enhance the economic status and livelihoods of vulnerable groups living in marginalized areas.

4.7 Adoption Status (%) of Improved Climate Change Adaptation Technologies

Figure 4.7 indicates the status of adoption (% respondents) of climate Smart adaptation technologies.

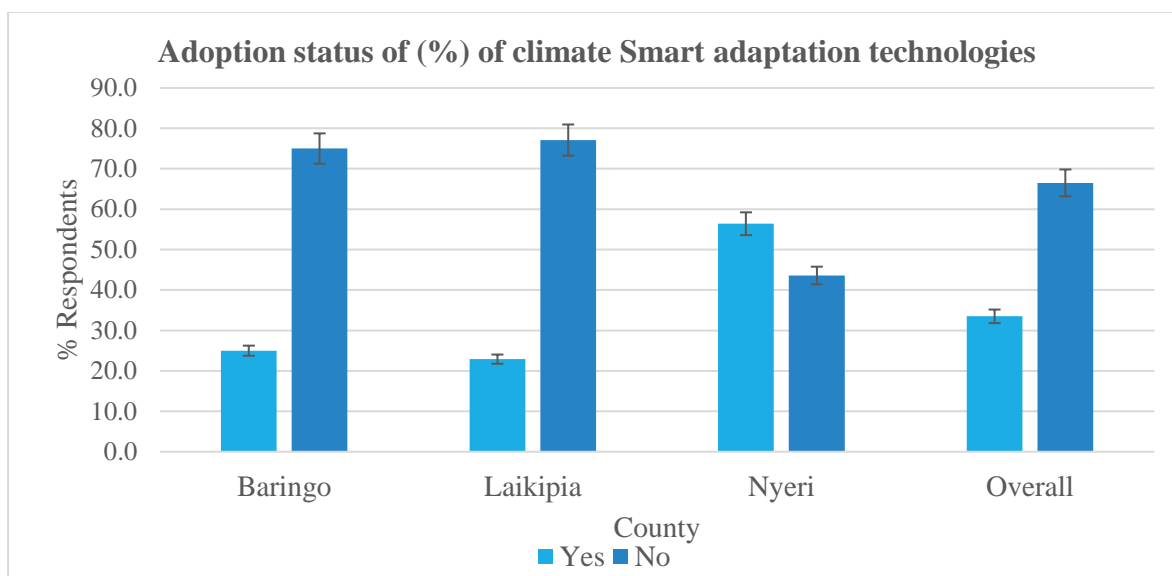


Figure 4.7 Adoption Status of (%) of Climate Smart adaptation technologies

Over 67% of the respondents indicated that they had not adopted climate Smart adaptation technologies such as feed conservation, concentrate supplementation etc. Baringo (75%) and Laikipia (77%) had the highest number of respondents who had not adopted these improved climatic changes adaptation technologies. However, Nyeri County reported a greater number (56%) of respondents who had adopted these technologies. These survey results implied that Baringo and Laikipia counties were more vulnerable to climate change risks than Nyeri County. Low adoption levels of improved climate adaptation technologies can reduce the adaptive capacity to climate change related risks to the pastoralists.

4.7.1 Main Reasons for Not Adopting Climate Smart Adaptation Strategies

The main reasons for poor adoption of climate smart adaptation strategies for climate change in the study areas by the pastoral and agro-pastoral communities is presented in Figure 4.8.

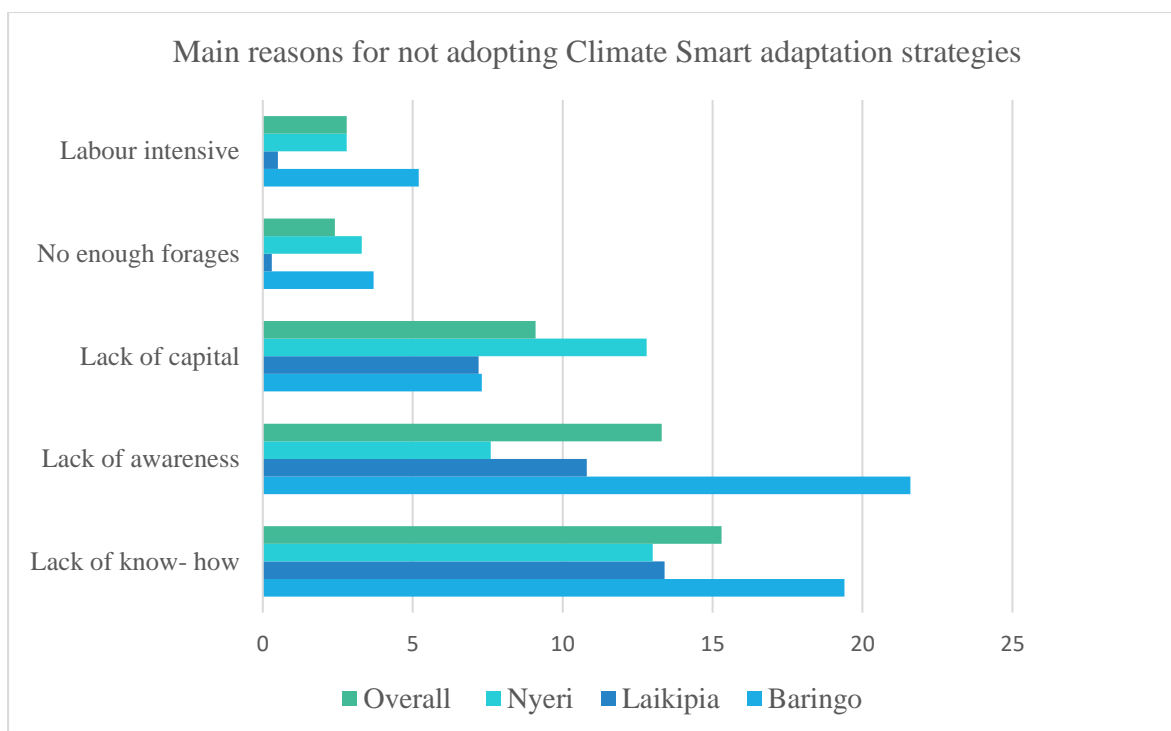


Figure 4.8: Main Reasons for not Adopting Climate Smart Adaptation Strategies

Overall, lack of technological know-how (15%) and poor awareness (13%) of increased climatic changes adaptation strategies were the main hinderance of adopting these technologies in the three study counties (Baringo, Laikipia and Nyeri). Baringo County had the highest percentage of respondents who lacked the technological know-how (19%) and awareness (22%) of these improved technologies as compared to the other two counties (Laikipia and Nyeri).

Poor adoption of improved climate change adaption strategies would expose the relevant counties to climate change related risks such as loss of livestock due to feed scarcity. This would in turn lead to loss of livelihood resulting to chronic poverty (Opiyo et al., 2016). Capacity building, training and on-farm demonstrations on selected improved climate change technologies such as feed conservation in form of hay and silage can enhance the adaptive capacity and resilience of these pastoral and agro-pastoral communities. Moreover, traditional knowledge of adjusting to adverse effects of climate change needs to be boosted with new knowledge generated from research in order to reduce climate related risks to enhance pastoral communities' livelihoods and reduce hunger.

4.7.2 Adoption Level (%) of various Improved Climate Change Adaptation

Technologies

Overall, change of livestock species (46%) was the most adopted improved agricultural technology that can reduce the vulnerability of livestock systems to climate change impacts (Table 4.5).

Table 4.5: Adoption Level (%) of various Improved Climate Change Adaptation

Technologies

Adaptation technology	Adoption level (%)			
	Baringo n=170	Laikipia n=82	Nyeri n=65	Overall N=317
Change of livestock species	36.3	48.6	53.5	46
Improved pasture/fodder varieties	24.1	10	64.9	33
Concentrate supplementation	20.1	6.1	50	25.4
Feed conservation	23.8	0	33.8	19.2
Total mixed rations	23	0	17.8	13.6
Overall sample	25.5	12.9	44	27.4

Nyeri County had the highest number of respondents (65%) who adopted improved pasture/forage varieties (Table 4.5). The same County (Nyeri) was leading in the overall number of adopters (44%) of improved agricultural technologies. Laikipia County ranked the least (13%) in adoption of improved agricultural technologies. Overall, all the selected improved agricultural technologies that can adapt livestock systems to climate change impacts were poorly adopted in the study sites (27%), implying 73% were non adopters (Table 4.5).

A chi-square test was used to compare the association between independent variables influencing adoption of various improved climate change adaptation technologies. A highly significant ($p < 0.001$) relationship was observed between gender of respondent, age and education level and adoption of climate change adaptation technologies (Table 4.6). This can best be attributed to the technological know-how and/or expertise in the implementation of scientifically tested agricultural technologies such as fodder conservation in form of hay, feed

formulation and water harvesting technologies. Illiterate people may lack the required technological know-how to implement these improved agricultural technologies. As indicated by the findings of the study, there is an association between demographic characteristics of the respondents (age, gender and literacy levels) and adoption of various improved livestock related climate change adaptation technologies. This evidence implies that the null hypothesis (H_{01}) in this study cannot be supported. Significant adoption of improved technologies by the rural communities in the dry lands could reduce the negative impacts of climate change impacts on pastoral and agro-pastoral livestock production systems (Table 4.6).

Table 4.6: Association between Demographic Characteristics of Respondents and Adoption of Improved Climate Change Adaptation Technologies

Variable	χ^2	df	<i>p</i> -value (0.05)
Change of livestock species	6.62	2	0.037*
Improved pasture/fodder varieties	46.1	2	0.001***
Concentrate supplementation	31.23	2	0.001***
Feed conservation	13.4	2	0.001***
Total mixed rations	8.62	2	0.013*

Significance: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Technical options are available to mitigate negative effects of climate change to livestock systems such as improved livestock diets, feed conservation, supplementary feeding, water harvesting technologies and better manure management. Overall, improved potential climate change adaptation technologies were least adopted in Laikipia County (13%), followed by Baringo (26%) and Nyeri (44%) took the lead. As observed elsewhere in this study (Table 4.7), this can be associated with the more efficient extension services reported in Nyeri County than in other Counties where, for instance village elders posed as extension workers to deliver scientific information for improving agriculture as in the case of Baringo County.

Although Indigenous Traditional Knowledge (ITK) should be incorporated in research to set up benchmarks, it should work to add value to scientifically tested agricultural technologies. However, there is a need for research and extension to liaise in sharing climate change adaptation technologies with end users of the targeted technologies so as to understand and contextualize climate change impacts on livestock production as a source of livelihood and possible adaptation strategies customized to suit their situation.

According to Nicholson (2014), change of livestock herd species have been documented as an important mechanism of enhancing the pastoral communities resilience to climate change adverse impacts. Approximately 46% of the households interviewed diversified their livestock, for instance from large ruminants to shoats, chicken and rabbits. Main reported livestock species kept included cattle (83%), sheep (64%), and indigenous chicken (50%), goats (43% and rabbits (36%) This is supported by previous research findings by Opiyo et al. (2015) who indicated that pastoral communities in Kenya were embracing camel production, as opposed to cattle, goats and sheep, which used to be a cultural taboo. Camels are more resilient, for instance they can go without water for about seven days, thus more resilient to climate risks than other livestock species.

4.8 Perceptions and Utilization of Cactus and *Prosopis juliflora* (% respondents)

Figures 4.9 indicates the perceptions and utilization of Cactus (*Opuntia ficus indica*) by in the respondents in the study sites. Most of the respondents (87%) in Baringo County perceived the Cactus species was an invasive species, which colonized their pasture land at the expense of forages for their livestock. In Laikipia and Nyeri counties, Cactus species was perceived to be affecting the health of their livestock by the presence of clochids and spines.

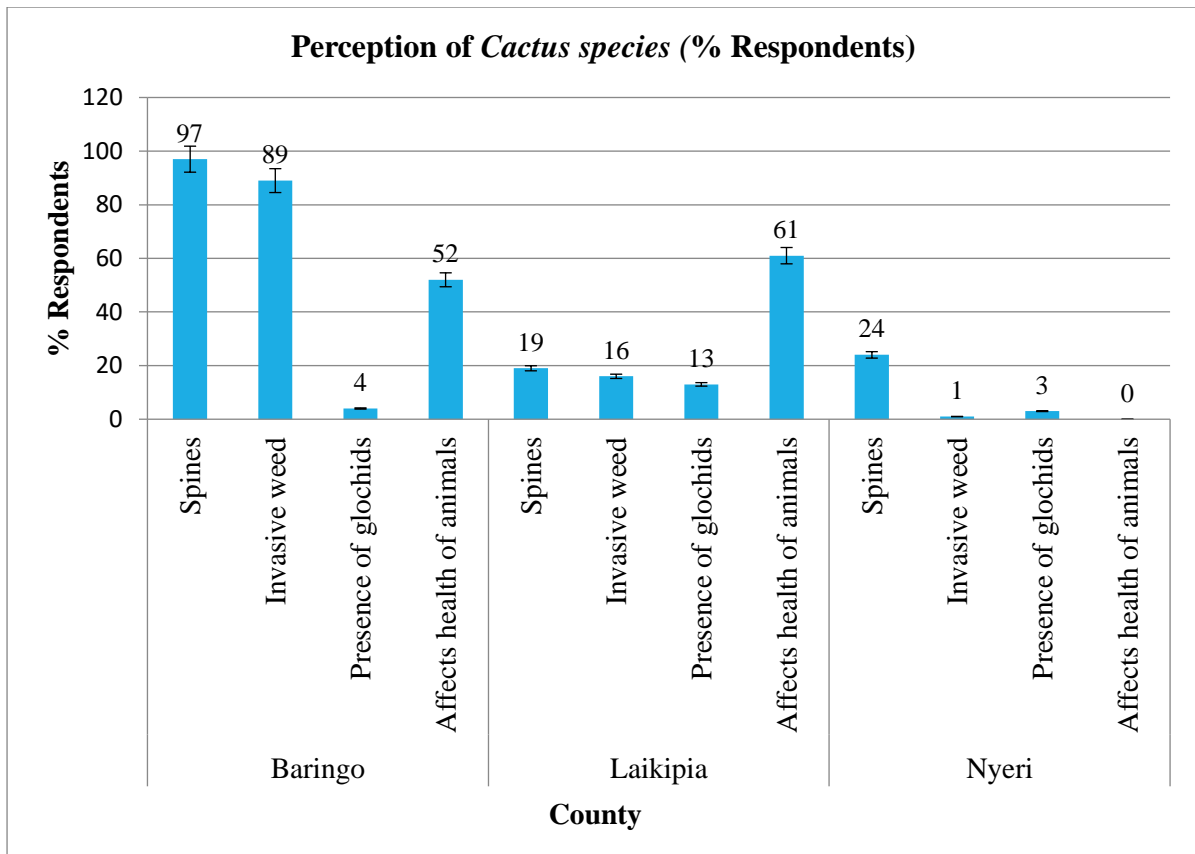


Figure 4.9: Perception of Cactus species (% Respondents)

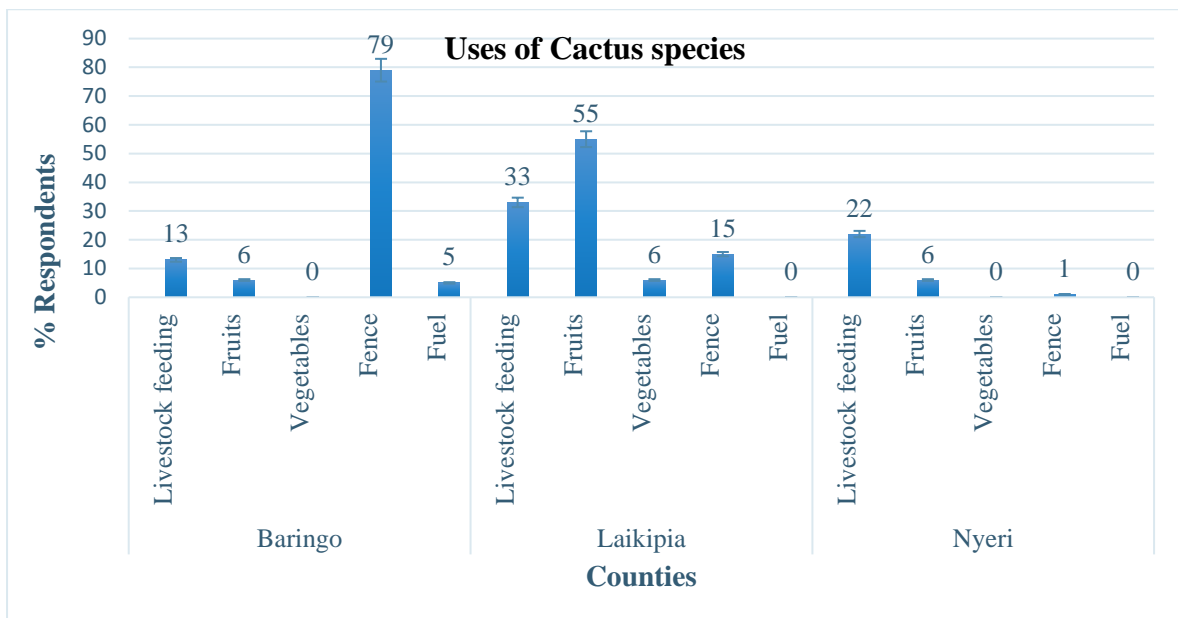


Figure 4.10: Uses of Cactus species (% Respondents)

However, Cactus species had many other uses as cited by respondents (Figure 4.10), which also varied by County. For instance, the Cacti species was more used as fence in Baringo

County (79%), while in Laikipia it was more used as fruit (55%), and a small percentage of respondents were using it as livestock feed in Nyeri County (22%). According to Dubeux et al. (2016), Cactus species is one of the most suitable forage crop species for arid and semi-arid climate. It has remarkable ability to withstand long period of dry spell due to inherent physiological adaptations such as CAM photosynthetic pathway. On the other hand, Cactus species forms a good component in the dry land ecosystem due to its high water use efficiency, thereby countering the effect of climate change. Previous research findings by Ben Salem and Louhaichi (2014) showed Cactus species as a rich source of minerals such as Ca, Mg, Na, P and K that are vital in livestock nutrition. Cactus species contains more than 85% of water, thus it can be fed with other fodder crops during dry spell condition thereby overcoming water scarcity situation in arid and semi-arid regions.

Besides water, previous research findings by Dubeux (2016) have showed that Cactus (*Opuntia ficus indica*) cladodes contain high amounts of soluble sugars, ash and vitamins A and C. Most of the nitrogen in Cactus species is present as non-protein nitrogen (NPN). The older the cladode, the lower is its CP content. The cladodes are highly palatable, and have a high Ca: P ratio. The nutritive value of cladodes varies with species and cultivars, and also varies according to season, agronomic condition, soil, rainfall and fertilization. This is backed up by the current results in this study which has revealed that different plant parts significantly ($p < 0.05$) influenced the nutrient composition of the Cactus species (spiny and spineless). The crude protein (CP) content of young cladodes of studies Cactus species was significantly ($p < 0.05$) different (14.9%) as compared to the mature cladodes which ranged from 11 to 13% for both spineless and spiny Cactus (Table 4.9). However, the CP content of ripe and un-ripe fruits did not differ in CP content. Significantly higher ($P < 0.05$) nitrogen free extracts (NFE) were observed (36%) in mature cladodes of both spiny and spineless.

The NFE values for ripe and un-ripe fruits did not differ significantly ($p > 0.05$) (Table 4.9). However, despite the benefits of Cactus species (*Opuntia ficus indica*) as a promising fodder for dry areas, its utilization as forage for livestock is minimal, and is regarded as a noxious weed, and requesting the Government to initiate eradication programmes in Kenya (Figure 4.11). There is therefore a need to promote Cactus as livestock feed under the Kenyan context. Promoting domestication and cultivation of *Cactus species* as livestock feed will enhance livestock productivity in the ASALs, a fact that will also address livelihood issues in these ecosystems.

Perceptions of *Prosopis juliflora* is presented in Figure 4.11. *Prosopis juliflora* was perceived as a noxious weed (66%) in Baringo County. Most respondents (73%) perceived that the Kenyan Government should initiate the eradication programs for the prosopis species.

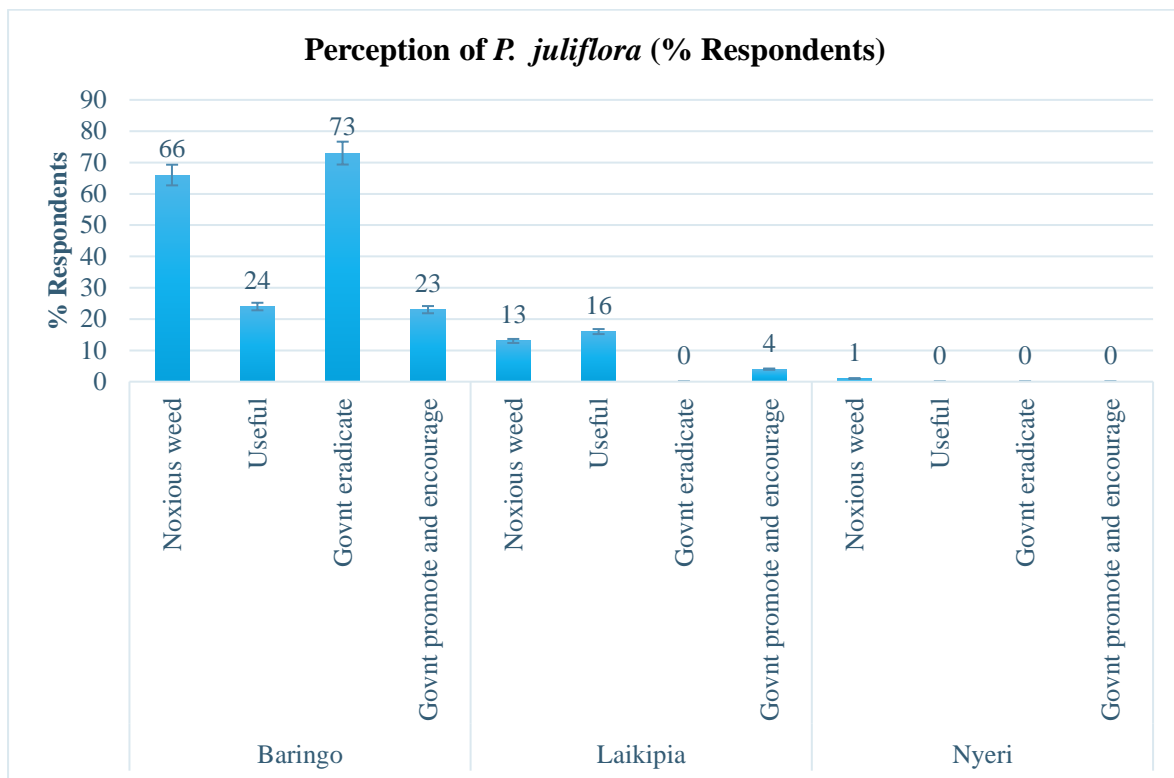


Figure 4.11 Perception of *Prosopis juliflora* (% Respondent)

The *Prosopis juliflora* has been progressively reported as an important invasive encroacher bush thicket, mainly found in flooded areas, along road stretches and near big towns. The massive infestation of the pasture lands by *Prosopis juliflora* plant species, is projected and foreseen to cause an ecological and socio-economic constraints (Opiyo et al., 2016). The most reported negative effects of *P. juliflora* vegetation are due to its large canopy, which suppress undergrowth plant species, mainly the herbaceous species which play an important nutritional role as livestock feed. They have also been reported to compete with other plant species for the limited moisture and available nutrients in the soil (Maundu et al., 2009). Other research findings documented that livestock, mainly the sheep and goats (sheeps) lost teeth, with several deaths recorded when *P. juliflora* pods were consumed by the animal in large quantities (Choge et al., 2002).

However, feed formulation with *P. juliflora* as ingredients was reported to enhance the performance of goats in the Kenya's ASALs, with a reported average daily weight gains of 400

g/kg (Koech et al., 2011). Thus, there is need for awareness creation campaigns, capacity building and field demonstrations on utilization and benefits of *P. juliflora* as animal feed.

The main uses of *P. juliflora* plant in Baringo County were mainly as fuel (charcoal and fire wood) (44%) and fencing (43%) (Figure 4.12). Only a small percentage of the respondents reported using the *P. juliflora* as livestock feeds (23%). Utilization of *P. juliflora* plant species in the other study counties (Laikipia and Nyeri) was limited, a factor attributed to the low colonization by this plant species in those sites.

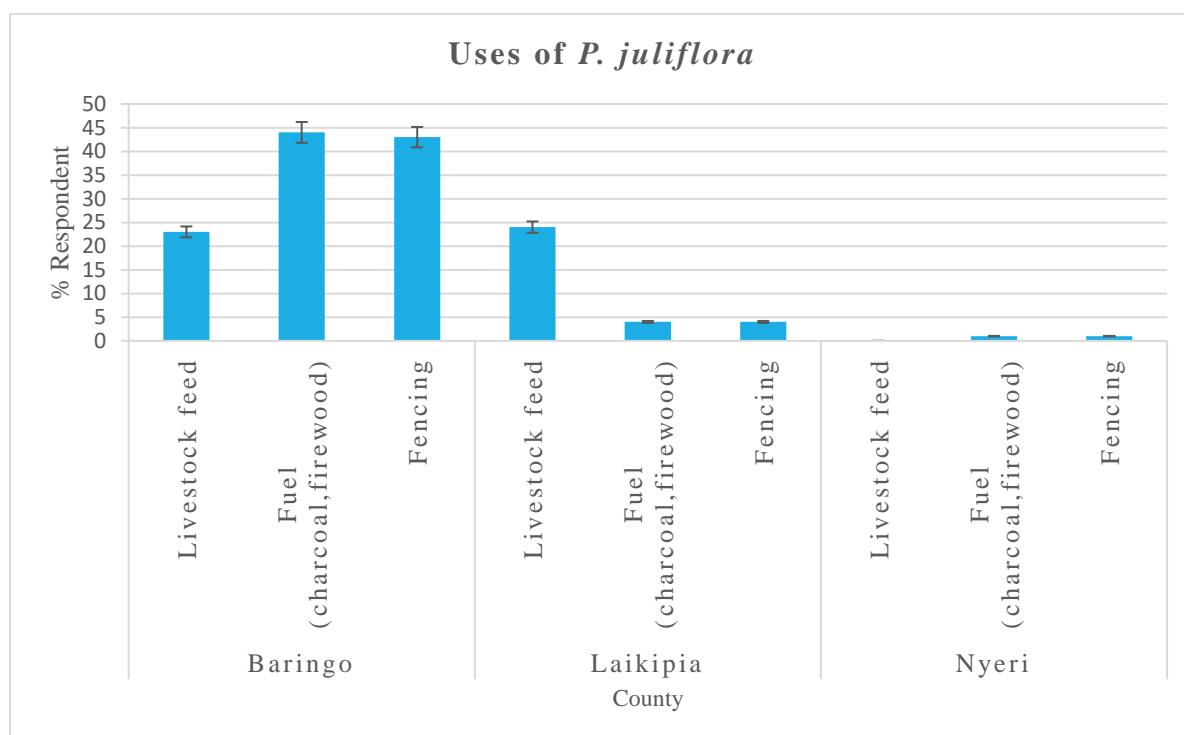


Figure 4.12: Uses of *P. juliflora* (% Respondents)

4.9 Sources, Access, and Utilization of Agricultural Information by Gender

Out of all the six sources of agricultural information identified, 56% of the respondents reported that they were getting their information from the chiefs' baraza (Table 4.7). This source of information was commonly available (86%) in Baringo County. More than 50% of the respondents indicated that radio was their main source of agricultural information. Extension services and radio (44 and 49% respectively) were most preferred channels of agricultural information in Nyeri County. Overall, men had good access to agricultural information (64%) than women (34%). The youth had limited access to agricultural information (0.3%) in the study areas (Table 4.7).

Table 4.7: Sources, Access and Utilization of Agricultural Information by Gender (% respondents)

Major sources of agricultural information in households (% Respondents)				
Source of agricultural information	Baringo n=170	Laikipia n=82	Nyeri n=65	Overall N=317
Chiefs' baraza	86	37.8	6.7	56.3
Radio	7	55.4	49.3	28.1
Extension	0	0	44	10.3
Village elders	2.3	5.4	0	2.5
Television	2.3	1.4	0	1.6
Newspaper	1.8	0	0	0.9
Access to agricultural information by gender (% Respondents)				
Men	64.1	67.7	58.7	63.5
Women	32.9	29	41.3	34.2
Youth	0.6	0	0	0.3
Use of agricultural information by households (% Respondents)				
Sometimes	80.6	59.7	66.7	73
Apply it immediately	14.7	19.4	26.7	18.6
None	3.5	21	6.7	10.4

Overall, 73% of the respondents were not using the received agricultural information satisfactorily (Table 4.7). Only 19% of the respondents reported applying the agricultural information immediately they received it. It was revealed in the study that most respondents in the study areas sought agricultural information from various sources like chiefs' baraza, radio, extension, newspapers, television, and a small percentage from village elders (Table 4.7). Radio (49%) and extension (44%) was most preferred channel of obtaining agricultural information in Nyeri County, while *chiefs' barazas* were the main source of agricultural information in Baringo County.

Radio was an important channel in disseminating agricultural information in Laikipia County. This was likely to be associated with the low levels of education observed in this County (Laikipia). This is supported by similar studies by Lopondo (2017) who documented the

importance of radio which no education was required to channel any agricultural information. With regards to radio, limited or no requirement for higher educational qualifications to be effective. *Chiefs' barazas* had the highest percentage in Baringo County, while radio and extension services were the major dissemination channels for agricultural information in Nyeri County.

These results implied how the different dissemination channels were equally important in various households. Different dissemination channels demonstrated a clear complement to each other in terms of the academic status of the communities. However, the effectiveness of some of the channels like the use of *chiefs' barazas* to pass agricultural information to communities have many limitations (Zendera, 2010). This may be attributed to the fact that the chiefs may not be having the required agricultural expertise in agriculture for informing others. Radio as source of agricultural information has many limitations such as the frequency of receiving this information, where the information may be aired once a month in the radio. Therefore, although these types of information sources are effective, they are not effective enough, thus still not solving the challenges associated with climate change risks to pastoral communities due to their inadequacy. It was noted in the study that women and youth had limited access to agricultural information than men.

Similar findings by Chenyambuga et al. (2014) showed that cultural taboos threaten to reinforce gender inequalities. Women's limited access to resources and restricted rights make them more vulnerable than men. This is also supported by research finding by Bitende et al. (2001) who observed that cultural norms and traditions in many communities in East Africa still do not recognize the key role of women and youth in the livestock sector. Often, they are relegated to low resources and hampered from accessing livestock and production resources such as land, knowledge and skills. There are also negative cultural norms and traditions that put disadvantaged women and youths at lower social position in communities.

Mainstreaming gender issues in designing action research to address the specific constraints of the target groups related to gender inequalities in regards to access and control of resources is vital. Bitende et al. (2001) reported that women play a unique role in stewardship of natural resources and support to household (Care for children, the sick, the old and the disabled). With their knowledge, they can shape adaptive mechanisms in vulnerable areas to improve food security. It is therefore vital that women and youth be empowered to gain technological know-how and skills to enable them be in the front line in poverty eradication. It is a global concern

that young people do not have jobs and countries are grappling with food insecurity. To solve problems of youth unemployment and food insecurity, youth can be encouraged to engage in agriculture to give a solution to both problems. Since food security and nutrition is not possible without income, there is need for capacity building on how to utilize available natural and animal resources to make sustainable livelihoods as a means of job creation to fill the unemployment gap and low incomes. Overall, a small number (3%) of the respondents indicated they had attended agricultural training and seminars (Table 4.8). Capacity building in agricultural practices can enhance agricultural productivity.

Table 4.8: Mean Percent (%) of Respondents who attended various Agricultural Trainings and Seminars

Agricultural training	Baringo n=170	Laikipia n=82	Nyeri n=65	Overall N=317
Livestock production	4.7	9.1	6.7	6.1
Crop production	4.7	0	5.3	3.8
Water conservation	1.8	3	1.3	1.9
Farmer field schools	1.8	0	1.3	1.3
Overall	3.3	3.1	3.7	2.5

4.10 Membership to Agricultural groups

Findings of the study showed that 67% of the respondents were not members of any particular agricultural group (Figure 4.13).

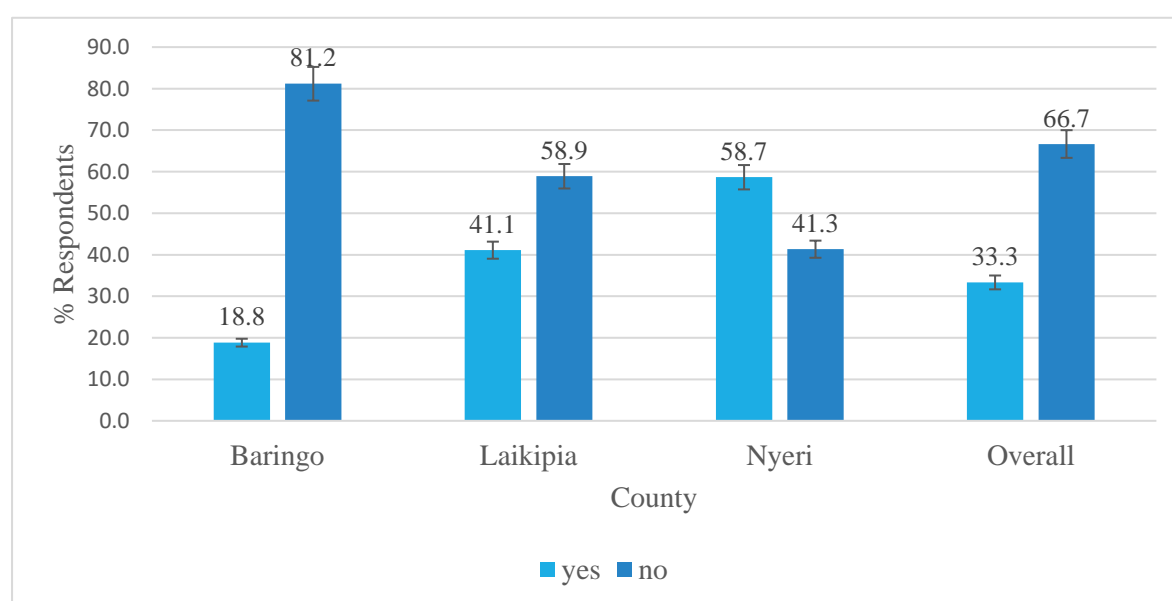


Figure 4.13: Percentage of Respondents with Membership to Agricultural Groups

However, highest number (59%) of membership to agricultural groups was observed in Nyeri County (Figure 4.13). Nyeri County recorded the highest number of respondents who had registered membership to social groups, followed by Laikipia (41%) and Baringo County recorded the least (19%). Membership to social group is important as it allows the enrolled members to develop effective networks for useful information that can assist assist in improving their farm productivity. When members of households do not accept to join social groups has adverse effects of isolating the members from important networks for agricultural information exchange, a factor that would increase their vulnerability to the impacts of climate change variability and environmental degradation. The current findings concurs with those of Zendera (2010) who documented the importance of scientific information exchange as a vital tool for a successful weather adaptation strategy as a result of climatic changes in Baringo County.

4.11 Nutritional Characterization of Cactus (*Opuntia ficus indica*) and *Prosopis juliflora*

The chemical composition of various parts of Cactus (*Opuntia ficus-indica*) and *Prosopis juliflora* are recorded in Table 4.9. The different plant parts influenced significantly the nutrient composition of the studied plant species at $p < 0.05$. However, Cactus species (spiny and spineless) did not significantly ($p > 0.05$) influence the nutritional composition of various plant parts (Table 4.9). As expected, lower DM content of different parts of Cactus ranged from 82-88%. Dry matter (DM) content of ripe (88%) and un-ripe fruits (86%) was highly significant than in all other plant parts (mature and young cladodes) of Cactus at $p < 0.001$. Dry matter (DM) content of mature cladodes (84%) and young cladodes (82%) were significantly ($p < 0.001$) different as influenced by phenological stage of growth.

The crude protein (CP) content of young cladodes of Cactus was significantly ($p < 0.05$) different (14.9%) in comparison to the mature cladodes which ranged from 11 to 13% for both spineless and spiny Cactus (Table 4.9). However, the CP content of ripe and un-ripe fruits was not significantly ($p > 0.05$) different. The phenological stage of growth of the cladodes significantly ($p > 0.05$) influenced the crude fibre (CF) content of Cactus (Table 4.9). The CF content ranged from 31 to 32% in mature cladodes of Cactus. Crude fibre (CF) content of young cladodes ranged from 25 to 26% for Cactus (Table 4.9).

Table 4.9: Proximate Composition of Different parts of *Opuntia ficus indica* and *Prosopis juliflora* (%DM)

Species	Part	Chemical composition (%)					
		DM	CP	CF	EE	Ash	NFE
Spineless Cactus	Mature cladodes	84.2 ^b	11.1 ^b	32.3 ^a	5.42 ^a	3.9 ^a	36.0 ^a
	Young cladodes	82.2 ^c	14.9 ^a	25.8 ^b	6.06 ^a	3.9 ^a	27.5 ^b
Spiny Cactus	Mature cladodes	84.4 ^b	12.7 ^b	30.5 ^a	5.54 ^a	3.8 ^a	35.8 ^a
	Young cladodes	82.8 ^c	14.9 ^a	25.3 ^b	5.46 ^a	2.7 ^a	32.2 ^b
	Ripe fruits	88.2 ^a	10.2 ^b	30.7 ^a	5.5 ^a	2.2 ^a	39.6 ^a
	Un-ripe fruits	86.2 ^{ab}	12.2 ^b	30.0 ^a	5.7 ^a	2.6 ^a	35.6 ^a
	<i>p</i> -value	0.008 ^{**}	0.002 ^{**}	0.017 [*]	0.663 ^{NS}	0.098 ^{NS}	0.046 [*]
	SEM	0.41	0.53	1.42	0.16	0.49	1.62
	LSD	1.2	1.54	4.13	0.46	1.43	4.7
<i>Prosopis juliflora</i>	Green pods	93.7 ^a	10.9 ^d	27.5 ^c	3.14 ^c	8.8 ^c	43.4 ^a
	Dry pods	92.0 ^c	13.45 ^c	29.8 ^b	2.6 ^d	7.9 ^d	38.2 ^b
	Young shoots	90.4 ^d	26.3 ^a	14.2 ^e	11.2 ^b	0.2 ^e	38.6 ^b
	Mature shoots	89.0 ^e	14.3 ^b	19.2 ^d	12.8 ^a	9.8 ^b	32.9 ^c
	Mature barks	92.8 ^b	4.8 ^e	58.1 ^a	3.1 ^c	14.4 ^a	12.4 ^d
	Young barks	92.5 ^b	4.4 ^e	58.2 ^a	3.3 ^c	13.9 ^a	12.7 ^d
	<i>p</i> -value	0.001 ^{***}	0.001 ^{***}	0.001 ^{***}	0.001 ^{***}	0.001 ^{***}	0.001 ^{***}
SEM	0.27	0.35	0.07	0.19	0.45	0.27	
LSD	0.25	0.32	0.06	0.17	0.41	0.25	

Means with same superscript letters along the same column do not differ significantly ($p > 0.05$).

Significance: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Abbreviations: SEM= Standard error of mean, NS= Not significant, LSD= Least significant differences of mean (5% level), DM= Dry matter, CP= Crude protein, CF= Crude fibre, EE= Ether extracts, NFE= Nitrogen free extracts

The CF of spiny and spineless species of Cactus were not significantly different at $p > 0.05$ (Table 4.9). The stage of growth did not significantly ($p > 0.05$) influence the ether extract (EE) and ash contents of both spiny and spineless Cactus. The desired ash content range is 5 to 8% (Zailan et al., 2018). All the reported ash values in spiny and spineless Cactus were lower than

these values. Significantly higher ($p<0.05$) nitrogen free extracts (NFE) were observed (36%) in mature cladodes of both spiny and spineless. The NFE values for ripe and un-ripe fruits were not significantly ($p>0.05$) different (Table 4.9).

The nutrient levels of various parts of *Prosopis juliflora* is shown in Table 4.9. The DM of mature and young barks of the *Prosopis juliflora* were not significantly ($p>0.05$) different in the study. However, the means of DM content were significantly different ($p<0.05$) across various plant parts of *Prosopis juliflora* with green pods exhibiting the highest values (94%) of DM content. The crude protein (CP) content of *Prosopis juliflora* varied widely, being particularly ($p<0.001$) highest for young shoot (26%), mature shoots (14%), dry pods (14%) and green pods (11%).

The highest contents of crude fibre (CF) were observed in the mature and young bark (58% each) of *P. juliflora*. The CF of dry pods (30%) was highly significantly ($p<0.001$) different from that for green pods (28%) (Table 4.9). Lower levels of CF ($p<0.001$) were observed in the young shoots (14%). Results from this study also reported significantly ($p<0.001$) higher content (13%) of ether extracts (EE) in mature shoots of *P. juliflora*. Ether extract (EE) in mature and young barks were significantly different ($p<0.001$). However, both mature and young barks had highest ($p<0.001$) ash content (Table 4.9), and lowest in NFE contents (12 and 13% respectively (Table 4.9). Dry matter (DM) of *Prosopis juliflora* was positively correlated significantly with CF ($r^2=0.44$, $p<0.05$) (Appendix 5). However, a significant negative correlation was observed between DM and CP ($r^2= -0.50$).

The results as depicted by the study, various parts of both spiny and spineless Cactus (*Opuntia ficus indica*) and *Prosopis juliflora* (mature and young cladodes/shoots, mature and young barks, green leaves, dry leaves, ripe and un-ripe fruits) significantly influences the forage quality (DM, CP, CF, EE, ash and NFE) as livestock feed. This evidence implies that the null hypothesis (H_{01}) was rejected. However, the species of the Cactus plant (spiny and spineless (*Opuntia ficus indica*)) did not significantly ($p>0.05$) influence the nutritional quality of various parts of this plant, thus this part of the hypothesis was accepted.

In this study, the chemical composition of selected drought-tolerant plant species of *Prosopis juliflora* and Cactus (*Opuntia ficus indica*) were investigated as they were hypothesized to be influenced by various plant parts and species. According to Mostafa et al. (2017), the stage of plant growth influences the chemical composition of forages. While the protein levels reduce as the forage plant matures, the dry matter (DM) and structural components (cellulose, hemi-

cellulose and lignin) increase with increase in plant maturity (Kholif et al., 2016). This fact is supported in by the significant negative correlation observed between DM and CP ($r^2 = -0.50$) in this study. Jafari et al. (2015) reported increased crude fibre (CF) contents of almond hulls as livestock feed as the plant matured. These research findings report a similar trend with the findings of the current study where Dry matter (DM) of *Prosopis juliflora* was positively correlated with CF ($r^2 = 0.44$, $p < 0.05$) (Appendix 5).

Crude fibre is a measure of the quantity of the indigestible or fairly indigestible components in feeds such as cellulose, hemi-cellulose, lignin and pentosans (Mostafa et al., 2017). When CF is higher, the energy content of corresponding feed is lower because most of the CF components are considered indigestible (cellulose and lignin). A crude fibre (CF) threshold of between 17 and 23% is required in ruminant animals for normal rumen function, as source of energy and for enhancing feed digestibility (Zailan et al., 2018). However, the higher CF levels (26-32%) in Cactus (*Opuntia ficus indica*) in the current study were higher than the normal acceptable range of 17-23% (Ben Salem et al., 1996; Samah et al., 2015). From the current findings, Crude fibre (CF) as a measure of cell wall content of forages was influenced by phenological stage of plant growth. The higher the CF value, the higher the stage of plant growth and lower the quality of the feed.

A crude fibre (CF) threshold of between 17 to 23% is required in ruminant animals for normal rumen function, and as source of energy and for enhancing feed digestibility (Zailan et al., 2018). In contrast, Ben Salem and Louhaichi (2014) recorded CF values ranging from 15-16% in Cactus (*Opuntia ficus indica*) species, which when compared to what we found in this study the values were lower. The variations in CF levels in forages is due to the variability in the atmospheric conditions because the higher temperatures and reduced precipitation process increases the fraction of the cell wall while reducing the plants soluble materials (Samah et al., 2015). Phenologically, there is a positive correlation between forage DM levels and CF. As the forage plants mature, CF increase with the increasing plant DM, mainly due to accumulation of structural components in the plant (cellulose, hemicellulose and lignin), a factor that determines the quality of forage feeds in terms of intake, digestibility, nitrogen balance and conversion ratio (Samah et al., 2015).

In the current study, CP content of Cactus (*Opuntia ficus indica*) were not significantly different. However, significant differences ($p < 0.05$) were observed between CP content of young and mature cladodes of Cactus (*Opuntia ficus indica*), where highest significant levels

of CP were recorded in the young cladodes. Differences in CP content of the forage species under study can be explained by inherent characteristic of each species' ability to extract and accumulate nutrients from the soil (Mostafa et al., 2017). These findings agree with those of Ben Salem and Louhaichi (2014) who reported high Phosphorus (P) uptake by Cactus (*Opuntia ficus indica*) after fertilization with Superphosphates inorganic fertilizers. Crude protein (CP) content in forages reflects the maturity stage as well as fertilization levels. For instance, where good quality forages harvested at the right stages of maturity generally will have higher protein content of >9% for grasses and >15% for leguminous forages (Kholif et al., 2016).

Other research findings by Kariuki et al. (2016) reported a protein content of more than 15% in Napier grass (*Pennisetum purpuream*) cultivars harvested at optimum stage of 6-8 weeks regrowth. Other studies reported up to 22% CP contents of Napier grass accessions under different nitrogenous fertilizer application levels (Feedipedia, 2015). The recorded CP content (11-15%) of Cactus (*Opuntia ficus indica*) were higher than the minimum 7-8% optimum levels required for microbial cell synthesis for maintenance in ruminants (Mostafa et al., 2017). The reported CP levels were also within the acceptable levels of 14-18% required for animal growth and milk production (Agricultural Research Council [ARC], 1984). Elsewhere, Ben Salem and Louhaichi (2014) reported lower CP range of 5.4-6.4% DM for Cactus (*Opuntia ficus indica*). In contrast, these results are not consistent with those of the present study which has reported higher CP levels of 11-15%.

Since the studied Cactus species in the current study contained CP content of over 8% (critical threshold for microbial cell synthesis for maintenance in ruminants), it can be considered as intermediate quality forage feed for range lands. This reported CP range in this study is sufficient to enhance ammonia production required for the growth and activity of ruminal microorganisms (Jafari et al., 2015; Kholif et al., 2015). The higher CP levels of Cactus (*Opuntia ficus indica*) reported in this study is linked to good fertile soils where samples were collected. Samah et al. (2015) indicated that application of chemical fertilizers such as Superphosphate increased CP content of cladodes of Cactus (*Opuntia ficus indica*) from 5 to 10%.

A goal for a profitable livestock feeding program is to achieve an appropriate balance among available feed ingredients where total ration nutrient composition meets daily nutritional requirements of the animals. Results from the present study indicates that both spiny and spineless Cactus species may be used as supplementary feed to low quality feeds such as crop residues. The reported CP content in this study were comparable with those of

Mostafa et al. (2007) who reported similar higher content of CP of soybean straws as the stage of maturity of these plants advanced. Previous research findings by Nefzaoui and Ben Salem (2001) reported CP levels of 3-5% in cladodes of *Opuntia ficus indica*. The CP levels observed in this current study were higher than these values.

Highest content of Nitrogen Free Extracts (NFE) was observed in ripe and un-ripe fruits, and mature cladodes of Cactus. Nitrogen Free Extracts (NFE) in forages constitutes the carbohydrates, starch and sugars (Samah et al., 2015). According to Zailan et al. (2018), an optimum threshold levels of NFE in ruminants is 30-43%. The NFE content reported in this study is within this range, with fairly high energy value for ruminant animals with comparable energy value to cereal grains such as barley. The NFE content of the studied plant species were consistent with values reported by Nefzaoui et al. (2013) who suggested that Cactus species was capable of significantly reducing the requirement for conventional feeds with high energy content such as maize and wheat bran.

Excessive consumption of Cactus species is safe for the ruminant livestock, where it does not cause metabolic diseases such as acidosis and bloat in animals consuming these feeds. This is due to the high levels of mucilage found in Cactus (*Opuntia* species), which enhance salivation and avoid serious decrease in pH unlike these other conventional crops (Dubeux, 2016; Nefzaoui et al., 2013). Dried Cactus cladodes have been reported to partially replace maize germ in a feeding trial for weaner lambs (Ben Salem & Louhaichi, 2014; Feedipedia, 2018). Therefore, Cactus species (both spiny and spineless) can be effectively utilized as non-conventional source of energy in formulating home-made feed rations for livestock in rangelands, due to its morphological adaptation of being a succulent drought tolerant plant with high reported NFE content. However, it was shown in these reported results that NFE content of Cactus species increased with increase in plant maturity. This information would be of much help with regards to domesticating this plant and adopting good agricultural practices as a feed resource in future research work in Kenya's rangelands.

Highest contents of ash were recorded in the old barks of *Prosopis juliflora*, which is an indicator of high mineral content. Previous survey data revealed that greater percentage of pastoral communities do not supplement their livestock. Instead, they depend on natural salt licks located in specific areas of the rangelands, where animals are taken there at least once a month to lick salt for a whole day. Supplying mineral salts once a month implied that the animals were deficient of mineral salts. This fact is evidenced by massive de-barking of

Prosopis juliflora tree species that is believed to have phyto-therapeutic effects against mineral deficiency (J. Duyu, personal communication, August 6, 2014).

Dry pods meal from *Prosopis juliflora* was found to have the highest level of CP content. The observed high CP content of *Prosopis juliflora* justifies their use as supplement to poor quality natural pastures such as that of *C. ciliaris*. This fact is supported by research findings by Kyuma (2013) who reported a higher CP content of up to 28% in *Prosopis juliflora* pods in comparison to those of other commercial feed supplements found in the market, with sunflower seed cakes as a good example. This implies that *Prosopis juliflora* can be an important protein and energy feed supplement that is pocket-friendly for the resource constrained farmer in the ASALs. However, determination of suitable inclusion level in feed rations is required due to the fact that livestock, mainly small ruminants were reported to lose teeth after consuming large quantities of *Prosopis juliflora* pods with subsequent starvation to death (Choge et al., 2002). Other research findings by Kyuma (2013) documented that pastoral communities perceived *Prosopis juliflora* species as a bad omen.

Although higher CP content was recorded in young *Prosopis juliflora* shoots, it is reported to have high anti-nutritional factors owing to mainly condensed tannins, which reduces bioavailability of this nutrient to the animals (King'ori et al., 2011). The feed potential of *Prosopis* leaves based rations in the current study was fairly good as indicated by higher DM intake and digestibility. These findings are supported by research findings by Koech et al. (2011) who indicated that slow curing of *Prosopis juliflora* leaves under shade can reduce the tannin levels thereby increasing the feed intake. The *Prosopis juliflora* leaves used as an ingredient in the formulated test rations (T₃) were dried in a shed prior to experimentation.

Higher significant ($p < 0.001$) values of Nitrogen free extracts (NFE) were observed among various parts of *Prosopis juliflora*. Nitrogen free extracts (NFE) in plant forages are indicators of carbohydrates and starches available in that feed. *Prosopis juliflora* pods are high in sugar and protein and are a rich source of feed and food for livestock and humans (Choge et al., 2002). Extensive anthropological data on human food and feed uses of *Prosopis* pods (Felker, 1996). King'ori et al. (2011) indicated that *Prosopis juliflora* pods can be included at levels up to 10% in layer diets without affecting egg production and weight gain. However, *Prosopis juliflora* elicited many problems between the local communities and the Government who, unaware of its positive uses, advocated for an eradication approach to the situation (Choge et al., 2002). Research experiences from other countries show that *Prosopis juliflora* is extremely

difficult and costly to eradicate once it becomes established (Pasicznik et al., 2001). A more practicable and sustainable solution in such areas would be a more effective management through utilization and harvesting of marketable products along the *Prosopis juliflora* value chain (Choge et al., 2002).

4.12 Effects of Cactus (*Opuntia ficus indica*) and *Prosopis juliflora*-based Diets on Performance of Red Masai weaner lambs

Results from this study showed that the two studied Cactus species (spiny and spineless) were not significantly ($p>0.05$) different in their chemical content. Thus, the latter was selected for this feeding trial due to its ease of handling (spineless). The nutrient composition of the proportionally compounded experimental diets with spineless Cactus (*Opuntia ficus indica*), *Prosopis juliflora* and *C. ciliaris* hay is presented in Table 3.1. The nutrient composition of the experimental diets varied among the four formulated experimental rations.

The control diet (T₁ (*Cenchrus ciliaris* hay) had higher dry matter (DM) content (87%) than in the other test diets, while the lowest value of DM (70%) was recorded in T₄ (*Prosopis juliflora* pods-based rations). Among the test diets, the ash content (10%) in T₄ (*Prosopis juliflora* pods-based rations) was the lowest, and the highest (14%) was in the control diets (*C. ciliaris* hay (T₁). Crude protein (CP) content varied from 6% in the control diet (T₁) to 18.8% in T₄ (*Prosopis juliflora* pods-based rations). The control diets (*C. ciliaris* hay (T₁) recorded the highest neutral detergent fibre (NDF) content (76%), whereas the lowest (66%) was observed in T₄ (*Prosopis juliflora* pods-based rations) (Table 3.1).

The treatment effect (type of ration) significantly ($p<0.001$) influenced the dry matter (DM) intake of the Red Maasai weaner lambs (Table 4.10). The lambs that received *Prosopis juliflora* pods-based ration (T₄) consumed higher amounts of feed DM (863 g/d) as compared to those fed other rations (T₃ (*Prosopis juliflora* leaf meal-based ration), T₂ (spineless Cactus-based rations) and the control diets (T₁ (un-supplemented *C. liliaris* hay) (Table 4.10). The highest faecal output (498 g/d) was observed in the lambs fed *Prosopis juliflora* pods-based ration (T₄). Sheep that received T₄ rations had also the highest *in vivo* and *in vitro* nutrient digestibility (78 and 63% respectively).

Faecal output was positively correlated to DM intake ($r^2=0.88$, $p<0.001$), *in vivo* ($r^2=0.87$, $p<0.001$) and *in vitro* feed degradability ($r^2=0.87$, $p<0.001$). However, faecal Nitrogen was

negatively correlated ($r^2 = -0.64$, $p < 0.001$) to these values (DM intake, *in vivo* and *in vitro* feed degradability). *Prosopis juliflora* pods-based diets had significantly ($p < 0.001$) lower faecal Nitrogen excretion (0.88 g/d) as compared to other test diets. Highest faecal Nitrogen excretion (1.98 g/d) was recorded in the the control (T₁ (*C. ciliaris* hay) and *Prosopis juliflora* leaf meal-based diets (T₃ (1.58 g/d). Treatments T₃ (*Prosopis juliflora* leaf meal-based rations) and T₂ (spineless *Opuntia ficus indica* based rations) were not ($p > 0.05$) significantly different with respect to Nitrogen excretion (Table 4.10).

4.13 *In vivo* and *in vitro* Nutrient Degradability Coefficients

The data on the effects of the experimental rations on *in vivo* and *in vitro* degradability of nutrients is presented in Table 4.10. Results from this study observed a highly significantly ($p < 0.001$) increased in *in vivo* digestibility of neutral detergent fibre (NDF) of 78% in *Prosopis juliflora* pods-based diets (T₄) as compared to other test diets (Table 4.10).

Table 4.10: Effects of Spineless Cactus (*Opuntia ficus indica*) and *Prosopis Juliflora* - based Rations on Dry Matter Intake and Nutrient Digestibility of Red Maasai Weaner

Variable	Treatments				SEM	LSD	<i>p</i> -value (0.05)
	T ₁	T ₂	T ₃	T ₄			
DMI (g/d)	402 ^c	553 ^b	684 ^b	863 ^a	42.5	135.8	0.001 ^{***}
<i>In vivo</i> NDFD (%)	20.0 ^d	47.0 ^c	63.0 ^b	78 ^a	2.49	7.98	0.001 ^{***}
Faecal-N (g/d)	1.98 ^a	1.22 ^{bc}	1.58 ^{ab}	0.88 ^c	0.13	0.43	0.001 ^{***}
Faecal output (g/d)	163 ^c	266 ^b	331 ^b	498 ^a	23.8	76	0.001 ^{***}
IVDMD (%)	42 ^d	51 ^b	46 ^c	63 ^a	0.19	0.40	0.001 ^{***}

Means with different superscript letters along the same row differ significantly ($p < 0.05$).

Abbreviations: DMI: Dry matter intake, *In vivo* NDF-D: *In vivo* Neutral detergent fibre digestibility, Faecal-N: Faecal Nitrogen, IVDMD: *In vitro* dry matter digestibility, SEM: Standard error of means,

Significance: *** $p < 0.001$

LSD; LSD; Least significant differences of mean (5% level)

T₁: *C. ciliaris* (100% (control), T₂: *C. ciliaris* (80%) + Spineless cactus (20%), T₃: (*C. ciliaris* (50%) +Spineless cactus (20%) +*Prosopis juliflora* leaf meal (30%), T₄: (*C. ciliaris* (50%) +Spineless cactus (20%) +*Prosopis juliflora* pods meal (30%)

However, rations formulated from dry leaves of *Prosopis juliflora* (T₃) portrayed an optimum recommended degradability levels of above 50% for a good quality ration. The control diet (T₁ (*C.iliaris* hay) reported un-acceptable degradability coefficients of below 50%. Table 4.10 shows the *in vitro* dry matter (DM) degradability coefficients of the test diets in the study. The formulated ration treatments significantly ($p<0.001$) influenced the dry matter degradability *in vitro*, with various test feed formulae showing different DM degradability kinetics.

The *in vitro* degradability of experimental rations significantly differed ($p<0.05$) among the various treatments diets from 42% (*C.ciliaris* hay (T₁) to 63% for *Prosopis juliflora* pods-based treatment diets (T₄) which recorded the highest degradability pattern than the rest of the test diets, including the control treatment (T₁). The study revealed that spineless Cactus-based diets (T₂) had significantly ($p<0.001$) higher degradability (51%) than *Prosopis juliflora*-based leaf meal (46% T₃), a factor that was not expected (Table 4.10). *Prosopis juliflora* leaf meal-based test diet was expected to give a higher degradability percentage than those of Cactus (*Opuntia ficus indica*) because it is a leguminous tree shrub. Leguminous browses enhance the microbial protein synthesis in the rumen. However, condensed tannins found in these browse shrubs bind proteins in the feeds making it unavailable for absorption by animals. Previous research studies by Kyuma (2013) indicated higher tannin levels of 180 mg/g, with a protein precipitating capacity of 12.6% in *P. juliflora* leaf meals. Processing of the *P. juliflora* leaves by drying under shade prior to feeding to livestock has been shown to reduce the tannins concentration (Tewari et al., 2000). The dependent variables were highly significantly influenced by the treatment effects (Appendix 8).

The significance of the independent variables (Test diets T₁, T₂, T₃ and T₄ was found to be $p<0.001$ which is less than 0.05 (Table 4.10). This evidence implies that the null hypothesis (H₀₃) cannot be supported in this study. The effect of Cactus and *Prosopis juliflora*-based mixed rations on the performance of Red Maasai weaner lambs was significantly different ($p<0.05$) compared to that of the control diets T₁ (*C.iliaris* hay).

The highest dry matter (DM) content (87%) was observed in the control diets (T₁ (*C.iliaris*), while the lowest value (70%) was recorded in T₄ (*Prosopis juliflora* pods-based rations). These findings on the nutrient composition of the test diets were slightly lower than those reported by Bell et al. (2016) who recorded DM content of up to 92% in diets with potential for reducing enteric methane production in ruminants. On the other hand, ash content varied among the

formulated treatment rations, either with or without any form of a protein source. The level of ash content in various feed sources is an indication of mineral content in those feeds (Van Soest & Robertson, 1985). However, according to Ben Salem and Louhaichi (2014), high content of ash in forages can also be an implication of low energy that is available in those feeds. The variation in ash content among treatments in this study could also be attributed to growth stages of the basal forages at harvesting (FAO-ICARDA, 2017; Karimi & Ungar, 1986). The *C. ciliaris* hay was advanced in maturity, while the spineless Cactus (*Opuntia ficus indica*) and *Prosopis juliflora* were freshly harvested.

The crude protein (CP) of *Prosopis juliflora* pods-based feed ration was within the range of 13 and 19%, comparable to the commercial concentrate feeds available in the market (Kyuma, 2013). The relatively high CP values in T₃ (*Prosopis juliflora* leaf meal-based ration) and T₄ (*Prosopis juliflora* pods-based ration) appeared satisfactory for animal production since they exceeded the minimum protein level of 7-8% required for rumen microbial cell synthesis required mainly for maintenance (Ben Salem & Louhaichi, 2014), and 12% CP content required for milk production and growth (Ben Salem et al., 2010; Jafari et al., 2015; Kholif et al., 2016). This is an implication that these feeds are effective nutrition wise, and can be used as supplementary feed for livestock in the rangelands. They can therefore be used as an adaptation strategy to climate change vulnerability with respect to deterioration of feed quality in rangelands. However, the CP content of the control diet (T₁ (*C. ciliaris* hay) was lower than the minimum levels of 7-8% required for optimum rumen function for maintenance in ruminant animals. According to Mostafa et al. (2016), forage feeds with a CP content lower than 7% require a supplementation of nitrogenous feed source to improve their intake and digestion by the ruminants.

Cenchrus ciliaris hay had the highest recorded levels of Neutral detergent fibre (NDF) Neutral detergent fibre (NDF) consists of mainly structural components (Cellulose, hemi-cellulose and lignin), which increases as the plant matures (Bell et al., 2016; Preston, 1986). These findings are also supported by Ben Salem and Louhaichi (2014) who reported significant increase in cellulose and hemi-cellulose in forages at different harvesting intervals. The NDF content of all the experimental diets were above the critical value of 60%. According to Kholif et al. (2016), a NDF content in forage feeds above the critical level (60%) decreases voluntary feed intake, feed conversion efficiency and longer retention time of feeds in the gastro-intestinal tract in livestock.

Experimental rations formulated from pods of *Prosopis juliflora* (T₄) gave the highest dry matter intake among all the treatment diets. Previous research findings by Kyuma (2013) showed that *Prosopis juliflora* pods and their seeds had the highest CP content that ranged from 25 to 35%. Therefore, the recorded higher DM intake in experimental animals receiving T₄ rations was possibly associated with the high CP content found in this treatment, which could be linked to the observed high digestibility of rations formulated from *Prosopis juliflora* pods. Leng (2005) documented that rumen microorganisms require the Nitrogen present in the crude protein which they use to synthesis their own microbial cells. In such as scenario, they are multiplied in their numbers, which in turn enable them to degrade feeds with high structural components in their rumen, a factor which enhances the digestibility of these lignified feeds. The current study implies that feed intake is compromised when poor quality feeds are used as basal feeds without supplementation, a factor that can reduce livestock productivity.

Generally, protein supplementation significantly ($p < 0.05$) increased faecal output. The higher faecal output of animals in T₄ (*Prosopis juliflora* pods-based ration) was likely to have been attributed to the high CP content of 188 g kg⁻¹DM of these feeds as compared to 63 g kg⁻¹DM recorded in the control rations (T₁). These findings are similar to previous studies by Bengaly (1996) who found improvements in feed intake due to protein supplementation to animals given maize stovers as basal diet. Efficient feed digestibility improves rate of feed passage in the gastro-intestinal tract, thereby creating room for more rumen filling via intake, and subsequent faecal output (Ben Salem & Louhaichi, 2014; Ben Salem et al., 2010; Tolera & Sundstol, 2000a).

Current findings as depicted by the study showed that *Prosopis juliflora* pods-based rations led to decreased nitrogen output in the faecal material. Under normal circumstances, the results obtained were not as expected, as the feed that are supplemented with more proteins are expected to produce more faecal nitrogen. The higher levels of feed intake of this test diet (T₄) may have contributed to the reported increase in faecal nitrogen in this study. Additionally, the efficiency of nutrient utilization (nitrogen budget) is enhanced by optimum feed supplementation (upto 19% CP) with a more balanced diet, thus supplying the ruminal microorganisms with nutrient for the synthesis of self cells (Leng, 2005). Therefore, considering this, there is no wastage of excess nitrogen to the environments, as all will be utilized by rumen microbes for production of microbial protein. The formulated test diet (T₄) had acceptable optimum CP levels of 19%, implying that there was no nutrient (nitrogen) wastage in dung, thus the reduction in the faecal nitrogen in this test ration (T₄).

The current research results can also be supported by the fact that T₄ diet encouraged a high intake of dry matter (DM), coupled with high percentage of nutrient digestibility and nitrogen retention, with subsequent availability of more nutrients for tissue deposition. This was an indication that diet T₄ was the best bet ration that was well balanced nutritionally, that encouraged higher absorption of ingested nutrients efficiently. These findings are supported by reports by FAO-ICARDA-ISHS (2017) which showed that lambs fed on straw supplemented by Cactus (*Opuntia ficus indica*) and saltbush (*Atriplex numularia*) grew at a rate of 80 g per day, with a higher nitrogen balance as comparable to conventional feed resources such Rhodes grass hay. However, nitrogen imbalance (that was negative) was recorded when feeding process of the livestock with the stovers of maize was done without supplementing (Tolera & Sundstol, 2000b). Nitrogen excretion in the faeces was significantly influenced by protein supplementation, with reduced values of Nitrogen excretion observed in T₄ (Table 4.10).

This is supported by the fact that protein nutrition in ruminants provide minimum amounts of dietary crude protein (CP), and also adequate amounts of ruminally degraded protein (RDP) for optimal ruminal efficiency and microbial CP production. This in turn enhances feed digestibility intake and absorption of nutrients, with minimal excretion of vital nutrients such as Nitrogen when supplemented optimally (without over-supplementation (Leng, 2005). Over-supplementation of animals with more nutrients (such as CP and minerals) than body requirement has been reported to lead to excretion of the excess nutrients to the environment, thus leading to an adverse environmental degradation.

A maximum Neutral detergent fibre (NDF) requirement for a ruminant animal is 50-60% (Ben Salem & Louhaichi, 2014; Ben Salem et al., 2010). As reported in the current study, supplementation of the basal diet of *C. ciliaris* with Cactus and *Prosopis juliflora* pods significantly increased the NDF digestibility *in vivo*. These research findings are supported by Smith et al. (1989) who revealed that legume contains high amounts of Nitrogen content, which in turn enhanced the intake of maize stovers in ruminant diets. Nitrogen supply to the rumen improves the microbial population such as fibrolitic bacteria, which degrade fibre fractions in the rumen, a factor besides the increase in NDF digestibility in the current study (Leng, 2005). Neutral Detergent Fibre (NDF) degradability was significantly different in *Prosopis juliflora* pods and *Prosopis juliflora*-based leaf meals supplementation. This is attributed to more anti-nutritional factors present in *Prosopis juliflora*-based leaf meals (Kyuma, 2013).

Neutral-detergent fibre (NDF) consists of the major structural components in plant cells viz cellulose, hemicellulose and lignin. Acid detergent fibre (ADF) refers to the cell wall portions

of the forage that are made up of cellulose and lignin (Ben Salem & Louhaichi, 2014). The levels of ADF and NDF are critical because they impact animal productivity and digestion. In forages, NDF has a strong correlation with total organic matter digestibility and estimations of energy (MJ). As forages become more mature, structural components (NDF, ADF and lignin) increases, which in turn decreases their digestibility and intake by livestock. This is the underlying reason for ensuring that only the highest quality forages are fed to livestock. Fibre fractions have been reported to have negative correlation on feed digestibility and intake (Ben Salem & Louhaichi, 2014). Animals will consume less feeds as NDF in the forage increases, mainly due to low digestibility and slow rate of rumen turn over, with subsequent reduction in animal performance.

A maximum recommended NDF requirement for ruminant livestock is approximated at 50-60% (Ben Salem & Louhaichi, 2014; Ben Salem et al., 2010). Supplementation of *C. ciliaris* as basal diet with formulated rations containing graded levels of Cactus and pods of *Prosopis juliflora* significantly enhanced the NDF digestibility *in vivo*. This is scientifically supported by Smith et al. (1989) who documented an increase in Nitrogen content obtained from legumes supplementation to cattle, which in turn gave the highest intake of maize stover based basal diets. Optimum supply of Nitrogen and energy to the rumen improves the microbial population such as fibrolitic bacteria and their associated enzymes, which in turn degrade fibre fractions in the rumen, a factor responsible for the increase in NDF digestibility reported in this current study (Leng, 2005). The high energy levels in the Cactus (*Opuntia ficus indica*) and in the *Prosopis species* pods (outer layer) is linked to this increase NDF digestibility *in vivo*, where microbial cells use both energy and nitrogen to synthesis their cells, without which would compromise on feed intake and digestibility.

Unexpectedly, a higher *in vitro* DM digestibility was observed in the test diets containing spineless Cactus (T₂) than in T₃ (Rations containing dry leaf meal of *Prosopis juliflora*). High condensed tannins in *Prosopis juliflora* leaves have been reported in previous studies (Kyuma, 2013). Condensed tannins found in browse trees and shrubs form complexes with plant proteins which affect the activity rumen microorganisms, with subsequent reduction in their efficiency of fibre degradation processes in the rumen. Research findings by Kaitho (1998) indicated that condensed tannins bind the protein from digestion in the rumen and the small intestines, thus making it unavailable for absorption in the lower gut of animals. However, sun drying of tanniferous foliage from the browse plants has been reported to reduce the levels of tannins in these feeds (Jafari et al., 2015; King'ori et al., 2011; Koech et al., 2011).

Cactus (*Opuntia ficus indica*) has been utilized in the supplementation of low-quality forage feeds, for instance the straws and pastures (Costa et al., 2012). There is important positive effect when supplementation is done by other plant sources with higher sources of protein for instance the *Prosopis juliflora* (Costa et al., 2012). As per the study, the results were in agreement with research findings by Tegegne et al. (2007) in which they concluded that total dry matter (TDM) intake in lamb receiving pasture hay and Cactus increased up to 26% higher than in lamb fed on pasture hay alone.

Feeds that are rich in soluble carbohydrates for example the cactus and the molasses increase the palatability of the feed and improve the process of fermentation in the animal rumen, which in turn leads to improved diet intake and digestibility. Based on what the different diets contain or have, feeding Cactus (*O. ficus indica*) resulted in increased apparent organic matter (OM) digestibility. Studies conducted by Abidi et al. (2009a); Ben Salem et al. (2004); Costa et al. (2012); Gebremariam et al. (2006) and Tegegne et al. (2007) reported that there was increased OM diet digestibility recording the increase to be approximated to be 10 percentage in lambs receiving Cactus-based feed rations compared with Cactus-free diets. This could have been attributed by the increase in the fermentation process undergoing in the rumen. When Cactus is given to the lambs as supplement feed for those fed with pasture or teff straw, it caused a reduced digestibility in the apparent protein (crude) present in the diets. Gebremariam et al. (2006) concluded that the increased Cactus supplementation in the diets increased the amount of tannins in the feed and reduced the availability of the CP, and hence affecting the digestibility negatively. Studies have shown that tannins that are condensed have great affinity of the protein and hence hindering their availability to the microbes present in the rumen, and also to the livestock consuming the feed.

Report by Costa et al. (2012) reported that there was an elevated amount of digestibility in dry matter of approximately 13 percent in the diet of lambs when 50 percent of the Cactus was included. Souza et al. (2009) recorded values of 77 -80 percent in protein digestibility which were higher for the bucks being fed on *Cynodon grass species* hay, soybean husks and Cactus feeds. Ben Salem et al. (2002b); Gebremariam et al. (2006) and Misra et al. (2006) indicated that cactus had a positive impact on the digestibility of the NDF recording an elevation in the digestibility of NDF by in the 20-percentage ration containing cactus in comparison to the cactus free ration as control in the weaner lambs feeding. Research findings by Tegegne et al. (2007) indicated that Cactus (*Opuntia ficus indica*) supply had no negative effect on diet digestibility and intake of Cactus-based rations. Enhanced nutrient digestibility implies that

more nutrients are absorbed in to the animal system, than those released to the environment in form of GHGs such as methane (CH₄) and Carbon dioxide (CO₂).

Similar results were reported by Rubanza et al. (2003) who documented a low NDF digestibility below the recommended minimum (<50%) in *Prosopis* leaf meal, which concurred to the low *in vitro* DMD reported in the current study and that of *A. nilotica*. The high levels of anti-nutritional factors in form of condensed tannin and their interaction effects on feed digestibility can be the contributing factor to the observed low *in vivo* and *in vitro* DM digestibility in *Prosopis* leaf meals (Rubanza et al., 2003). According to Leng (2005), the recommended NDF digestibility should be 50% and above for ruminants, However, the control ration (T₁) recorded which is far below the recommended levels (>50%). The low nutritive quality of most roughages, crop residues and pasture grass hays viz *C. ciliaris* has a link to the low crude protein (CP) and the low NDF digestibility documented in this current study. The high proportion of fibre content recorded in the control diet (T₁) can be associated to the the low digestibility reported in this study (Table 4.10).

Reports by Fonseca et al. (1998) clearly defined the relationship between fibre fractions and the efficiency of feed digestibility. The portion of dry matter in a feed that is digested by animals at a specified level of feed intake is referred to as dry matter digestibility (DMD). This study showed a significant positive effect of spineless Cactus and *Prosopis juliflora* (as source of energy and protein respectively) supplementation on digestibility levels of DM. The relationship between digestibility and intake is linked to the quality of feeds offered to the animals. According to Hicks et al. (1990), the digestibility of feeds and their intake is inversely related when it comes to high quality feeds. However, the digestibility of feeds and their intake is directly related in in roughage feeds of low quality. For instance feed resources containing less than 7% CP generally do not support optimum rumen fermentation. The concentration of neutral detergent fibre (NDF) in forage-based diets is considered to be the main dietary factor limiting their intake. On the other hand, intake and digestibility are not optimum when forages contain low CP and high fibre content (Fonseca et al., 1998).

Additionally, animals consuming poor-quality forages do not obtain sufficient nutrients from their diet to meet maintenance requirements (Hicks et al., 1990). Therefore the low intake observed in the control diet (T₁) in this study was mainly attributed to its low digestibility. However, it was recorded that there was higher amount of ash content in the control diets as compared to the diets that were treated. Ash content in feeds is an indicator of the available

minerals in that feed (Arieli et al., 1989), and may also have been a contributing factor to the reported low digestibility in the control diet (T₁) in this study.

According to Ben Salem and Louhaichi (2014), the high levels of soluble salts in the plants mean that there is a low digestible organic matter in the dry matter so that animals still need to consume high levels of DM to meet their energy requirement (Masters et al., 2006; Norman et al., 2009). Research findings by Arieli et al. (1989) showed that high levels of salt can limit feed intake such that animals may not be able to eat enough energy to maintain their live weight. Further, high salt incurs a metabolic energy cost to process and can lower the efficiency of digestible energy (DE) to metabolizable energy (ME) by up to 10% (Arieli et al., 1989; Masters et al., 2006).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- i. From the findings of this study, there are indications that plausible pathways for the search of better livestock feeding practices in feed-constrained environments take into consideration socio-economic factors such as age, gender and literacy levels that can enhance the adoption of the existing sustainable climate change risks management strategies
- ii. Based on results in this study, the high CP content in young cladodes of *Opuntia ficus indica* as well as *Prosopis juliflora* shoots and pods authenticate the value of underutilized drought-resilient forages as alternative supplementary sources of feed for livestock in the truncated landscapes of Kenya.
- iii. As evidenced in this study, acceptable DM intake, nitrogen retention and nutrient digestibility (*in vivo* and *in vitro*) were achieved with supplementing *Cenchrus ciliaris* hay with rations formulated from combinations of Cactus (*Opuntia ficus indica*) and *Prosopis juliflora* as potential climate smart forages.

5.2 Recommendation for Management Action

- i. Socio-economic factors such as literacy levels, gender mainstreaming and capacity for technology uptake by pastoral and agro-pastoral communities should be addressed through policy frameworks to enhance sustainable and climate resilient livestock production systems in dry lands of Kenya.
- ii. Cactus species cladodes and fruits and *Prosopis juliflora* pod and leaf meals are ideal non-conventional feedstuffs, and are recommended as alternative feed resources for substituting scarce and expensive conventional protein and energy feed sources in Kenya's dry lands.
- iii. Promotional and awareness creation campaigns of Cactus species and *Prosopis juliflora*-based home-made rations (TMRs) formulations through on-farm demonstrations, capacity building, value addition and conservation of these

invasive tree species as supplementary feed for livestock during severe drought periods is recommended.

5.3 Recommendation for Further Study

- i. Both spiny and spineless Cactus are found in Kenya. There is need therefore for an exploratory cross-sectional survey to identify and characterize all the *Opuntia species* and varieties available in Kenya and database created.
- ii. The agronomic requirements of Cactus (*Opuntia ficus indica*) and *Prosopis juliflora* should be determined and agricultural value chain established in order to enhance adoption of feed-based rations of these species. The anti-nutritional factors in Cactus (*Opuntia ficus indica*) and *Prosopis juliflora* at different stages of growth and various physiological parts should also be determined in future research work
- iii. The effect of the effects of Cactus and *Prosopis species*-based rations on consumer acceptance and quality of the resultant products such as meat and milk need to be evaluated in future studies.

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APPENDICES

Appendix 1: Household Baseline Survey Questionnaire

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My name is Margaret Syomiti, a PhD student of Egerton University carrying out a study to quantify the vulnerability of pastoral and agro-pastoral livestock production systems to climate change risks, and the local coping mechanisms employed by the rural communities. We are interviewing people focusing mainly on climate change risks and vulnerability on livestock production systems in pastoral and agro-pastoral systems. The purpose of this questionnaire is only for academic and we would appreciate if you would participate in the survey. We assure your responses will be held strictly in confidence. If there are questions related to this study, please you can ask or contact the above mentioned person.

Name of the enumerator: _____

Affiliation: _____

Mobile number: _____

SECTION 1: Identification of the Farm and the Site.

1. Questionnaire serial No. _____	Date: _____
2. Farmer's name: _____	
1. County: _____ <i>Baringo</i> [1] <i>Laikipia</i> [2] <i>Nyeri</i> [3]	
2. Division: _____ [1.1] [1.2] [2.1] [2.2] [3.1] [3.2]	
3. Sampling point (GPS Location): _____	

SECTION 2: Respondents' Personal Data

Respondent Gender	Age	Occupation	Education Level	
[1] Male	18-35 [1]	[1] Farmer (crops	[1] Did not attend school	
[2] Female	36-45 [2]	[2] Farmer	[2] Lower primary	
	46-55 [3]	(livestock)	[3] Upper primary	
	56-65 [4]	[3] Farmer (Both)	[4] Adult education	
	66-75 [5]	[4] Civil servant	[5] Secondary	
	76+ [6]	[5] Pastoralists		

		[6] Herdsmen [7] Business [8] Fishing	[6] Technical College [7] University [8] Post graduate [9] <i>Other (Specify)</i>	
Marital Status <i>(Tick one)</i>		Type of Household	Major Sources of Agricultural information (Rank 1-8) (1=most important (8=least))	
[1] Single [2] Married [3] Widowed [4] Divorced		[1] Female Headed [2] Male headed [3] Child headed	Newspaper Television Radio Extension NGOs Elders Chiefs' barazas Others	
Type of Agricultural information useful to farmers		Information Access [1] Highly accessible [2] Fairly accessible [3] Not all	Information Use [1] not at all [2] sometimes [3] Use it immediately I learn about it (Always)	Information Access by Gender [1] Man [2] Woman [3] Youth boy [4] Youth girl [5]
[1] Livestock farming				
[2] Crop farming				
[3] Fodder conservation				
[4] Pasture & Fodder production & Management				
[5] Agro-meteorological information				
[6] Agro-forestry				
[7] Soil & Water conservation & management				
[8] Climate change				
Literacy level	Place of birth		Have you attended any of the following agriculture-based trainings? Short courses in:	
Are you able to read and write? [1] YES [2] NO If YES, in which language? [1] English	Were you born in this location? [1] YES [1] NO		[1] Agriculture/crops [2] Agriculture/animals [3] Farmer Field schools [4] Water conservation [5] Agro-forestry [6] Other [specify	

[2] Kiswahili [3] Local language [8] All of above [4] [9] Other (specify-----	If NO, where? -----	
---	-------------------------------	--

SECTION 3: HOUSEHOLD STRUCTURE AND FARM LABOUR USE

3.1. How many persons reside in the household according to their age groups and sex ?

Give numbers

Gender	0-5 yrs [1]	6-11yrs [2]	12-17 yrs [3]	18-35yrs [4]	36-60yrs [5]	>60yrs [6]	Total
Males							
Female							

3.2. How many persons in the household are involved in farming activities according to age group and sex? Give numbers [1] [2] [3] [4] [5] [6] [7] [8] [9] [10]

Gender	6-11yrs [1]	12-17 yrs [2]	18-35yrs [3]	36-60yrs [4]	>60yrs [5]	Total
Males						
Female						

3.3. How many people in this household fall in the following level of education categories? (Tick as above)

Gender	No formal education/did not attend schools	Primary	Secondary	Colleges	University	Madrassa	Total
Males							
Female							

SECTION 4: ECOLOGICAL AND STRUCTURAL ISSUES

4.1. How long have you lived here?

[1] Less than 5 yrs [2] 5-10 yrs [3] 11-15 yrs [4] 16-20 yrs [5] Over 20 yrs [3] Born here

4.2. Do you stay here permanently?

[1] YES [2] NO

4.3. If no, how is your stay?

[1] Semi permanent (Household stays, animals and herds men move)

[2] Nomadic (Animals and whole household move)

4.4. Who moves (Mobility?)

[1] Whole households and animals [2] Men and animals [3] Herd boys/morans and men

4.5. Why do you move?

[1] Search for pastures [2] Conflicts [3] Search for water [4] Search for larger pieces of land

[5] Culture [6] Disease outbreak [7]. Others (specify).....

4.6. Main Economic activities in the household by Gender

	Man [a]	Woman [b]	Youth boy [c]	Youth girl [d]
1. Formal employment				
2. Business				
3. Livestock farming				
4. Crops farming				
5. Fishing				
6. Social worker				
7. Hired labourer				
8. Other (specify)				

SECTION 5: HOUSEHOLD LAND OWNERSHIP AND USE (TENURE)

How is the land ownership in this household?

[1] Communal [2] Privately owned

5.3. Proportion of land under the following:

Forages/pastures [] Food crops [] Cash crops [] Vegetables []. Others (specify) []

Tick one (Of the total land owned) 3/4 [1] 1/2 [2] 1/4 [3] 1/8 [4] Whole [5]

SECTION 6: LIVESTOCK INVENTORY, HERD STRUCTURE AND FEEDING BY GENDER

6.1. What type of livestock do you keep on the farm and ownership by gender? (Rank them in order of importance)

(Rank from 1=most important to 5=least important)

SPECIES/TYPE	RANK					Ownership by Gender			
	1	2	3	4	5	Man	Wife	Boys	Girl
a. Local cattle	[]	[]	[]	[]	[]	[]	[]	[]	[]
b. Exotic cattle	[]	[]	[]	[]	[]	[]	[]	[]	[]
c. Sheep	[]	[]	[]	[]	[]	[]	[]	[]	[]
d. Local Goats	[]	[]	[]	[]	[]	[]	[]	[]	[]
e. Dairy goats	[]	[]	[]	[]	[]	[]	[]	[]	[]
f. Local chicken	[]	[]	[]	[]	[]	[]	[]	[]	[]
g. Exotic chicken	[]	[]	[]	[]	[]	[]	[]	[]	[]
h. Pigs	[]	[]	[]	[]	[]	[]	[]	[]	[]
i. Rabbits	[]	[]	[]	[]	[]	[]	[]	[]	[]
j. Others (specify-----)									

6.1.1. Indicate the numbers of the 3 top most ranked animal species.

[] 1-5 [] 6-10 [] 11-20 [] 21-30 [] 31-40 [] 41-50 [] 51-500 [] <100

6.2. Main livestock feeding systems

Extensive grazing [1] Semi-intensive [2] Intensive [3]

SECTION 7: CLIMATE CHANGE AND FEED RESOURCES AVAILABILITY, PRODUCTION AND UTILIZATION

7.1. What are the MAIN livestock feed resources available in this region? (Rank them 1-5 with 1 most important and 5 least important)

[1] Native pasture grasses

[2] Improved pastures

[3] Planted forages

[4] Tree shrubs (*Acacia spp. prosopis* etc)

[5] Crop residues

[6] Purchased feeds ([i] Hay [ii] crop residues [iii] planted forages, [vi] silages)

[7] Conserved feeds ([i] Silage [ii] Hay)

[8] Others (specify)

7.2. Do you practice livestock-crop integration farming system?

YES [a] NO [b]

7.3. If YES to above, what are the main crops grown?

Cereals: i. Maize ii. Sorghum iii. Millet iv. Oats v. Wheat vi. Rice vii. Barley viii. Others (specify)-----

Legumes: i. Beans ii. Cowpeas iii. Pigeon peas iv. V. Dolichos vi. Others specify-----

7.4. What are the MAIN USES of the crop residues from the above crops?

[a] Livestock feed [b] Mulch [c] Fuel [d] Building material [e] Sell [f] Others (specify) [g]

7.5. What are the main constraints associated with livestock keeping in this area?

(Rank as above 1-7)

[1] Lack of water

[2] Lack of Feeds

[3] Diseases

[4] Cattle raids

[5] Wildlife

[6] Fire outbreaks

[7] Others (specify)-----

7.6. Please comment on the current weather conditions

[1] Reliable

[2] Not reliable

[3] Do not understand it

SECTION 8: LOCAL CLIMATE CHANGE ADAPTATION STRATEGIES

8.1. How do you cope with changes in water/vegetation/pasture/livestock resources in times of floods and drought with respect to livestock feeds and feeding?

Impacted Resources	Coping mechanisms	
	1. Floods	2. Drought
1. Water	[a] Migrate [b] Water harvesting [(i) wells, (ii) ponds, (iii) tanks, (iv) dams] [c] Do nothing	[a] Migrate [b] Long distance walks [c] Obtain water reliefs [d] Use conserved waters during plenty [e] Do nothing
2. Vegetation	[a] Tree planting [b] Bush burning [c] Tree clearing [d] Do nothing	[a] Prevent tree cutting (laws) [b] Prevent bush burning [c] Do nothing

3. Pastures/Fodders	[a] Conserve feeds- Hay [b] Conserve feeds- Silage [c] Sell feeds [d] Donate feeds to others [e] Do nothing	[a] Migrate [b] Feed reliefs [c] Buy conserved feeds (Hay, crop residues) [d] Use my conserved feeds [e] Sell conserved feeds [f] Collect ponds and leaves [g] Do nothing
4. Livestock	[a] Migrate [b] Sell animals [c] Slaughter to sell meat [d] Give gifts [e] Do nothing	[a] Migrate [b] Sell animals [c] Slaughter to sell meat [d] Give gifts [e] Change livestock species [f] Temporally stay in friends [g] Get feed reliefs

9.0 Climate Change Improved Livestock Adaptation Strategies

Improved Adaptation Strategies	Adopted?		Reasons for not adopting (If NOT adopted) [1] Lack of know-how [2] Lack of awareness [3] No enough forages [4] Labour intensive [5] Lack of capital [6] Any other (Specify)
	[1] YES	[2] NO	
[1] Fodder Conservation-Hay			
[2] Fodder Conservation-Silage			
[3] Standing hay			
[4] Paddocking			
[5] Improved fodder/pasture varieties			
[6] Change livestock species			
[7] Tree planting/Agro-forestry			
[8] Soil & Water management			
[9] Improved food crop varieties			
[10] Manure management			
[11] Livestock feed supplementation			
[12] Water harvesting			
[13] Balanced Feeding programs (TMRs)			

9.1. How do you cope with low quality of feed resources during drought period?

- [a] Buy feed supplements
- [b] Collect and Conserve supplements (ponds, leaves)
- [c] Make my own feed/ration formulation
- [d] No supplementation at all

9.2. Drought tolerant feed resources:

9.2.1. *Prosopis spp* (Mathenge); Do you know or heard about *Prosopis spp* (Mathenge)?

Yes [1] No [2]

9.2.2. If YES to the above, how do you perceive it? (Tick where applicable)

- [1] Noxious weed (Hurt animals, human, invasive, Aggressive)
- [2] Useful
- [3] Do not understand it
- [4] Government should eradicate it
- [5] Government should promote and encourage its utilization.
- [6] Any other specify.

9.2.3. Do you use it in any way? Yes [1] No [2]

9.2.4. If YES to above, explain how you use it? (Tick where applicable)

- [1] Livestock feed
- [2] Fuel (Charcoal, firewood)
- [3] Fencing
- [4] Any other (Specify)

9.2.5. Do you know or have you heard about Cactus?

Yes [1] No [2]

9.2.6. If Yes (above), which type?

- [1] Thorny/spiny [1] Thornless/spineless

9.2.7. Do you use it in any way?

Yes [1] No [2]

9.2.8 If Yes to the above, how? (Tick where applicable)

- [1] Livestock feeding [2] Fruits [3] Vegetables [4] Fence [1] Fuel

9.2.9. What are the limitations in its utilization?

- [1] Spines [1] Invasive weed [1] Presence of glochids in the fruits [1] Affects the health of our livestock and children

10.0. Manure management: How do you use your manure from your cattle?

- [1]. Often sell
- [2]. Heaping in the yard
- [3]. Give to friends
- [4]. Planting
- [5]. Fuel (Raw)
- [6]. Fuel (Biogas)

10.1. Are you a member of any social or agricultural group?

[1]	YES	[]
[2]	NO	[]

10.2. If yes name the group(s)-----

10.3. If so how often do you attend meetings?

[0]	Not a member	[]
[1]	Sometimes	[]
[2]	One a week	[]
[3]	More than once a week	[]

SECTION 11: ACCESS TO EXTENSION SERVICES

11.1. Do you usually visit extension offices to request for services?

Yes [1] No [2]

11.2. If no to the above, why?

- [1] Extension offices too far
- [2] Service charges too high
- [3] I have not thought of it
- [4] Others specify.....

11.3. Perceptions of Scientific Weather Forecasts from Meteorological Departments

[1]	Not reliable	[]
[2]	Sometimes	[]
[3]	Always reliable	[]
[4]	Does not understand them	[]

SECTION 12: FARMERS NEEDS ASSESSMENT

12.1. Farmers Needs assessment with respect to Feeds and Feeding in the wake of climate change

Needs	Yes (1)	No (2)
1=Training and extension	[<input type="checkbox"/>]	[<input type="checkbox"/>]
3=Market outlets	[<input type="checkbox"/>]	[<input type="checkbox"/>]
4= Fodder conservation	[<input type="checkbox"/>]	[<input type="checkbox"/>]
5=Alternative feed resources		
6=Feed formulation	[<input type="checkbox"/>]	[<input type="checkbox"/>]

12.2. Finally, is there any thing else you would like to suggest which would improve the future of livestock in your location?

.....
.

THANK YOU VERY MUCH FOR YOUR TIME

Appendix 2: Checklist for Key Informants Interview

A study on vulnerability assessment of pastoral and agro-pastoral livestock production systems to climate change risks and the coping mechanisms in Baringo, Laikipia and Nyeri Counties.

Gender:----- [M] [F]

1. Who are the indigenous people of this area?
2. What kind of farming system do they practice? e.g Extensive livestock keeping, Semi-intensive, Intensive, Mixed-crop livestock farming etc
3. What are the main economic activities in this area?
4. What main constraints are facing farmers in this region in their farming activities?
5. What are the perceptions, knowledge/awareness and experiences with climate change in this area?
6. Are there on-going or ended project on climate change adaptation e.g Livestock insurance, feed reliefs etc? (By whom e.g NGOs, private partners etc).
7. How Prosopis species (Mathenge) is perceived in this area and how is it utilized?
8. Do you know a plant known as Cactus?
9. What species of Cactus are available in this area? (with spines, spineless)
10. How is it perceived in this area? (Noxious weed, Good)
11. What are the experiences in the utilization of Cactus in livestock feeding?
12. What are the main livestock species kept in this region?
13. What is the status of livestock marketing in this region?
14. What resources are available and at risk of climate change impacts? (Livestock, Crops, Water, Vegetation etc)
15. Are there organized and registered groups for men, women and youths?
16. With regards to climate change impacts, who can you, say is impacted most (men, women, youth or children? And why?
17. How is the government involved in addressing drought and flood disasters?
- 18. What is your advice on what needs to be done in order to address climate change related disasters on livelihoods?**

Appendix 3: Plates 3.1-3.6: *Opuntia ficus indica* and *Prosopis juliflora* as Potential Drought Tolerant Forage Species



Plate 3.1: *Prosopis spp* pods
(Source: Kyuma, 2013)



Plate 3.2: Spineless Cactus as feed in Marigat
(Source: Chirchir, Unpublished data)



Plate 3.3 & 3.4: Cactus fruits and cladodes as feed for livestock (Source: Ben Salem et al. et al., 1996)



Plate 3.5: Goats browsing on *P. juliflora* in Marigat. Plate 3.6: *Opuntia spp* sampling activity

Appendix 4: ANOVA Table for Nutrient Composition of Cactus (*Opuntia ficus indica*)

Variate: DM%	Source of variation	d.f.	S.S.	M.S.	F pr.	Sig
	Species	1	2.14	2.15	0.498	ns
	Plant parts	1	35.61	35.61	<.008	**
	Species.plant parts	1	0.54	0.54	0.733	ns
	Residual	48	220.55	4.65		
	Total	51	258.84			
Variate (CP%)	Source of variation	d.f.	S.S	M.S	F pr	Sig
	Species	1	5.88	5.88	0.382	ns
	Plant parts	1	78.99	78.99	<.002	**
	Species.plant parts	1	4.26	4.26	0.456	ns
	Residual	48	362.30	7.55		
	Total	51	451.44			
Variate (CF%)	Source of variation	d.f.	S.S	M.S.	F pr.	Sig
	Species	1	39.2	39.2	0.4	ns
	Plant parts	1	331.55	331.55	<.017	*
	Species.plant parts	1	8.34	8.34	0.697	ns
	Residual	48	2614.28	54.46		
	Total	51	2993.37			
Variate: EE%	Source of variation	d.f.	S.S	M.S.	F pr.	Sig
	Species	1	0.69	0.69	0.32	ns
	Plant parts	1	0.13	0.13	0.663	ns
	Species.plant parts	1	1.27	1.27	0.181	ns
	Residual	48	33.02	0.69		
	Total	51	35.11			
Variate: Ash%	Source of variation	d.f.	S.S	M.S	F pr.	Sig
	Species	1	6.25	6.25	0.332	ns
	Plant parts	1	18.56	18.56	0.098	ns
	Species.plant parts	1	5.83	5.83	0.349	ns
	Residual	48	312.41	6.51		
	Total	51	343.05			
Variate: NFE%	Source of variation	d.f.	S.S.	M.S	F pr.	Sig
	Species	1	74.49	74.49	0.309	ns
	Plant parts	1	295.29	295.29	<.046	*
	Species.plant parts	1	60.18	60.18	0.36	ns
	Residual	48	3381.24	70.44		
	Total	51	3811.19			

*Significance: * p<0.05, ** p<0.01, *** p<0.001*

Abbreviations: d.f= Degree of freedom, S.S=Sum of squares, M.S= Mean sum of squares, F.pr= p-value for F statistics, NDF: Neutral detergent fibre

Appendix 5: ANOVA Table for Nutrient Composition of *Prosopis Juliflora*

Variate: DM%	Source of variation	d.f.	S.S.	M.S.	F pr.	Sig
	Plant parts	5	46.27	9.25	<.001	***
	Residual	15	1.12	0.075		
	Total	20	47.39			
Variate: CP%	Source of variation	d.f.	S.S	M.S	F pr.	Sig
	Plant parts	5	599.99	119.99	<.001	***
	Residual	15	1.83	0.12		
	Total	20	601.81			
Variate: CF%	Source of variation	d.f.	S.S	M.S	F pr.	Sig
	Plant parts	5	5698.00	1140.00	<.001	***
	Residual	15	0.07	0.00		
	Total	20	5698.00			
Variate EE%	Source of variation	d.f.	S.S	M.S	F pr.	Sig
	Plant parts	5	288.64	57.73	<.001	***
	Residual	15	0.52	0.035		
	Total	20	289.15			
Variate: Ash%	Source of variation	d.f.	S.S	M.S	F pr.	Sig
	Plant parts	5	255.93	51.19	<.001	***
	Residual	15	3.04	0.20		
	Total	20	258.96			
Variate: NFE%	Source of variation	d.f.	S.S	M.S	F pr.	Sig
	Plant parts	5	3671.27	734.25	<.001	***
	Residual	15	1.11	0.074		
	Total	20	3672.37			

*Significance: * p<0.05, ** p<0.01, *** p<0.001*

Abbreviations: d.f.= Degree of freedom, S.S.=Sum of squares, M.S= Mean sum of squares, F.pr= p-value for F statistics, NDF: Neutral detergent fibre

Appendix 6: Correlation Analysis on the Nutritional Quality of Cactus (*Opuntia ficus indica* and *Prosopis juliflora*)

Prosopis juliflora

Correlations

N=20

	%NFE	Ash%	CF%	CP%	DM%	EE%
Ash%	-0.827***	1				
CF%	-0.909***	0.859***	1			
CP%	0.740***	-0.945***	-0.892***	1		
DM%	-0.050	0.277	0.437*	-0.502*	1	
EE%	0.164	-0.341	-0.551**	0.568**	-0.894**	1
Moist%	0.050	-0.277	-0.437*	0.502*	-1.000***	0.894***

*Significance: * p<0.05, ** p<0.01, *** p<0.001*

Abbreviations: NFE: Nitrogen Free Extract, CF: Crude fibre, CP: Crude protein, DM: Dry matter, EE: Ether extract

Cactus (Opuntia ficus indica)

Correlations

N=73

	%NFE	Ash%	CF%	CP%	DM%	EE%
Ash%	-0.156	1				
CF%	-0.819***	-0.208	1			
CP%	-0.613***	-0.202	0.394**	1		
DM%	0.064	-0.469***	0.410***	0.113	1	
EE%	-0.036	-0.291*	-0.125	0.161	-0.271*	1
Moist%	-0.064	0.469***	-0.410***	-0.113	-1.000***	0.271*

*Significance: * p<0.05, ** p<0.01, *** p<0.001*

Abbreviations: NFE: Nitrogen Free Extract, CF: Crude fibre, CP: Crude protein, DM: Dry matter, EE: Ether extract

Appendix 7: ANOVA Table for Treatment Ratios

Variate: Feed intake (g/d)	Source of variation	d.f.	S.S	M.S	F pr.	Sig
	Rep	3	7791	2597		
	Trt	3	460595	153532	<.001	***
	Residual	9	64886	7210		
	Total	15	533271			
Variate: Faecal output (g/d)	Source of variation	d.f.	S.S	M.S	F pr.	Sig
	Rep	3	11317	3772		
	Trt	3	238099	79366	<.001	***
	Residual	9	20311	2257		
	Total	15	269726			
Variate: Faecal-N excretion (g/d)	Source of variation	df	S.S	M.S.	F pr.	Sig
	Rep	3	0.90	0.30		
	Trt	3	2.69	0.89	<.001	***
	Residual	9	0.65	0.07		
	Total	15	4.23			
<i>In vivo</i> NDF digestibility (%)	Source of variation	d.f.	S.S	M.S.	F pr.	
	Rep	3	206.42	68.81		
	Trt	3	7330.11	2443.37	<.001	***
	Residual	9	223.92	24.88		
	Total	15	7760.44			
<i>In vitro</i> NDF digestibility (%)	Source of variation	d.f.	S.S	M.S.	F pr.	
	Rep	3	0.40	0.14		
	Trt	3	1003.07	334.36	<.001	***
	Residual	9	1.27	0.14		
	Total	15	1004.75			

*Significance: *p<0.05, **p <0.01, ***p<0.001*

Abbreviations: d.f= Degree of freedom, S.S=Sum of squares, M.S= Mean sum of squares, F.pr= p-value for F statistics, NDF: Neutral detergent fibre

Appendix 8: Correlations Analysis for Dependent Variables

Variate	IVDMD (%)	Faecal output (g/d)	DMI (g/d)	Faecal N excretion (g/d)	<i>In vivo</i> NDFD (%)
DMD <i>in vitro</i> _	-				
Faecal_output (g/d)	0.8507	-			
Feed intake (g/d)	0.7877	0.8808	-		
Faecal N excretion (g/d)	-0.77	-0.5701	-0.6069	-	
<i>In vivo</i> NDFD (%)	0.77	0.8763	0.8708	-0.6392	-

Abbreviations: IVDMD= in vitro dry matter digestibility, DMI= Dry matter intake, Faecal-N= Faecal Nitrogen, in vivo NDFD= in vivo Neutral detergent fibre digestibility

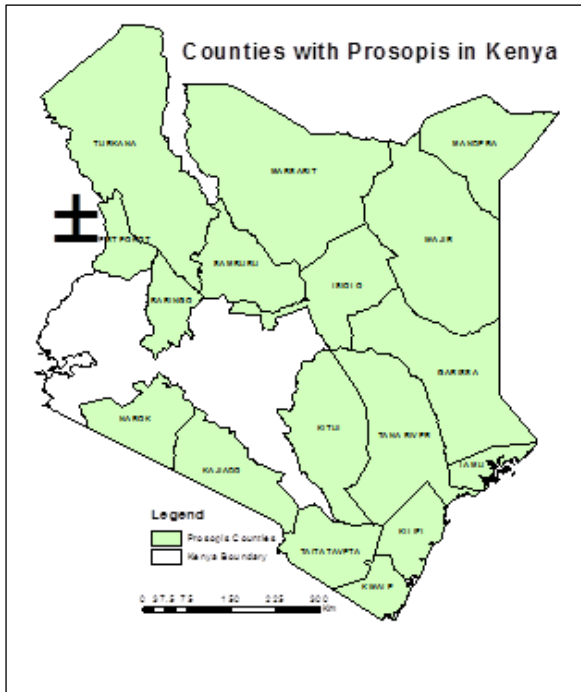
Significant test of the correlation matrix (*p*-values)

	IVDMD (%)	Faecal output (g/d)	DMI (g/d)	Faecal N excretion (g/d)	<i>In vivo</i> NDFD (%)
DMD <i>in vitro</i>	-				
Faecal output (g/d)	<0.001	-			
Feed intake (g/d)	<0.001	<0.001	-		
Faecal N excretion (g/d)	<0.001	0.0211	0.0127	-	
<i>In vivo</i> NDFD (%)	<0.001	<0.001	<0.001	0.0077	-

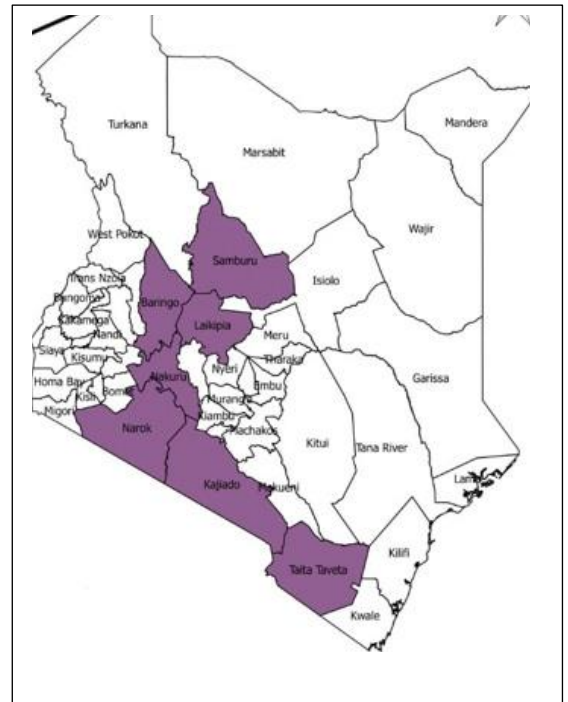
Significance: **p*<0.05, ***p*<0.01, ****p*<0.001

Abbreviations: DMD=Dry matter digestibility, NDFD= Neutral detergent fibre digestibility, g/d=grams per day, IVDMD= In vitro dry matter digestibility, DMI=Dry matter intake

Appendix 9: Major Areas covered with Cactus (*Opuntia ficus indica*) and *Prosopis juliflora* Invasions in Kenya







Prosopis juliflora level of invasions in Kenya in Kenya (Source: Kyuma, 2013)



Opuntia species invasions (Source: Githae, 2018).

Appendix 10: Research Permit from NACOSTI

 REPUBLIC OF KENYA	 NATIONAL COMMISSION SCIENCE, TECHNOLOGY & INNOVATION
Ref 98708	Date of Issue: /JANUARY 2020
RESEARCH LICENSE	
	
This is to Certify that Ms.: Margaret Mutenge of Egerton University, has been licensed to conduct research in Baringo, Laikipia, Nyeri on the topic: EVALUATION OF CACTUS (OPUNTIA FICUS INDICA) AND PROSOPIS JULIFLORA AS POTENTIAL FEED RESOURCES IN DROUGHT-PRONE AREAS OF KENYA for the period ending : 07/January/2021.	
License No: 98708	NACOSTI/P/20/2220 
Applicant Identification Number	Director
	NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY INNOVATION
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Appendix 11: Letter from the University

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OFFICE OF THE DIRECTOR GRADUATE SCHOOL

ND11/0387/13

Ref:

23rd September, 2019

Date:

The Director General
National Commission for Science Technology and Innovation,
P. O. Box 30623-00100
NAIROBI

Dear Sir,

**RE: REQUEST FOR RESEARCH PERMIT- MS. SYOMITI MARGARET
MUTENG'E REG. NO. ND11/0387/13**

This is to introduce and confirm to you that the above named student is in the Department of Natural Resources, Faculty of Environmental Science, Egerton University.

She is a bona-fide registered PhD student in this University. Her research topic is "Evaluation of Cactus and Prosopis species as Potential Feed Resources in Drought Prone areas of Kenya."

She is at the stage of collecting field data. Please issue her with a research permit to enable her undertake the studies.

Your kind assistance to her will be highly appreciated.

Yours faithfully,

25 SEP 2019


Prof. Nzula Kitaka
DIRECTOR, BOARD OF POSTGRADUATE STUDIES

"Transforming Lives Through Quality Education"

Appendix 12: List of Publications

Appendix 12.1 Publication 1 - Journal paper

www.ijird.com

May, 2021

Vol 10 Issue 5



ISSN 2278 0211 (Online)

Evaluation of Cactus (*Opuntia Ficus Indica*) and *Prosopis Juliflora*-Based Feed Rations on Performance of Red Masai Weaner Lambs in Kenya

Margaret Syomiti

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Elias K. Maranga (PhD)

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Gilbert O. Obwoyere (PhD)

*Associate Professor, Department of Natural Resources Management,
Egerton University, Kenya*

Abstract

The purpose of this study was to determine plausible pathways to combat feed scarcity and quality in dry lands using locally available and under-utilized feed resources. Red Maasai weaner lambs were blocked on the basis of body weight and physiological condition. The treatment diets included pure rations of *Cenchrus ciliaris* hay (control) and proportionally determined combinations of *P. juliflora* pod meal, spineless (*O. ficus indica*) Cactus leaf meal and *C. ciliaris* hay. Analysis of variance (ANOVA) methods were used to isolate significant treatment effects on Cactus and *P. juliflora* based feed rations. Coefficient of correlation was computed to assess whether there was relationship between the independent and dependent variables in the test rations. Sheep that received T₄ rations recorded the highest *in vivo* and *in vitro* nutrient digestibility (78 and 63% respectively). Faecal output was positively correlated to DM intake ($r^2=0.88$, $p<0.001$),

in vivo ($r^2=0.87$, $p<0.001$) and *in vitro* feed degradability ($r^2=0.87$, $p<0.001$). Faecal Nitrogen was negatively correlated ($r^2= -0.64$, $p<0.001$) to these values. The high dry matter intake, *in vitro* and *in vivo* DM digestibility of Cactus cladodes and *P. juliflora*-based supplementary rations authenticate their value as under-utilized drought-tolerant supplementary forages for livestock in the truncated landscapes of Kenya. Awareness creation and/or promotional campaigns of *Cactus species* and *Prosopis juliflora*-based homemade rations (TMR) formulations, on-farm demonstrations, capacity building, value addition and conservation of these invasive tree species as supplementary feed for livestock during severe drought periods is recommended in this current study.

Keywords: Drought resilience, feed resources, livestock, Climate change

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DOI No. : 10.24940/ijird/2021/v10/i5/MAY21005



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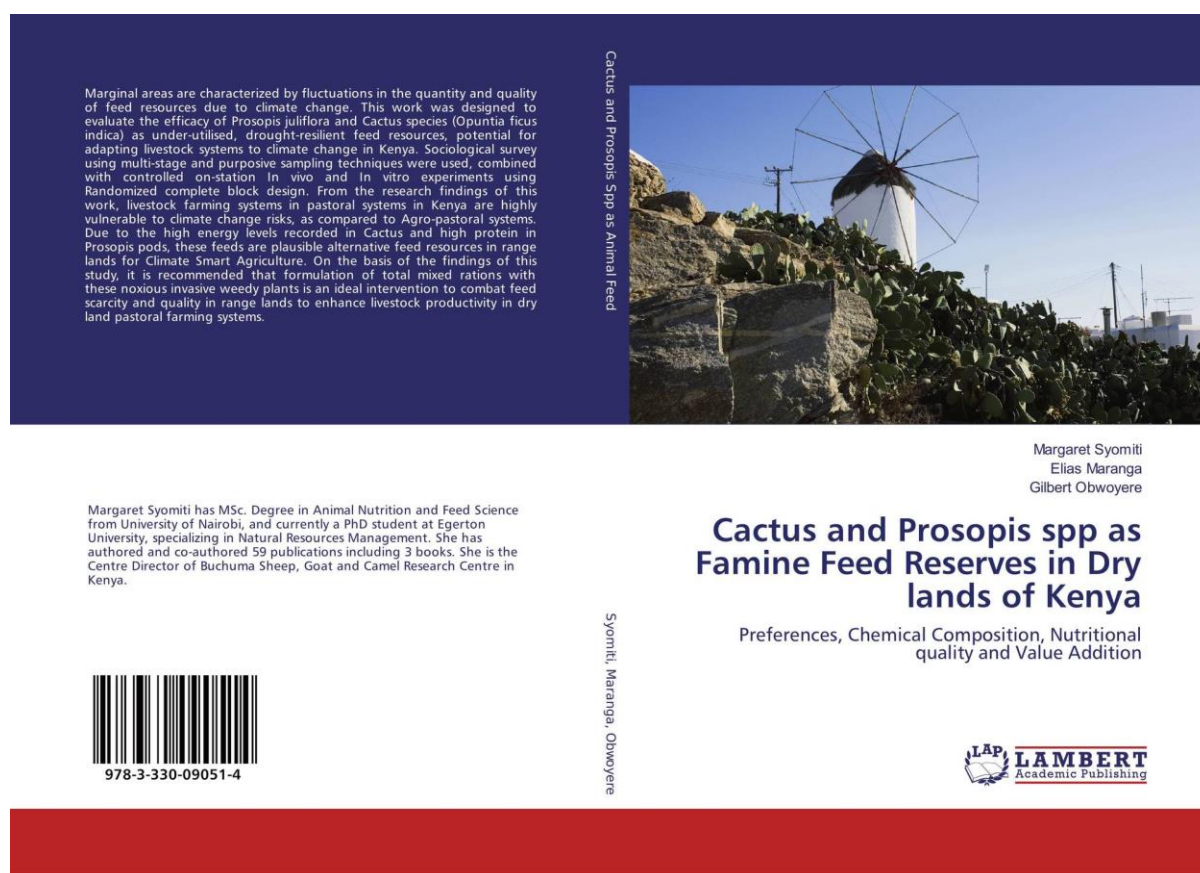
**Is hereby awarding this certificate to
Margaret Syomiti & Elias Maranga
In recognition of the publication of the paper entitled
Evaluation of Cactus (*Opuntia Ficus Indica*) and *Prosopis Juliflora*-Based Rations on
Performance of Red Masai Weaner Lambs in Kenya
Published in IJIRD Journal, Volume 10, Issue 5, May, 2021
DOI No. : 10.24940/ijird/2021/v10/i5/MAY21005**



S. S. Das

**Dr. S. S. Das
Editor In Chief**

Appendix 12.2: Publication 2 - Book



Margaret Syomiti has MSc. Degree in Animal Nutrition and Feed Science from University of Nairobi, and currently a PhD student at Egerton University, specializing in Natural Resources Management. She has authored and co-authored 59 publications including 3 books. She is the Centre Director of Buchuma Sheep, Goat and Camel Research Centre in Kenya.



978-3-330-09051-4

Cactus and Prosopis spp as Animal Feed

Syomiti, Maranga, Obwoyere

Margaret Syomiti
Elias Maranga
Gilbert Obwoyere

Cactus and Prosopis spp as Famine Feed Reserves in Dry lands of Kenya

Preferences, Chemical Composition, Nutritional quality and Value Addition



ISBN-13: 978-3-330-09051-4 ISBN-10: 3330090510 EAN: 9783330090514

Book language: English Blurb/Short text: Marginal areas are characterized by fluctuations in the quantity and quality of feed resources due to climate change. This work was designed to evaluate the efficacy of *Prosopis juliflora* and Cactus species (*Opuntia ficus indica*) as under-utilized, drought-resilient feed resources, potential for adapting livestock systems to climate change in Kenya. Sociological survey using multi-stage and purposive sampling techniques were used, combined with controlled on-station *in vivo* and *in vitro* experiments using randomized block design. From the research findings of this work, livestock farming systems in pastoral systems in Kenya were highly vulnerable to climate change risks, as compared to Agro-pastoral systems. Due to the high energy levels recorded in Cactus and high protein in *Prosopis pods*, these feeds are plausible alternative feed resources in range lands for Climate Smart Agriculture. From the finding of the study, it was recommended that it was appropriate during the formulation of the different feed ration to mix with the noxious weedy plants to curb the problem associates with the scarcity of feeds in the rangelands to enhance livestock productivity in these pastoral farming systems.

Publishing house: LAP LAMBERT Academic Publishing Website: <https://www.lap-publishing.com/>

By (author): Margaret Syomiti, Elias Maranga, Gilbert Obwoyere

Number of pages: 152

Published on: 2017-09-19 Stock: Available Category: Agriculture, horticulture, forestry, fishery, nutrition Price: 55.90 € Keywords: Climate Smart Agriculture, drought tolerant, Feed Resources, *Prosopis*, *Opuntia spp.*

Appendix 12.3: Publication 3 - Journal paper

[Livestock Research for Rural Development 27 \(12\) 2015](#)

[Guide for preparation of papers](#)

[LRRD Newsletter](#)

[Citation of this paper](#)

The Adaptive and Coping Strategies of Pastoralists to Climate Change in Baringo, Laikipia and Nyeri counties of Kenya

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Abstract

Fodder and pasture production has been low in most of the Kenya's rangelands as a result of low rainfall and unpredictable weather conditions. Sustainability of the pastoral livelihood has been threatened and interfered with by the frequent and unpredictable changes in the climatic conditions, characterized by erratic rainfall and prolonged droughts. Therefore, there is a need to design appropriate technologies that aid in enhancing the resilience of the rural communities to respond and adapt to the upcoming and existing harsh conditions. This study was aimed at elaborating and documenting different tactics and methods that the rural communities in the selected arid areas in Laikipia, Nyeri and Baringo counties in Kenya were adapting to different climatic changes and the mechanism they use in coping with the associated impacts. Findings of the study recorded that more than 60 percent of respondents from Laikipia County had not gone to school, while in Baringo and Nyeri 39 percent and 45 percent respectively had attended school. From the respondents in Nyeri County, 61 percent claimed that the feed scarcity was the main constraint in the rearing of the livestock, while 38 percent and 50 percent of the respondent in Baringo and Laikipia respectively mentioned water as the major challenge in these areas. Also, the findings showed that 97 percent of the respondent in Baringo and 64 percent from Laikipia, indicated that the main method they cope with harsh conditions such as floods and droughts is by migrating for their safety and in search of greener pastures. On the other hand, migration was not an option for the respondent (about 99 percent) in Nyeri County. For those in Nyeri, almost 67 percent, preferred harvesting water from the rain as a coping strategy to the adverse changes in climate. Looking into how the different respondents in the different counties adapted to the improved climatic change adaptation strategies, Nyeri County followed by the Baringo and then Laikipia County had the highest adoption rate of adoption.

Respondents in Nyeri (61%) used off-farm purchasing of animal feed supplements to cope with the lack of feed in the region, whereas in Baringo and Laikipia counties, supplements were not well used (43 percent and 44 percent respectively). Also, the study indicated that almost all the respondents from the County of Baringo were seeking agricultural knowledge from different sources for instance NGOs (100 percent), Newspapers (100 percent), *baraza* organized by chief (80 percent), television (80 percent) and others from the village elders (45 percent). In Nyeri County, most of the respondents (100 percent) obtained information on agricultural related issues from agricultural extension. In Laikipia, 42 percent obtained agricultural information from the elders in the villages. In conclusion, livestock farming still remained the back-borne of the livelihoods in Nyeri, Baringo and Laikipia counties. However, vulnerability of this economic activity to climatic changes was more in Baringo and Laikipia counties as compared to Nyeri County. Despite the fact that Nyeri County respondents had effective and efficient means of getting information on agricultural activities, the main challenge they faced was the the purchase of animal feeds off-farm which remain expensive and hard to sustain the livelihood among the individuals in the area.

Key words: Livestock, Feeds and Feeding, Drought resilience, Climate variability

Appendix 12.4: Publication 4 - Journal paper

Journal of Environment Natural Resources Management and Society (JENRS): 41-47, 2014

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Corresponding Author E-mail: syomitimargaret@yahoo.com

Chemical Composition of Cactus (*Opuntia ficus-indica*) and *Prosopis juliflora* as Drought-resilient Feed Resources in Kenya

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State

University, ⁴MARIL-Ethiopia

Abstract

One of the major threats that the pastoral communities face is lack of feeds that are of quality and enough for their livestock which in turn affect their livelihood negatively. Climatic changes have been seen to aggravate the problem of inadequate feeds and nutrient deficiencies in these feeds. Previous research work has shown that *Prosopis* and *Cactus species* are a potential alternative that can be used as feed in the pastoral areas since they are drought resistant. The aim of the study was to establish the effect of the *Cactus* and *Prosopis species* and their role as livestock feed in Kenya's ASALs. Different samples were collected from Nyeri, Laikipia and Baringo counties for the experiment. From the species, different parts of the plant were taken, sampled and various chemical analysis done. The samples taken from different parts of the plants included the ripe and unripe fruits, young and old plant leaves, young and mature barks, pods, dry and green leaves of *Prosopis juliflora* and Cacti species. They were analysed and the results recorded. For the mature and young cladodes of Cactus species, the dry matter was in the range of 158 to 180 g/kg for the spineless *Opuntia species* and 153 to 172 g/kg dry matter (DM) for the spiny *Opuntia species*. *Opuntia species* had a crude fibre range of 134 to 305 g/kg dry matter (DM) for spiny mature and young species. The spineless species of *Opuntia* were found to contain 254 to 323 g/kg DM range for both the mature and the young cladodes. As the *Opuntia* Species matures, the crude fibre was observed to increase with maturity. Also, the

Opuntia species were found to contain higher starch amounts. The mature cladodes recorded higher amount of starch as compared to the younger species. The spiny *Opuntia species* had higher starch content ranging from 61 to 243 g/kg DM (young and mature cladodes respectively) as compared to spineless *Opuntia species* which ranged from 61 to 95g/kg DM. The ripe fruits also recorded higher amount of starch as compared to the unripe ones (fruits). The unripe fruits had 136 g/kg DM while the ripe had 146 g/kg DM for the spiny *Opuntia species*. Higher ash content in the *Opuntia species* was observed in the mature cladodes (54 g/Kg DM) while younger cladodes recorded ash content of 39 g/kg DM. Similarly, bark from the mature *P. juliflora* recorded higher ash content of 144 g/kg in comparison to other parts of the plant. Seeds of *Prosopis juliflora* were found to have higher amount of crude protein (CP) approximating to 400 g/kg DM, and starch content of 129 g/kg DM. There were also higher records of crude protein in the green and the dry leaves (150 g/kg DM and 200 g/kg DM respectively). From the experiment, it was deduced that there was generally high content of crude proteins in the pods and leaf meals of *P. juliflora*, and higher amount of starch in the *Opuntia species*. With these findings, it can be concluded that the high energy and CP pools available in *P. juliflora* and *Opuntia species* can be used in the supplementation of livestock in the ASALs that have constant problem of protein and energy fluctuations, unpredictable climatic changes and frequent occurrence of severe droughts.

Key words: Feeds, Livestock, Climate change, Resilience, Adaptive capacity

Study on Nutritional Characterization of Cactus (*Opuntia ficus indica*) as Forage in Kenya's Rangelands

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Abstract

Under-utilization of the drought-resistant Cactus species (*Opuntia ficus indica*) and lack of realizing its potential as a supplement for livestock in Kenya's ASALs is indisputable. The study was aimed at determining plausible pathways that can aid in the process of getting alternative feeding innovations to curb scarcity of feeds while improving on their quality. It was also aimed at providing appropriate intervention techniques to be used in the adaptability of climate resilient livestock production systems. Due to the prevalence of Cactus (*Opuntia ficus indica*) in Nyeri, Laikipia and Baringo in the Kenya's ASALs, these areas were selected for the study. The qualitative changes in nutrient content of Cactus (*Opuntia ficus indica*) are hypothesized to be linked to anatomical characteristics, physiological condition as well as phenological stage of plant growth. Nutritional content of the Cactus (*Opuntia ficus indica*) was determined using proximate analysis for each sample collected on the farm. Data obtained was analyzed using SPSS and their variances analyzed using ANOVA which was meant for isolating the presence or absence of morphological and plant stage effect of growth and significant treatment effects on Cactus (*Opuntia ficus indica*) samples. The young spineless and spiny cladodes of Cactus had highly significant effect ($p < 0.001$) for the crude protein (CP) content (14.9%). Spineless and spiny (*Opuntia ficus indica*) Cactus were not ($p > 0.05$) different in relation to their nutritional content. Higher fibre content of approximately 32 percent was observed in the mature cladodes of spineless Cactus. The results showed that there was ($p < 0.05$) difference in the nitrogen free extract (NFE) content among the different parts of the plant. A percentage of 39.6% was seen in the ripe fruits of Cactus (*Opuntia ficus indica*) which was much higher as compared to other parts of the plants. With the higher recorded crude protein (39.6 percent) in the Cactus species and the ability of Cactus to withstand drought and other harsh conditions, this shows how the plant has great potential as an alternative supplementary feed in the Kenyan ASALs. Therefore, from the findings, the Cactus (*Opuntia*

ficus indica) fruits and the cladodes possess a great potential for livestock feeds and feeding. Despite the under-utilization of *Opuntia species* in Kenya, it has proved to be an alternative feed supplement that can substitute the expensive and unavailable conventional feed materials outsourced to aid in livestock feeding in the ASALs.

Keywords words: , *Feed resources, drought resilience, Changing climate, Opuntia spp*

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Subject: Acceptance letter for manuscript (2021/BP/2623F) as a book chapter of Cutting-edge Research in Agricultural Sciences (International Book)

Dear Colleague,

We are pleased to inform that your manuscript (Ref. no.2021/BP/2623F) entitled “**Study on Nutritional Characterization of Cactus (Opuntia ficus indica) as Forage in Kenya’s Rangelands**” is ACCEPTED for publication as a **book chapter in the following book:**

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Thanking you.

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