

**Effects of grazing and housing management systems on greenhouse gas
emissions, blood profiles and meat quality of Nguni goats**

By

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Declaration

I, **Allen Tapiwa Chikwanda**, vow that this dissertation has not been submitted to any university, and that it is my original work conducted under the supervision of Professor V Muchenje. All assistance towards the production of this work and all the references contained herein have been fully acknowledged. The research was approved by the University of Fort Hare Research Ethics Committee (Certificate number: MUC101SCHI01)



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Abstract

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The broad objective of this study was to evaluate the effects of grazing and housing management systems on greenhouse gas emissions, blood profiles and meat quality of Nguni goats. A total of 64 castrated Nguni goats were used and a housing structure was designed to accommodate the goats as well as evaluate effects of type of floor on greenhouse gases, meat quality, blood metabolites and fatty acid profiles.

In the first experiment: Forty eight castrated Nguni goats, at 6-7 months old were used for herding (H) or tethering (T) management systems and randomly allocated to pens with earth (E) or slatted (S) floors. Gas sampling was done using static chambers and analysed using a SRI 8610C gas chromatography machine. The highest CH₄ fluxes were from the manure of herded goats on earth floors (HE). The highest CO₂ fluxes were from manure of herded goats that were housed on slatted floors (HS): The highest N₂O fluxes were from the manure of tethered goats that were sheltered on slatted floors (TS). It was concluded from the first experiment that goat manure is an important source of GHG that is influenced by grazing and floor type management systems.

The second experiment was done to evaluate greenhouse gas (GHG) emission from disused (DP) vs occupied goat pens (OP) with earth (EF) or slatted (SF) floors. Eight previously occupied pens were used in this study. Sixteen goats were randomly put in the pens labelled occupied pens with earth floors (OPEF) and occupied pens with slatted floors (OPSF) resulting in four goats per OP. There were month by pen use; month by floor type; and use by floor type interaction effects ($P < 0.05$) on CH₄ production. Floor type, use (DP vs OP) and month affected ($P < 0.05$) CH₄ production. Manure on earth floors of occupied pens (OPEF) emitted the highest ($P < 0.05$) methane followed by earth floors of disused pens (DPEF). The least CH₄ was emitted from DPSF. There was pen use (DP vs OP) by floor type interaction effect ($P < 0.05$) on CO₂ emission. Floor type and pen use affected ($P < 0.05$) CO₂ production. Manure in occupied pens with slatted floors (OPSF) produced the highest CO₂ and the least CO₂ was from disused pens with slatted floors (DPSF). Floor type and month influenced ($P < 0.05$) N₂O production. It was concluded that continued use of goat pens increased GHG emissions. However, disused goat pens with manure remain an important source of GHG as they continued to emit quantifiable levels of CH₄, CO₂ and N₂O.

The third experiment was done to determine the effects of grazing and housing management systems on the concentrations of blood metabolites, activity of creatine kinase, body weight (BW), body condition score (BCS) and carcass characteristics using 48 castrated Nguni goats. Tethered goats had higher ($P < 0.05$): urea, creatinine, total protein, globulin concentrations and more activity of CK than herded goats. On the other hand, herded goats had higher

($P < 0.05$) plasma glucose (H: 3.39 ± 0.020 vs T: 3.23 ± 0.020 mmol/L), serum albumin (H: 15.30 ± 0.147 vs T: 14.82 ± 0.144 g/L) concentration. It was concluded that serum concentrations of all the metabolites and the activity of CK were sensitive to grazing system. Herding of goats promoted more glucose concentration and preservation of muscle protein and hence superior body weights and BCS than tethered goats.

The fourth experiment was done to determine the effects of grazing and housing management systems on the activity of creatine kinase (CK) and cortisol concentration, and chevon quality. Further, the effect of muscle type [*Muscularis longissimus thoracis et. Lumborum* (LTL) and *triceps brachii* (TB)] on chevon quality was also investigated. Forty eight castrated Nguni goats aged 6- 7 months were randomly allocated to tethering (n=24) and herding (n=24) treatments. Floor type affected meat ($P < 0.05$) pH₂₄. Tethered goats had higher ($P < 0.05$) L* and CL % than herded goats. Muscle type had a significant influence ($P < 0.05$) on a*, WBSF and pH. It was observed and concluded that T resulted in higher L* and more CL% whilst SF lowered the pH₂₄ of chevon; at the same time meat from the TB muscle was more tender, despite having a higher pH₂₄ and more CL % relative to LTH cuts.

The fifth experiment was done to determine the effect of grazing and floor type on fatty acid composition of chevon from tethered and herded Nguni goats. Floor type had no effect on fatty acid composition. Oleic, stearic, palmitic and linoleic were the major fatty acids. Chevon from tethered goats had higher ($P < 0.05$) proportions of long chain polyunsaturated fatty acids (PUFAs): eicosapentaenoic, docosapentaenoic, docosahexaenoic, conjugated linoleic acid (CLA) and more total SFA, total PUFA, total Omega- 6 and total omega 3 fatty acids than herded goats. On the other hand, chevon from herded goats had more ($P < 0.05$) C18:1c9, C18:2t9, 12 (n-6), C20:3c11, 14, 17 (n-3) and total MUFA than tethered goats. However, there was no difference ($P > 0.05$) in the PUFA: SFA and n-6/n-3 fatty acid ratios between the herded and tethered goats. It was concluded that tethering promoted higher proportions of beneficial PUFAs which were more in TB than LTH muscle.

The overall conclusions from the whole study were that goat manure is an important source of GHG with high CH₄ being emitted from earth floors of herded goats. High CO₂ and N₂O are emitted from SF of herded and tethered goats, respectively. There were no major differences in meat quality between herded and tethered goats. However, herding promoted more live weight gain than tethering. On the other hand, tethering promoted more beneficial fatty acids. Therefore depending on the objective of the enterprise, smallholder farmers can safely tether or herd their goats. Further, there is need to develop technologies to harness CH₄ from goat manure.

Key words: Greenhouse gases, blood metabolites, chevon quality, Fatty acid profiles

Dedication

To my Family. I cherish your all-time moral support and patience.

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Abbreviations

a*	redness of meat
AG	albumin- globulin ratio
AU	animal unit
b*	yellowness of meat
BCS	body condition score
CH ₄	methane
CK	creatinine kinase
CIE	Commission International De I' Eclairage
CO ₂	carbon dioxide
EDTA	ethylene diamine tetra acetic acid
FAO	Food and Agricultural organisation
GC	gas chromatography
GLM	generalised linear model
H ₂	hydrogen gas
L*	lightness of meat
MUFA	monounsaturated fatty acid
NH ₄ ⁺	ammonium ion
N ₂ O	nitrous oxide
n-3	omega- 3 fatty acids
n- 6	omega- 6 fatty acids

PUFA	polyunsaturated fatty acid
TAU	Tropical animal unit
WBSF	Warner Bratzler Shear Force
vs	versus
AI	Atherogenicity index
TI	Thrombogenicity Index

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CHAPTER 1

1.0 General Introduction

Meat consumers are increasingly becoming health conscious and are concerned about the safety and quality of the meat that they take (Muchenje *et al.*, 2009; Mapiye *et al.*, 2011; Nantapo *et al.*, 2015). The meat consumers also advocate for livestock rearing practices and housing facilities that confer good welfare to the animals (Toma *et al.*, 2012) and are cognisant of environmental impact of livestock. It is desirable to come up with grazing systems and housing facilities that enhance nutrient flow to animals, minimise stress, improve the quality of meat, increase the proportion of beneficial fatty acids and reduce the contribution of livestock to greenhouse gas (GHG) emission, global warming and climate change (Capper, 2013).

In the recent past, the consumption of beef, veal and mutton in South Africa has shown a downward trend which has been attributed to meat quality, human health, animal welfare (Taljaard *et al.*, 2006) and environmental concerns. Beef and mutton have higher proportions saturated fatty acids (SFA) which have a strong propensity to cause some forms of cancer and cardio-vascular challenges (Gogus and Smith, 2010; Lopez- Garcia *et al.*, 2005). On the other hand, there is increased demand of goat meat (chevon) in most parts of the world. People in such regions frequently consume chevon citing: better visual appeal of the cooked meat (Sen *et al.*, 2004; Webb *et al.*, 2005), favourable sensory evaluation scores, leanness of the meat (Moyo *et al.*, 2013) as well as health benefitting fatty acid profile.

The majority of goats in developing countries are kept by smallholder farmers (Shabalala and Mosima, 2002; Roets and Kirsten, 2005). Most of the smallholder farmers who are into crop-

livestock systems normally practise tethering or heading of goats to prevent damage of crops in fields or grain in storage (Romney *et al.*, 1996; Kusina and Kusina 2000; Moniruzzaman *et al.*, 2002; Chikwanda, 2004). Further, the increasing cases of stock theft (Scholtz and Bester, 2010) may make it necessary for farmers to closely monitor their flocks during grazing by either hiring shepherds to herd or tether their goats. Herded goats forage freely in search of nutritious forages and have the privilege to access water whenever they get thirsty. On the other hand, goats that are tethered are limited on selective foraging behaviour by the length of the tether (Bayer and Zemmerlink, 1988). Composition of ingested forages is thought to be influenced by the frequency of changing tethering sites and the variety of forages available at each tethering spot.

Sometimes the goats on leash can entangle themselves thereby grossly reducing the length of the tether (Ogebe *et al.*, 2000). In other situation strangulation by the rope occurs and the goats maybe severely stressed, injured or may suffocate to death (Ogebe *et al.*, 2000). Tethered goats may become easy prey to predators or are attacked by other goats. It is hypothesised that the fear of predators and aggression, from roaming goat flocks, experienced by the tethered goat constitute stress and may increase the concentration of stress indicators in the blood. Stress has been found to reduce the quality of beef (Muchenje *et al.*, 2009b) and mutton (Chulayo and Muchenje, 2013). However, most of the studies relating stress to meat quality have been limited to other livestock species, leaving out goats. Further, such investigations have been tilted towards the immediate pre-slaughter window but neglected the influence of grazing practices and housing on blood metabolites and meat quality (Chulayo and Muchenje, 2013).

It is common practice by small holder farmers to release goats from pens for short periods of grazing time (Chikwanda, 2004). The goats are then penned for extended periods of time stretching up to 19 hours per day (Kusina and Kusina, 2000). There is deposition and accumulation of goat faeces and urine in the in the animal houses. Sometimes goat faeces get soaked by urine or rain water and cause appalling conditions in the pens. The manure is normally removed from pens once annually to be used as organic fertiliser in crop fields or gardens (Wuta and Nyamugafata, 2012). Prior to the removal of the manure, the welfare of the goats is sometimes compromised. The goats that are in direct contact with wet manure may spend whole penning time standing dreading to lie down on the damp manure. It is postulated that the unnecessary standing leads to expenditure of body reserves and compromise goat welfare. It is thought that when such goats are released into the grazing areas they are tired from standing and take the opportunity to lie down to rest in the veld for long periods instead of foraging. Damp manure conditions are also hypothesised to soften the hooves and make them susceptible to injury and or infection by foot rot pathogens. Goats with affected feet limp and are not able to forage normally. They are thought to lurch in pain and fail to assume the bipedal stance that ordinarily enables them to browse from overhead hanging bush branches. Therefore, diet selection by the goats and hence nutrient flow, blood metabolites, body weights, body condition and quality of meat are assumed to be influenced by the manure condition and grazing system. It is hypothesised that the condition and the state of manure is a function of animal contact and housing floor type.

There are various types of goat housing that are used by smallholder farmers but the majority of them have earth or slatted floors (Chikwanda *et al.*, 2013). The goats that stay on earth floors are in direct contact with their manure, whereas those on slates are separated from their

excreta. Wet manure on earth floors may affect feet condition and disturb the comfort and welfare of goats. Further, wet manure and compaction from goat hooves may favour anaerobic conditions that may promote methanogenesis (Chadwick, 2005) or denitrification that yields Nitrous oxide (N_2O) (Davidson *et al.*, 2000). On the other hand, dry goat faecal pellets leave air spaces between them that may create aerobic manure conditions. Aerobic conditions of manure may favour oxidation reactions and nitrification process (Davidson *et al.*, 2000) that can emit carbon dioxide (CO_2) and nitrous oxide (N_2O), respectively. The CH_4 , CO_2 and N_2O are chief greenhouse gases that contribute to global warming and climate change. Methane and N_2O have 23-25 and 320 global warming potential (GWP) compared to the standard reference CO_2 , respectively (Eckard *et al.*, 2010; Nyamadzawo *et al.*, 2012; Agrawal *et al.*, 2014). World statistics on nitrous oxide emission from livestock is ranked as: cattle (60 %), small ruminants (18.83 %), pigs (11.89%) and poultry (9.73) (Zervas and Tsiplakou, 2012).

There is limited information on GHG emission, nutritional adequacy, stress and meat quality of tethered and herded goats that are accommodated in pens with earth or slatted floors. The objective of this study was, therefore, to determine the effect of grazing system (tethering or herding) and floor type (slatted vs earth) on GHG emission from manure, blood metabolic concentrations, growth performance, carcass characteristics, physico- chemical properties and fatty acid profiles of Nguni goats.

1.1 Problem statement

About 8-11 % of all human influenced greenhouse gas (GHG) emissions come from ruminant livestock operations (O'Mara, 2011). The chief GHG that are produced from ruminants are

CH₄, N₂O and CO₂ (Cortus *et al.*, 2015; de Vries and de Boer, 2010). These GHG contribute to global warming and climate change which has been linked to increased frequency of droughts or flooding, increase in temperature over oceans and land as well as animal and human diseases. The increasing temperatures and water scarcity are evidence of pointers to climate change in South Africa and other countries or regions. Out of the 80 Mt of CH₄ emitted from livestock, 720g/kg is attributable to cattle (Johnson and Johnson, 1995) and 200g/kg from sheep and goats enteric activities (Animut *et al.*, 2008). Greenhouse gases from ruminants are a product of enteric activities, manure management in houses or pasture and fodder production. A lot of research work has been done to quantify GHG emissions from cattle using dynamic chambers (Zervas and Tsiplakou, 2012; Cortus *et al.*, 2015). However, there is a paucity of information on the contribution of goat manure to greenhouse gas emission (Zervas and Tsiplakou, 2012) regardless of the increasing goat population that are associated with little offtake. Most of the manure from goats is deposited in overnight houses where they are penned for extended periods of time (Chikwanda, 2004).

The majority of the goat housing structures are constructed on either earth floors or on raised slatted floors. Earth floors may promote anaerobic conditions due to possible compaction of the manure by the hooves and bodies of the animals during overnight penning as well as accumulation of mud. On the other hand, slatted floors favour aerobic conditions as animals rarely come into contact with the manure. Aerobic conditions of manure promote the emission of N₂O and CO₂ (Eckard *et al.*, 2010), whereas anaerobic conditions promote the emission of CH₄ (Adviento- Borbe *et al.*, 2010). The different types of goat housing floors may, therefore, affect the composition of greenhouse gas emission, welfare of the goats, foraging ability and subsequently their nutritional status. Nutritional adequacy may be

affected by the amount of rest or overnight fatigue that is influenced by the condition of the house floor. The manure conditions vary with type of housing or manure management strategy. However, the potential GHG emission from the different types of floors in goat housing systems is not known.

Damp manure conditions, such as those sometimes observed on earth floors, may force goats to spend whole nights standing, without lying down to rest which may stress the animals and deplete the energy required to forage when they are eventually released for grazing. However, there is lack of information with regards to the effect of different housing floors on: blood biochemistry, growth rate, goat welfare as measured by stress hormones, fatty acid profiles and meat quality parameters. In addition, the amount of energy expended, daily, as goats get onto and down from raised floors may constitute exercise that may modify blood profiles and possibly, muscle development and toughness of meat.

The management of animals may also influence nutritional adequacy, behaviour (Forkman *et al.*, 2007) blood biochemistry profiles (Moolchandani *et al.*, 2008; Chulayo and Muchenje, 2013), growth, fatty acid profiles and meat quality. Smallholder farmers especially those into crop livestock farming systems practise herding and tethering of goats to prevent damage of cultivated crops or vegetable gardens. Tethering and herding of goats modify foraging capacity of the animals and the types of forages or plant parts, species diversity that can be accessed by the animals. The tethering or herding of goats may, therefore, affect nutritional adequacy to the goats, blood profiles, greenhouse gases emitted from their manure as well as the chevon quality. Nitrous oxide emission from manure was reported to be dependent on the level of nitrogen intake from the diet. Despite the practise of herding, tethering and

accommodation of goats on earth or slatted floors, by a lot of smallholder farmers, there is a gap in information on their effect on GHG, the growth rate, blood profiles and chevon quality.

1.2 Justification

Thomson *et al.* (2010) made recommendations of agricultural production approaches that reduce anthropogenic GHG emissions but enhance productivity. Similarly, Scholtz *et al.* (2013) further advocate for livestock practices that result in less carbon footprint per unit of product made. There is need to establish the type of goat housing system (slatted or earth floor) and grazing practice (tethering or herding), commonly used by smallholder farmers, that contributes to less GHG, improves animal welfare, nutritional status (blood profiles) and meat quality. The progression of degradation of goat manure and the gaseous products of degradation of the manure are partly influenced by the diet foraged by the animals and also the condition of the manure in the housing. The information generated from this study contributes towards establishing the composition of GHG emitted from manure. Furthermore, it assists in devising strategies for mitigating greenhouse gas emissions from smallholder goat housing and grazing practices. It is envisaged that the study leads to appropriate manure management strategies which minimise production of greenhouse gas emissions. In addition, usable gases emitted from manure such as methane may be harnessed for use as fuel if produced in sufficiently large amounts.

The composition of diet foraged on by goats maybe influenced by the grazing practice. The majority of the goats that are kept by smallholder famers are either raised through tethering or herding (Romney *et al.*, 1996; Chikwanda, 2004). Dietary strategies have been used to

improve ruminant performance as well as reduce GHG emissions from enteric activities. Tethering and herding influence the composition of bites taken by goats during foraging. Information generated from herding and tethering trial prescribes approaches that enhance growth performance and meat quality while minimising GHG emission. The results generated from the tethering, herding and floor type trials, therefore, help generate ideas of coming up with informed decisions on which grazing strategy to recommend to smallholder farmers under the crop- livestock system that enhance the nutritional status of the animals (blood profiles), production in terms of growth rate, body condition scores and meat quality. Thomson *et al.* (2010) highlight the importance of accounting for feedbacks from land use options such livestock production, in global climate change mitigation strategies. There has been a dearth of information on the contribution of smallholder goat production to GHG emission. It is envisaged that the results from the current study contribute towards generating the knowledge which leads to better understanding of the tethering and herding grazing systems.

Consumers are increasingly becoming concerned about the manner in which the animals that they eat were raised and housed. This is largely driven by the view that the manner in which animals were raised or housed influences their meat quality as well as animal welfare. Further, informed consumers are concerned about fatty acid composition and ratios. The study seeks to establish which rearing practice between tethering and herding promotes more desirable fatty acids that reduce vulnerability to cardiovascular challenges and cancer.

1.3 Objectives

The main objective of the study was to determine the effects of grazing and housing management systems on greenhouse gas emission, blood profiles, physico-chemical characteristics and fatty acid profiles of meat from Nguni goats.

The specific objectives were:

- (1) to determine the effects of grazing management (T vs H) and floor type (EF vs SF) on greenhouse gas emissions from goat manure
- (2) to determine GHG emission from manure in disused and occupied goat pens
- (3) to determine effect of grazing management (T vs H) and floor type (EF vs SF) on blood profiles, growth performance and carcass characteristics
- (4) to determine the effect of grazing management (T vs H) and floor type (EF vs SF) on concentration of cortisol, activity of creatine kinase and physico-chemical characteristics of goat meat
- (5) to determine effect of grazing management (T vs H) and floor type (EF vs SF) on chevon fatty acid profiles

1.4 Hypotheses:

The specific hypotheses to the study were:

- (1) There is no effect of grazing management (T vs H) and floor type (EF vs SF) on GHG emission from manure
- (2) There is no difference in GHG emission from disused and occupied goat pens
- (3) There is no effect of grazing management (T vs H) and floor type (EF vs SF) on blood profiles, growth performance and carcass characteristics
- (4) There is no effect of grazing management (T vs H) and floor type (EF vs SF) on the

concentration of cortisol, activity of creatine kinase and physico-chemical properties of goat meat

(5) There is no effect of grazing management (T vs H) and floor type (EF vs SF) on fatty acid profiles of chevon

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CHAPTER 2: Literature Review

2.0 Introduction

There is a projected two fold increase in the demand for safe, healthy, good quality meat and milk products by 2050 resulting from growth in human population, improving lifestyles and urbanisation (Muchenje *et al.*, 2009; Thornton, 2010; Kristensen *et al.*, 2011; Mapiye *et al.*, 2011; United Nations Population Division (UNPD), 2011; Zervas and Tsiplakou, 2012). There is drive to produce good quality meat in systems that ensure good animal welfare (Petherick, 2005; Toma *et al.*, 2012) and are friendly to the environment. The increase in livestock populations to match projected demand for meat and milk products is feared to increase greenhouse gas (GHG) emission from animal respiratory, enteric and manure handling (Olander *et al.*, 2013).

Current beef, mutton and pork production levels are not adequate to meet the projected future demand for meat [Department of Agriculture, Forestry and Fisheries (DAFF), 2011] and it is prudent to consider consumption of other meat types. In some countries the consumption of goat meat (chevon) is still low compared to mutton and beef (DAFF, 2013). The low offtake of goats has led to a substantial growth in goat population. The increase in goat numbers without significant offtake elicits growing concern on their potential impact on the environment and climate shift emanating from greenhouse gas emissions. Greenhouse gases negatively impacts on the global climate and animal welfare (Scholtz *et al.*, 2013). Extremes of weather conditions, experienced thereafter, such as droughts and floods, diminish crop yields and productivity, thereby, reducing available food and causing food related inflation (Zervas and Tsiplakou, 2012; Phillipe *et al.*, 2013).

The majority of goats are kept by small holder farmers under tethering and herding management systems (Kusina and Kusina, 2000; Ogebe *et al.*, 2000; Chikwanda, 2004). The goats are let out for short grazing periods and are penned for extended periods of time. The prolonged penning and infrequent removal of manure (Wuta and Nyamugafata, 2012) leads to accumulation of goat faeces and urine which may emit GHG from goat pens. There is a gap in literature on the effect of tethering, herding and housing floor types on GHG emission, blood metabolites, chevon quality and fatty acid profiles.

The objective of this review is to discuss the possible contribution of livestock management system and housing systems to GHG emissions, blood metabolites, meat quality and fatty acid profiles. The likely implications of accumulation of manure in animal shelter to goat production, goat and human welfare as well as the environment and climate change. Further, factors pertaining to blood metabolites, fatty acid composition and meat quality are also discussed.

2.1 Manure accumulation in animal housing facilities

Goats greatly contribute to livelihoods of the rural poor by providing a number of products including meat, milk, skins and manure (Kusina and Kusina, 2000; Chikwanda, 2004; Wuta and Nyamugafata, 2012). Under the smallholder cattle and goat production systems, manure (faeces and urine) is allowed to accumulate in their overnight shelters and are occasionally removed once a year or periods exceeding a year, for spreading in crop fields or vegetable gardens as an organic fertiliser (Wuta and Nyamugafata, 2012). The use of manure replaces nutrients such as nitrogen (N), phosphorus (P), sulphur (S), magnesium (Mg) and potassium (K) in the soil and helps improve soil characteristics (Grant, 1981). The majority of goat rearing systems that provide manure as an organic fertiliser are characterised by the animals

foraging in the veld for part of the day and penned in kraals overnight. The overnight provision of shelter for goats in the smallholder sector has mostly focused on protecting the animals from the harsh effects of bad weather, theft, predation and susceptibility to diseases (Chikwanda *et al.*, 2013) but gave little focus on the effect of manure accumulation on environmental pollution, greenhouse gas emission, climate change, meat quality, animal and human health.

2.2 Greenhouse gas emission from livestock

Greenhouse gases such as nitrous oxide (N₂O), methane (CH₄) and carbon dioxide (CO₂) may be emitted from the manure in animal shelter (Guiziou and Beline, 2005; Philippe *et al.*, 2011; Ulens *et al.*, 2014). The GHG contribute to global warming. Further, obnoxious emissions such as NH₃ compromise the provision of good housing and comfort to animals (Botreau *et al.*, 2007).

Objectives in livestock production have in the past been focused on efficiency, cost cutting and maximisation of profit (Zervas and Tsiplakou, 2012). However, nowadays it is prudent to incorporate environment, climate change, animal welfare, food safety and security in the formulation of animal rearing objectives (Petherick, 2005; Toma *et al.*, 2012; Zervas and Tsiplakou, 2012). According to Scholtz *et al.* (2013), extensive livestock production system may not be exceptionally environmentally friendly. Capper (2011) demonstrated that intensive systems produce less GHG per quantity of product compared to extensive livestock systems.

Livestock manure and enteric activities contribute, significantly, to the emission of NH₃ and

the GHG: N₂O, CH₄ and CO₂ (Amon *et al.* 2001; Guiziou and Béline, 2005). The NH₃, N₂O, CH₄ and CO₂ that is released from manure is emitted at different levels depending on dung management processes e.g. slurry, deep litter or slates (Zervas and Tsiplakou, 2012), and are products of microbiological, chemical and physical processes (Amon *et al.*, 2001). Methane production comes from two sources, i.e. animal respiration and fermentation from manure (Zervas and Tsiplakou, 2012). The N₂O is produced from coupled nitrification and denitrification that occurs in manure during storage under aerobic or anaerobic conditions, respectively (Philippe *et al.*, 2013). According to Zervas and Tsiplakou (2012), GHG release can cause global warming which is responsible for extremes of weather. Climate change has potential to negatively affect future animal production, food supplies and food prices. Nyamadzawo *et al.* (2012), postulate that GHGs contribute to global warming by trapping radiation that is reflected from the earth, thereby raising temperatures in the atmosphere.

Nitrous oxide participates in the destruction of the ozone layer (Philippe *et al.*, 2013). The ozone layer is important for absorbing ultraviolet (UV) radiation from the sun and prevents it from getting to the earth's surface. The ozone layer, therefore, protects people from getting skin cancer from UV radiation. Nitrous oxide has been reported to have the highest potency to global warming. It is ranked at 310 times more than that of the standard reference, CO₂ (Eckard *et al.*, 2010; Nyamadzawo *et al.*, 2012; Zervas and Tsiplakou, 2012). The scale of potency is then followed by CH₄ which is 21-25 times that of CO₂ (Eckard *et al.*, 2010; Nyamadzawo *et al.*, 2012; Agrawal *et al.*, 2014). However, CH₄ has a shorter half-life of 8 compared to 100 years of CO₂, implying that the later has a longer residence time. Carbon dioxide emitted from livestock to the atmosphere is not considered a major problem because the amount released is utilised by plants during photosynthesis.

Global statistics attribute the highest N₂O emission to cattle (60 %), followed by small ruminants (18.83 %), pigs (11.89%) and lastly poultry (9.73 %) (Zervas and Tsiplakou, 2012). Studies on carbon foot printing (CF) on piggery by Nguyen *et al.* (2010) showed that the major contributor to CF was N₂O from feed production, followed by CO₂ from energy use and CH₄ from manure handling. Enteric fermentation is the major contributor of methane emissions in animal housing (Amom *et al.*, 2001). The Kyoto Protocol does not consider livestock respiration to be a net emitter of carbon dioxide since amounts emitted are equivalent to amounts absorbed by plants (Zervas and Tsiplakou, 2012). According to Philippe *et al.* (2008) methane production is a function of fibre intake and can be estimated from the equation they put forward:

$$\text{CH}_4 = 7.05 \text{ NSP} + 3.05$$

Where:

NSP represented non-starch polysaccharides.

A significant proportion of the gaseous emissions from swine, cattle and poultry were found to emanate from livestock buildings (Guiziou and Béline, 2005). FAO (2006) reported that intensive cattle production systems released more CH₄ from manure than from enteric emission. Methane enteric emission was reported to be very high from beef cattle raised on extensive veld conditions compared to those on concentrates (Peters *et al.*, 2010; Veysset *et al.*, 2010). This was attributed to higher digestibility of concentrate based diets compared to forage on natural veld (Peters *et al.*, 2010; Veysset *et al.*, 2010). On the other hand, high stocking densities of animals on intensive production compacted litter and promoted anaerobic fermentation which favour emission of CH₄ from manure (Philippe *et al.*, 2013). The production and release of N₂O and CH₄ also depends on the digestibility and

composition of feed, type of animal, manure management and weather conditions (Gupta *et al.*, 2007). Kavolelis (2006) ranks the emissions of gases from livestock in decreasing order from the highest to the lowest as: cattle, followed by pig and lastly poultry. Information on ranking of goats as an emitter of greenhouse gases is scanty. A lot of research work has been done on the contribution of cattle, swine and poultry housing systems to greenhouse gas emissions (Amom *et al.*, 2001; Guiziou and Béline, 2005; Philippe *et al.*, 2013; Koger *et al.* 2014). The research concentrated on commercial production systems. Very little has been done on the contribution of smallholder goat production systems to greenhouse gas emission and, therefore, warrants research attention.

Dämmgen and Hutching (2008) suggest that it is necessary to distinguish among livestock species when computing emissions from manure management systems. They argue that the level of nitrogenous emissions from livestock is a function of nitrogen excreted which itself is influenced by nitrogen ingested. There are different sources of nitrogenous gaseous emissions in the process chain that include: grazing, animal housing, storage of manure and field applied manure (Dämmgen and Hutching, 2008). However, specific emissions from goats have been skirted in reports despite the observation that sheep, a closely related small ruminant, emits significant N₂O based on per unit body mass.

2.3 Greenhouse gases, the environment and climate change

There has been an increase in the level of nitrogenous gaseous components in the atmosphere, which include: N₂O, NH₃ and particulate matter (PM) (Dämmgen and Hutching, 2008). The effects of these gaseous emissions on climate change and their projected impact on livestock production has been reviewed and extensively discussed by various authors

(Thornton *et al.*, 2009; Gregory, 2010; Nardone *et al.*, 2010; Rust and Rust, 2013). The authors discussed the negative and positive influence of climate change on production of dairy and beef cattle, small ruminants, and monogastric animal production, as well as feed quantity and quality, water, diseases, biodiversity and meat quality. Frequent occurrences of droughts or floods were reported to reduce dry matter (DM) yield from plants or cause N leaching (Hopkins and Del Prado, 2007). Furthermore, changes in the species composition of pastures, i.e. in terms of grasses and legumes are expected to occur coupled with changes in the levels of C: N in plants.

2.4 Impact of greenhouse gases on livestock and humans

The effect of GHG is encompassed in their effect on climate change which in turn will affect livestock and humans. Zervas and Tsiplakou (2012) state that greenhouse gases are projected to cause global warming which will lead to extremes of weather conditions that reduce crop yields and productivity, diminish food supplies and propel food prices to go up. Thornton *et al.* (2009) postulates that flooding associated with climate change could increase risk of exposure of livestock and people to diseases. Furthermore, amplified susceptibility to disease is attributed to an increase in ambient temperature which could promote the proliferation of pathogens, parasites and vectors (Thornton *et al.*, 2009). Such a scenario would exacerbate disease prevalence since the livestock or human immunity level is compromised at extremes of temperature (Bayis and Githeko, 2006).

Zervas and Tsiplakou (2012) pointed out that climate change is likely to have negative effects on animal metabolism, health, fertility and general productivity. Transported, heat stressed animals have been known to lose weight and in worse cases suffer high mortality (Hail,

1978). Rust and Rust (2013) reviewed the effects of climate change on livestock production. According to Rust and Rust (2013) cattle (beef and dairy), small ruminants (sheep and goats) and monogastric animals (poultry and pigs) are affected differently by climate change. Table 2.1 summarises the projected effects of climate change on cattle, sheep and goats and possible mitigating strategies. Figure 1 shows a schematic view of the likely effects of global warming on livestock production.

Extreme temperatures during transportation of animals to abattoirs caused microbial overload leading to increase in carcass contamination and diarrhoeal cases (Gregory, 2010). Such assertions are based on observed high incidences of elevated microbial load on carcasses during hot summer days which were associated with diarrhoeal cases in humans (Domínguez *et al.*, 2007). Heat stress may also trigger adrenaline stress response that can lead to glycogenolysis which results in poor meat quality (Muchenje *et al.*, 2009; Gregory, 2010). Gregory, (2010) further reported a high prevalence of dark firm dry (DFD) and high ultimate pH (pH_u) in meat from animals that have been exposed to high heat stress. According to Muchenje *et al.* (2008), a high level of catecholamines is released under stress in cattle and these cause the depletion of glycogen reserves leading to an increase in ultimate pH (pH_u). Rapid depletion of muscle glycogen during stressful handling or transportation results in DFD meat (Muchenje *et al.*, 2009a; Vimiso and Muchenje, 2013). Dark firm dry meat is of poor quality, has shorter shelf life, and is disliked by consumers (Muchenje *et al.*, 2009a).

The majority of people in developing countries are closely dependent on the natural environment for their livelihood, hence, are very vulnerable to any changes to the environment and are likely to be affected the most by climate change (Ribbink, 2012).

Table 2.1: Effect of climate change on ruminant animal production systems

Animal	Effect of climate change	Proposed mitigating strategies
Beef and dairy	High feed cost, reduced pasture and grain production due to droughts/flooding	Adoption technologies to improve forage and grain production
	Change in species composition and forage quality as temperatures increase there will be more tropical (C4) than temperate (C3) species Reduced milk production	Improve the digestibility of feed for cattle Augment milk production through dairy goat production (i.e. change of livestock species)
Beef and dairy	Reduced reproductive efficiency (e.g. long inter-calving periods (ICP))	Adopt reproduction improvement technology e.g. multiple ovulation and embryo transfer (MOET)
	Low growth rates	Manipulate nutrition
	Possible increase of internal and external parasites as well as other health challenges	Incorporate genes that are tolerant to parasitic challenges
	Heat stress	Use smaller animals with coat and hair colours that reflect heat, Infuse genes of tropically adapted breeds in herd provide shed, misters/foggers and evaporative cooling (sprinklers)
Sheep and goats	Heavy reliance on natural veld forages as a feed source affect indigenous small ruminant breeds	Raise sheep and goats together so that they complement veld use. Supplement feed where necessary.
	Increase in heat stress and diseases	Develop breeds that are more disease and heat tolerant

Developed from: Henry *et al.* (2012); Olander *et al.* (2013); Rust and Rust, 2013

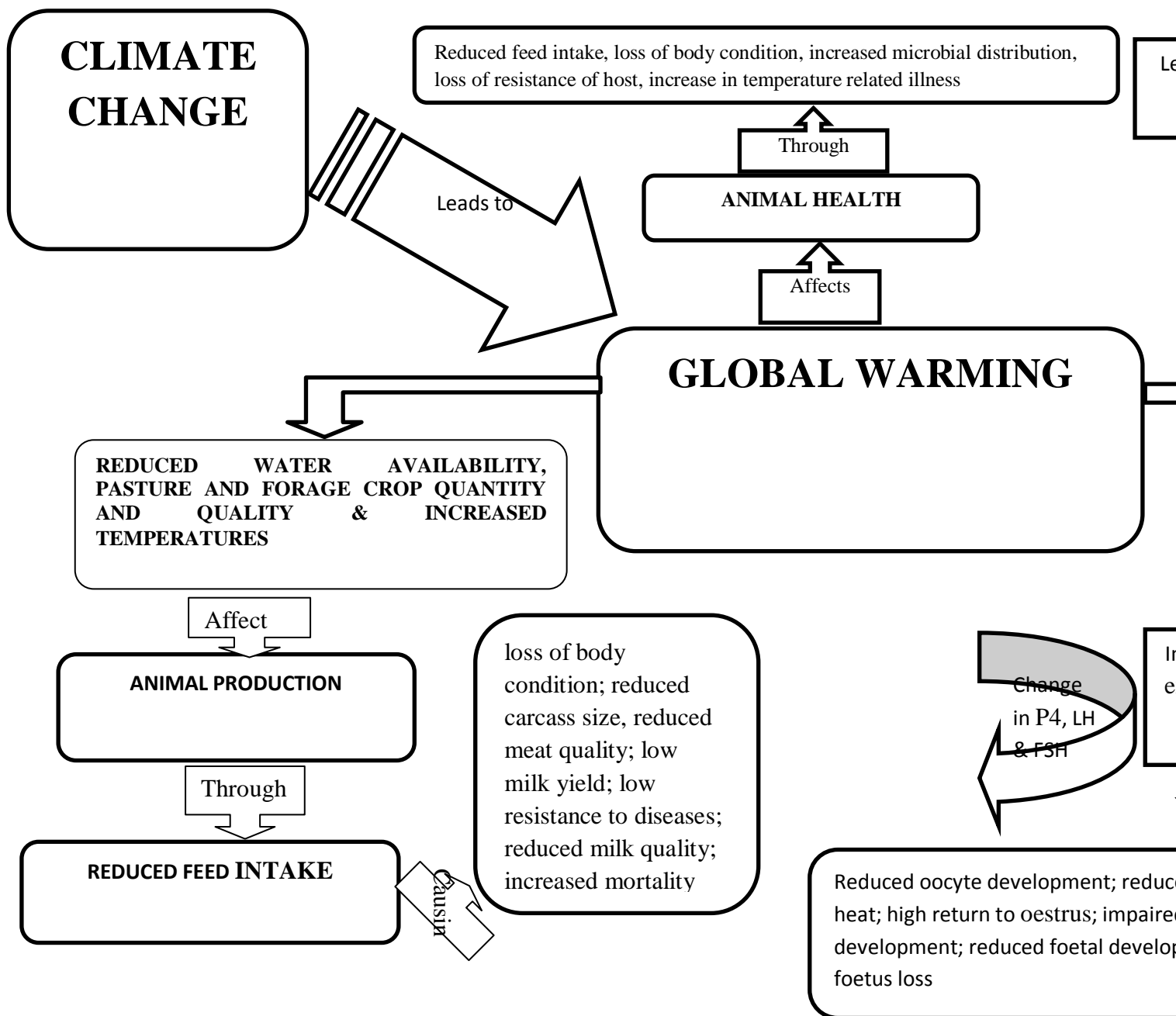


Figure 2.1: Effects of global warming on livestock: Developed from Henry *et al.*, 2012;

Nardone *et al.*, 2010

For example, the majority of the people of Africa are rural inhabitants who depend on crops and livestock for livelihood (Ribbink, 2012). Droughts or floods are most likely to erode crop harvests and simultaneously affect the body condition and health of livestock or result in very high mortality. Rural people, who are resource poor, have little adaptive capacity to cope with climate change (IPCC, 2007). For example, the Eastern Cape Province has the most low resource endowed rural people of South Africa (Davies, 2009) who depend on government grants, livestock and little crop production (Musemwa *et al.*, 2010). High frequency of droughts or floods will result in severe loss of harvest for the few who engage in crop production, depletion of grazing areas and death of livestock (Ribbink, 2012). Many people are likely to become food insecure as grants alone may not be enough to sustain their livelihoods. Table 2.2 Summarises possible impacts of global warming to people and mitigating strategies.

2.5 Mitigation strategies on greenhouse gas emissions from livestock

2.5.1 Dietary strategies

Various mitigating strategies have been proposed as a means of reducing GHG emissions from livestock. Benchaar *et al.* (2001) cited in Kristensen *et al.* (2011) reported that diet manipulation could be used as a means to reduce methane emission. For example, 32 % of methane emitted could be reduced by replacing grass forages with those of legume origin or by replacing fibre based concentrates with those that are derived from starch. Scholtz *et al.* (2013) made recommendations to reduce carbon foot prints to include the breeding of new forage and pasture species that have lower CH₄ emissions when consumed by ruminants.

Table 2.2 Effects of global warming to people's livelihoods

Item	Possible effect of Climate change	Mitigation strategies
Food	Cereal productivity is negatively affected in low latitude, reduces grain available for humans and livestock Cereal productivity increase in high latitude	Develop varieties that grow better in such areas- crops of the future (moisture stress tolerant and short season varieties) Increase production to export to less productive areas
Ecosystems	Increased fire risk due to higher temperatures leading to destruction of habitats and extinction of some species	Put fire prevention and management strategies
Health	Increased incidences of undernourished people, cardio-respiratory ailments and infectious disease spread. The impact is likely to be worse in developing countries who already have poor health facilities High morbidity (illness, injury and disease) and mortality from heat waves, floods and droughts	Invest in health facilities, development of medical drugs, vaccines; pest and vector control
Coasts	Coastal wetlands loss due to flooding requiring relocation of people. People's livelihoods will be lost as they have to learn new ways of surviving	Relocation of people to higher ground
Water	Reduced precipitation and water availability in mid to low latitude Increased precipitation in moist tropics and elevated latitudes Many people, globally will be subjected to increased water stress	Need to put in place water conservation and harvesting techniques

Developed from: IPCC (2007)

Capper (2010) reported that beef cattle on feedlot emit less enteric methane per unit of meat produced compared to those that were extensively raised, highlighting the importance of improved nutrition as a mitigating strategy.

Incorporation of condensed tannins (CTs) in extensive livestock production systems can be used to reduce methanogenesis, CH₄ (Hess *et al.*, 2006; Naumann *et al.*, 2013) and NH₃ (Mhlambo and Mapiye, 2015) emission from livestock. The CTs may bind to protozoa and reduce their capacity to produce hydrogen (H₂) (Patra *et al.*, 2006). Protozoa normally generate high levels of hydrogen and formate in the absence of CTs (Shibata and Terada, 2010). *Methanogenic archaea* need H₂ to reduce CO₂ to methane. A decrease in H₂ availability by use of CTs, therefore, reduces methanogenesis and ultimately CH₄ emission (Shibata and Terada, 2010; Mhlambo and Mapiye, 2015). Condensed tannins were found to form stronger complexes with cellulolytic bacteria more than they did with forage proteins (Min *et al.*, 2005). The numbers of cellulolytic bacteria also decrease in the presence of CTs (Animut *et al.*, 2008) thereby contributing to reduction in H₂ and methanogenesis. In addition, condensed tannins hinder microbial enzymes from degrading feed as well as prevent the attachment of cellulose digesting microbes to ingested forages hence also reduce CH₄. Carulla *et al.* (2005) demonstrated that the dietary inclusion of tannin containing *Acacia mearnsii* in sheep feed significantly lowered CH₄ emission. Similarly, Anantasook *et al.* (2014) reported that addition of tannin reduced ruminal methane production. *In vitro* studies by Gemedda and Hassen (2015) demonstrated that some tropical browse species emitted less methane when incubated with rumen microbes and suggested that the finding could be manipulated in mitigation strategies to reduce methane emission from ruminants. Hashimoto *et al.* (1981) noted that CH₄ emission from faeces increased when forage based diets were

replaced by concentrates. According to Hashimoto *et al.* (1981) concentrates promote fibre digestion in the manure and caused higher methane emission in faeces. Kreuzer and Hindrichsen (2006) found a seven fold increase in emission of CH₄ from the dung of cattle fed concentrate diets compared to those fed fibre based diets.

Complexes can be formed between CTs and dietary proteins in the rumen. The formation of such complexes reduces protein degradation and digestion (Animut *et al.* 2008; Eckard *et al.* (2010). A reduction in digestion and degradation of protein reduces amount of urine nitrogen and promotes high excretion of nitrogen in faeces (Grainger *et al.*, 2009). Faecal nitrogen does not easily mineralise to NH₄⁺ and decomposes more slowly and hence reduces N₂O emission from faeces (Eckard *et al.*, 2010). Nitrous oxide emitted from faeces is an intermediate product of nitrification and denitrification processes of manure (Adviento-Borbe *et al.*, 2010). Faecal nitrogen is mostly of organic form and is less volatile than urinal N which is predominantly urea (De Klein and Ledgard, 2005). The emission of N₂O is, therefore, reduced by feeding diets containing CTs. Sheep fed condensed tannin (CT) extracts had more faecal N than in urine (Carulla *et al.*, 2005). Given that the majority of tropical trees and browse species contain CTs (Mlambo *et al.*, 2008), grazing practices that modify the extent of access to browse species by goats or other ruminants are, therefore, hypothesised to alter the emission of the GHG: CH₄ and N₂O. Smallholder goat farmers engage shepherd who determine where goats forage by tethering or herding the small ruminants. The foraging sites chosen by the shepherds determine the composition of the diet ingested by the goats. Further, the selected tethering spot determine whether the goat will access browse species or not. There is, however, scant literature on the effect of tethering or herding grazing management practices of goats on GHG emission. It is necessary to establish how the traditional grazing

practices influence the emission of GHG.

2.5.2 Reduction of stocking densities

Casey and Holden (2005) advocate for a combination of selecting high producing ruminants and culling less productive ones as a strategy to reduce GHG emission. Scholtz *et al.* (2013) concur with this approach and recommend the reduction of ruminant numbers aimed at increasing production per animal in order to lower carbon and water foot print. Furthermore, the retention of animals that have low residual feed intake (RFI) was encouraged since they are considered more efficient at production. Reduction of stocking densities as a mitigation strategy on animal numbers geared to reduce GHG emission may find relevance in traditional goat management system where goat populations continue to grow but with little offtake (Musemwa *et al.*, 2010). It is prudent to consider production and value addition strategies that are geared towards improvement on chevon quality so as to promote local and export chevon marketing.

2.5.3 Livestock Housing

Information that is largely available in literature on livestock housing and methane emission is mainly from dairy cattle and pig production studies (Philippe *et al.*, 2013). Two major sources of CH₄ from dairy and pig houses have been reported to be enteric and manure. Various studies have been done on NH₃ and GHG emission in pig production enterprises on different litter. Philippe *et al.* (2013) used infrared photo acoustic detector to measure NH₃, N₂O, CH₄, CO₂ emissions from group housed gestation sows on deep litter straw and partly bedded floors. According to Philippe *et al.* (2013), litter with low pH, high C: N ratio and highly degradable carbohydrates reduced NH₃ emissions through N immobilisation.

Immobilisation is the progression by which nitrate and ammonium are taken up by microorganisms and become unavailable to crops or plants. Philippe *et al.* (2011) suggest that regular removal of manure; flushing and separation of urine from manure can significantly reduce NH_3 emissions from buildings by 50%.

The GHG such as N_2O and CH_4 are not much of a challenge in broiler production. Guiziou and Béline (2005) used closed flux chambers and an infrared gas analyser to measure N_2O and CH_4 gas in broiler houses and reported that the levels of these gases were lower than detection quantities of 5 ppm. The authors recommended that such low levels are not a cause for concern. However, ammonia levels, in broilers, need to be kept low to ensure that they do not pose a health challenge to the birds and people or pollute the environment. Guiziou and Béline (2005) found NH_3 levels in broiler houses of between 0.8 and 32 ppm. Mpofo (2004), however, warned that levels of NH_3 above 50 ppm could cause severe eye irritation and respiratory challenges. Goat housing are usually associated with a pungent smell that is similar to ammonia. However, studies on quantification of ammonia from goat houses are scant in literature.

There are various types of goat housing structures that are used by smallholder farmers (Chikwanda, 2004). Most of the structures are built from various wall construction materials to include: brick, pole, timber and zinc (Chikwanda, 2004). Common among the houses is that most of them either have earth or slatted floors (Chikwanda *et al.*, 2013). The majority of the farmers allow goat manure to accumulate in the houses only to be removed once a year and used as organic fertiliser in crop or vegetable gardens (Wuta and Nyamugafata, 2012). Goats that are accommodated on earth floors are in direct contact with their faeces and urine

whereas those in slates have minimum or no contact with the manure. Faecal pellets in slatted houses maintain their structure most of the time as the manure remains undisturbed by the goats. Goat manure on earth floors sometimes gets muddy from the compaction and constant mixing of urine and faeces by hooves. The compaction and wet conditions on earth floors creates anaerobic conditions of the manure that promote methanogenic bacteria to produce more methane (Chadwick, 2005). In addition, anaerobic wet manure reduces nitrate production and hinders formation of N_2O (Chadwick, 2005). The aerobic conditions that are postulated to exist between goat faecal pellets in houses with slatted floors may increase breakdown of protein in faeces to liberate CO_2 (Tamminga, 1992). It is possible that aerobic conditions in slatted houses may also increase nitrification in manure which can produce N_2O as an intermediate product. Davidson *et al.* (2000) suggested the “hole in the pipe model” where N_2O is simultaneously be produced in nitrification and denitrification processes where aerobic or anaerobic condition exist, respectively. However, in that model, more nitrification would occur if conditions are tilted more towards aerobic as hypothesised in manure under slatted floors. There is, however, scant literature on NH_3 and GHG emission from goat houses with earth or slatted floors.

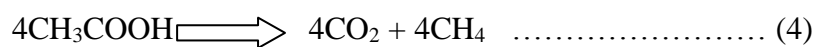
2.5.4 Harvesting renewable energy from GHG emissions

There is growing interest in the capture of methane gas as a measure to combat GHG emission, global warming and climate change (Tasneem Abbasi *et al.*, 2012). Exhaled methane is difficult to capture, unlike CH_4 produced from manure which can be captured and harnessed for use as burning fuel (Tauseef *et al.*, 2013). Decomposition of organic matter or manure under anaerobic condition yields gas composed of 40-70 % CH_4 , a significant amount of CO_2 and traces of other gases (Møller *et al.*, 2004; Tasneem Abbasi *et al.*, 2012).

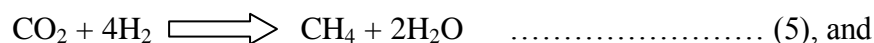
According to Tasneem Abbasi *et al.* (2012) the CH₄-CO₂ mixture is usually in the ratio of 3:1 and is regarded as clean fuel as it burns without smell. When captured in the rural areas, use of methane gas can reduce the need of firewood and can work towards conservation of forests through the use of the clean and renewable energy source. Forests contribute to the capture of carbon dioxide from the atmosphere which they sequester. Generally, methane production from livestock is expected to increase by 16.5% by the year 2030 from the levels produced in 2005 (Tauseef *et al.*, 2013). Continued production of methane without converting it to beneficial use is a serious threat to global warming (Møller *et al.*, 2004). Tauseef *et al.* (2013) describe a four step process from 3 phases that is associated with the generation of methane as summarised in Table 2.3. Tauseef *et al.* (2013) gave a detailed account of the different types of manure- specific methane capture systems that are commonly known as biogas digesters.

According to Galan *et al.* (2002) the fourth step found in phase III proceeds through three biochemical pathways i.e. acetotropic, hydrogenotropic and methylotrophic pathways as follows:

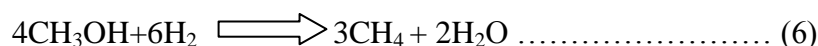
Acetotropic pathway, being the major methane producing route:



Hydrogenotropic pathway:



Methylotrophic pathway:



Biogas digesters that are suitable for rural family use can be a viable way of reducing

Table 2.3: Phases and steps in the production of methane

Phase	Steps and processes involved
Phase I: Hydrolytic phase	<p>Step 1: Breakdown of fats, carbohydrates, proteins and other macromolecules into amino acids, long chain fatty acids and sugars. The reaction is catalysed by exoenzymes present in facultative and obligatory anaerobic bacteria</p>
Phase II: Acidic phase	<p>Step 2: Involves acidogenesis reaction whereby monomers are converted to shorter chain (C1- C5) volatile fatty acids (VFA) mainly: lactic, propionic, butyric and valeric acid.</p> <p>Step 3: Utilisation of VFAs by homoacetogenic microbes to form acetic acid, carbon dioxide and hydrogen.</p>
Phase III: Methane phase	<p>Step 4: Methanogenesis occurs whereby anaerobic methanogenic bacteria act on acetate, hydrogen and CO₂ to yield methane</p>

Developed from Tauseef *et al.* (2013)

methane emission, conservation of forests and trees in rural environments by moderating the cutting down of trees for energy purposes. Trees and plants help in carbon sequestration by absorbing CO₂ and hence reduce the GHG from the atmosphere. Furthermore, plants take up nitrogen in manure deposited in the veld. According to Tauseef *et al.* (2013), common biogas digesters include Floating dome biogas plants (the Khadi and Industry Commission (KVIC) model, the Indian Agricultural Research Institute (IARI) model, the Application of Science and Technology to Rural Areas (ASTRA) model and the Botswana model. There is paucity of information of methane production from goat manure in literature. The prospects of harvesting methane from goat manure hinges on quantities of emissions. Therefore, it is necessary to explore the quantities of methane that are released from goat manure deposited on earth and slatted floors considering the abundance of the livestock species in the rural areas.

2.6 Tethering and herding

Goat keeping is a common practice done all over the world (Webb 2005), and the goats are a major source of livelihood of most smallholder farmers (Kusina and Kusina, 2000). The majority of goats in most developing countries, including South Africa (Romney *et al.*, 1996; Kusina and Kusina, 2000; Shabalala and Mosima, 2002; Roets and Kirsten, 2005) are kept by smallholder farmers. The smallholder farmers generally, appear to have an inclination to rear indigenous breeds (Kusina and Kusina, 2000; Bakare and Chimonyo 2011). The farmers who are into crop- livestock production either tether or herd their goats (Romney *et al.*, 1996; Kusina and Kusina, 1998) during the cropping season and allow the small ruminants to forage freely during the dry season (Chikwanda, 2004). Tethering or herding management practices are done to prevent crop damage (Chikwanda, 2004) or harvested grain in storage.

The emergence of stock theft as a major challenge in the livestock industry (Scholtz and Bester, 2010) may see the growing relevance of tethering or herding as a way of monitoring or security of grazing goats in addition to just preventing cropping damage.

A few studies have been done to assess the behaviour or production performance of goats under tethering (Karua and Banda, 1994; Romney *et al.*, 1996; Ogebe *et al.* 2000; Moniruzzaman *et al.*, 2002) and free ranging management system. Some goats got entangled, injured or died whilst tethered (Ogebe *et al.* 2000). However, studies on traditional systems of goat management have skirted investigating the impact of such management practices on blood biochemistry, chevon quality, fatty acid profiles as well as the effect of such systems on GHG emissions. Stress, welfare and nutritional adequacy to animals has been studied by monitoring changes in hormonal concentration, blood metabolites and behavioural indicators (Silanikov, 2000; Kannan *et al.*, 2000; Kadim *et al.*, 2006; Forkman *et al.*, 2007). Cortisol hormonal levels were reported to increase in animals subjected to stressful situations (Nazif *et al.*, 2003).

There have been reports of overutilization of the tethering spots especially in cases of infrequent changing of the tethering site. Overuse of the tethering site has been blamed for over grazing and soil erosion (Chikwanda, 2004). Infrequent changing of the tethering spot has also been linked to decline in growth rate of goats (Chikwanda, 2004). Tethered goats tend to be restricted by the length of the leash on the diversity of forages they consume. When goats are tethered on areas with moribund herbage they have no option but to consume what is presented. On the contrary, herded goats are relatively free to move across the veld selecting different palatable plant species and forage parts with high nutrient content.

However, the impact of grazing practice on the diet selected, blood metabolites the deposition of manure in housing structures and the related GHG emission has not been aggressively investigated in literature.

Resource endowed smallholder farmers assign shepherd(s) to guide goats to preferred foraging areas (Bayer and Zemmerlink, 1988). However, most smallholder farmers are resource constrained and await the return of their children from school so that the young boys or girls can take the goats to grazing areas in the afternoon (Chikwanda, 2004). In such cases, there is prolonged stay of the goats in the pens which compromises foraging time, growth rates and may increase quantities of faeces and urine excreted in pens. Deposition of manure and urine within animal facilities and poor manure management may cause increased greenhouse gas emission as observed in dairy (Sommer, 2001; Adviento- Borbe *et al.*, 2010; Cortus *et al.*, 2015), beef and sheep enterprises. There is need to investigate the effect of grazing system (tethering or herding) and floor type (earth vs slatted) on nutritional adequacy, GHG emission, physico- chemical properties of chevon and fatty acid profiles.

2.7 Measures of nutritional adequacy and welfare of goats

Nutritionally adequacy in livestock maybe identified through observable physical attributes such as live weights and body condition scores (BCS) (Chimonyo *et al.*, 2002). However, the condition of the animal involved may have deteriorated by the time the weights or BCS start reflecting insufficient nourishment. Olafadefan (2011) and Dampthey *et al.*, 2014 state that blood metabolites may be used to detect adequacy of feed offered to animals well before the condition of the animal has deteriorated. According to Pambu- Golla *et al.* (2000) the use of blood metabolites as indicators of nutritional status is independent of physiological status i.e.

lactating, pregnant, or whether a male is intact or castrated. Dampthey *et al.* (2014) point out that the protein status of an animal may be evaluated using the concentrations of serum urea, creatinine, total protein, albumin and globulin. High urea concentration indicates either muscle catabolism under fasting or high rumen ammonia for animal under high plane of nutrition (Rumosa Gwaze *et al.*, 2010). Low albumin is a reflection of diet deficiency in protein (Mapiye *et al.*, 2010; Olafadehan, 2011). In addition, albumin concentration may be indicative of health status of an animal. Low albumin concentrations were observed when animals fell sick (Solaiman *et al.*, 2010). A combination of high globulin and low albumin is indicative of presence of infection and occurs when the animal's immune system is fighting that infection (Ndlovu *et al.*, 2009; Dampthey *et al.*, 2014). On the other hand, low albumin to globulin ratio (A:G) may be observed if the albumin is too low coupled with a high concentration of globulin (Mapiye *et al.*, 2010)

Creatinine concentrations that are lower than the optimal range indicate lean muscle that is usually observed in young or smaller animals (Rumosa Gwaze *et al.*, 2010; Dampthey *et al.*, 2014). Total protein ordinarily stays at optimum range of healthy goats and will only start to decrease when dietary protein is low (Pambu-Golla *et al.*, 2000). Chimonyo *et al.* (2002) used blood glucose, urea and non-esterified fatty acids (NEFAs) concentrations to assess the nutritional status of working cows. They concluded that use of cows for draught purpose resulted in the mobilisation of body fat and protein to meet the demands of draught power. Rumosa- Gwaze *et al.* (2010) found a negative linear relationship between internal parasites burden and nutritionally related blood metabolites in Nguni goats. The authors concluded that the nutritional blood metabolites could be used in monitoring the health (Rumosa- Gwaze *et al.* 2010) and nutritional adequacy of goats.

However, despite the reliability of the concentrations of nutritional related blood metabolites as indicators of protein or energy adequacy, there has been an apparent gap in literature in their use to evaluate the nutritional status of tethered or herded indigenous goats. Further, there has been a dearth of information on monitoring the welfare of the tethered or herded goats using cortisol concentration and activity of Creatinine kinase (CK).

2.8 Stress indicators in livestock

Stress in livestock may be experienced on the farm, in transit to the abattoir or in lairage at the abattoir. Stress responses may be influenced by type of management system. Grandin, (2007) cited in Hoffman and Lühl (2012) states that extensively reared animals are normally more frightened by strange environments compared to those raised under intensive systems but they quickly return to a calm mode better than the latter group. The intensively reared animals are postulated to be more familiar with people, handling and showed less signs of stress in the presence of human beings. Stress has been demonstrated to negatively affect the quality of meat (Muchenje *et al.*, 2009a; Chulayo and Muchenje, 2013) Stress in slaughter animals is measured by cortisol concentration, activity of creatine kinase and behavioural displays. There is a gap in literature on the stress responses by goats reared under traditional tethering and herding systems. Further, the effect of type of housing floors i.e. earth and slatted on the concentration of cortisol, and activity of creatine kinase and meat quality is barely known.

2.8.1 Cortisol concentration

The concentration of serum cortisol increases when small ruminants are subjected to stress (Wise *et al.*, 1988; Kaushish *et al.*, 1997; Nazifi *et al.*, 2003). A surge in cortisol

concentration was observed when Alpine x Beetle goat crosses were subjected to thermal stress and feed restriction (Hooda and Upadhyay, 2014). Moolchandani *et al.* (2008) observed increased cortisol concentration in sheep subjected to restraint and isolation stress. However, in the studies by Moolchandani *et al.* (2008), as the animals got used to the stressors, the cortisol concentration fell. It is postulated that tethering and herding of goats that have not been previously subjected to such guided foraging may be stressed in the initial stages of such a trial. However, frequent handling of tethered goats may adjust them to tolerate human presence even when taken to the abattoir for slaughter as opposed to extensively foraged herded or free ranging goats. However, there is scarce information in literature on response to stressful abattoir situation by goats previously raised under tethering and herding grazing systems.

2.8.2 Creatine kinase

Forkman *et al.* (2007), and Chulayo and Muchenje (2013) assert that high activity of creatine kinase (CK) may occur due to anxiety, aggressive animal to animal contact and restlessness normally experienced in lairage. Creatine kinase is normally used to maintain a balance of ATP required in sustaining the activity of muscles (Dieni and Story, 2009). Nazif *et al.* (2003) found high CK activity at 95.90 U/L in fat tailed sheep exposed to 40°C. Zimmerman *et al.* (2011) observed that subjecting goats to exercise raised CK activity to 206- 276 U/L. Chulayo and Muchenje (2013) obtained much higher CK activity (723.3 ± 77.75 and 1026.3 ± 105.06 U/L) in sheep slaughtered at a commercial abattoir following a 24 hour lairage time. The activity of creatine kinase in goats that have previously been managed by tethering or herding is not known.

2.8.3 Physiological responses to stress

Animals that are engulfed with fear may show aggression, overt alertness, and avoidance or escape behaviour (Ferguson and Warner, 2008). Other physiological responses to stress include increased breathing rate, raised body temperature channelling of viscera blood to the skeletal muscles and the brain (Ferguson and Warner, 2008). These changes are caused by activation of the sympathetic nervous system. The parasympathetic nervous system restores normal metabolic rate, breathing rate and other functions such as digestion and sleep when the stressor has been removed (Wilke *et al.*, 2009).

The autonomic nervous system (ANS) controls the nerves of the inner organs of which an animal has no conscious control e.g. heartbeat, breathing rate and digestion. The ANS consists of three parts which are: the sympathetic, parasympathetic and enteric nervous systems. The sympathetic nervous system (SNS) and the hypothalamic- pituitary- adrenal (HPA) axis are activated by acute stressors such as fear (Ferguson and Warner, 2008). These neuroendocrine systems play a fundamental role in the regulation of energy fluxes (Muchenje *et al.*, 2009). The autonomic nervous system is activated by severe and sudden stimulus such as unaccustomed human handling. In the face of stress the sympathetic nervous system (SNS) causes a surge in the secretion of catecholamines (epinephrine and norepinephrine) in the blood which increases depletion of energy stores i.e. glycogen and lipids in animals awaiting slaughter (Muchenje *et al.*, 2009). Reduced glycogen reserves i.e. below the critical 45- 55 mmol/ kg result in high ultimate pH (pHu) i.e. above the optimum pH of 5.5- 5.6, that hinders the conversion of muscle to meat (Muchenje *et al.*, 2009). The normal glycogen levels in the bovine and ovine species is 75- 120 mmol/ kg (Ferguson and Warner, 2008). Injection of the catecholamine epinephrine resulted in an elevated glycogenolysis compared to the levels

observed in normal fasting (Ferguson and Warner, 2008). Meat with high ultimate pH is less tender and has a dark colour that is disliked by modern consumers.

2.9 Meat quality

Vimiso *et al.* (2012) define meat quality in respect to attributes such as wholesomeness, freshness, nutritional value, texture, smell, colour, aroma and flavour. According to the authors meat quality has intrinsic and extrinsic attributes. The intrinsic attributes of meat refer to meat colour, fat marbling, leanness, freshness, juiciness, tenderness. On the other hand, extrinsic attributes refer to the meat class, place of slaughter, package label and price (Vimiso *et al.*, 2012). Muchenje *et al.* (2009a) defines meat quality as referring to its composition and palatability. The authors further highlight important parameters in measuring meat quality as including its appearance, tenderness, juiciness and flavour. The parameters are influenced by the level of intra muscular fat, whose presence improves meat quality (Muchenje *et al.*, 2009). Meat quality is influenced by the glycogen status of muscle prior to slaughter (Muchenje *et al.*, 2008). According to Adzitey *et al.* (2011) and Vimiso and Muchenje (2013) depleted glycogen reserves raises muscle pH and results in dark firm dry (DFD) meat. Dark firm dry meat has an undesirable dark colour, is tough to chew and is detested by consumers (Muchenje *et al.*, 2009). Some studies done with South African indigenous goats gave very high Warner Bratzler Shear Force values of 66.9 to 74.8 N. The observation was postulated to be a result of inherent breed effects (Simela *et al.*, 2004) and possibly the manner in which they are fed and raised. However, there is a gap in literature on meat quality of goats raised under traditional tethering or heading grazing practices. Further, the effect of housing type on meat quality has largely been skirted in literature.

2.9.1 Measures of meat quality

2.9.1.1 Ultimate pH (pHu)

Ultimate pH (pH_u) influences meat quality (Muchenje *et al.*, 2009). Mutton of pH in the ranges of 5.75- 6.0 gave rise to tough meat (Gregory, 2008). Heat stressed Omani and Somali goats were observed by Kadim *et al.* (2008) to produce meat of pH range 5.65 to 5.81. Good meat quality was achieved at low chevon pH_u coupled with slow chilling rate (Simela *et al.*, 2004). Yu *et al.* (2009) explain that higher tissue pH promote the degradation of muscle proteins by calpain proteinases as well as increase absorbance of light by the meat and this makes the meat to appear dark and promotes incidences of dark firm dry (DFD).

Relationships were observed to sometimes exist between meat quality traits (Muchenje *et al.*, 2008). For instance, ultimate pH (pHu) influences meat tenderness and meat colour (Strydom *et al.*, 2000). Higher pH_u was associated with meat of an undesirable darker colour (Hoffman *et al.*, 2003; Muchenje *et al.*, 2009) that is despised by consumers (Esenbuga *et al.*, 2009; Chulayo and Muchenje, 2013). Lomiwes *et al.* (2014) affirms the relationship between ultimate pH (pHu) tenderness. According to Lomiwes *et al.* (2014) meat of high pH that is greater than 6.2 and that of low pH (< 5.79) is referred to as being acceptably tender. However, it is postulated that the reaction that are responsible for tenderising meat from the high and low pH are different. According to Lemiwes *et al.* (2014b), meat tenderness at high pH (> 6.2) is ascribed to fast proteolytic degradation, by the enzyme μ -calpain, of big proteins, for example, filamin and titin. On the other hand, tenderness observed at low pH was a result of the sum degradation of big protein molecules by μ - calpain and small proteins by cathepsins as meat aging progresses (Lemiwes *et al.*, 2014b). Lemiwes *et al.* (2014a) further explain that tenderness is ascribed to the weakening of myofibrillar structure resulting

from the catabolic degradation of proteins by calpains and cathepsins enzyme systems post slaughter. Meat cuts of pH higher than 5.9 have an undesirable dark colour, short shelf life, less palatable and is tough (Ferguson and Warner, 2008; Muchenje *et al.*, 2009). Studies done with beef showed that meat of low pH value between 5.4- 5.8 had a desirable red colour and felt tender at sensory evaluations (Lomiwes *et al.*, 2014a). Simela *et al.* (2004) reported of high pH values in indigenous goats in the range 5.88- 6.03. In addition, the pH values cited in a review by Webb *et al.* (2005) showed that most of the pH value from goat meat were above pH 5.77. However, there is a devoid of information of the nature of relationships within South Africa indigenous goats raised under tethering, herding and free ranging on natural pasture. A high level of catecholamines was released under stress in cattle and they caused the depletion of glycogen that lead to an increase in ultimate pH (Muchenje *et al.*, 2008)

2.9.1.2 Meat colour

Muchenje *et al.* (2009a) state that meat should have an attractive colour that is consistent throughout the entire portion. Webb *et al.* (2005) reported that chevon colour was darker red in colour than mutton. However, according to Babiker *et al.* (1990) some consumers could not distinguish between lamb and kid meat based on colour. Meat colour is objectively measured according to three colour coordinates i.e. L*, a* and b* (Commission International De' Eclairage, 1976). According to the system, L* is a measure of lightness, where (100 = white and 0 = black); a* represents positive red, negative green and b* represents positive yellow negative green. In a review, Webb *et al.* (2005) indicated that some research studies have been able to detect differences between chevon and lamb using the CIE (1976) colour coordinate system. Among the studies cited in the review where differences were picked between lamb and kid meat was work by Sheradin *et al.* (2003) and Vergara *et al.* (1999).

Rapid depletion of muscle glycogen during stressful handling or transportation results in dark firm dry (DFD) meat (Muchenje *et al.*, 2009). Dark firm dry meat is of poor quality, has shorter shelf life, and is disliked by consumers. According Muchenje *et al.* (2008), the colour of meat and external fat cover influences the readiness and visual acceptability of meat by consumers. Meat colour is influenced by the extend of intramuscular fat, moisture content as well as age related variations in myoglobin content (Muchenje *et al.*, 2008).

2.9.1.3 Juiciness, tenderness and flavour

Muchenje *et al.* (2009a) highlight that juiciness and flavour of meat is affected by fatty acid composition and water holding capacity. Muchenje *et al.* (2008) list myofibrillar fragment length (MFL), sarcomere length (SL) and Warner Bratzler Shear force (WBS) values as measures of meat tenderness. Revilla and Vivar- Quintana (2006) ascribed negative correlations between WBS values and sarcomere lengths to that short sarcomere length are generally tough. The tenderness of meat refers to those attributes of the cut that relate to its softness to the tongue and resistance to tooth pressure (Revilla and Vivar- Quintana, 2006). Tenderness is influenced by the age, live weight, sex, breed of the animal, pre- slaughter stress as well as rate of chilling of the carcass post slaughter. As animals age, their meat becomes tough. Slow maturing breeds tend to have tough meat as they take a long time before they reach slaughter age. Rapid chilling causes the muscle fibres to shorten very fast and this would result in more force being required to shear the meat. In a study with cattle, Muchenje *et al.* (2008) found that meat tenderness improved with aging of the muscle. Monsón *et al.* (2005) explain meat tenderness to be a function of collagen content, myofibrillar structure and heat stability of the muscle. The calpain proteolytic enzymes can also influence the myofibrillar component of tenderness during post- mortem aging of carcass

(Muchenje *et al.*, 2008). The authors further explain that when animals are slaughtered at a young age i.e. when muscles are still low in connective tissue, the myofibrillar component becomes a more relevant explanation of meat tenderness. These assertions concur with reports by Sañudo *et al.* (2004) that shear force values of cooked meat may be taken as a measure of its myofibrillar toughness.

2.10 Conclusion

Goat populations continue to expand due to their fecundity and poor offtake in countries such as South Africa. The proliferation of these small ruminants is likely to contribute significant levels of GHG emissions. Goat shelter is associated with a characteristic pungent smell that resembles ammonia. Ammonia is broken down to nitrogen precursors that can be oxidised to form nitrous oxide, a key GHG, which has 310 times global warming potential compared to the standard reference carbon dioxide. Further, manure from ruminant emits carbon dioxide and methane. However, research has had a bias on measuring GHG from other livestock species but avoiding goats. Many developing countries are not able to procure sophisticated equipment to measure such emissions which raises the need to explore and adopt affordable but accurate methods of GHG measurement. Static chamber methods are a potential candidate technique for such studies that may need to be adopted in livestock studies. Many small holder goat farmers practice tethering and herding. The satisfaction of adequate nutrient supply, quality of chevon as well as the fatty acid profiles under tethering and herding grazing practices of goats is barely known. It is necessary to fill in the gap in literature on how traditional grazing systems (tethering and herding) and housing floor type (slatted and earth) affect the GHG emission from manure, blood metabolites, physico-chemical characteristics and fatty acids profiles from goat meat.

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CHAPTER 3: Effect of grazing and floor type on greenhouse gas emissions from goat

manure

Abstract

The objective of this study was to determine the effects of grazing system (tethering vs herding) and floor type (earth vs slatted) on methane (CH₄), carbon dioxide (CO₂) and nitrous oxide (N₂O) emissions from goat manure. Forty eight castrated Nguni goats, at 6-7 months old, were randomly allocated to herding (H) or tethering (T) treatments and accommodated on earth (E) or slatted (S) floor types. Gas sampling was done monthly, for 5 months from their manure, which was excreted on the floors, using static chambers. Gas analysis was done using a SRI 8610C gas chromatography machine. There were management by floor type; month of sampling by management; as well as month by floor type interactions that significantly ($P < 0.05$) affected GHG flux. The highest CH₄ fluxes were from the manure of herded goats that were accommodated on earth floors (HE): $0.78 \pm 0.091 \text{ mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$ ($0.25 \pm 0.090 \text{ g CH}_4 \text{ AU}^{-1} \text{ d}^{-1}$). The highest CO₂ fluxes were from manure of herded goats that were accommodated on slatted floors (HS): $226.13 \pm 10.613 \text{ mg CO}_2 \text{ m}^{-2} \text{ hr}^{-1}$ ($73.26 \pm 3.438 \text{ g CO}_2 \text{ AU}^{-1} \text{ d}^{-1}$). The highest N₂O fluxes were from the manure of tethered goats that were sheltered on slatted floors (TS): $2.43 \pm 0.456 \text{ mg m}^{-2} \text{ hr}^{-1}$ ($0.79 \pm 0.148 \text{ g AU}^{-1} \text{ d}^{-1}$). A positive correlation was observed between N₂O and CO₂ ($r = 0.54$) emission. On the other hand, a weak negative correlation existed between CH₄ and CO₂ ($r = -0.14$) emission as well as between CH₄ and N₂O ($r = -0.12$). It was concluded that goat manure is an important source of GHG that is influenced by grazing system and floor type. Manure of HE emitted the most CH₄, whereas, HS emitted the most CO₂ and N₂O. Therefore, the management of foraging goats and design of houses should be considered in emission mitigation strategies at farm level.

Key words: goat manure, GHG, management, housing, chamber

3.1 Introduction

Agriculture contributes between 9- 12 % of the total human influenced greenhouse gas (GHG) emissions (Eckard *et al.*, 2010; Kristensen, 2011; Vellinga *et al.*, 2011), of which 8- 11 % of these gaseous emissions come from ruminant livestock operations (O'Mara, 2011). Ruminants, wetlands (*dambo*) and rice paddies form the main sources of CH₄ (Dengel *et al.*, 2011). The chief GHG that are produced from ruminants are methane (CH₄), nitrous oxide (N₂O) and carbon dioxide (CO₂) (de Vries and de Boer, 2010; Cortus *et al.*, 2015). According to Zervas and Tsiplakou, (2012), CH₄, CO₂ and N₂O are emitted from enteric, respiratory activities and manure management, respectively. Anaerobic degradation of animal manure results in the production of CH₄ and CO₂ (Møller *et al.*, 2004; Steinfeld *et al.*, 2006). Methane and N₂O have high global warming potential (GWP) in the region of 21- 25 (CH₄) and 298- 320 (N₂O), over a 100 year period, when measured against the standard reference CO₂ (Nyamadzawo *et al.*, 2012; Krol *et al.*, 2015). The GWP of a gas is its residence time in the atmosphere and its ability to trap infrared radiation (Hadorn *et al.*, 2015).

The amount of GHG from animal sources is expected to increase in importance owing to growth in ruminant numbers (Kristensen, 2011). The population of cattle and small ruminants is being driven by the surge in demand of protein of animal origin from people (Krol *et al.*, 2015) who are increasingly becoming selective on the quality of meat they consume (Muchenje *et al.*, 2009). The global human population is expected to reach 9.5 billion by 2050 (FAO, 2009; UNPD, 2011) up from the current figure of 7.2 billion. FAO (2006) statistics claims that 56 billion animals are slaughtered annually for meat and that the level of offtake will double by 2050.

As the ruminant population grows, a lot of studies have been done to quantify GHG but they have, however, focused on enteric CH_4 (Kreuzer and Hindrichsen, 2006) and CO_2 from respiration in cattle but neglected the emission of these GHG and N_2O from manure in goat facilities (Zervas and Tsiplakou, 2010). Kreuzer and Hindrichsen (2006) explained that heaps of manure promote anaerobic conditions. This leads to the digestion of carbohydrates, protein and lipids in the manure (Møller *et al.*, 2004) thereby, producing up to 27 % of gross CH_4 emission from ruminants.

About 75- 90 % of nitrogen intake by foraging ruminants is deposited as manure (Krol *et al.*, 2015) and this nitrogen rich base constitutes a potential substrate for nitrification and denitrification, processes that lead to emission of N_2O . Nitrous oxide plays a role in the destruction of the ozone layer (Philippe *et al.*, 2013) and contributes to change in climate. The level of N_2O in the atmosphere has been reported to have increased by 20 % in the last century and will continue to grow at an annual rate of 0.2-0.3% (Thomson *et al.*, 2012). Manure from goats and cattle is commonly used as an organic fertiliser by low resource endowed smallholder farmers (Wuta and Nyamugafata, 2012). The manure is often left to accumulate in the kraals or housing facilities to be removed once a year and fed to crop fields or vegetable gardens as organic manure. Wuta and Nyamugafata (2012) lament on the apparent scantiness of research work on goat manure, yet it forms a vital component of the smallholder farming inputs and is perceived to be a high quality organic fertiliser. In the Eastern Cape Province of South Africa, there is a lot of build-up of goat manure in animal pens, due to very low formal goat offtake (Soji, *et al.*, 2015) and little cropping activity that would otherwise absorb the manure as fertiliser. The goat population in South Africa stands at 7 million (Du Toit *et al.*, 2013) and is growing, thus signalling a lot of possible GHG

emissions from the small ruminant species.

Vergé *et al.* (2009) advocate for the determination of GHG emission for livestock products and the authors emphasize on the inclusion of CH₄, CO₂ and N₂O in such evaluations. Ulens *et al.* (2014) regard housing facilities as carrying aerial emissions of the GHG that have a negative impact on the environment. However, there appears to be a huge bias in literature on studies done on dairy cattle (Lovett *et al.*, 2006; Kristensen, 2011; Joo *et al.*, 2015) and swine species (Vergé *et al.*, 2009; Philippe: 2013; Ulens *et al.*, 2014) but skirting goats. Zervas and Tsiplakou (2012) confirm that there are limited original research articles published on GHG emissions from sheep and goats. To our knowledge, this trial reports the first such study that was done in housing facilities of traditionally managed goats using static chambers. The objective of the current study was to determine the level of GHG flux (CH₄, CO₂ and N₂O) emitted from the manure (faeces and urine) excreted by tethered and herded goats sheltered on earth and slatted floors using static chambers and gas chromatography.

3.2. Material and Methods

The methods used in this study were approved by the University of Fort Hare's Research Ethics Committee (UREC) and awarded ethical certificate number: MUC101SCH101.

3.2.1 Study site

The study was carried out at the University of Fort Hare -Honeydale Research Farm (UFH-RF) which is located on GPS location 32° 46' S and 26° 51' E at 520 m above sea level, in the Eastern Cape Province of South Africa. The topography is characterised by a few slopes that receive an annual rainfall of 490 mm. The vegetation is described as a "False Thorn Veld of

Eastern Cape” (Acocks, 1988) and is composed of browse species such as *Acacia karroo*, *Scurtia myrtina* and *Grewia occidentalis* as well as the following dominant grass species: *Themeda triandra*, *Digitaria eriantha*, *Panicum maximum*, *Cynodon dactylon*, *Eragrostis spp* and *Pennisetum clandestinum* (Acocks, 1988).

3.2.2 Experimental goat houses

Two types of housing were designed and built with timber, zinc sheets and nails as construction material. The first type of housing was made on slatted floor with 1.2 cm inter plank space, at 1.2 m above the ground (Appendix 1), with six compartments that worked as replicates. Each compartment measured 1.8 m x 1.5 m (Area: 2.7 m²) and accommodated four goats. The compartments were partitioned by a solid wall of zinc sheets that were driven 20 cm into the ground to prevent cross movement of excreta between compartments. One compartment for EF and one for SF were left without goats and these worked as control (C) compartment. An exact replica of the house design on slatted floors and compartments was made but having earth floor (Appendix 2) instead of slates. The houses provided daily shelter for the goats for five months (January- May 2015) from 1300 hrs of a day to 0800 hrs of the next day for the duration of the study period. Manure was not removed for the duration of the monitoring period.

3.2.3 Study animals

Forty eight castrated Nguni goats that were at approximately 6- 7 months old (average live weight of 22 kg) were randomly allocated to the twelve compartments of the two types of goat housing (slatted floor and earth floors). The goats were taken for foraging every morning at 0800 hrs and brought back into designated compartments at 1300 hours every day. The

goats on the tethering treatment were tethered individually to *acacia* bushes with 3 m length ropes and the tethering spot changed 3-4 times for the duration of the foraging time. The goats that were herded were free to forage within the vicinity of those that were tethered. Each goat had a specific identification tag number that corresponded to an exact compartment of the two types of housing that they were penned in throughout the duration of the study.

3.2.4 Chamber design

Static gas chambers were made from 20 L PVC containers (Sapkota *et al.*, 2014). Each static chamber had two small holes drilled at the same radius on opposite positions from the centre of the base of the chamber. The small holes were plugged with air tight butyl rubber septa. The first rubber septum was used as the sampling septum and the second one was used as the exit point of an electric cable that was used to connect a computer cabinet fan (Appendix 3) used to homogenise air in the chamber headspace to prevent bias of vertical trace gas concentration gradients (Jørgensen *et al.*, 2012). Silicon was applied on the septa around the cable so as to provide an air tight seal. The computer cabinet fans were connected to an 18U PSU 12VOLT POWER SUPPLY 18 WAY electric board that was used to provide electric current to drive the fans for homogenising the head space in the static gas chambers.

3.2.5 Chamber deployment

In order to ensure representativeness of gas sampling, on the measured footprint relative to the compartment floor area, three static chamber replicates were randomly deployed per compartment (Appendix 4). The static chambers were deployed for one hour in the morning between 0900 hours and 1200 hours of the sampling day, following procedures recommended by Kelliher *et al.* (2011) and Sapkota *et al.* (2014). The three gas chambers per compartment

were randomly placed on the manure and driven 5 cm into the manure. The fans were then connected to the 18U PSU 12VOLT POWER SUPPLY 18 WAY to mix the chamber head space gas.

3.2.6 Collection and storage of air samples

Gas samples were collected monthly (mid of every month), using 20 ml plastic syringes connected to 20 gauge needles, at 0 (t₀), 30 (t₃₀) and 60 minutes (t₆₀) post setting up (Nyamadzawo *et al.*, 2012; van der Weerden *et al.*, 2013). The sampling was done through the air tight septum at the top of the chamber (Appendix 5). The gas samples were immediately transferred by injecting into round bottomed, evacuated 12 ml Borosilicate Exetainer vials (Labco Ltd, UK) for storage until analysis with a GC. The 12 ml Borosilicate Labco vials were stored at room temperature until analysis. Storage time took cognisance of Rochette and Bertrand, (2003)'s recommendations that the gas samples can be stored for up to 126 days without significant loss of trace gases.

3.2.7 Detection and measurement of GHG concentration from air samples

The detection and determination of gas concentration for CH₄, CO₂ and N₂O was done using a SRI 8610C gas chromatography machine. The GC was equipped with HAYSEP D column and Flame Ionisation Detector (FID) with methaniser for the detection of CH₄ and CO₂; and an Electron Capture Detector (ECD) for the detection of Nitrous Oxide (N₂O). The injection loop was 1 mm and the carrier gas used was Nitrogen base line 5.0 (AFROX). The GC instrument was set at the following parameters: oven temperature 100°C and held for 8 minutes. Detector temperature for both the FID and ECD was set at 300 °C. The components were: CH₄ and CO₂ for FID then N₂O for ECD.

The reference standards were also obtained from AFROX. The samples from individual chambers were injected into the GC injector port and fluxes determined in sequence (i.e. sample of Chamber 1 at (t₀), (t₃₀) and (t₆₀) of deployment time before analysing the next set i.e. from Chamber 2's (t₀), (t₃₀) and (t₆₀). The sequence format was done in order to avoid problems associated with GC drift (Sapkota *et al.*, 2014). Fluxes for the gases were computed according to Hutchinson and Mosier (1981).

3.2.8 Gas flux computations

Gas concentrations were measured at 0 (t₀), 30 (t₃₀) and 60 minutes (t₆₀) and were denoted by C₀, C₁ and C₂, respectively. Generally, the gas concentrations progressively increased with time and gave $(C_1 - C_0) / (C_2 - C_1) > 1$ and followed a curvilinear relationship, the fluxes for CH₄, CO₂ and N₂O where, therefore, calculated as described by Hutchinson and Mosier (1981) as shown in Equation [3.1]:

$$F = (V/A) \times [(C_1 - C_0) / (2 \times C_1 - C_2 - C_0) \times t] \times \ln[(C_1 - C_0) / (C_2 - C_1)] \dots\dots\dots \text{Equation [3.1]}$$

Where:

F = the gas flux measured in mg m⁻² hr⁻¹

V = the chamber space air volume

C = the gas concentration in parts per million (ppm) for CH₄, CO₂ and N₂O

T = the time duration from C₀ to C₁

A = the area on the floor covered by a static chamber

Gas flux data were computed in mg Trace gas flux m⁻² hr⁻¹ and then converted to g TAU⁻¹ d⁻¹ taking into consideration that one goat is equal to 0.1 tropical animal unit (TAU= 250 kg)

(Peden, 1987), and further converted to measurements based on per animal unit (AU=500kg) to enable wide comparisons to be made with results of studies done in AU.

3.2.9 Data analysis

All gas concentrations (ppm Trace gas) and fluxes ($\text{mg Trace gas m}^{-2} \text{ hr}^{-1}$; $\text{g Trace gas AU}^{-1} \text{ d}^{-1}$) were analysed using the PROC GLM procedures of Statistical Analysis System (SAS, 2003). Significant differences between least square group means were compared using Tukey's Studentized Range (HSD) test. Correlation analysis between trace gas fluxes was done for CH_4 , CO_2 and N_2O using PROC CORR procedures of SAS (2003).

3.3. Results

Figure 3.1 shows the mean monthly maximum and minimum temperatures experienced in the study area during the period of gas sampling. There was a gradual decrease in mean monthly temperature from 23°C in January to 15.5°C in May. Considerable GHG (CH_4 , CO_2 and N_2O) concentrations were detected from surface to air samples that were taken above the manure (faeces and urine) that were excreted on earth floors and below slatted floors, by goats that were reared either by heading or tethering management systems. A negative correlation ($r = -0.136$) was picked between ppm CH_4 emission and CO_2 ($P > 0.05$) at t60 (Table 3.1). Nitrous oxide concentration at t60 also showed a weaknegative correlation relationship with CH_4 ($r = -0.123$). However, a strong positive correlation relationship ($P < 0.05$) was observed between ppm N_2O and ppm CO_2 at t60 ($r = 0.545$).

3.3.1 Methane flux

Figure 3.2 shows the overall $\text{mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$ fluxes by month of sampling for the control compartments and those that accommodated herded or tethered goats. The methane fluxes were affected by management of the goats, type of floor, housing as well as the interaction of

management by type of house floor ($P < 0.05$). Methane fluxes showed an initial rise from a

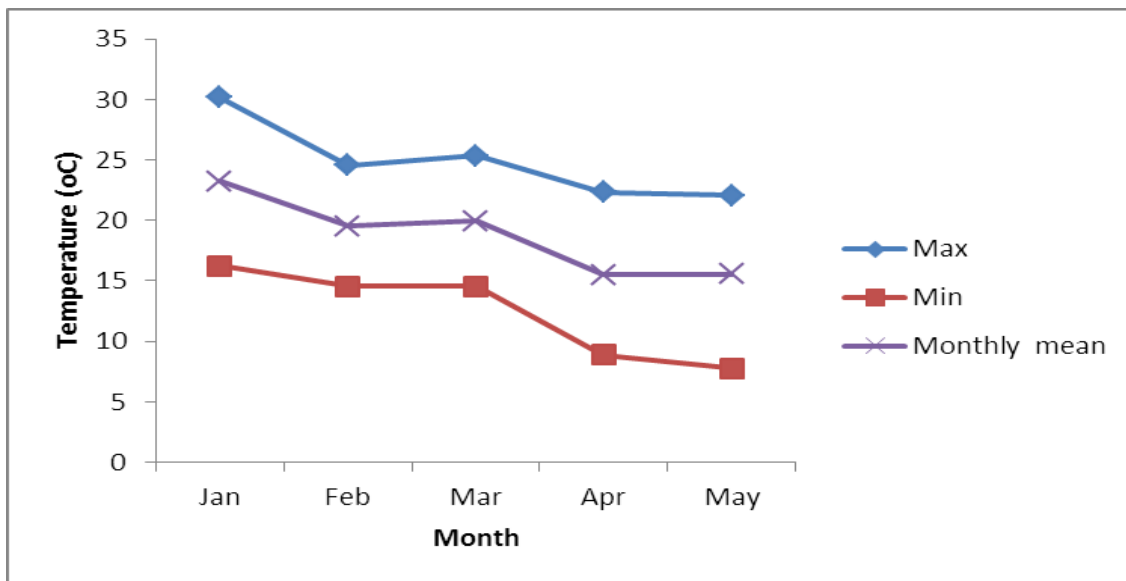


Figure 3.1 Average monthly ambient temperatures (°C) for University of Fort Hare Honeydale Research farm

Max= Maximum; Min= Minimum;

Table 3.1
Correlations between ppm GHG gas concentrations at t60

Trace gas	Trace gas		
	CH ₄	CO ₂	N ₂ O
CH ₄	1.000	-0.136 ^{NS}	-0.123 ^{NS}
CO ₂	-0.136 ^{NS}	1.000	0.545*
N ₂ O	-0.123 ^{NS}	0.545*	1.000

CH₄ = Methane; CO₂ = Carbon dioxide; N₂O = Nitrous oxide; t60 is chamber deployment time of 60 minutes
Significant difference: * P < 0.05

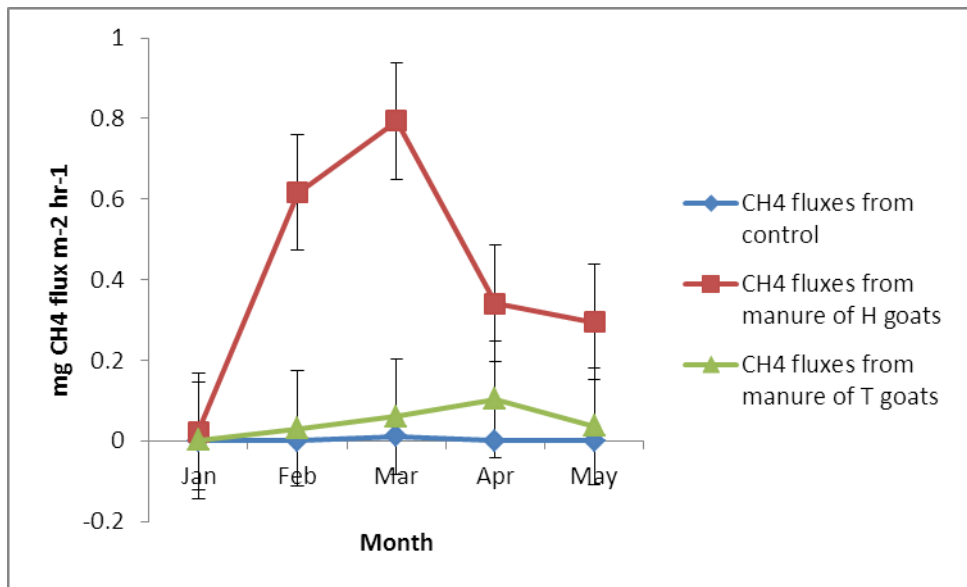


Figure 3.2: Monthly methane flux (LSMean \pm se mg CH₄ flux m⁻² hr⁻¹) from manure as affected by herding (H) or tethering (T) of goats.

value close to zero in January reaching a peak in March and April for the compartments that housed herded and tethered flocks, respectively. The $\text{mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$ from the control compartments was low and close to zero for the duration of the study. The type of goat management had a significant ($P < 0.05$) effect on methane fluxes as displayed in Figure 3.3. The methane fluxes were: highest in the herded goat compartments $0.41 \pm 0.064 \text{ mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$ ($0.13 \pm 0.021 \text{ g AU}^{-1} \text{ d}^{-1}$) and lowest in the control compartments at $0.00 \pm 0.111 \text{ mg m}^{-2} \text{ hr}^{-1}$. Methane fluxes were also significantly ($P < 0.05$) affected by house floor type as shown in Figure 3.4. The average methane emission per floor type were $0.29 \pm 0.068 \text{ mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$ ($0.09 \pm 0.022 \text{ AU}^{-1} \text{ d}^{-1}$) and $0.02 \pm 0.068 \text{ mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$ ($0.01 \pm 0.022 \text{ AU}^{-1} \text{ d}^{-1}$) for the earth floor and slatted floor compartments, respectively. Methane emission was affected ($P < 0.05$) by the interaction of goat management and floor type as shown in Fig 3.5. The highest methane flux were from manure of herded goats that were accommodated in compartments with earth floors $0.78 \pm 0.091 \text{ mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$ ($0.25 \pm 0.029 \text{ AU}^{-1} \text{ d}^{-1}$) followed by tethered goats accommodated in earth floors $0.08 \pm 0.091 \text{ mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$ ($0.03 \pm 0.029 \text{ AU}^{-1} \text{ d}^{-1}$) and the least were in the control slatted side $0.00 \pm 0.158 \text{ mg CH}_4 \text{ m}^{-2}$.

3.3.2 Carbon dioxide flux

Carbon dioxide flux from manure was significantly affected ($P < 0.05$) by month of gas sampling, goat management practice, floor type, the interaction of month and management, as well as by the interaction of goat management and floor type. Figure 3.6 shows the trends in $\text{mg CO}_2 \text{ flux m}^{-2} \text{ hr}^{-1}$ from January to May 2015. There was a notable peak in February across all treatments followed by a general downward trend in $\text{mg CO}_2 \text{ flux m}^{-2} \text{ hr}^{-1}$. The flux from

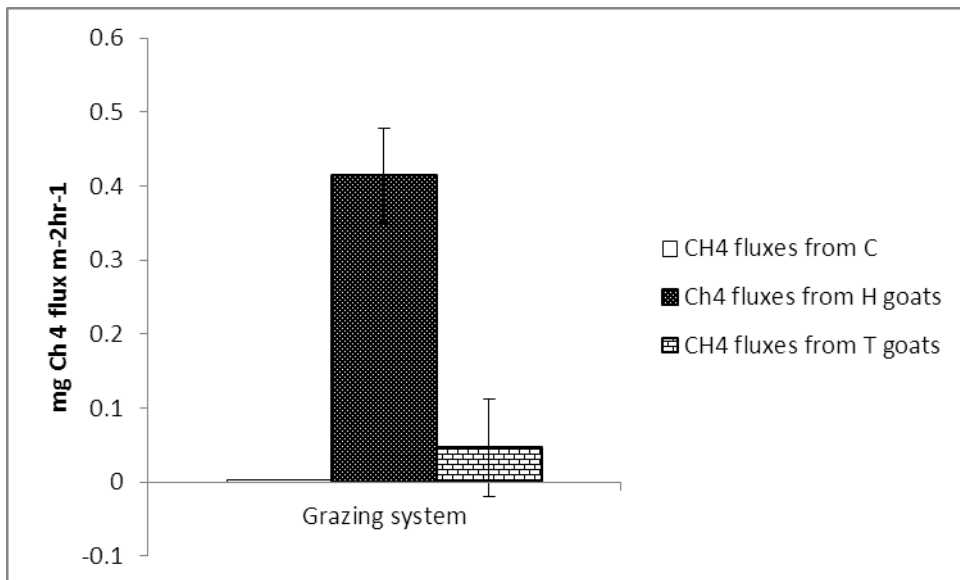


Figure 3.3: Methane flux (LSMean \pm se mg CH₄ flux m⁻² hr⁻¹) from manure as influenced by tethering (T) or herding (H) of goats.

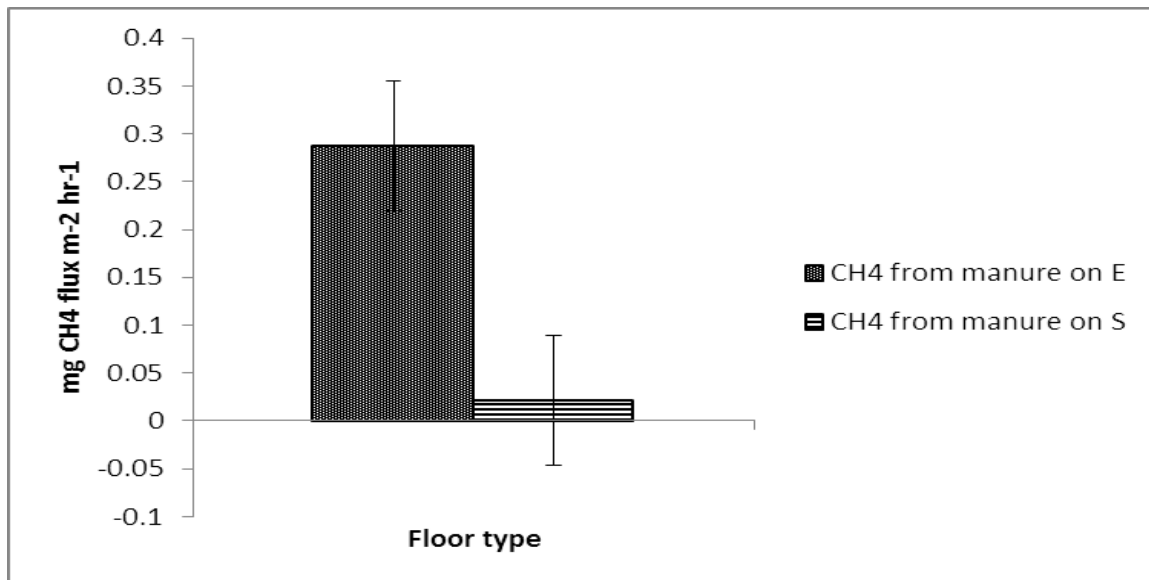


Figure 3.4: Methane flux (LSMean \pm se mg CH₄ flux m⁻² hr⁻¹) from goat manure as affected by floor type. E= earth floor, S= slatted floor

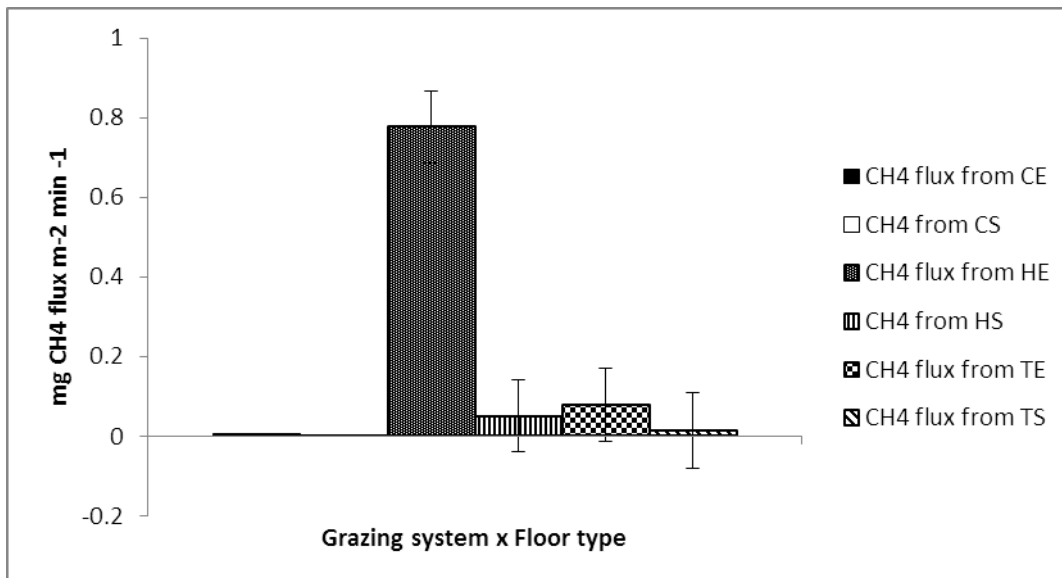


Figure 3.5: Methane flux (LSMean \pm se mg CH₄ flux m⁻² hr⁻¹) from goat manure as affected by the interaction of management by floor type (CE, CS, HE, HS, TE & TS).
 CE= Control compartment on earth floor side, CS control compartment on slatted floor side, HE= manure of herded goat on earth floor side, HS= manure of herded goats under slatted floors; TE= manure of tethered goats on earth floor; TS= manure of tethered goats under slatted floors

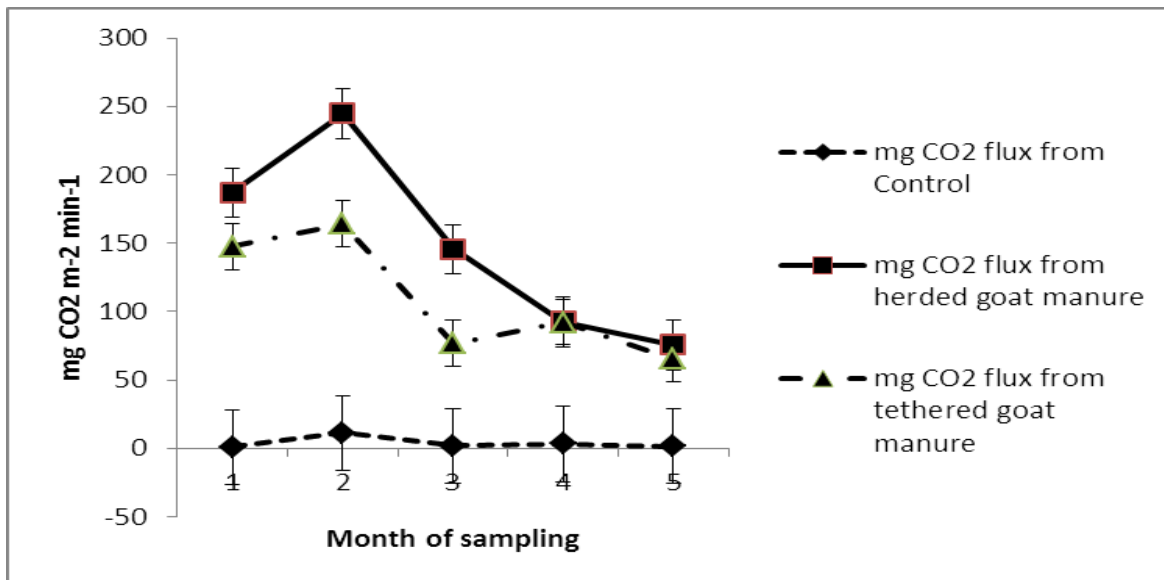


Figure 3.6: Mean monthly carbon dioxide flux (LSMean \pm se mg CO₂ flux m⁻² hr⁻¹) from manure as influenced by herding (H) or tethering (T) of goats

manure of goats that were herded had the highest peak of $244.77 \pm 15.820 \text{ mg CO}_2 \text{ m}^{-2} \text{ hr}^{-1}$ ($79.31 \pm 5.126 \text{ g CO}_2 \text{ AU}^{-1} \text{ d}^{-1}$). The trend of high CO_2 emission from herded goats was maintained throughout the duration of the study. The CO_2 flux from excreta of both tethered and herded flocks converged and almost superimposed each other in April. The control compartments showed the least $\text{mg CO}_2 \text{ flux m}^{-2} \text{ hr}^{-1}$ that was consistently close to zero and parallel to the x-axis. Herding of goats resulted in significantly higher ($P < 0.05$) CO_2 flux from their manure compared to that of tethered and control compartments as shown in Figure 3.7.

Figure 3.8 shows the effects of the interaction of goat management and type of floor on $\text{mg CO}_2 \text{ flux m}^{-2} \text{ hr}^{-1}$ from goat manure. The highest CO_2 flux was recorded from manure of goats that were herded and were accommodated in slatted floors (HS) $226.13 \pm 10.613 \text{ mg CO}_2 \text{ m}^{-2} \text{ hr}^{-1}$ ($73.26 \pm 3.438 \text{ AU}^{-1} \text{ d}^{-1}$) and the least was in the control on the earth floor (CE) compartments $1.35 \pm 17.330 \text{ mg CO}_2 \text{ flux m}^{-2} \text{ hr}^{-1}$. Table 2 shows mg CO_2 fluxes $\text{m}^{-2} \text{ hr}^{-1}$ and $\text{g CO}_2 \text{ AU}^{-1} \text{ d}^{-1}$ from manure of goats that were either herded or tethered. The highest CO_2 flux was from compartments that housed herded goats and the least was observed in the control compartments.

3.3.3 Nitrous Oxide flux

The ratio of $(C_1 - C_0) / (C_2 - C_1)$ in ppm N_2O emission in herded goats that were kept on earth floors (HE) was zero. Subsequently, comparisons of N_2O emission that were done incorporating HE treatment were based on Nitrous oxide parts per million (ppm N_2O) concentration at t60 (i.e. C_2). However, the ratio $(C_1 - C_0) / (C_2 - C_1)$ N_2O was positive for N_2O emissions from the manure in CS; HS; TS and TE, hence, the trace gas concentrations were

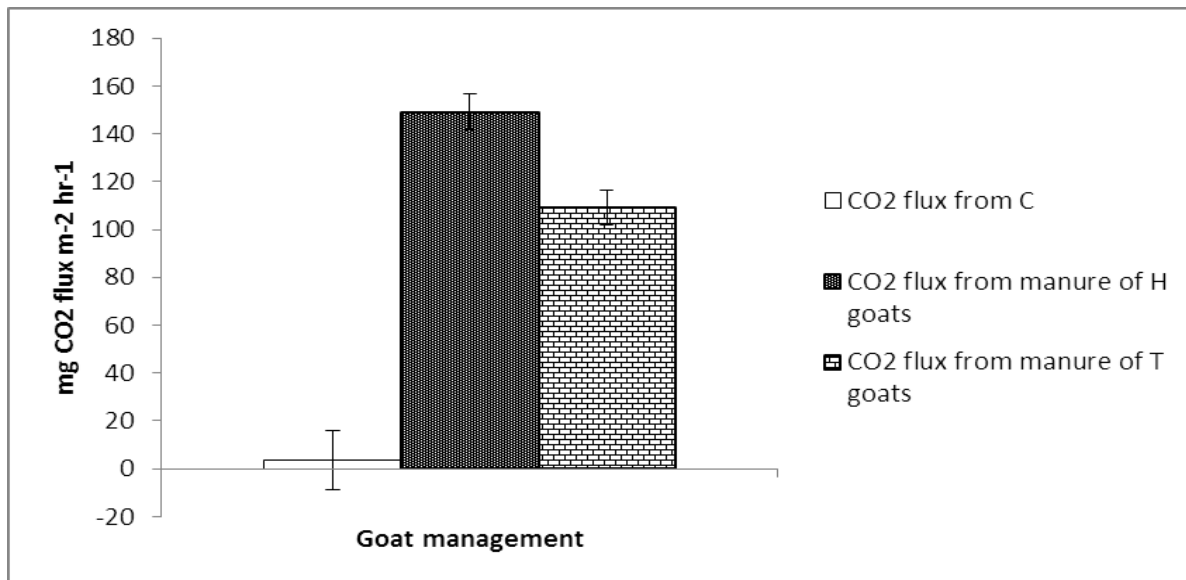


Figure 3.7: Carbon dioxide flux (LSMean \pm se mg CO₂ flux m⁻² hr⁻¹) from manure as affected by herding (H) or tethering (T) of goats

C= control compartments, H= herded goats, T= tethered goats CO₂ flux emitted

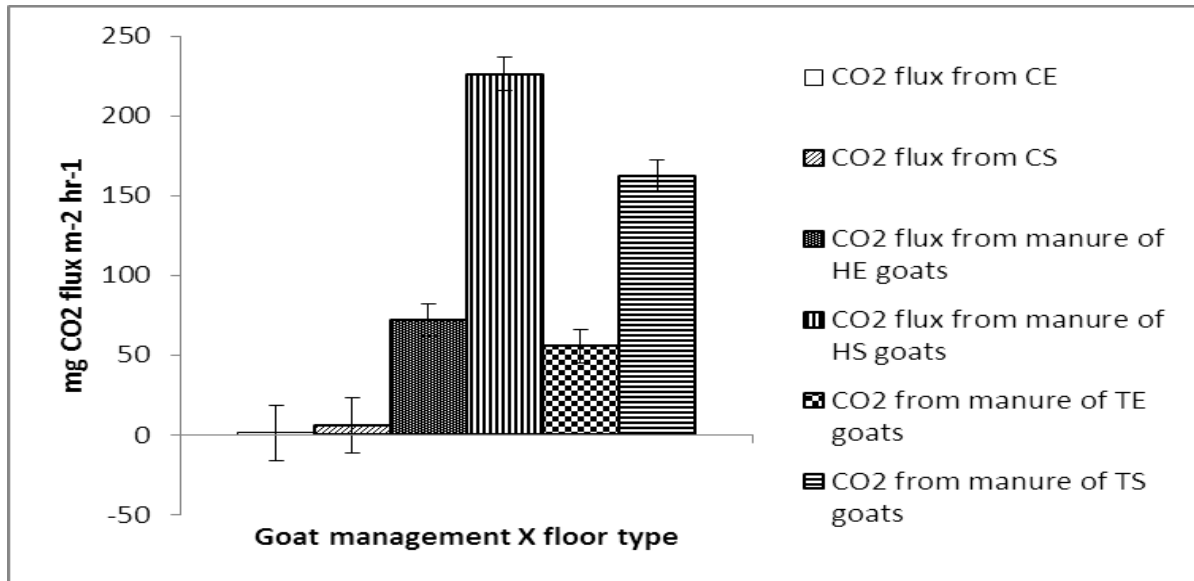


Figure 3.8: Carbon dioxide flux (LSMean \pm se mg CO₂ flux m⁻² hr⁻¹) from goat manure as affected by the **interaction of** goat management by floor type (CE, CS, HE, HS, TE, TS). CE= Control compartment on earth floor side, CS control compartment on slatted floor side, HE= manure of herded goat on earth floor side, HS= manure of herded goats under slatted floors; TE= manure of tethered goats on earth floor; TS= manure of tethered goats under slatted floors

Table 3.2

Least square mean values \pm standard error for CO₂ fluxes from goat manure as affected by management system

Management	CO ₂ flux (mg CO ₂ m ⁻² hr ⁻¹)	CO ₂ flux (AU ⁻¹ d ⁻¹)
Control	3.63 ^a \pm 12.25	N/ A
Herding	149.07 ^b \pm 7.38	48.30 ^b \pm 2.39
Tethering	109.14 ^c \pm 7.25	35.36 ^c \pm 3.44

LSMeans within the same column with different super scripts were significantly different (P < 0.05)

mg CO₂ m⁻² hr⁻¹ = milligrams Carbon dioxide flux per square meter per hour

CO₂ flux (AU⁻¹ - d⁻¹) = Carbon dioxide flux per Animal Unit per day

N/ A = Control compartments had no animals in them so it was not applicable to report in AU

converted to fluxes in $\text{mg N}_2\text{O m}^{-2} \text{hr}^{-1}$ and also $\text{g N}_2\text{O AU}^{-1} \text{d}^{-1}$.

The emitted N_2O in ppm was significantly ($P < 0.05$) affected by the interaction of management and house as well as the interaction of month of sampling and house. The concentration at **t60** of N_2O emission (i.e. C_2) from the manure excreted through slatted floors [S] (55.58 ± 5.100 ppm N_2O) was significantly higher ($P < 0.05$) than that from manure on earth floor [E] (0.09 ± 5.100 ppm N_2O). The ppm N_2O emissions levels for the slatted floors showed a steady increase from January (18.27 ± 11.404 ppm N_2O) and reaching a peak in April (101.47 ± 11.404 ppm N_2O) before declining low May levels (Figure 3.9). The N_2O emissions from manure on earth floor were very low throughout the five months monitoring period. Figure 3.10 shows the interaction effects of management X house. The highest N_2O concentration in ppm at **t60** was obtained in TS 92.62 ± 6.843 ppm N_2O . The least N_2O emission was in HE at 0.04 ± 6.84 ppm N_2O at (**t60**).

Trends on $\text{mg N}_2\text{O m}^{-2} \text{hr}^{-1}$ showed interaction effect of management by house as demonstrated in Figure 3.10. During the first half of the monitoring period manure from HS goats had the highest fluxes at 1.63 ± 0.483 $\text{mg N}_2\text{O m}^{-2} \text{hr}^{-1}$ (0.53 ± 0.157 $\text{g N}_2\text{O AU}^{-1} \text{d}^{-1}$). However, in the later half fluxes from TS exceeded fluxes from all the other treatment

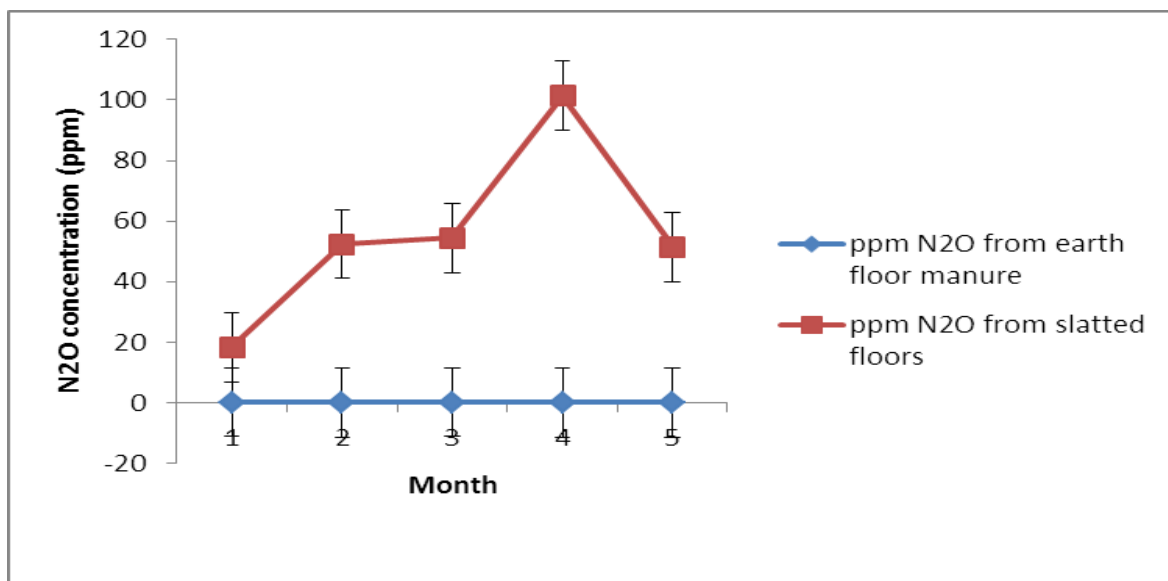


Figure 3.9: Emission of Nitrous oxide (LSMean \pm se ppm N₂O) from goat manure as affected by floor type (earth vs slatted floors)

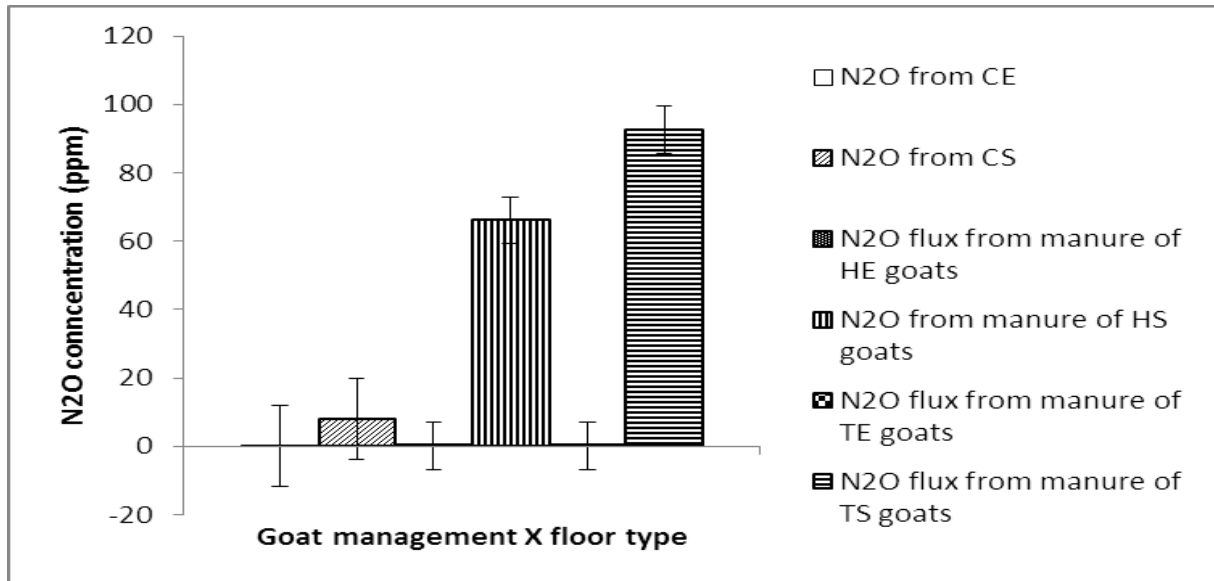


Figure 3.10: Nitrous oxide emission (LSMean \pm se ppm N₂O) from manure as influenced by the interaction of goat management (tethering or herding) by floor type (earth or slatted)
 CE= Control compartment on earth floor side, CS control compartment on slatted floor side, HE= manure of herded goat on earth floor side, HS= manure of herded goats under slatted floors; TE= manure of tethered goats on earth floor; TS= manure of tethered goats under slatted floors

groups. Fluxes from CS and TE were almost close to zero for the entire duration of the study period. The highest peak flux was from TS in April with $2.43 \pm 0.456 \text{ mg N}_2\text{O m}^{-2} \text{ hr}^{-1}$ ($0.79 \pm 0.148 \text{ g N}_2\text{O AU}^{-1} \text{ d}^{-1}$).

3.4. Discussion

Emissions of CH_4 and N_2O are the major GHG of concern from livestock buildings with 21-25 and 298-310 global warming potential (GWP) measured against the standard reference, CO_2 , respectively (Nyamadzawo *et al.*, 2012; Cortus *et al.*, 2015). Carbon dioxide, especially from animal respiration, is often omitted in GHG reports as it is considered a net zero since what is emitted by animals is taken up by plants during photosynthesis (Cortus *et al.*, 2015).

In the current study, subjecting goats to tethering and herding management practices coupled with the provision of housing of different floor types altered the production of GHG fluxes. Methane fluxes from the manure herded goats were higher than that from the excreta of those were tethered. Comparison across floor types revealed that earth floors had higher CH_4 emissions than slatted floors. However, the results obtained in this study on the highest CH_4 emission of $0.26 \pm 0.047 \text{ g AU}^{-1} \text{ d}^{-1}$ was much lower than the $19 \text{ g AU}^{-1} \text{ d}^{-1}$ obtained by Samer *et al.* (2011) in experiments done to study the air exchange rates in natural ventilated dairy barns. However, the results of Samer *et al.* (2011) were based the CO_2 balance method which they said was not very reliable and subject to many errors. Unfortunately, the other method that they used i.e. $^{85} \text{Kr}$, was still at a stage that required further development, as drawn in the authors' conclusion. The methane emission results for the flocks that were herded in the current study were also lower than those obtained ($290 \text{ g AU}^{-1} \text{ d}^{-1}$) in dairy barns by Cortus *et al.* (2015). The CH_4 flux results obtained in the current study was based on

emissions from the manure and yet Cortus *et al.* (2015) combined emissions from both manure and enteric sources. The equivalent of CH₄ flux obtained for HE in this study, after employing Kreuzer and Hindrichsen (2006)'s correction factor (i.e. enteric CH₄ emission = 1000 times the methane from manure), are higher than the July to December value of 20.5 g CH₄ per sheep per day, and much higher than January to June (14 g per sheep per day) obtained by Dengel *et al.* (2011) when they used the Eddy covariant (EC) method. The authors explained that the sheep in their study were still young lambs in the first half of the year, hence emitted less methane. The EC method used by Dengel *et al.* (2011) has a limitation in that it assumes homogeneity in the flux foot print yet in their study the sheep are moving objects which at some point there were no, or more, sheep in the area measured.

Zervas and Tsiplakou, (2012) stated in their review that 83 % of the gross methane emitted from livestock was of enteric origin whilst only 17 % of the methane was from the manure. Similarly, Kreuzer and Hindrichsen (2006) had earlier on explained, in a review, that the gross (enteric, respiratory and manure) CH₄ emission from an animal unit per day is approximately 1000 times that produced from its manure. Apparently, taking into account the factor of 1000 stated by Kreuzer and Hindrichsen (2006) in the results obtained in the current study for the flocks that were herded it would bring our flux result to similar levels to the findings of Cortus *et al.* (2015). It is, therefore, possible that the component of flux coming from manure, in Cortus *et al.* (2015) study, may have been similar to our results. As expected, CH₄ emission results obtained by Amon *et al.* (2001) [194 g AU⁻¹ d⁻¹] were higher than that obtained in the current study. Amon *et al.* (2001) explained that 80 % of the total methane emission from dairy farms was due to enteric source and only 20 % came from the manure. The present study, therefore, recorded only about a fifth of the gross methane that

would be expected from such animal houses.

The average methane flux from earth floors [E] ($0.09 \pm 0.22 \text{ g CH}_4 \text{ AU}^{-1} \text{ d}^{-1}$) obtained in this study were on the lower side compared to results of Amon *et al.* (2001) and Cortus *et al.* (2015) even after taking into account Kreuzer and Hindrichsen (2006)'s correction factor of 1000. It is possible that the diet consumed by the goats which was mainly browse, could have contributed to the low emission of methane from manure in the current study. Bakare and Chimonyo (2011); and Chikwanda *et al.* (2013) observed an apparent preference of browse species by Mashona and Nguni goats, respectively. According to Mlambo *et al.* (2008) most trees and shrubs from tropical regions contain tannins. In a review, Mlambo and Mapiye (2015) state that *dicotyledonous* species such as *Acacia* contain high levels of tannins and saponins. Tannins and saponins are compounds that have anti-protozoal effects that reduce methane emission from ruminants (Patra *et al.*, 2006). The CTs could have found their way to the hind gut and manure possibly having sustained effect, post defecation, in reducing CH_4 production. Animut *et al.* (2008) discusses that there is a possible re-formation of CT- amino acid complexes in the small intestines, or the slow release of amino acids from the CT- amino acid complexes formed in the rumen which are subsequently excreted as faeces. Animut *et al.* (2008) found a reduction in the rumen population of cellulolytic bacteria when goats were fed CT containing diets which led to a reduction in CH_4 production. Significant reduction in CH_4 emissions were also observed when sheep (Carulla *et al.*, 2005); and goats (Puchala *et al.*, 2005) were given diets containing tannins. It is postulated, in the current study, that CTs contained in the *acacia* species browsed by the Nguni goats could have impaired the function of methanogenic microorganisms. The mechanism of depressed methanogenesis by tannins is through reduced cellulolytic bacteria (McSweeney *et al.*, 2001) and protozoa populations,

increased establishment of tanning- cellulose complexes and the limited contact of methanogenic bacteria to free cellulose (Animut *et al.*, 2008).

A review by Sedorovich *et al.* (2007) cited in Cortus *et al.* (2015) reports of high CH₄ emissions compared to what was measured in the current study. But again the work done on the dairy farms combines both emissions from the manure and enteric fermentation whereas that of the current study focused on emissions from manure. In addition to dietary and animal species difference, between the studies cited by Sedorovich *et al.* (2007) and the current study, there is a difference in the source of methane being manure alone in the current study compared to a combination of enteric, respiratory and manure in the other studies.

According to Oenema *et al.* (2005) and Sommer *et al.* (2007) cited in Adviento- Borbe *et al.* (2010), methane from manure is a product of methanogenesis during the anaerobic decomposition of faeces and the escape of gas bubbles that would have been trapped by faeces as they progress through the gastro intestinal tract (GIT). The enteric CH₄ is a result of anaerobic fermentation by methanogenic *Archaea* in the rumen that utilises CO₂ and H₂ to produce CH₄ (McAllister and Newbold, 2008). According to Zervas and Tsiplakou, (2012) the level of methane production in ruminants is influenced by many factors which include type and quality of ingested feed, level of intake ambient temperature, body weight and level of activity. In the current study, effort was made to hold the variables uniform between the herded and tethered goats with the only variation being floor type in overnight accommodation and level of movement permitted by the management system. The results from the current study (i.e. 79.31 ± 5.13 g CO₂ AU⁻¹ d⁻¹ and 0.26 ± 0.047 g CH₄ AU⁻¹ d⁻¹ flux from herded goats, obtained in February and March, respectively) are lower but comparable

to those obtained by Adviento- Borbe *et al.* (2010), who found highest emissions of 580 g CO₂ AU⁻¹ d⁻¹ and 10 g CH₄ AU⁻¹ d⁻¹ . The observation by Adviento- Borbe *et al.* (2010) of there being no diurnal effects on GHG flux on the measurements done for CH₄ and CO₂, substantiates the protocol followed in this study to measure gas fluxes between mid- morning to late morning which happens to be representative of the average day's flux (Kelliher *et al.*, 2011; Rochette *et al.*, 2011).

The methane flux rates obtained in the current study are similar to the lower and upper quartile ranges obtained by Borhan *et al.* (2011) who measured 0.25-0.60 g CH₄ hd⁻¹ d⁻¹ in manure lane, 0.19- 0.99 g CH₄ hd⁻¹ d⁻¹ in bedding area and 1.24- 5.11 g CH₄ hd⁻¹ d⁻¹ in their studies on GHG emissions in dairy and cattle feedlot areas. The authors used similar techniques as those employed in the current study except that in their trials they used a GC that was mounted on a mobile trailer. The results by Borhan *et al.* (2011) were slightly higher than in the current study possibly due to concentrate diets offered to dairy cattle. Lodman *et al.* (1993), cited in the review by Kreuzer and Hindrichsen (2006), found seven fold increases in CH₄ emission from faeces of cattle on a high concentrate diet. Within the same review, Hashimoto *et al.* (1981) found an increase in CH₄ emission from faeces when forage based diets were replaced by concentrates. Concentrate based diets such as those used in commercial dairy and feedlots promote fibre digestion in the manure which would lead to higher methane emission in their faeces.

In the current study, goats were raised primarily on veld forages, which had plenty of browse species. In accordance with Chikwanda (2004), the goats generally selected plant parts of high nutrient quality i.e. the young shoots and acacia leaves, by making use of their mobile

upper lip and prehensile tongue. Forages of high protein content are readily digested and absorbed and reduce manure based methane. The observed methane emission was low due to possible effects of selected and ingested browse bites which are reported to be rich in condensed tannins which could have suppressed methanogenic organisms (Patra *et al.*, 2006). Theart *et al.* (2014) found up to 90 % reduction in methane production when browse species *Monechma incanum* and *Acacia luederitzii* were incubated alone compared to incubations with polyethylene glycol (PEG) and concluded that tannins were responsible for the observed decrease. Gemedda and Hassen (2015) noted low methanogenic capacity of some browse species which they postulated could be used to manipulate the rumen microflora in order to reduce enteric methane emission.

In the current study, observations made on floor conditions showed that the rain proof earth floor compartments with goats that were herded tended to be soaked in urine especially during the wet months compared to those that had tethered goats. It followed that the herded goats were relatively free in their movements and had more access to drink water from open water puddles leading to excretion of more urine in the houses when they were eventually penned for the day. The observation of relatively more methane production from manure in compartments that accommodated herded goats could be attributed to moisture saturated manure conditions, due to the urine, which promoted methanogenesis. In studies done on *Dambo* rice fields, Nyamadzawo *et al.* (2013) observed that when the soil was saturated with water during the rainy period CH₄ fluxes were high. However, as the water table fell, the amount of methane measured in their study also decreased. Moisture saturated conditions are devoid of sufficient aeration and are inclined towards anaerobic conditions which are conducive for methanogenesis.

The mean methane flux values from herded goats (H: $0.41 \pm 0.064 \text{ mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$) and those of herded goats accommodated in compartments with earth floors (HE: $0.78 \pm 0.091 \text{ mg m}^{-2} \text{ hr}^{-1}$) were comparable to those measured by Nyamadzawo *et al.* (2012) who used static chambers in their study to measure CH_4 production from dambo termite mounds (average = 0.78 and span 0.48- 1.35 $\text{mg m}^{-2} \text{ hr}^{-1}$) as well as Nyamadzawo *et al.* (2013) who used static chambers to measure greenhouse gas fluxes from rice cultivated in dambo (average 0.35 and 1.6 $\text{mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$ maximum). Dambo termite mounds are considered important sources of GHG and the observation of similar CH_4 flux levels from goat manure dictate that GHG emissions from goat excreta also requires similar serious levels of attention.

In the current study compartments with earth floors promoted more CH_4 production. In addition to the damp conditions, it is postulated that the effect of the hooves and weight of the goats as they stood on or lay down directly on the manure compacted the manure. According to Chadwick (2005), compaction of farm yard manure created anaerobic conditions that promoted methanogenic bacteria. It is possible that the effect of methanogenesis could have by far exceeded the action of methanotrophs (prokaryotes which use up CH_4 to obtain carbon and energy) and this scenario could have resulted in more CH_4 fluxes in compartments with earth floors. Compaction is thought to reduce aerobicity and slow down decomposition of manure in heaps (Chadwick, 2005). The effects of compaction on increased CH_4 were reported to be significant in warm weather but not during winter because the reduced temperature lowered microbial activities (Chadwick, 2005). In a study by Borhan *et al.* (2011), the authors noted that high summer temperatures heavily contributed to methane production. In the current study, there was a gradual decrease in average monthly

temperatures from 23 °C (January) to 15.5 °C (May) and observations made appear to suggest that methane was influenced mainly by a combination of manure accumulation and anaerobic conditions that were modified by manure moisture saturation levels. The flocks that were herded and accommodated in earth floors had their compartments consistently soaked in urine and resulted in anaerobic conditions of the manure leading to high methane emission. Further, the compaction of the excretory material caused by the goat hooves and the animals lying directly on the manure may have added to conditions favourable for methanogenesis.

In the current study, weak negative correlations were noted between methane production and carbon dioxide. The observation is consistent with the fact that part of the carbon dioxide is a result of cellular respiration or the oxidation of methane as it passes through aerobic zones. On the other hand, methanogenesis requires anaerobic conditions to take place. According to Nyamadzawo *et al.* (2010), carbon dioxide from the soil is formed from various processes which include cellular respiration, methanogenic fermentation and oxidation of CH₄ as it passes through aerobic zones. The compartments with slatted floors prevented the compaction of manure, hence allowed some air spaces to exist between the faecal pellets thereby providing aerobicity, to aerobic organisms to thrive, with concomitant production of carbon dioxide. According to Tamminga (1992), cited in Adviento- Borbe *et al.* (2010) carbon dioxide from manure is a product of aerobic heterotrophic breakdown of protein in faeces, which includes microbial protein, undigested protein from ingested feed as well as enzymes and sloughed off lining of the gastro intestinal tract. Adviento- Borbe *et al.* (2010) further states that additional carbon dioxide is produced during urea hydrolysis in the reaction of H⁺ ions with ammonium carbonate (NH₄)₂CO₃. The earth floor compartments, which accommodated herded goats and were persistently soaked with urine during wet months,

emitted low CO₂ in this study possibly due to reduced respiration in the manure. According to Aarnink *et al.* (1992), CO₂ emitted from manure (faeces and urine) is less than 5 % that produced from respiration. Therefore, it is critical to take into consideration that emission values that incorporate both enteric and manure urine might appear much higher than those obtained in the current study.

Carbon dioxide emission was comparatively high in compartments with slatted floors that accommodated herded goats. It is possible that methane production could have occurred in the deeper layers of manure of goats that were herded and accommodated in slatted floors. It is further conceivable that as the methane dispersed, through the loosely packed faecal pellets which had air spaces between them got oxidised to produce CO₂. In related studies, Le *et al.* (2001) state that a significant portion of CH₄ gets oxidised to CO₂ as the former gas disperses across oxidised soil layers to the soil surface. Our results agree with the observation by Nyamadzawo *et al.* (2013) who also noted that high soil moisture levels (but in the current study, saturated manure moisture conditions) promoted high CH₄ emission. But as the manure gets dry as in the dry months or in slatted floors, less methane was emitted with a concomitant increase in CO₂ production.

The average carbon dioxide flux rates obtained in this study from the manure of herded goats (48.30 ± 2.391 g CO₂ AU⁻¹d⁻¹) tethered goats (35.36 ± 2.349 g CO₂ AU⁻¹d⁻¹) are slightly lower but comparable to the findings of Borhan *et al.* (2011). However, carbon dioxide flux from excreta of herded goats deposited on slatted floors (73.26 ± 3.438 g CO₂ AU⁻¹d⁻¹) fell within the estimated lower and upper quartile emission rate ranges obtained by Borhan *et al.* (2011) who measured 84- 93 g CO₂ hd⁻¹ d⁻¹ in manure lane and 67- 71 g CO₂ hd⁻¹ d⁻¹ in

bedding area. Our results on CO₂ fluxes [HS: $226 \pm 10.61 \text{ mg CO}_2 \text{ m}^{-2} \text{ h}^{-1}$ (73.26 ± 3.438); H: $244.77 \pm 15.82 \text{ mg CO}_2 \text{ m}^{-2} \text{ h}^{-1}$) were lower compared to those of Nyamadzawo *et al.* (2012) who obtained an average of $1,360 \text{ mg m}^{-2} \text{ h}^{-1}$ in their studies on GHG measurements with static chambers from termite mounds. This is possibly because termites are higher order aerobic heterotrophs and they respired out more CO₂.

Caution need to be exercised when comparing results on CO₂ and methane emissions from livestock facilities because some studies, especially those using large dynamic chambers (Amon *et al.*, 2001) combine enteric (CH₄), respiration (CO₂) and manure emissions. On the other hand, studies such as the current one sampled and quantified carbon dioxide from the surface (manure) to air interface. In the earlier case of using large dynamic chambers to measure carbon dioxide, huge quantities of (CO₂) maybe recorded but amount emitted are similar to those absorbed in photosynthesis and, as such respiration, is not considered a net emitter of CO₂ (Zervas and Tsiplakou, 2012). Vergé *et al.* (2007) found out that 80 % of the CO₂ emitted from dairy facility was from enteric fermentation whilst only 20 % was from manure.

Ruminants produce nitrous oxide (N₂O) via manure (Cornejo and Wilkie, 2010). The authors further stated that the amount of N₂O emitted is affected by the oxygen and liquid content of the manure as well as the bacterial species associated with the decomposition. According to the report by Intergovernmental Panel on Climate Change (IPCC), [2006], fluxes of N₂O from manure are also influenced by nitrogen to carbon content of the manure as well as the manure treatment and period of storage of the manure. Also according to Zervas and Tsiplakou, (2012) the contribution to N₂O emission from manure across livestock species

revealed that small ruminants (18.83 %) were second to cattle (60 %). They attributed the comparatively high contribution of sheep and goats to poor manure management by the small ruminant farmers.

In the current study, the emission of N_2O from HE goats was low and the Hutchinson and Mosier (1981) flux model did not apply for this treatment group. Observation of these compartments during the course of the study indicated that the faeces were almost always saturated with urine a situation that might have created anaerobic conditions that are not conducive for nitrification (Eckard *et al.*, 2010). In addition, it compromised the welfare of the animals. The goats spent the better part of the penning time standing and rarely lay down to rest on the muddy floor. According to Chadwick *et al.* (1999), anaerobic damp manure conditions impede nitrate production and thus hinder the formation of N_2O . Aerobic conditions would have allowed the oxidative conversion of the ammonium ion (NH_4^+) to nitrate (NO_3^-) a reaction that yield N_2O as a by- product (Eckard *et al.*, 2010). In addition to nitrification, denitrification converts nitrate to N_2 and N_2O as an intermediate product. However, the denitrification process requires some form of anaerobic conditions and the presence of NO_3^- . The inhibition of N_2O formation is, further, thought to be due to hippuric acid (HA), a constituent of urine from ruminants (Clough *et al.*, 2009). According to Bristow *et al.* (1992) HA is a combination of glycine and benzoic acid, and is referred to as a natural inhibitor to N_2O emission (van Groenigen *et al.*, 2006). Benzoic acid has antimicrobial and anti-enzymatic properties that hinder the denitrification (Fenner *et al.*, 2005; van Groenigen *et al.*, 2006), and possibly nitrification processes. According to van Groenigen *et al.* (2006) treatment of soils with benzoic acid (which is also a natural product of the breakdown of hippuric acid) reduced the denitrification and consequently emissions of N_2O by 50 % in their

experiments. In the current study, the earth floor compartments that accommodated goats that were managed by herding had faeces that were soaked in urine the majority of the time. It was postulated that the urine- faecal matter mixture had high levels of HA that could have prevented emissions of N₂O. This assumption is further strengthened by the fact that free ranging goat select plant parts of high nutrient content (Chikwanda, 2004) and the assertion that that ruminants on high protein diets produce high levels of HA. It is further possible that the goats that were on earth floors tended to compact the manure owing to the pressure exerted by the hooves and their body in those rare events that they lied down to rest on the manure. A study by Chadwick (2005) revealed that compaction of farm yard manure reduced the emission of N₂O due to creation of anaerobic conditions that reduced nitrification and subsequently lowered N₂O emission.

The emission of NO₂ was high in the manure of goats that were tethered and accommodated in houses with slatted floors. The manure conditions were relatively dry on the surface and to a fair 16 cm manure depth as determined through sampling with an auger. The range of values of N₂O emissions obtained in the current study i.e. highest for TS (0.79 ± 0.148 g N₂O AU⁻¹ d⁻¹) and highest for HS (0.53 ± 0.157 g AU⁻¹ d⁻¹) are similar to the findings of Amon et al. (2001) who reported of 0.6 g N₂O AU⁻¹ d⁻¹ and comparable to those of Jungbluth et al. (2001) who got 1.6 g N₂O AU⁻¹ d⁻¹ from dairy housing structures. Again the N₂O emission in this study was lower than the 9 g per sow per day but comparable to the range of 3- 6 g per sow per, obtained by Gac *et al.*, (2007) and Philippe *et al.*, (2013), respectively. However, the differences observed when making comparisons in N₂O emission from swine data are expected owing to the high protein diets given to pigs as well as differences in digestive system between monogastric and ruminant animals.

The goats, in the current, were observed to browse most of the time on *acacia* shrub species. According to Mlambo *et al.* (2008) most trees and shrubs from tropical regions contain tannins. In a review, Mlambo and Mapiye (2015) state that dicotyledonous species such as *Acacia* contain high levels of tannins. In studies conducted by Carulla *et al.*, (2005), sheep fed condensed tannin (CT) extracts increased the proportion of N excreted in faeces than in urine. Grainger *et al.* (2009) also observed a positive correlation in the partitioning of nitrogen from urine to faeces when dairy cows were given graded levels of CT in *Acacia mearnsii*. Eckard *et al.* (2010) explained that CTs bind to ingested protein forming CT-protein complexes that are difficult to digest. The CT- protein complexes reduce the amount of nitrogen (N) lost in urine as the N gets deposited as undigested protein in faeces. According to De Klein and Ledgard (2005), N in the faeces is largely in the organic form hence less volatile compared to N in urine which is mainly in the form of urea which can go through the process of nitrification and produce N₂O as an intermediate product. Eckard *et al.* (2010) further assert that CT- protein complexes do not mineralise easily to NH₄⁺ and decompose more slowly and hence N₂O emission is reduced. Nitrous oxide from faeces is produced by nitrifying and denitrifying bacteria in the manure Adviento- Borbe *et al.* (2010) and is an intermediated product from both nitrification and denitrification that occurs under aerobic conditions following the Equations [3.2] and [3.3], respectively (Nyamadzawo *et al.* 2012):



According to Adviento- Borbe *et al.* (2010) N₂O is either produced as nitrifiers oxidise hydroxylamine (NH₂OH) in the manure or when nitrifier denitrification reduces nitrite

through N₂O as an intermediate product to the liberation of N₂ gas. Manure samples in slatted floors appeared to be drier and this suggested that they allowed more aeration and promoted aerobic conditions that are required for nitrification processes. The highest N₂O flux obtained in the current study of $2.43 \pm 0.456 \text{ mg N}_2\text{O m}^{-2} \text{ hr}^{-1}$ was higher than the highest N₂O fluxes obtained by Nyamadzawo *et al.* (2012) [$0.115 \text{ mg N}_2\text{O m}^{-2} \text{ h}^{-1}$], who used static chambers, to measure GHG from lower slope dambo termite mound and also results cited by the same authors from other studies in rice fields in India ($0.03 \text{ mg N}_2\text{O m}^{-2} \text{ h}^{-1}$) and dambo rice fields in Zimbabwe [$0.0049 \text{ mg N}_2\text{O m}^{-2} \text{ h}^{-1}$] (Nyamadzawo *et al.*, 2013). Again this observation shows that goat manure is an important source of N₂O emissions comparable to other critical sources of GHG.

The results obtained in the current study appear to suggest that herded goats that were more extensive in the manner in which they foraged, leading to higher GHG which, to some extent, contradicts the general misconception that extensive systems are generally eco-friendly (Scholtz *et al.*, 2013). The findings from this study of significant quantities of GHG from goat manure and the observation that there is scant literature on GHG fluxes from goat manure are a clear reflection that an important source of these gases is being overlooked. It is necessary to reflect on any possible GHG emission mitigation strategies from farm level (Lovett *et al.*, 2008). Smallholder communities that keep goats but do not apply caprine excreta as organic fertiliser may need to consider making use of the manure for biogas or heat energy by burning with expected possible energy yields of 17.8 MJ/dry kg (Touray *et al.*, 2014). The culling of less productive animals and remaining only with the more productive ones could also contribute to the reduction of GHG emission (Kristensen, 2011).

3.5. Conclusion

It was concluded that goat manure is an important source of GHG (CH₄, CO₂ and N₂O). Furthermore, the emission of GHG was affected by the interaction of goat management by type of floor of housing facility. The manure from HE promoted the emission of higher levels of CH₄. On the other hand more carbon dioxide and N₂O were emitted from the manure of HS. It is recommended that considerations be made to do studies on use of goat manure in anaerobic biogas digesters so as to convert methane produced to useful energy as well as limit the carbon dioxide, and nitrous oxide which has high GWP.

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CHAPTER 4: Greenhouse gas emission from manure in disused versus occupied goat pens with earth and slatted floors

Abstract

The objective of the study was to evaluate greenhouse (GHG) gas emission from disused (DP) vs occupied goat pens (OP) with earth (EF) or slatted (SF) floors. Eight previously occupied pens were used in this study, where 4 of the pens had EF and the other 4 were on slatted floors. Half of the pens with EF (n=2) and half the pens with slatted floors (n=2) were randomly labelled disused pen with earth floor (DPEF) and disused pen with slatted floor (DPSF). The remaining pens with earth floor (n=2) and those with slatted floor (n=2) were labelled: occupied pen with earth floor (OPEF) and occupied pen with slatted floor (OPSF). Sixteen goats were randomly put in the pens labelled OPEF and OPSF resulting in four goats per OP. Twenty-four by 20 L static gas chambers were used to collect monthly air samples from the manure, at the rate of 3 static chambers per pen, at 0, 30 and 60 minutes deployment times. The collected air samples were analysed using SRI 8610C gas chromatography machine. There were month by pen use; month by floor type; and use by floor type interaction effects ($P < 0.05$) on CH_4 production. Floor type, use (DP vs OP) and month affected ($P < 0.05$) CH_4 production. Manure on earth floors of occupied pens (OPEF) emitted the highest ($P < 0.05$) methane ($0.45 \pm 0.049 \text{ mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$; $0.15 \pm 0.016 \text{ g CH}_4 \text{ AU}^{-1} \text{ d}^{-1}$) followed by earth floors of disused pens (DPEF) ($0.09 \pm 0.039 \text{ mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$; $0.03 \pm 0.013 \text{ g CH}_4 \text{ AU}^{-1} \text{ d}^{-1}$). The highest methane was produced in OP in October ($0.49 \pm 0.091 \text{ mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$). The least CH_4 was emitted from DPSF (0.00 ± 0.060). There was pen use (DP vs OP) by floor type interaction effect ($P < 0.05$) on carbon dioxide (CO_2) emission. Floor type and pen use affected ($P < 0.05$) CO_2 production. Manure in occupied pens with slatted floors (OPSF) produced the highest carbon dioxide ($61.83 \pm 5.609 \text{ mg CO}_2 \text{ m}^{-2} \text{ hr}^{-1}$; $20.03 \pm 1.817 \text{ g CO}_2 \text{ AU}^{-1} \text{ d}^{-1}$) and the least CO_2 was from disused pens with slatted floors (DPSF) ($10.41 \pm 8.724 \text{ mg CO}_2 \text{ m}^{-2} \text{ hr}^{-1}$; $3.37 \pm 2.827 \text{ g CO}_2 \text{ AU}^{-1} \text{ d}^{-1}$). The interaction of month by floor type affected ($P < 0.05$) nitrous oxide (N_2O) emission. Floor type and month influenced ($P < 0.05$) N_2O production. The highest N_2O ($1.75 \pm 0.179 \text{ mg N}_2\text{O m}^{-2} \text{ hr}^{-1}$) was emitted in September in SF and very low levels from the manure on EF. It was concluded that continued use of goat pens increased GHG emissions. However, disused goat pens with manure remain an important source of GHG as they continued to emit quantifiable levels of CH_4 , CO_2 and N_2O .

Key words: Disused pens; goat manure; Greenhouse gases

4.1 Introduction

Goat populations are increasing and contribute to the livelihood of most smallholder farmers in developing countries (Agrawal *et al.*, 2014). The smallholder goat farmers pen their goats, daily, as a measure to protect them from harsh weather (Chikwanda, 2004) and stock theft that has become rampant (Scholtz and Bester, 2010). During penning, there is accumulation of goat manure in the pens. The manure is normally used as an organic fertiliser for field crops and vegetable gardens by most smallholder farmers (Wuta and Nyamugafata, 2012). Removal of manure from the pens is usually done once a year. During manure accumulation, pen floors sometimes become saturated with moisture, from rain or urine, to an extent that the pens temporarily become uninhabitable to the goats. In such cases, some farmers move the goats to fresh pens so that the damp pen(s) can dry up. Some pens that remain dry continue to be used throughout the year.

The numbers of goats and other ruminants which are kept by smallholder farmers are increasing owing to minimal offtake (Musemwa *et al.*, 2010). Respiratory, enteric, feed production activities and manure deposition on pasture and animal housing by the increasing number of goats and other ruminants are a potential threat to global warming due to greenhouse gases (GHG) that they emit (Steinfeld *et al.*, 2006; Grainger *et al.*, 2009; Dengel *et al.*, 2011; Broucek, 2014; Bueno *et al.*, 2015; Ososanya *et al.*, 2015). According to Sommer (2001), degradation of manure contribute 5- 6 %, and about 7 % of the total global emission of CH₄ and N₂O, respectively. Reports that about 15 % of total global CH₄ emission comes from cattle (Lassey *et al.*, 1997) suggest that small ruminants (goats and sheep) emit significant quantities of GHG. Emissions of GHG are increasingly becoming worrisome due to their contribution to global warming (Chianese *et al.*, 2009). According to Møller *et al.*

(2004) and Steinfeld *et al.* (2006), the anaerobic degradation of manure emits CH₄ and CO₂ to the atmosphere. Additionally, coupled nitrification and denitrification of manure emits nitrous oxide (N₂O) to the atmosphere. Methane and N₂O are potent GHG with estimated 23-25 and 310 times global warming potential than CO₂, respectively, (Eckard *et al.*, 2010; Nyamadzawo *et al.*, 2012; Agrawal *et al.*, 2014; Broucek, 2014). According to Broucek (2014), up to 15 % of the total amount of GHG is from manure handling and storage. The accumulation of manure in pens in accommodated and disused pens is a course of concern because of the potential of the decomposing manure to release greenhouse gases to the environment.

Methane production is a product of anaerobic fermentation of manure by thermophilic bacteria called *Methanogenic archaea* (Daquiado *et al.*, 2014). *Methanogenic archaea* utilise H₂ and CO₂ as substrates to produce methane (Morgavi *et al.*, 2010). The H₂ is a product of protozoa activities (Agrawal *et al.*, 2014) whilst the carbon dioxide comes from microbial decomposition of organic matter from manure. *Methanogenic archaea* reduce CO₂ to methane as in Equation [4.1] (Broucek, 2014; Ososanya and Faniyi, 2015).



Shibata and Terada (2010) recommended the exploration of feasible ways of reducing GHG emission from ruminants. Ruminants spent a large proportion of their daily time in housing facilities. Therefore, the design and use of the structures maybe a potential area of developing mitigation strategies for reducing GHG emissions. A lot of studies on the estimation of GHG emissions from ruminants have largely combined respiration, enteric and manure in housing facilities (Chianese *et al.*, 2009). Abandonment of kraals or pens is common especially in

communal areas when they become saturated with water or urine. Pens may be rotated or may never be used again. However, there has been an apparent gap in the evaluation of GHG emissions from indigenous goat manure in disused (i.e. pens that were once used but got abandoned after some time) versus occupied pens. The objective of this study was, therefore, to evaluate the greenhouse gas (GHG) [methane (CH_4), carbon dioxide (CO_2) and Nitrous oxide (N_2O)] emission from manure on earth (EF) or slatted (SF) floors of disused and occupied goat pens.

4.2 Material and Methods

4.2.1 Study site

The study was carried out at the University of Fort Hare -Honeydale Research Farm (UFH-RF) whose description was given in Section 3.2.1.

4.2.2 Experimental goat houses

A total of 8 (1.8m * 1.5 m) pens that previously accommodated goats and had accumulated manure over five months, were used in this study. The design of the houses is as described in Chapter 3, Section 3.2.2. Briefly, 4 of the pens had earth floors (EF) and the other 4 had slatted floors (SF). Half of the pens with earth floors (n=2) and half of the pens on slatted floors (n=2) were randomly labelled disused pen with earth floor (DPEF) and disused pen with slatted floor (DPSF), respectively. The remaining pens were labelled occupied pen with earth floor (OPEF) and occupied pen with slatted floor (OPSF), respectively. Sixteen goats were then randomly allocated to pens that had been labelled occupied at the rate of four goats per pen i.e. two pens on earth floors had 4 goats each and 2 pens with slatted floors had 4 goats each. At the same time, 2 pens on earth floor and 2 pens on slatted floors remained vacant

(disused/ were left without goats). All the pens had been left vacant for one month after the first batch of goats had been removed before resuming use of occupied pens (OP), followed by two weeks of acclimatisation period and commencement of gas sampling. The OP accommodated goats from 1300hrs of one day to 0800 hrs of the following day, for four months (July to October 2015).

4.2.3 Study animals

Sixteen castrated Nguni goats of approximately 6- 7 months old were randomly allocated to the four compartments of the two types of goat housing (slatted floor and earth floors). The goats were taken for unrestricted foraging every morning at 0800 hrs and brought back into designated compartments at 1300 hours every day. All goats were ear-tagged for identification and put in designated pens every day for the duration of the study.

4.2.4 Gas sampling and analysis

The deployment of static chambers, gas sampling and storage; detection and flux computations were as described in Section 3.2.5 to 3.2.8.

4.2.5 Statistical analysis

All gas concentrations were analysed using the PROC GLM procedures of Statistical Analysis System (SAS, 2003). Significant differences between least square group means were compared using Tukey's Studentized Range (HSD) test. Correlation analysis between trace gas fluxes was done for CH₄, CO₂ and N₂O using PROC CORR procedures of SAS (2003). The statistical model that was used was as follows:

$$Y_{ijkl} = \mu + M_i + H_j + C_k + (MH)_{ij} + (MC)_{ik} + (HC)_{jk} + (M*H*C)_{ijk} + E_{ijkl}$$

Where,

Y_{ijkl} = Gas flux (e.g. mg CH₄ m⁻² hr⁻¹, mg CO₂ m⁻² hr⁻¹; mg N₂O m⁻² hr⁻¹),

μ = overall mean,

U_i = effect due to pen use i.e. disused or occupied ($i = 1$ to 2),

F_j = effect due to floor type ($j = 1$ to 2),

M_k = effect due to month of sampling ($k = 1$ to 4),

$(UF)_{ij}$ = interaction of pen use and floor type,

$(UM)_{ik}$ = interaction of pen use and month of sampling,

$(FM)_{jk}$ = interaction of floor type and month of collection,

$(UFM)_{ijk}$ = interaction of management system, housing floor type and muscle cut from carcass, and

E_{ijkl} = random residual error distributed as $\sim N(0; I\delta\epsilon^2)$.

4.3 Results

Figure 4.1 shows the mean monthly maximum and minimum temperatures experienced in the study area during the period of gas sampling. Quantifiable levels of CH₄, CO₂ and N₂O were measured from air samples collected from above the surface of accumulated manure (faeces and urine) on earth (EF) or slatted (SF) floors of disused (DP) and occupied (OP) goat pens. Significant positive correlation ($P < 0.001$) existed between CO₂ and N₂O ($r = 0.78$) as shown in Table 4.1. On the other hand, some weak positive correlation ($P > 0.05$) was detected between CH₄ and CO₂ as well as a weak negative correlation ($P > 0.05$) CH₄ and N₂O ($r = -0.07$).

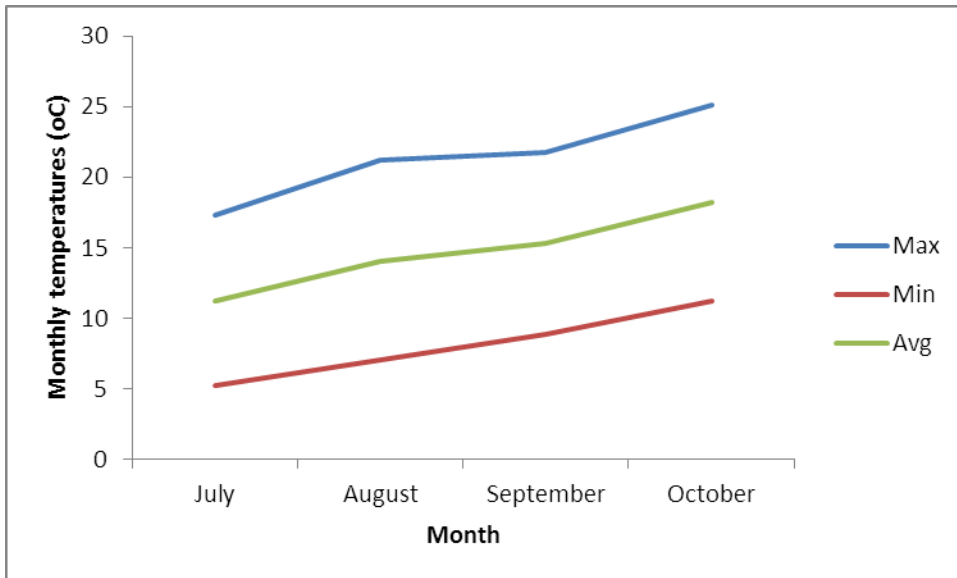


Figure 4.1: Monthly Maximum (Max), minimum (Min) and mean monthly temperatures in degrees Celsius (°C)

Table 4.1 Correlations (r) between GHG gas fluxes

GHG	GHG		
	CH ₄	CO ₂	N ₂ O
CH ₄	1.00	0.04 ^{NS}	-0.18 ^{NS}
CO ₂	0.04 ^{NS}	1.00	0.78*
N ₂ O	-0.18 ^{NS}	0.78*	1.00

GHG = Greenhouse gas; CH₄ = methane; CO₂ = Carbon dioxide; N₂O = Nitrous oxide

* Significant at (P<0.05); NS= Not significant

4.3.1 Methane emission

There were month by use; month by floor type; and use by floor type interaction effects ($P < 0.05$) on CH_4 emission. Furthermore, floor type, use (DP vs OP) and month affected ($P < 0.05$) CH_4 production. Figure 4.2 shows the monthly CH_4 emission as influenced by pen use. There was a sharp and continuous increase in CH_4 emission in OP from the beginning to the end of the study compared to DP, which the later was characterised by an initial low rate that was near constant for the first 1.5 months and, afterwards, attained a small peak in September. Figure 4.3 shows the monthly CH_4 emission from manure on EF and SF. Methane emission from the manure on EF showed a sharp rise for the entire duration of the study period. On the contrary, CH_4 emission from SF was very low and almost flat. The interaction effects of pen use and floor type on CH_4 emission are displayed in Fig 4.4. Manure on earth floors of occupied pens (OPEF) emitted the highest ($P < 0.05$) methane followed by earth floors of disused pens (DPEF). The manure on slatted floors of disused pens (DPSF) and occupied pens with slatted floors showed the least CH_4 emissions.

Generally, the manure in OP emitted more ($P < 0.05$) CH_4 than that in DP. The highest CH_4 emission was in October and coincided with the highest mean monthly temperatures. Additionally, faecal and urine material on EF ($0.27 \pm 0.031 \text{ mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$; $0.09 \pm 0.010 \text{ g CH}_4 \text{ AU}^{-1} \text{ d}^{-1}$) generally emitted more CH_4 gas than SF ($0.01 \pm 0.038 \text{ mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$; $0.00 \pm 0.012 \text{ g CH}_4 \text{ AU}^{-1} \text{ d}^{-1}$).

4.3.2 Carbon dioxide emission

There was some pen use by floor type interaction effect ($P < 0.05$) on CO_2 emission as shown in Figure 4.5. Manure on OPSF emitted the highest CO_2 followed by OPEF and the

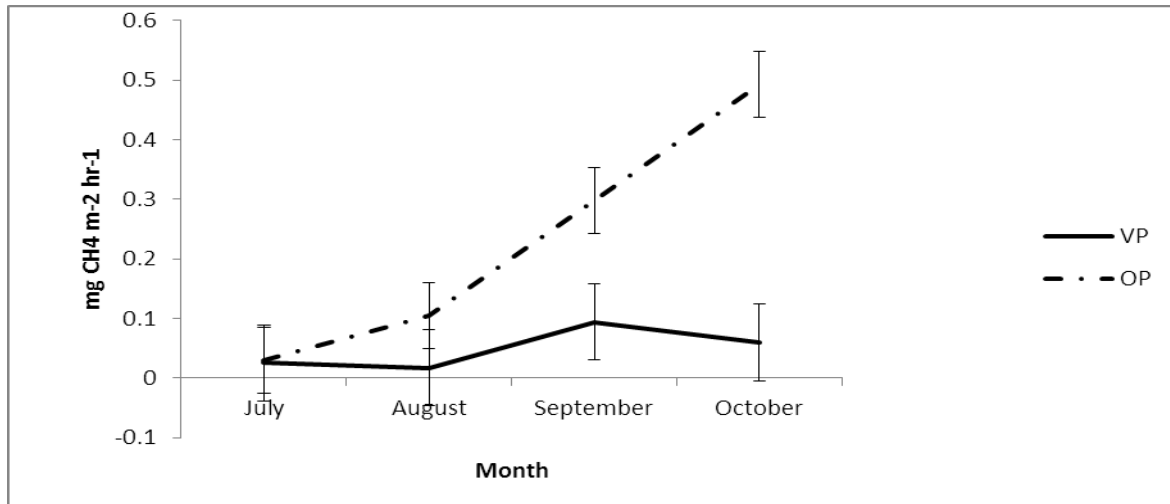


Figure 4.2 Monthly least square means (\pm se) of methane ($\text{mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$) emitted from manure in vacated pens (VP) and occupied pens (OP)

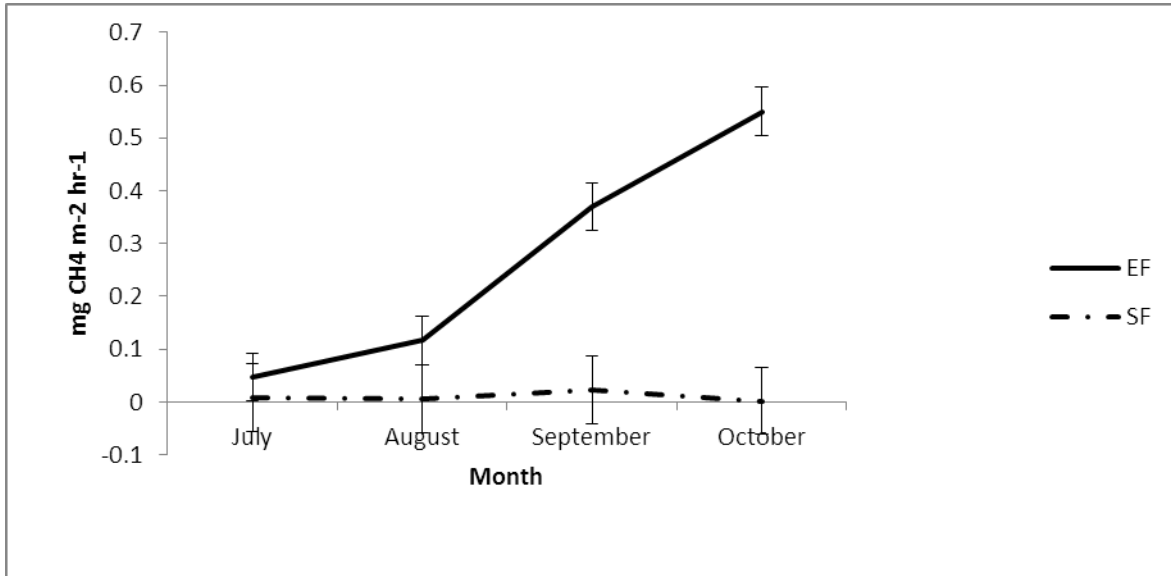


Figure 4.3 Monthly methane flux (LSMean \pm se $\text{mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$) from manure as affected by earth floor (EF) and slatted floors

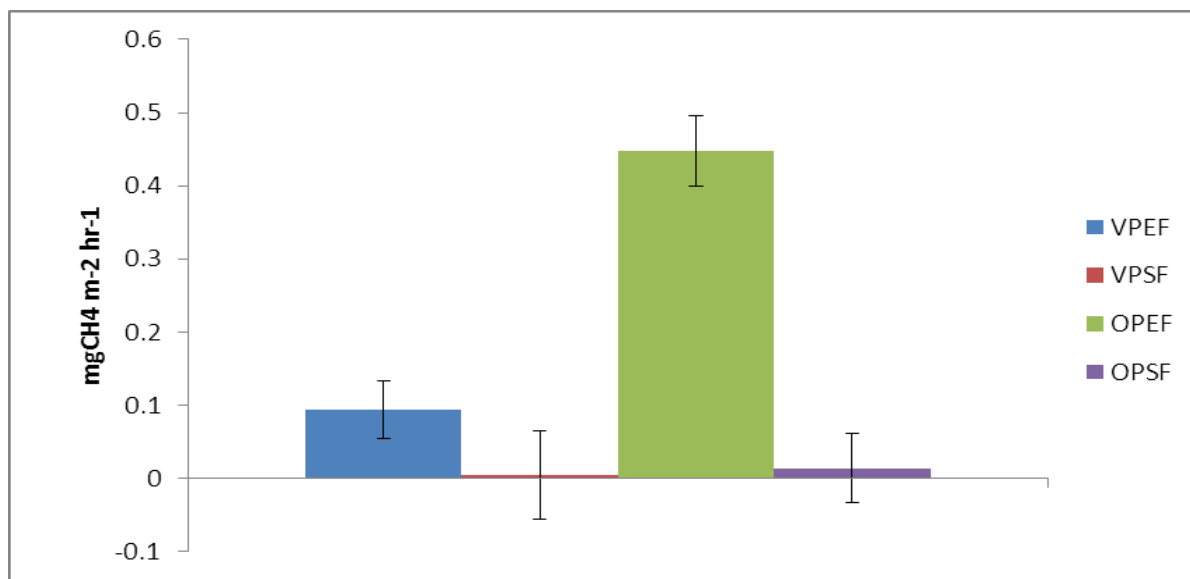


Figure 4.4 Least square means (\pm se) of methane ($\text{mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$) emitted from manure in vacated pens with earth floors (VPEF), vacated pens with slatted floors (VPSF), occupied pens with earth floors (OPEF) and occupied pens with slatted floors (OPSF)

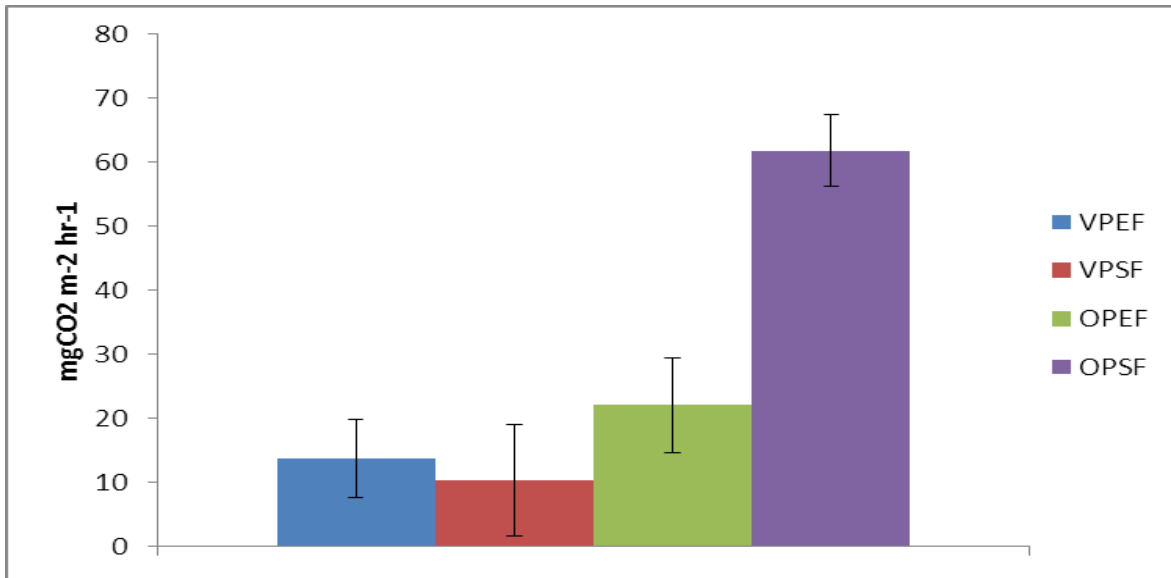


Figure 4.5 Least square means (\pm se) of carbon dioxide ($\text{mg CO}_2 \text{ m}^{-2} \text{ hr}^{-1}$) emitted from manure in vacated pens with earth floors (VPEF), vacated pens with slatted floors (VPSF), occupied pens with earth floors (OPEF) and occupied pens with slatted floors (OPSF)

least emissions were from DPSF. Additionally, floor type and pen use affected ($P < 0.05$) CO_2 production. The carbon dioxide emission was significantly higher ($P < 0.05$) in SF [$36.12 \pm 5.186 \text{ mg CO}_2 \text{ m}^{-2} \text{ hr}^{-1}$ ($11.70 \pm 1.680 \text{ g CO}_2 \text{ AU}^{-1} \text{ d}^{-1}$)] than EF [$17.96 \pm 4.792 \text{ mg CO}_2 \text{ m}^{-2} \text{ hr}^{-1}$ ($5.82 \pm 1.552 \text{ g CO}_2 \text{ AU}^{-1} \text{ d}^{-1}$)]. Further, in terms of pen use, the carbon dioxide emissions were $12.12 \pm 5.330 \text{ mg CO}_2 \text{ m}^{-2} \text{ hr}^{-1}$ ($3.93 \pm 1.727 \text{ g CO}_2 \text{ AU}^{-1} \text{ d}^{-1}$) and $41.95 \pm 4.630 \text{ mg CO}_2 \text{ m}^{-2} \text{ hr}^{-1}$ ($13.59 \pm 1.500 \text{ g CO}_2 \text{ AU}^{-1} \text{ d}^{-1}$) for DP and OP, respectively. Generally, OP produced more CO_2 than DP and simultaneously SF had higher ($P < 0.05$) emissions of the same GHG than EF.

4.3.3 Nitrous oxide emission

There were month by floor type interaction effects ($P < 0.05$) on Nitrous oxide (N_2O) emission as shown in Figure 4.6. Furthermore, house and month influenced ($P < 0.05$) N_2O production. The highest N_2O ($0.18 \text{ mg N}_2\text{O m}^{-2} \text{ hr}^{-1}$; $0.57 \pm 0.058 \text{ g N}_2\text{O AU}^{-1} \text{ d}^{-1}$) was recorded in September from manure on SF and very low levels from the manure on EF.

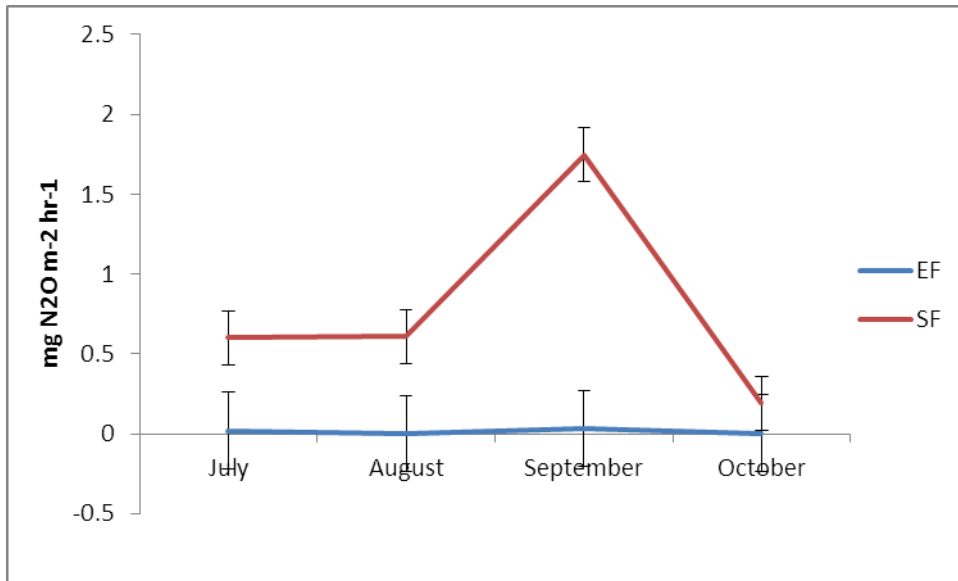


Figure 4.6 Monthly nitrous oxide flux (LSMean \pm se $\text{mg N}_2\text{O m}^{-2} \text{ hr}^{-1}$) from manure as affected by earth floor (EF) and slatted floors (SF)

4.4 Discussion

In the current study, manure from OP of goat housing emitted higher levels of methane (CH₄) than from disused pens (DP). The CH₄ emission from OP increased with prolonged duration of pen occupation. On the other hand, DP emitted persistently low levels of CH₄ which had a minute peak in September. Furthermore, the occupied pens with EF released the most methane. The methane values obtained in the current study for DPEF were lower than the EF ($0.29 \pm 0.067 \text{ mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$; $0.09 \pm 0.022 \text{ g CH}_4 \text{ AU}^{-1} \text{ d}^{-1}$) obtained in Chapter 3, Section 3.3.1. However, the persistent occupation of EF in the current study as OPEF showed increased CH₄ emission to ($0.48 \pm 0.085 \text{ mg CH}_4 \text{ m}^{-2} \text{ hr}^{-1}$), which was higher than that of EF obtained in Section 3.3.1. On the contrary, methane emission in slatted floors remained similar between the results obtained in Chapter 3 compared to those of the current study. The higher levels in methane emitted in the current study for OPEF compared to earth floors used in Chapter 3 could be a result of increased anaerobic conditions within the lower layers of manure as faecal heaps continued to accumulate in the pens (Sommer, 2001) from additional defecation in occupied pens. Further, the sustained moisture saturation from the urine, and compaction from the manure-animal contact (hooves or body) could have created more anaerobic conditions (Chadwick, 2005) which promoted methanogenesis. Chadwick (2005) observed that CH₄ emission was sometimes increased by compaction of manure heaps.

According to Chianese *et al.* (2009), the fermentation of cellulose, in manure, by faecal microbes yields Hydrogen (H₂) and CO₂ which are then used as substrates by *methanogenic archaea* under anaerobic conditions to produce CH₄. Goats accommodated on the earth floors had direct contact with the manure either when standing or lying down. It appears that the presence of goats provided damp urine conditions and compaction of the manure by their

hooves or body. Manure saturated with moisture (Chianese *et al.*, 2009) and compaction (Chadwick, 2005) lead to oxygen deprivation and promote the anaerobic reduction of CO₂ by H₂ to CH₄ by *Methanogenic archaea* (McAllister and Newbold, 2008). Chianese *et al.* (2009) further explain that there is a negative correlation relationship between moisture and oxygen. At high moisture conditions, the manure heap becomes deprived of oxygen and the situation promotes anaerobic CH₄ production. Nyamadzawo *et al.* (2013) also commented on a similar relationship between soil moisture saturation in rice fields which created anaerobic conditions that promoted CH₄ emission. The anaerobic production of CH₄ from manure (Adviento-Borbe *et al.*, 2010) occurs through similar mechanisms as the enteric degradation of feed (Broucek, 2014). According to Chianese *et al.* (2009), similar substrates i.e. H₂ and CO₂ are utilised in the production of methane in the rumen as well as in the rectum or manure. Broucek (2014) explained that the H₂ and CO₂ are by-products of the anaerobic fermentation of endogenous and undigested protein, as well as fats and carbohydrates in the manure, that are utilised by anaerobic microbes as food for growth and multiplication. The increase in microbial protein from the multiplication is accompanied by a concomitant release of CH₄ and CO₂ as by-products.

Disused pens with earth floors (DPEF) were the second highest in methane production. Observations in Chapter 3 showed that occupation of pens by goats compacted their manure (i.e. faeces mixed with urine). Compaction of the old manure could have enhanced anaerobic conditions (Chadwick, 2005) that were probably sustained to the current trial. However, as the old manure from the previous flock dried on the floors, some cracking on the surface was noted and this was thought to have created some fissures that allowed air with oxygen to disperse through sections of the dry caked manure. The possible presence of traces oxygen

that filtered through the cracks in manure could have reduced the amount of methane emitted in the disused pens with earth floors by creation of some aerobic sections within the manure heap. Chadwick (2005) also observed inconsistencies in the emission of methane and attributed the finding to varying anaerobic conditions and temperature changes. It is also possible that, in the current study, some of the methane was produced within the manure that had fissures on surfaces but the CH₄ got oxidised as it diffused through the aerobic sections or at the manure-air interface (Chianese *et al.*, 2009; Nyamadzawo *et al.*, 2013), hence reducing the amount of measured CH₄.

The methane flux obtained in OPEF in the current study are lower but comparable to those obtained by Borhan *et al.* (2011) (range: 0.19- 0.99 g CH₄ hd⁻¹ d⁻¹) in the bedding area of dairy cattle. Results obtained in this study where the measured methane was less than the findings of Borhan *et al.* (2011) concur with the finding by Bueno *et al.* (2015) that large ruminants emitted more methane than small ruminants. Mould *et al.* (2005) attribute differences in gas production from ruminants to animal effects, time of gas sampling and nutrition. Animal effects emanate from the preferred forage types which influence type of rumen or hind gut microbes. Unlike goats, cattle preferred to graze more than they browsed. Most browse species contain tannins. Bueno *et al.* (2015) found that ingested tannins inhibited the fermentation process to a larger extent in large ruminants than when the same compounds were present in small ruminants. This observation explained the higher CH₄ production from the large ruminants compared to small ruminants.

Condensed tannins have been reported to bind with ingested feed, microbes or microbial enzymes and protein (Waghorn, 2008; Bueno *et al.*, 2015). The addition of condensed tannin

to feed in studies by Bueno *et al.* (2015) reduced feed degradation and consequently lowered the amount of gas produced. According to Bodas *et al.* (2012), reduction in gas production is a result of formation of CT- protein complexes that impaired fermentation, reduced acetate, carbon dioxide and hydrogen production and consequently resulted in less CH₄ emission.

The binding of tannins to protozoa induces some anti protozoal effect (Patra *et al.*, 2006). Protozoa normally generate high levels of hydrogen and formate (Shibata and Terada 2010). Hydrogen is required by *methanogenic archaea* to reduce CO₂ in a reaction that yields CH₄. Any decline in the levels of H₂ such as resulting from defaunation (Shibata and Terada, 2010) or impairment in the function of protozoa (Patra *et al.*, 2006) is likely to diminish methane emission. According to Itibashi (1984), methane emission was reduced by 20 % in defaunated goats. Condensed tannins have also been reported to readily form complexes with cellulolytic bacteria more than they did with forage proteins (Min *et al.*, 2005). The combined effect of high affinity of condensed tannins to protozoa (Patra *et al.*, 2006) and suppressive influence of CT on the population of cellulolytic bacteria (Animut *et al.*, 2008), results in further reduction in the quantities of methane. The CTs also inhibit microbial enzymes from degrading feed as well as hinder the attachment of fibrolytic microbes to ingested forages thus contributing to reduced gas production. According to Carulla *et al.* (2005), supplementary feeding of sheep diet with *Acacia mearnsii* significantly lowered CH₄ emission and was ascribed to the presence of tannins in the supplement. Anantasook *et al.* (2014) also reported that addition of tannin reduced ruminal methane production. In a study on *in vitro* degradability of various forage species Gemedu and Hassen (2015) reported that some tropical browse species emitted less methane during incubations and could be used in mitigation strategies to reduce methane emission.

Weather conditions also influence CH₄ production. High ambient temperatures experienced in the afternoon or in the hot seasons result in high CH₄ emissions (Rochette *et al.*, 2011). Borhan *et al.* (2011) noted that a decrease in temperature from 20 to 10 °C reduced CH₄ emission by up to 50 %. Shibata and Terada (2010) reported that high seasonal temperatures tended to increase the indigestible cell wall contents of forages thus lead to increased methane production. Further, Shibata and Terada (2010) asserted that high roughage feeding at high temperatures increased CH₄ production compared to lower methane production from degradation of the same type of feed under lower temperatures. In the current study, gas sampling was done between 0900 to 1200 hrs which, according to Rochette *et al.* (2011), represent the daily average temperatures. The sharp rise in CH₄ production in EF that increased with heightened temperatures from July to October are in accordance to the observations of Chadwick *et al.* (2005) who asserted that temperature increases promoted CH₄ release in compacted manure. Chianese *et al.* (2009) explained that GHG emission would increase with temperature up to a certain thermal threshold beyond which production rate falls or ceases.

Compaction of manure by goats on OPEF was largely responsible for the elevated levels of CH₄ production. This assertion was substantiated by the low levels of methane in OPSF where goats did not have contact with their manure. The goats in OPSF had no direct contact with their faeces which were deposited below the slatted floors. Thus, the faecal pellets in OPSF maintained their structure which left air spaces between them, thus creating aerobic zones in the manure. According to Chianese *et al.* (2009), under conditions of low moisture content there is more aerobic situation and there is more CH₄ oxidation leading to less methane emission. Further, the presence of goats in OP could have continued to replenish

methanogenic microbes and fresh faecal matter substrate for degradation to produce methane. Methanogenic bacteria commonly use H_2 as the electron donor and CO_2 as the source of carbon in the hydrogenotropic pathway in the production and release of methane (Morgavi *et al.*, 2010). Extrapolating to annual rates, the highest values of CH_4 emission in the current study of 0.058; 0.065 and 0.052 $kg\ year^{-1}$ for OP, EP and OPEF, respectively, were lower than the 33.2, 2.0 and 0.3 $kg\ head^{-1}\ year^{-1}$ obtained by Merino *et al.* (2011) for dairy, beef cattle and sheep. However, the average CH_4 emission obtained in the current study of 42.56 ppm (v) was higher than the 2.07- 2.80 ppm obtained in dairy pens by Bjorneberg *et al.* (2009). The low CH_4 values obtained by Bjorneberg *et al.* (2009) could be a result of better feed offered to dairy cows which are meant to minimise energy loss. Borhan *et al.* (2012) state that incorporating concentrate diets in ruminants subjected to high levels of feed intake reduced CH_4 production but could increase CO_2 and N_2O emission.

In the current study there was use by floor type interaction effect on CO_2 production. The highest CO_2 emission was from OPSF. Carbon dioxide is a product of the aerobic degradation of manure. The presence of the goats in the OPSF continued to supply the required substrate (fresh faeces and urine) and aerobic bacteria in the manure on the floor. Faecal pellets that are not compacted maintain their structure and the interspaces between the faecal pellets provided the gaps for oxygen to disperse. The production of CO_2 was negatively correlated to CH_4 emission. The OPSF which emitted the highest CO_2 conversely had very low CH_4 emissions. The observation is attributable to the fact that aerobic conditions leading to the production of CO_2 are detrimental to anaerobic methanogenic bacteria. Whilst it is possible that some methane production could have occurred within the deeper anaerobic layers of previous flock manure, the CH_4 could have been converted to CO_2

as it passed through the aerobic zones close to the surface (Nyamadzawo *et al.*, 2012).

The range of CO₂ levels obtained in the current study are lower than those obtained in Chapter 3, as well as less than those obtained in other studies (Borhan *et al.*, 2011). In Chapter 3, the 13.92 ± 2.446 g CO₂ AU⁻¹d⁻¹ and 42.61 ± 2.452 g CO₂ AU⁻¹d⁻¹ obtained for EF and SF, respectively, were twice the values obtained for the OPEF and OPSF, respectively, in the current study. The observation could be ascribed to reduced levels of aeration (oxygen) in the lower levels of manure as the manure heap continue to accumulate thereby reducing respiration in the manure heap. Reduced respiration in the manure heap is likely to have contributed to the observed lower CO₂ levels in the current study. However, comparison between OPEF and OPSF showed that the later had higher CO₂ than the corresponding DPEF and DPSF suggesting that the deposition of fresh faeces and urine supplied the necessary aerobic microorganisms and substrate for degradation to yield CO₂ as a by- product. In addition, the possible existence of aerobic conditions in the manure on OPSF could have enhanced CO₂ production. Mould *et al.* (2005) highlighted that bacterial populations increased in the first 5 hours post feeding and remained constant for 10 hrs then followed by a decline. The occupation of pens thus continued to supply the floor manure with inoculum to at least the 19 hours the goats were penned.

In the current study, manure on occupied slatted (OPSF) floors emitted more N₂O than DPSF and DPEF floors. It appears the deposition of fresh manure (faeces and urine) added substrate for the continued nitrification and denitrification that increased N₂O emission in OPSF. Bhandaral *et al.* (2004) observed immediate increases in N₂O emissions soon after irrigation of pasture with dairy, piggery and abattoir effluents. Several other studies (Russel and

Cooper, 1987; Whalen *et al.*, 2000) observed similar trends of peak N₂O emissions a few hours following irrigation of pasture with farm effluent. The authors attributed the surge in N₂O emission soon after the irrigation with effluent to conditions favourable to denitrification i.e. anaerobic conditions arising from the water, and the presence of increased inorganic nitrogen. It is, therefore, conceivable that, in the current study, the presence of goats in OPSF provided urine with urea that was possibly converted to the NH₄⁺ and further to nitrate (NO₃⁻) and N₂ in nitrification processes. It is postulated that denitrification occurred in the lower levels where urine collected (anaerobic) whilst nitrification is assumed to have occurred in higher levels of the manure heap where aerobic conditions prevailed in the spaces between the separate faecal pellets. The low values of N₂O obtained in the disused pens compared to the results obtained in Chapter 3 as well as those of occupied pens in the current study are consistent with the observations of Bhandaral *et al.* (2004) who noted a surge in N₂O soon after irrigation with farm effluent, which is synonymous with dropping of faeces and urination in goat pens in the current study and Chapter 3. However, the observed surge in N₂O emission had no residual effect in the long term. The disused pens continued to emit some trace levels of N₂O but which were much lower than the occupied pens which continued to be replenished with fresh faecal matter and urine as sources of microbes/ urease enzyme for the conversion of urea to inorganic nitrogen (N). Inorganic N in the form of NH₄⁺ is an important ingredient for nitrification (Davidson *et al.*, 2000; Nyamadzawo *et al.*, 2012).

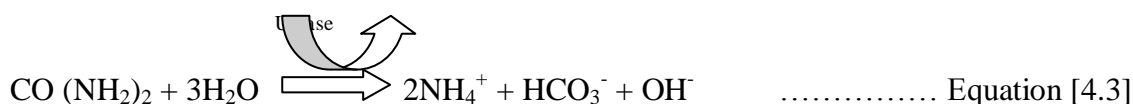
The highest N₂O that was measured in the current study was less than the highest values of N₂O emission that were obtained in Chapter 3. Further, The N₂O obtained in the current study was less than the 1.6 g N₂O AU⁻¹d⁻¹ obtained by Jungbluth *et al.* (2001) but higher than the 0.6 g N₂O AU⁻¹d⁻¹ obtained by Amon *et al.* (2001). The low values of N₂O obtained in

the current study may be a result of a combination of limited substrate in unoccupied pens, reduced aerobic conditions and possible effect of condensed tannins (CT).

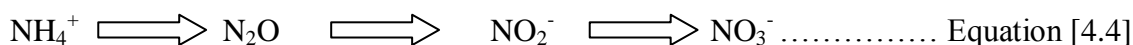
The unoccupied pens may have suffered from the lack of replenishment of enzymes and microbes responsible for the ureolysis (Cortus *et al.*, 2008) and nitrification/ denitrification (Davidson *et al.*, 2000; Parton *et al.*, 2001; Nyamadzawo *et al.*, 2012) processes. Further, anaerobic conditions may have been a result of increased height of manure heaps in the occupied pens which depressed the nitrification process which is important in the emission of N₂O as well as function as a preceding process for denitrification. Nitrification and denitrification are two pathways that produce N₂O as an intermediate product (Davidson *et al.*, 2000). In the current study, it is thought that manure under the slatted floors allowed some aeration and nitrification could have taken place, oxidising NH₄⁺ to NO₃⁻, and in the process produced N₂O as an intermediate product (Chianese *et al.*, 2009).

A possible simultaneous denitrification conversion of the NO₃⁻ is also postulated to have occurred yielding N₂O in the process as explained by (Chadwick, 2005) and as suggested in the “hole in the pipe model” of Davidson *et al.* (2000). In the current study, it is thought that the aerobic process predominated since aerated manure conditions are thought to have prevailed mostly in the OPSF where faecal pellets remained dry and separate in the high levels of the manure heap. Minimal levels of nitrous oxide were detected in the DPEF (0.02 ± 0.230 mg N₂O m⁻² hr⁻¹) and this was thought to have been supported by the dry conditions of the manure as well as the caked fissures that occurred on the surface of the dry manure. The production of N₂O had positive correlation with that of CO₂ an observation that is attributed to the fact that the emission of both gases requires aerobic conditions.

Condensed tannins (CTs) presumed to have been present in the browse species foraged on by the goats are thought to have been bound to dietary protein hence reduced the degradability of protein (Waghorn, 2008) and resulted in diminished NH_3 absorption from the rumen and less nitrogen in urine. Nitrogen in urine is normally in the form of urea which is quickly hydrolysed to ammonium ion (NH_4^+) followed by nitrification to NO_3^- with concomitant release of N_2O . According to Grainger *et al.* (2009), presence of tannins in diet consumed increased nitrogen partitioning from urine to faeces. Faecal nitrogen is organic and less volatile and thus reduces the amount of N_2O gas emitted. The mechanism of reduced N_2O emission is such that a drop in urine nitrogen limits the amount of urea available for ureolysis i.e. a process that is depicted in Equation [4.3] (Cortus *et al.*, 2008). Ureolysis is the hydrolysis of urea to ammonium ion (NH_4^+) which is an important step preceding nitrification.



Nitrification is the oxidation of the ammonium ion to nitrate (NO_3^-) under aerobic conditions yielding Nitrous oxide (N_2O) and Nitrite oxides (NO_x) as intermediate products as shown in Equation [4.4] (Davidson *et al.*, 2000; Nyamadzawo *et al.*, 2012):



Further, denitrification which is expected to occur simultaneously with nitrification may also have been impaired, if the nitrification process had been hindered by low levels of urea. Denitrification is the anaerobic conversion of Nitrate to N_2 gas and in the process also yields

N₂O and NO_x as intermediates (Chianese *et al.*, 2009). Faecal nitrogen is in organic form, less volatile and has limited availability for nitrification and denitrification (De Klein and Ledgard, 2005).

4.5 Conclusion and recommendations

The results of this study indicated low net positive emissions of methane and nitrous oxide from the manure in goat housing. Occupied pens on earth floors emitted the highest CH₄ due to the anaerobic and damp conditions of the pens. On the other hand, occupied pens on slatted floors emitted high N₂O. Carbon dioxide is less worrisome because agricultural systems and vegetation absorb CO₂ during photosynthesis and, therefore, act as a sink to the gas. It is necessary to consider making use of methane emissions from damp manure conditions by removing the manure and adding it to bio digesters so as to generate green fuel from the methane. Maintaining dry manure conditions in the pen is also recommended in order to reduce methane emissions from the pens. The periodic removal of manure to bio-digesters will also reduce the amount of substrate available for nitrification/ denitrification hence reducing N₂O in the process.

4.6 References

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CHAPTER 5: The Effects of Grazing System and Floor type on Blood Biochemistry, Growth, Body Condition Score and Carcass Characteristics of Nguni Goats

(Sections of this Chapter were presented as a poster at the South African Society of Animal Science 2015 Congress and submitted to the AJAS)

Abstract

The study was conducted to determine the effects of grazing management (tethering vs herding) and floor type (earth vs slatted) on the concentrations of blood metabolites, activity of creatine kinase, body weight (BW), body condition score (BCS) and carcass characteristics of castrated Nguni goats. Forty eight, 7 month old, castrated Nguni goats were randomly allocated to herding (H) and tethering (T) treatments and accommodated in pens with slatted (SF) and earth (EF) floors. The T and H treatments were imposed daily, for 5 months, between 0800- 1300 hours followed by penning. Blood sampling was done at 0700 hours once every two weeks by jugular venipuncture, processed into plasma or serum and analysed for the metabolites. Body weights were measured in the morning soon after every bleeding session. Grazing system significantly ($P < 0.05$) affected BCS, body weights and all the measured blood metabolites except activity of CK. Herded goats had higher ($P < 0.05$) mean body weights (24.56 ± 0.351 vs 22.60 ± 0.344 kg) and BCS (3.25 ± 0.022 vs 3.17 ± 0.022) than the tethered group. Tethered goats had higher ($P < 0.05$) urea (5.11 ± 0.073 vs 4.61 ± 0.074 mmol/L) and the TE group had the highest: creatinine (57.53 ± 0.0850 μ mol/L), total protein (66.20 ± 0.767 g/L), globulin (51.76 ± 0.759 g/L). On the other hand, herded goats had higher ($P < 0.05$) plasma glucose (3.39 ± 0.020 vs 3.23 ± 0.020 mmol/L), serum albumin (15.30 ± 0.147 v 14.82 ± 0.144 g/L). The interaction of grazing system by week of sampling significantly affected the concentrations of urea ($P < 0.0001$); creatinine and glucose ($P < 0.001$); and total protein ($P < 0.05$). It was concluded that serum concentrations of all the metabolites were sensitive to grazing system. Herding system resulted in more glucose, preservation of muscle protein, superior body weights and BCS than tethered goats.

Key Words: Blood Biochemistry, Floor type, Grazing system, Goat

5.1 Introduction

Goat grazing systems determine the extent to which the animals access forages and possibly the degree to which they satisfy their nutritional requirements. In various parts of developing countries, it is common practice among smallholder farmers under the crop- livestock farming systems to tether or herd goats (Moniruzzaman *et al.*, 2002). The grazing systems are mainly done to prevent the goats from damaging crops or grain in storage. Further, the emergence of stock theft as one of the major challenges in the livestock industry (Scholtz and Bester, 2010), may make it imperative for smallholder farmers to closely monitor goats as they forage either by the use of shepherds or tethering.

Small holder goats are penned for extended periods of time stretching for up to 19 hours. The comfort and welfare accorded to goats in their pens may determine the extent of fatigue, rest, foot condition and exposure to internal parasites. Some goat pens may become too muddy (Chikwanda *et al.*, 2013), a situation which forces the goats to spend nights standing without lying down to rest. It is hypothesised that goats that are not able to lie down to rest and spend the bulk of the night standing in pens will be too tired to adequately forage. Foot rot pathogens may infest muddy pens and affect goats which may impair their foraging ability. In addition, goats that are in contact with worm infested manure on earth floor pens maybe infected with internal parasites (Chikwanda *et al.*, 2013). Internal parasites impair the efficient utilisation of ingested feed by goats (Rumosa Gwaze *et al.*, 2010). It, therefore, appears that the obtaining of adequate nourishment from the veld maybe influenced by grazing system, type of housing floor and the capacity to search and select nutritious forages.

Reduced body condition scores (BCS) of animals maybe indicative of inadequate

nourishment that triggers mobilisation of body reserves (Chimonyo *et al.*, 2002). In addition, the nutritional state of foraging ruminants may be evaluated by using blood metabolites concentrations that act as pointers to its adequacy (Dampney *et al.*, 2014). The appreciation of metabolic profiles is important in correcting metabolic limitations before they cause serious deficiency syndromes. Olafadehan (2011) concurs to that variation in nutritional balance maybe assessed through biochemical and physiological changes that are elicited well before the animal's body condition deteriorates or mortality occurs. Blood biochemistry gives a reliable and consolidated measure of the sufficiency of dietary nutrients that can be used regardless of the physiological state of the animal (Pambu-Golla *et al.*, 2000). Metabolites that reflect an animal's protein balance include: albumin, globulin, total protein, creatinine and urea (Dampney *et al.*, 2014). Serum urea and creatinine are good indicators of kidney function and protein metabolism. Albumin concentration decrease when an animal is exposed to in adequate dietary protein (Mapiye *et al.*, 2010). Compromised nourishment leads to the mobilisation of muscle which is shown by reduced body condition, loss of weight and an increase in blood urea levels (Chimonyo *et al.*, 2002). On the other hand, measures of the energy status in an animal include glucose, non- esterified fatty acids (NEFAs) and cholesterol (Dampney *et al.*, 2014). Of these metabolites, glucose is the main source of energy.

To our knowledge, there is limited information on the levels of nutritional metabolites and carcass characteristics of tethered and herded goats that are accommodated in pens with earth or slatted floors. The objective of this study was, therefore, to determine the effect of grazing system (tethering or herding) and floor type (slatted vs earth) on blood metabolic concentrations and carcass characteristics of goats.

5.2 Materials and methods

5.2.1 Study site

This trial was performed at the University of Fort Hare, Honeydale Research Farm whose description was given in Section 3.2.1.

5.2.2 Study animals

Forty eight clinically healthy Nguni goats were used in this study. The goats were given prophylactic treatment of antibiotic (HI- TET 200 LA Gold), spray dipped against ectoparasites, dewormed and acclimatised to the treatments for 14 days. Twenty four of the Nguni goats were tethered and the remaining 24 were guided, by shepherds, to forage within the vicinity of the tethered goats. The goats were let out from pens for foraging at 0800 hours and re- penned at 1300 hrs daily for five months.

Individual neck collars were put on goats under the tethering treatment. The tethered goats were driven to the foraging site in groups of four held together by 65 cm polyvinyl chloride (PVC) pipes fitted with shackles that were attached to the neck collar by snap hooks. The snap hooks made it easy to detach the goats from the groups of four to be individually tethered, by 3 m ropes, to browse trees. The tethering spots were changed at frequencies of 3-4 times every 5 hours of foraging time. The herded goats had unrestricted access to water troughs in the foraging site. The tethered and herded goats were allowed access to water prior to being penned. Ten millilitres of blood were collected per goat, twice a month, for 5 months. At the completion of the study the goats were slaughtered, in a humane way following the abattoir procedures.

5.2.3 Design of the study

The study was a 2 X 2 factorial arrangement of treatments in a Completely Randomised

Design (CRD). The two factors were grazing system (tethering vs herding) and house floor type (earth vs slatted). Each grazing system was randomly assigned 3 pens per floor type and each pen accommodated 4 goats.

5.2.4 Blood Sampling, processing and analysis

Two sets of blood samples were collected from all the goats by jugular venipuncture into 2 x 5 ml vacutainer tubes (BD vacutainer systems, Plymouth UK) twice a month, at 0730 hrs. Blood samples for glucose analysis were put in 5 ml grey top BD vacutainer tubes with anti-coagulant, Ethylene diamine tetra acetic acid (EDTA) and immediately put on ice in a cooler box pending separation of plasma. Blood samples for the analysis of creatinine, urea, CK, total protein and albumin were collected in 5 ml gold top BD vacutainer tubes with clot activator and gently inverted 3 times to ensure mixing of the blood with clot activator. The tubes were labelled with the animal identification number and put in a cooler box containing ice until processed into serum within two hours of blood collection.

The blood samples in the tubes were centrifuged at 3500 rounds per minute (rpm), at a temperature of 10°C for 15 minutes (Model 5403 centrifuge, Gatenbay Eppendorf GmbH, Engelsdorp, Germany) to separate serum or plasma from the cell components of the blood. The serum or plasma samples were then transferred to 1.8 ml cryovials and frozen at -20 °C until the determination of blood metabolites. Glucose was analysed from plasma and the other metabolites were determined from the serum samples. The activity of CK activity was determined according to Horder *et al.*, 1991). Plasma samples were analysed for glucose following the method described by Gochman and Schmitz (1972). Serum samples were analysed for total protein (TP), albumin and creatinine as described by Lowry *et al.* (1951); Pinnell and Northam (1978); and Tietz (1995), respectively. Serum urea concentration was

also quantified as described by Tietz (1995). Globulin was calculated as the difference in concentration between TP and albumin.

5.2.5 Body weight measurement

Body weight measurements were done using a salter suspended weigher (Model 235) attached to a walk in weighing crate. The measurements were done once every two weeks at 0730 hrs of the weighing day before the goats were taken out for foraging.

5.2.6 Body condition scoring

Body condition scoring was done on a five point scale (range 1 to 5) with intermediate 0.5 units (Santucci and Maestrini, 1985). Briefly, muscle and fat cover around the lumbar vertebrae; the amount of fat around the sternum were assessed by feeling the quantity of fat that could be pinched; and the fat covering the ribs and intercostal muscle jointly gave the overall BCS (Santucci and Maestrini, 1985).

5.2.7 Goat transportation to abattoir and slaughter

The Nguni goats were taken to a commercial abattoir for slaughter at the end of the monitoring period. Care was taken in the loading, transportation and offloading of the goats. Loading density was 0.3m² per goat. Loading was done at 0800 hrs and the goats immediately transported to the abattoir located 120 km from the study site. Upon arrival at the abattoir, offloading was done calmly and the goats were put in lairage with *ad libitum* access to water. Slaughter was done the following day at 0630 hrs.

The goats were electro stunned at 650 V for five seconds and made unconscious. Sticking was then done and the carcass hung by the hind leg on an overhead pulley and bled for 6 minutes. This was followed by skinning and evisceration. The hot carcass weight (HCW) was the weight after removal of head; abdominal viscera and internal organs; skin; hind feet

(at tarsal- metatarsal joint) and front feet (at carpal- metacarpal joint) (Sebsibe et al., 2007). Cold carcass weight (CCW) was the weight of the carcass after ageing for 24 hours of between 2- 4°C. The dressing percentage (DP) was computed as the ratio of hot carcass weight to body weight before slaughter (WBS) expressed as a percentage [i.e. (HCW) / (WBS)*100]. The chilling loss (%) was calculated as [(HCW-CCW) / (HCW)*100] (Sebsibe et al., 2007). Carcass grading and classification was done by a trained and certified meat grader.

5.2.8 Statistical analysis

The effects of grazing system (T vs H), floor type (EF vs SF) on blood metabolites, live weights and body condition score of Nguni goats were analysed using the General Linear models (GLM) procedure of SAS (2003). Significant differences between least square group means were compared using Tukey's Studentized Range (HSD) test. The Chi- square test was used to test for relationship between the grazing system and: age, fat and conformation class. Pearson's correlation coefficient among blood metabolites, live weight and BCS were determined using SAS (2003). The statistical model used was:

$$Y_{ijkl} = \mu + G_i + H_j + W_k + (G \times H)_{ij} + (G \times W)_{ik} + (H \times W)_{jk} + (G \times H \times W)_{ijk} + e_{ijkl}$$

Where:

- Y_{ijkl} = Is the response variable (e.g. metabolite, Glucose, urea),
- μ = Population mean,
- G_i = Effects of grazing system (i = 1, 2),
- H_j = Effect due to housing (j = 1, 2),
- W_k = Effects of due to week of collection (j = 1, 2, ...20 weeks),
- $(G \times H)_{ij}$ = Effects due to interaction of grazing system and housing

$(G \times W)_{ik}$ = Effects due to interaction of grazing system by week,
 e_{ijkl} = Random residual error distributed as $\sim N(0; I\delta e^2)$.

5.3 Results

5.3.1 Blood metabolites

There were no treatment effects on activity of CK ($P > 0.05$). The activity of CK ranged from 195.75 ± 7.759 to 202.15 ± 7.653 U/ L for the two grazing systems and 203.08 ± 7.453 to 194.82 ± 7.951 U/ L for the two floor types. Table 5.1 shows the least square means (\pm SE) of the blood chemistry parameters as affected by the interaction of grazing system by floor type. Tethered goats accommodated on earth floors (TE) had higher ($P < 0.05$) creatinine, total protein and globulin; and ($P < 0.0001$) urea, than goats under the other treatments. On the other hand, herded goats accommodated on earth and slatted floors had higher A/G ratio than their tethered counterparts on earth and slatted floors. In addition, herded goats had higher ($P < 0.05$) concentration of serum albumin and plasma glucose than the tethered treatment as shown in Table 5.2 and Figure 5.1, respectively. The interaction of week of sampling by management significantly affected the concentrations of glucose ($P < 0.001$) and urea ($P < 0.0001$) as shown in Figure 5.1 and Figure 5.2, respectively. From week 2 to week 8, and week 18 to 20 the goats had similar concentrations of urea. However, tethered goats had higher ($P < 0.05$) concentrations of serum urea from week 10 to 16.

Table 5.1: Least square means (\pm SE) of blood chemistry parameters of Nguni goats as affected by grazing and floor type

Blood	Herding		Tethering	
	E	S	E	S
Metabolite				
Creatinine ($\mu\text{mol/L}$)	52.59 ^a \pm 0.862	56.23 ^{bc} \pm 0.933	57.53 ^b \pm 0.850	55.30 ^c \pm 0.890
Total protein (g/L)	61.52 ^a \pm 0.770	62.84 ^a \pm 0.838	66.20 ^b \pm 0.767	63.20 ^a \pm 0.800
Globulin (g/L)	46.42 ^a \pm 0.761	47.37 ^a \pm 0.829	51.76 ^b \pm 0.759	47.93 ^a \pm 0.791
A/G ratio	0.35 ^c \pm 0.012	0.33 ^c \pm 0.013	0.29 ^a \pm 0.012	0.32 ^b \pm 0.013

T= Tethering management system; H= Herding management system

LSMeans with different superscripts within the same row were significantly different ($P < 0.05$).

Table 5.2: Least square means (\pm SE) of albumin, urea, body weight and body condition score of tethered and herded Nguni goats

Parameter	Grazing System		Level of Significance
	H	T	
Albumin (g/L)	15.30 ^b \pm 0.148	14.84 ^a \pm 0.144	*
Urea (mmol/L)	4.61 ^a \pm 0.075	5.11 ^b \pm 0.074	***
Body weight (kg)	24.56 ^b \pm 0.351	22.60 ^a \pm 0.344	**
BCS	3.25 ^b \pm 0.022	3.17 ^a \pm 0.022	*

T= Tethering management system; H= herding management system

BCS on a point scale 1 to 5 (Santucci and Maestrini, 1985)

^{a,b}LSMeans with different superscripts within the same row differ significantly

Significant difference: * (P < 0.05); ** (P < 0.001); *** (P < 0.0001)

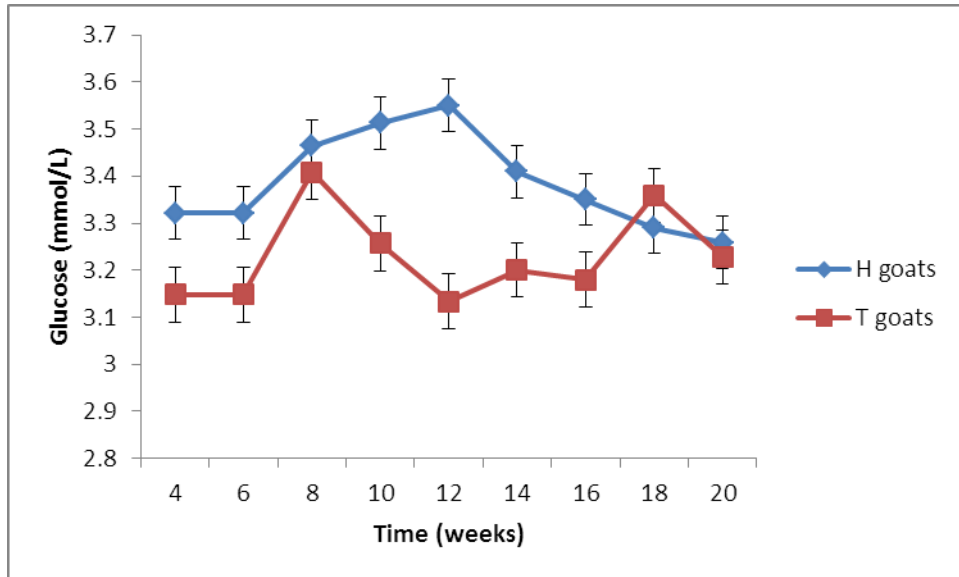


Figure 5.1: Least squares means (\pm SE) of plasma glucose concentrations (mmol/L) in herded (H) and tethered (T) Nguni goats.

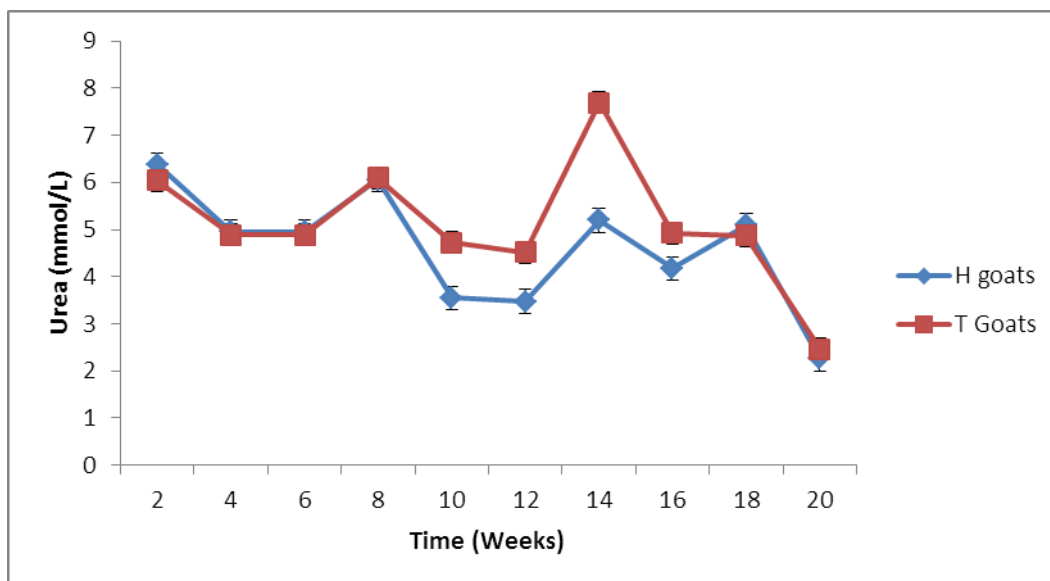


Figure 5.2: Least square means (\pm SE) of serum urea concentrations (mmol/L) in tethered (T) and herded (H) goats.

5.3.2 Body condition scores and body weights

Grazing system significantly affected body weights (BW) ($P < 0.001$) and body condition scores (BCS) ($P < 0.05$) as shown in Table 2. In general, herded goats had higher ($P < 0.05$) body weights and better BCS than tethered goats. Further, week of sampling significantly affected ($P < 0.0001$) body weights and BCS. Tethered and herded goats had similar BW for the first 8 weeks, as shown in Figure 3. However, from week 10 to the end of the study herded goats had significantly higher ($P < 0.05$) body weights than those that were tethered.

5.3.3 Carcass characteristics

The carcass characteristics of tethered and herded Nguni goats are shown in Table 3 and Table 4. The Chi-square results for test of independence between grazing system and: age, fat and conformation. The Chi-square values were very small for the age, fat and

confirmation class indicating that there was no relationship between grazing system and the tested parameters. Briefly almost equal proportions of tethered and herded goats had the same number of carcasses classified into the same categories of age, fat and confirmation. The herded goats had higher ($P < 0.05$) body weights taken before slaughter, hot carcass weight (HCW), cold carcass weight (CCW) and dressing percentage (DP %) than those of tethered goats. The shrink loss (%) [SL%] were not significantly different ($P > 0.05$) between tethered and herded goats.

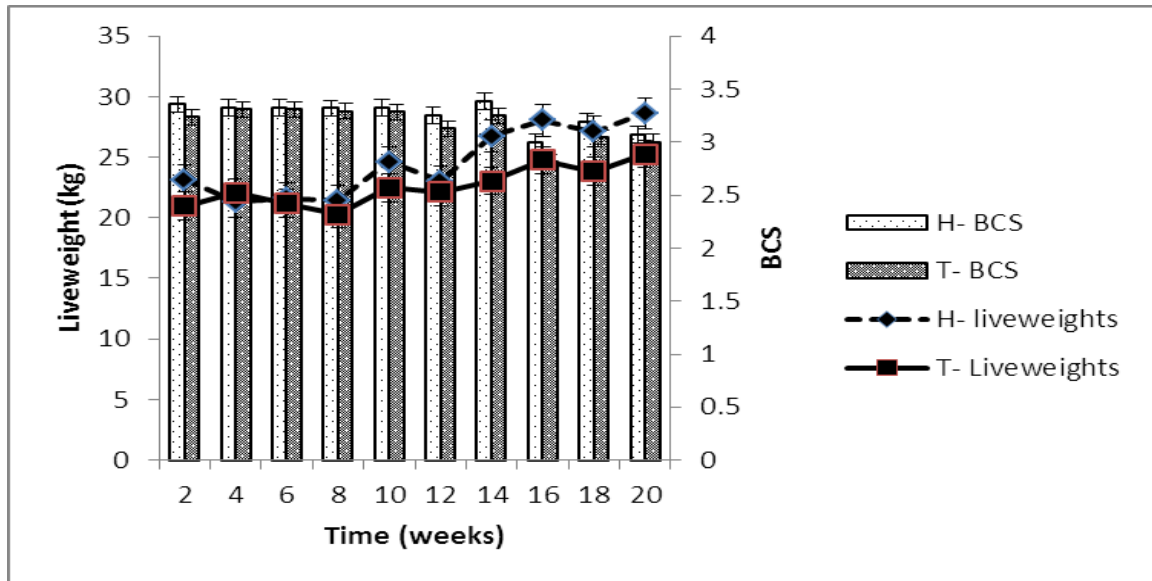


Figure 5.3: Least squares means (\pm SE) of body weight measurements (kg) and BCS of T and H goats taken every two weeks. H= Herding; T= tethering; BCS= Body condition score on a point scale of 1 to 5

Table 5.3: Chi- square test of independence between grazing system and: age, fat and conformation class

Parameter	Grazing System		DF	Chi-square value	P value
	H	T			
Age class: A (%)	32.61	34.78			
Age class: AB (%)	17.39	15.22	1	0.10	0.753
Fat class 0 (%)	39.13	47.83			
Fat class 1 (%)	10.87	2.17	1	3.07	0.080
Conformation class 1 (%)	2.17	8.70			
Conformation class 2 (%)	47.83	41.30	1	2.02	0.160

H= Herded; T= Tethered;

Age class: A= no permanent incisors; Age class: AB= At least one but not more than two permanent incisors (Soji et al., 2015)

Fat class: 0 = no fat; Fat class: 1= very lean (Soji et al., 2015)

Conformation class: 1= very flat; Conformation class: 2 = flat (Soji et al., 2015)

Table 5.4 Least square means (\pm SE) of carcass characteristics of tethered and herded Nguni goats.

Parameter	Management system	
	H (n=23)	T (n=23)
Slaughter weight (kg)	28.81 ^b \pm 1.084	25.13 ^a \pm 1.084
Warm weight (kg)	12.60 ^b \pm 0.542	10.39 ^a \pm 0.542
Cold carcass weight (kg)	12.23 ^b \pm 0.526	10.08 ^a \pm 0.526
Chilling loss %	2.97 ^a \pm 0.065	3.02 ^a \pm 0.065
Dressing percentage (%)	43.53 ^b \pm 0.599	41.24 ^a \pm 0.599

H= Herded; T= Tethered;

Age class: A= no permanent incisors; Age class: AB= At least one but not more than two permanent incisors (Soji *et al.*, 2015)

Fat class: 0 = no fat; Fat class: 1= very lean (Soji *et al.*, 2015)

Conformation class: 1= very flat; Conformation class: 2 = flat (Soji *et al.*, 2015)

^{a,b}LSMeans with different superscripts within the same row differ significantly ($P < 0.05$)

5.4 Discussion

5.4.1 Creatine kinase

The activity of Creatine kinase (CK) obtained in the current study was way above the normal expected 0.8 to 8.9 U/L range of values for healthy goats (Kaneko *et al.*, 2008). The activity of Creatine kinase tends to be high with increase in muscle activity or in cases of injury (Chulayo and Muchenje, 2013). The goats in the current study were very agile, moved very fast when taken to foraging areas and engaged in playful fights which could have elevated their activity of CK. According to Kannan *et al.* (2007), goats are easily excited and their CK levels may be high especially in high temperament breeds. Chulayo and Muchenje (2013) explain that increased activity of CK maybe due to elevated demands of ATP occurring in periods of high physical activity in order to hasten metabolic and respiratory rate that are required to support rapid movements.

Creatine kinase catalyses the conversion of creatine into phosphocreatine when ATP is converted into ADP with concomitant release of rapid energy. Solaiman *et al.* (2010) found increased physical activity in goats on high tannin diet and attributed the observation to the elevated activity of CK that was promoted by high dietary CT. It is, therefore, possible that the apparent preference of browse by goats in the current study could have contributed to the observed high activity of CK.

5.4.2 Urea and creatinine

Serum urea in tethered goats was higher than that obtained in the herding grazing system. However, the urea concentration obtained for both grazing systems was within the normal range of 3.57- 7.14 found in blood of healthy goats (Kaneko *et al.*, 2008). According to

Rumosa Gwaze *et al.* (2010), elevated urea concentration is a result of increased rumen ammonia, in cases of high plane of nutrition or catabolism of muscle for fasted animals or those under feed deprivation or on diets with less available nitrogen. Urea and creatinine are indicators of protein catabolism. High urea concentration when associated with low glucose levels are a sign that muscle protein is being catabolised (Pambu-Golla *et al.*, 2000).

The observed negative correlation between glucose and urea concentration, in the current study, was in accordance to Nuttall and Gannon (2013) who stated that there is very little or no conversion of ingested protein to glucose. In the current study, the obtained glucose and urea concentration was equivalent to that of healthy goats (Kaneko *et al.*, 2008). The within normal range of serum urea concentration that was observed in the current study for the two grazing systems suggests that there was adequate nourishment and the dietary protein was sufficient to prevent catabolism and preserve muscle protein (Pambu-Golla *et al.*, 2000). Nonaka *et al.* (2008) stated that serum urea concentration is inversely related to efficiency of utilisation of protein in the animal. It, therefore, means that the herded goats that had lower serum urea were more efficient in nitrogen utilisation. This may be affirmed by the heavier body weights and higher BCS in herded goats than tethered goats observed in the current study. A decrease in urea concentration signals improvement in the plane of nutrition to the animals. Prolonged feed deprivation would otherwise lead to breakdown of muscle protein to release urea (Pambu-Golla *et al.*, 2000).

Rumosa Gwaze *et al.* (2010) found higher urea concentration of 7.22 and 6.17 mmol/L during the dry and wet season and 6.88 and 6.51 mmol/L for young and mature Nguni goats, respectively. Similarly, Olafadeham (2011) found higher concentration of urea at 7.69 and

7.27 mmol/L in goats fed *Andropogon gayanus* or a tannin-rich browse plant *Pterocarpus erinaceus* as sole diets, respectively. Solaiman *et al.* (2010) obtained 5.17 to 6.17 mmol/L of urea in sera of goats fed graded levels of tannin containing forage sericea lespedeza. The within normal range of urea concentration, obtained in the current study, was attributed to possible increase in by-pass protein, due to likely influence of tannin containing browse species, which make the protein evade rumen degradation (i.e. avoid conversion to ammonia a precursor of urea) to be hydrolysed in the abomasum to amino acids.

The observed mean creatinine concentration for herded and tethered goats was below the normal expected range of 88.40 to 159 $\mu\text{mol/L}$. The low creatinine suggests that the goats had lean muscle. Rumosa Gwaze *et al.* (2010) found higher concentrations of creatinine in mature (78.7 $\mu\text{mol/L}$) goats than young (67.9 $\mu\text{mol/L}$) and attributed the observation to more muscle in the former than later age group. Dampthey *et al.* (2014) reinforces the view that excretion of creatinine is closely related to muscle mass being high in bigger animals. The observed below normal range of creatinine value are in accordance with the general understanding that animals with less muscle or are young exhibit less creatinine. In accordance to Rumosa Gwaze *et al.* (2010) the goats that were used in the current study would have been classified as young and, therefore, associated with low levels of creatinine due to less muscle build up. The observation of higher creatinine in tethered goats, which had lower body weights and lower BCS, than herded goats, was perplexing.

5.4.3 Total protein, albumin and globulin

Tethered goats had higher total protein and globulin concentration compared to herded goats. However, albumin concentration was higher in herded than tethered goats. The total serum

protein concentration for tethering treatment group was within the expected normal range of 64- 70 g/L of healthy goats (Kaneko *et al.*, 2008), whilst that for herded goats was slightly lower than the optimum range. According to Pambu-Golla *et al.* (2000), plasma protein concentration is normally maintained at optimum level and will only start to fall when the dietary protein is low.

The serum albumin concentration obtained for both the herded and tethered goats were far below the expected normal range of 27 to 39 g/L for healthy goats (Kaneko *et al.*, 2008). They were also lower than the 24.9 to 25.8 g/L range obtained by Solaiman *et al.* (2010) in Kiko goats fed graded levels of tannin diet. According to Mapiye *et al.* (2010), serum albumin concentration is indicative of protein status of an animal and the concentration of albumin falls under cases of dietary protein deficiency. The protein concentration was found to be slightly lower in herded treatment group than the reference range for healthy goats. Olafadehan (2011) found low albumin value of 28.03 g/L in goats fed grass with low protein (9.2 % on DM basis) compared to 34.80 g/L those offered a denser protein (16 % on DM basis) browse species, respectively. In the current study, positive correlation ($r=0.20$) was obtained between albumin and BCS. Positive correlations between albumin and optimum nutritional conditions as well as body condition have been reported in other studies (Dampety *et al.*, 2014). The finding lower albumin concentration in goats that were tethered which apparently had higher protein concentration was not expected. The unexpected observation suggests other contributory factors in addition to nutrition. Solaiman *et al.* (2010) highlighted that albumin in addition to being an indicator of nutritional status, was also a pointer of animal health status whose level decreased when an animal fell sick. The finding of below normal ranges of albumin, in the current study, suggest compromised nutritional protein and

or immune status of the goats under both treatments.

The general globulin concentration for herded and tethered was higher than the expected normal range of 27 to 41 g/L (Kaneko *et al.*, 2008). The high globulin concentration coupled with low albumin obtained in the current study lead to the very low albumin: globulin ratio. Mapiye *et al.* (2010) also observed very low A:G ratio in Nguni cattle which was ascribed to low albumin and high globulin concentration in their study. Elevated concentration of globulin and low albumin may occur as a result of infection (Ndlovu *et al.*, 2009), and reflect a state when the animal is fighting infection (Dampney *et al.*, 2014). There were some recorded incidences of bacterial infections, foot rot, orf (*contagious echthyma*) and pneumonia especially during the wet months that necessitated the use of injectable antibiotics, copper sulphate solution and or wound remedies. Even though blood sampling was normally done from apparently healthy goats, sub- clinical cases of such health challenges could have increased globulin concentrations. The increased globulin level may reflect susceptibility infection (Mapiye *et al.*, 2010) of the goats as they battled with infection. The observation of high globulin concentrations especially the tethered kept on earth floors (TE) is at variance with assertions that Nguni goats are resistant to diseases and parasites (Rumosa Gwaze *et al.* 2010). The smaller A:G ratio in tethered goats especially those housed in earth floors (TE) could imply that they were more vulnerable to infection than the herded goats. The combination of stress from tethering coupled with spending nights standing on earth floors appears to have exacerbated their welfare. Herded goats may have had access to a variety of forage species that helped them develop immunity but remained a reservoir of infection to those that were tethered.

The goats in the current study showed an apparent preference to consume browse and it is thought that the browse species contained condensed tannins (CT). Solaiman *et al.* (2010) found decreased white blood cells and increased lymphocytes at elevated CT levels in goat diets which compromised their immunity. In the current study, it is postulated that similar mechanisms could have compromised the immunity level of herded and tethered goats leading to the observed high globulin concentrations. Rumosa Gwaze *et al.* (2010) attributed high globulin values in their study to internal parasite infestations. In the current study, goats went through a routine deworming schedule and are thought to have been adequately protected against internal parasites. The compromised immunity of goats in the current study appears to point at the opportunistic infection in cases of foot rot, pneumonia and *orf* that were occasionally observed.

5.4.4 Glucose

The goats that were herded in this study had higher glucose concentration than tethered goats. It is probable that herded goats were better able to select younger herbage material across the spatially distributed plants and obtain more easily digestible carbohydrates that were broken down to glucose than tethered goats. However, the mean glucose concentration for herded and tethered goats was within the normal range for goats of 2.78- 4.16mmols/ L (Kaneko *et al.*, 2008). The results in the current study on glucose are comparable to the 3.584 to 3.7 mmol/L obtained by Solaiman *et al.* (2010) in Kiko goats, but higher than those obtained by Rumosa Gwaze *et al.* (2010), range: 2.99±0.76 to 2.65±0.109, for the same breed of goats. Further, the observation on glucose concentration obtained in the current study confirm that the imposed herding and tethering grazing treatments allowed the goats to have adequate dietary energy intake from the veld forages.

5.4.5 Body condition scores and body weights

Mean BCS and BW were higher in herded goats than tethered goats. However, BCS under both grazing systems were within the optimum range for the 1- 5 scale (Santucci and Maestrini, 1985). The observed optimum body condition scores in the current study suggest that the goats were not emaciated but received fair nourishment from the veld. The lower BCS in tethered compared to herding grazing system was an indication that tethering contributes to low nutrient uptake and reduced body condition in goats. Although the vegetation that goats under both grazing systems were subjected to was similar the selective foraging behaviour of tethered goats was limited. Similar to observations by Ogebe *et al.* (2000), the tethered goats in the current study sometimes entangled themselves with ropes thus reducing the length of the foraging radius permissible by the tether. Further, the herded goats were free to access water puddles and troughs whenever they got thirsty hence giving optimum dry matter and moisture balance during foraging that may have improved utilisation of ingested feed. It is postulated that the assumed improved utilisation of ingested food in herded goats led to their better BCS than in tethered goats. Ogebe *et al.* (2000) commended that exposure to heat at the same tethering site reduced feeding time. The stress from heat and restriction on movement could have contributed to reduced weights and BCS in tethered goats. The finding of positive correlation between total protein and body weight suggest that the measured weights are a useful indicator of ingested protein. A similar relationship between body weight and total serum protein levels was observed by Mapiye *et al.* (2010). The static growth rate during the first 8 weeks was attributed to poor veld conditions due to dry conditions early that year. The improvement in body weights that occurred in the current study from week 10 to 20 was indicative of better nutrient supply (Dampthey *et al.*, 2014). The possibility of internal parasites that normally cause stunted growth (Chikwanda *et al.*, 2013)

was eliminated in the current study by routinely drenching the goats.

The near flat body weight curve during the first 8 weeks for both treatment groups suggests inadequate nutrients flow to the goats during that period, despite observed optimum BCS 2.5-4.0 (Santucci and Maestrini, 1985). Evaluation of nutrition status of an animal using the BCS technique alone, therefore, exposes limitations of the tool. Animals may possibly lose bioenergy more than what is visible through BCS (Chagas *et al.*, 2007), and the technique is subjective and depends on the experience of the assessor. Therefore, BCS needs to be used in combination with other monitoring tools such as blood metabolites and body weights. The persistent gain in body weight from week 8 to the end of the study was evidence that the veld offered sufficient nutrient to promote growth.

5.4.6 Carcass characteristics

The estimation of age by dentition that was used at the abattoir was as reviewed by Soji *et al.* (2015). The estimation of age was similar to their actual ages as noted from their birth records. The age, fat and conformation class were not influenced by grazing system. However, the weight related carcass characteristics obtained in the current study were better in herded than tethered goats in terms of higher dressing percentage (DP), more cold carcass weight (CCW), less shrinkage loss. Solaiman *et al.* (2010) obtained lower DP (range: 37.6 to 39.1) and shrinkage loss (range; 1.18 to 2.89 %) than were obtained in this study. The DP values obtained in the current study were similar to the 39.5 to 43.1 % range that has been reported in various goat studies (Sebsibe *et al.*, 2007; Simela *et al.*, 2011). Differences in DP may be attributed to gut contents. However, in the current study, the goats were weighed after fasting.

Dressing percentage is affected by factors that include body weight before slaughter, time between the animal being taken off feed and slaughter, gut contents, breed, masculine and fatness (Webb *et al.*, 2005). Simela *et al.* (2011) explain that gut content largely accounts for the variation observed in DP, and further cite that up to 26 % of the live weight is attributable to gut content. The observation of higher DP in herded goats that had heavier carcass is consistent with the finding of Simella *et al.* (2011) who concluded that heavier carcasses, more fat cover and improved plane of nutrition increased DP. More masculine animals have a higher dressing percentage than smaller animals. Additionally, fatter stock will have higher DP. However, trimmings of extra fat may lower the DP as the abattoir prepares saleable meat portions. Normally, goats on diets higher in ME have higher dressing percentages and carcass weights. The observation appear to be in agreement with the results obtained in the current study were herded goats had higher glucose levels and tended to have higher DP and carcass weights.

Simela *et al.* (2011) commented that low fat cover is the major thing that attracts health conscious consumers to chevon. However, the consistently low fat cover on the goat carcass, as observed in the current study, is worrisome as far as cold shortening is concerned and downgrading in abattoirs that adopted sheep carcass classification for evaluation of goats (Simela *et al.*, 2005). Lean carcasses are also prone to high shrinkage loss during chilling (Webb *et al.*, 2005). It is worth noting that the current fat classification of goats in commercial abattoirs may need improvements since it is based on sheep but huge differences in carcass characteristics exist between the two species (Webb *et al.*, 2005).

The lower fat values obtained for the goats can be ascribed to possible influence of

condensed tannins (CT) in browse species consumed by goats. Solaiman *et al.* (2010) found a linear decrease in the fat thickness with increase in the level of CT in diets of sheep. Solaiman *et al.* (2010) postulated that CT containing diets decreased the bio-hydrogenation of fats in the rumen.

In the current study, shrink loss (SL) % were low and similar between the two grazing systems. The SL % values obtained in this study were comparable to those obtained for supplemented goats (range 2.5 to 3.1 %) by Sebsibe *et al.* (2007), which the authors described as low. The usually high SL % for goats is ascribed to their low fat content. Shrink loss % are important in that they ultimately determine the economic value that the abattoir will realise from the sale of the carcasses. The value placed on a carcass depends on the weight of the potentially saleable meat yield.

The majority of the carcasses of both tethered and herded goats were flat on conformation. According to Sebsibe *et al.* (2007) carcass conformation is a critical subjective visual criterial that impart value to assessed carcass. Additionally, Sebsibe *et al.* (2007) explain that some researchers viewed conformation as a biased tool in sheep carcasses as it only accounted for less than 10 % of the variation observed in meat yield. The flat carcasses observed in the current study appeared to occur in animals that had exhibited low serum creatinine concentrations in both treatment groups. Dampney *et al.* (2014) indicated that high creatinine is associated with more muscle mass and the metabolite being higher in bigger animals. Rumosa Gwaze *et al.* (2010) also reported that more creatinine was found in mature animals that had more muscle compared to the young animals. It is possible that the diet consumed by the goats was limiting in available protein possibly due to the detrimental effects of tannins.

Diets deficient in protein give rise to narrow or flat carcasses.

5.5 Conclusion and recommendation

Combined effects of grazing system and floor type were observed for the protein related metabolites. Herding of goats led to more serum glucose, less urea, improved efficiency in utilisation of protein, superior body weights and BCS than tethered goats. Observed high globulin and low albumin in tethered goats accommodated on earth floors indicate more susceptibility to infections and lower immunity. Both grazing systems resulted in lean carcasses with flat conformation, implying a possible need to supplement the diet of herded or tethered goats with concentrates to in order to improve fat cover and conformation. Herding system led to desirable high weight related carcass characteristics and is, therefore, an encouraged grazing system for goat farmers whose main objective is to obtain more revenue from weight based payment systems. Slatted floors improved the welfare of goats. Further studies are required to investigate the possible cause of the abnormally high levels of creatine kinase and determine effect of grazing system and floor type on meat quality, fatty acid profiles and greenhouse gas emissions.

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CHAPTER 6: Effects of grazing and floor type management on stress indicators and physico-chemical properties of Nguni goat meat

Abstract

The objective of the study was to determine the effects of grazing practice (tethering or herding); and floor type [earth floor (EF) vs slatted floor (SF)] management, on creatine kinase (CK) and cortisol levels, and chevon quality. Further, the effect of muscle type [*Muscularis longissimus thoracis et. Lumborum* (LTL) and *triceps brachii* (TB)] on chevon quality was also investigated. Forty eight castrated Nguni goats aged 6- 7 months and of average weight 22 kg were randomly allocated to tethering (T) (n=24) and herding (H) (n=24) treatments. Monthly blood samples were collected by jugular venipuncture for cortisol analysis. The goats were slaughtered at 12 months of age. Exsanguination blood was collected for CK analysis and meat samples were taken from the LTL and TB. The effects of T, H, EF and SF on physico-chemical characteristics were evaluated. There was month by grazing practice interaction effect ($P < 0.05$) on cortisol levels. The goats on EF had higher ($P < 0.05$) meat pH_{24} . Tethered goats had higher ($P < 0.05$) L^* (37.48 ± 0.320 vs 36.20 ± 0.324) and $CL\%$ (25.50 ± 0.528 vs 23.30 ± 0.546) than herded goats. The TB muscle had higher ($P < 0.05$) a^* , pH , but lower WBSF. Significant positive correlations ($P < 0.05$) existed between L^* and $CL\%$. On the other hand, significant negative correlation existed between: pH and WBSF ($r=0.22$); a^* and L^* ($r=-0.28$); $CL\%$ and CK ($r=-0.29$). It was concluded that T resulted in higher L^* and more $CL\%$ whilst SF lowered the pH_{24} of chevon; at the same time meat from the TB muscle was more tender, despite having a higher pH and more $CL\%$ relative to LTH cuts.

Key words: tethering; herding; floor type; stress indicators; physico- chemical properties

6.1 Introduction

Smallholder communities that practise crop- livestock farming either hire shepherd(s) to herd goats in foraging areas or tether their goats in crop alleys or veld (Romney *et al.*, 1996; Chikwanda, 2004). Goats that are herded are free to select foraging stations in the foraging areas. Tethered goats are restricted in movements by ropes attached to trees or pegs (Bayer and Zemelink, 1998). Expression of normal behaviour under tethering is, therefore, curtailed and the goats maybe exposed to stressors: aggressive counterparts, predators, strangulation, thermal or dehydration and fear. Ogebe *et al.* (2000) observed that tethered bucks tussled and sometimes got injured, entangled, or were strangled to death by leashes. Herded goats often come across unfamiliar flocks on communally owned veld and log into fights as they establish hierarchy. Muscle injuries or bruises maybe incurred in these fights. Bruises reduce the quality, quantity of harvested meat from carcasses and economic returns as affected areas have to be trimmed off (Hoffman and Lühl, 2012). Muscle injuries may also elicit the release of creatine kinase (CK) (Chulayo and Muchenje, 2013). Fear generated in tethered or herded goats can possibly elevate cortisol concentrations which may reduce the quality of meat (Muchenje *et al.*, 2009; Adzitey, 2011; Chulayo and Muchenje, 2013).

It is thus inevitable that some routine management practices that may seem normal may be stressful to the animals (Moolchandani *et al.*, 2008). Stress in goats has been studied using many different physiological indicators which include: changes in blood metabolites, hormones and behavioural displays (Kadim *et al.*, 2006; Forkman *et al.*, 2007). Kannan *et al.* (2000), Nazifi *et al.* (2003) and Silanikove (2000) highlighted that increased cortisol concentration is the most significant response of an animal to stressful conditions. In addition, cortisol promotes physiological adjustments that permit the animal to tolerate the

stressor. However, elevated cortisol concentrations reflect an animal in much poorer welfare situation which may reduce the quality of meat from such an animal.

It is postulated that the level of comfort accorded to goats during the extended periods of penning may influence fatigue, their foraging ability and consequently live weights and body condition. Goats that are penned in muddy conditions are thought to spend the bulk of the penning time standing and are assumed to suffer fatigue and maybe tired by the time they are released for grazing. It is further, hypothesised, that they tend to lie down to rest in the veld instead of foraging thus compromise the obtaining of adequate nutritional requirements. In addition, there may be depletion of glycogen reserves (Muchenje *et al.*, 2009) loss of body condition, reduced live weight gains and negative effect on the physico- chemical properties of goat meat. Therefore, it is postulated that efforts which are aimed at improving the welfare and rest of goats during overnight accommodation and appropriate grazing practice of goats may, probably, indirectly improve meat quality. It is further thought that the level of activity as modified by type of grazing practice or housing may exercise some muscles more than others leading to differences in physico- chemical properties of meat and fatty acid profiles from such muscles.

The majority of studies done on meat quality have focused on other livestock species and concentrated on the narrow window of the immediate pre- slaughter period i.e. from transportation to stunning (Adzitey *et al.*, 2011; Chulayo and Muchenje, 2013; Vimiso and Muchenje, 2013). However, there is scant literature on the effect of traditional goat grazing practices such as tethering and herding; and housing facilities on cortisol concentration, the activity of serum CK and physico- chemical characteristics. The objective of this study was,

therefore, to evaluate the effect of grazing practice (tethering vs herding) and type of housing floor (earth vs slatted) on cortisol concentration, activity of CK, physico- chemical properties of chevon.

6.2 Materials and methods

6.2.1. Study site

The study was done at the University of Fort Hare, Research Farm situated which was described in Section 3.2.1.

6.2.2 Study animals

Forty eight clinically healthy castrated Nguni goats aged between 6-7 months were randomly selected from about 120 weaners (average live weight of 22 kg), ear tagged for identification and used in this trial. The study goats received prophylactic treatment of injectable LA antibiotic, dipped against ticks and dewormed. The goats were then randomly allocated to tethering (n=24) and herding (n=24) grazing management treatments and further randomly assigned to earth floor (EF) and slatted floor (SF) houses at the rate of 6 pens per floor type. Goats under each grazing management treatment had 3 pens for each floor type and were accommodated at stocking density of 4 goats per pen. Each pen had floor dimensions of 1.8m x 1.5m. The goats were then acclimatised to the treatments over a 14 day period.

The goats were released in the morning at 0800 hours, for foraging, and brought back to the housing facility at 1300 hrs every day for penning. The goats under the tethering management had individual neck collars. The tethered goats were driven from the goat shelter in groups of four pen companions. Each group of four goats was kept together by the use of shackles

fastened on light 65 cm long polyvinyl chloride (PVC) pipes and snap hooks attached on the collars to facilitate ease of catching them when they got to the tethering sites. The goats were then individually tethered by 3 m length ropes to *Acacia* trees. The tethering sites were changed 3-4 times over the 5 hour daily foraging time. The goats that were herded were driven by shepherds to paddocks together with those that were tethered. However, the goats under the herding practice could graze freely within the vicinity of those that were tethered. The goats that were herded had free access to water troughs and puddles in the foraging sites at any given time. Both groups of goats were given access to water before being penned. At 1300 hours of everyday the goats were penned in their respective compartments as depicted by the ear tag identification and pen code. About 5 ml of blood samples were collected once a month per goat for 5 months for serum cortisol concentration analysis. At the end of the five months period the goats were slaughtered at a commercial abattoir in accordance to their slaughter procedures.

6.2.3. Design of the study

The study was a 2 X 2 factorial arrangement of treatments in a Completely Randomised Design (CRD) where the factors were two grazing treatments (tethering and herding) and two house floor treatments (earth and slatted). The goats under each management practice were randomly assigned to 3 pens with slatted floors and 3 pens with earth floors at the rate of 4 goats per pen.

6.2.4. Blood Sampling and processing

Blood samples for cortisol analysis were collected once a month, at 0730 hrs, by jugular venipuncture, using disposable 20 gauge needles and put in 5 ml gold top BD vacutainer

tubes (BD vacutainer systems, Plymouth UK) with clot activator and gently inverted 3 times to ensure mixing of the blood with clot activator. Blood samples for CK analysis was collected at exsanguination and put in similar tubes as those used for cortisol analysis. The tubes were labelled with the animal identification number and put into a cooler box containing ice until processed into serum within two hours of blood collection. The blood samples in the tubes were centrifuged at 3500 rounds per minute (rpm), at a temperature of 10°C for 15 minutes (Model 5403 centrifuge, Gatenbay Eppendorf GmbH, Engelsdorf, Germany) to separate serum from the cell components of the blood. The serum was then transferred to 1.8 ml cryovials and frozen at -20 °C until the determination of the concentration of serum cortisol and activity of creatine kinase (CK). Cortisol hormone analysis was determined according to Palme and Möstl (1997) The activity of CK was determined according to Horder *et al.* (1991)

6.2.5. Goat transportation to abattoir and slaughter

At the end of the monitoring period, the Nguni goats were taken to a commercial abattoir and slaughtered. The goats were transported to the abattoir in a calm and humanely way (Minka and Ayo, 2013) at a stocking rate of 0.3m² per animal as prescribed by Richardson (2002). The goats were loaded in the morning at 0800 hrs when the temperature was still cool and transported to the abattoir which is 120 km from the research site. Upon arrival at the abattoir, the goats were placed in lairage and presented with water *ad libitum* until slaughter on the following morning at 0630 hrs. The goats were stunned with electric current set at 650V for five seconds which made them unconscious. Their throats were then slit and the carcass hung by their hind leg to an overhead pulley and allowed to bleed for 6 minutes. The skins were then removed and the carcasses eviscerated. The carcasses were then chilled for

24 hours at 4 °C.

6.2.6. Physico- chemical properties of chevon

Representative samples of chevon (8 cm X 3m X 2.6cm) were obtained from the region of the last five ribs of the *Muscularis longismus thoracis et. lumborum* (LTL) and *triceps brachii* (TB), from the same half side of the carcass. The meat samples were collected 24 hours post slaughter after chilling at 4 °C while the carcass was still hanging, for the measurement of ultimate pH (pH₂₄), colour (L*, a* and b*) and determination of cooking loss (CL %), tenderness and fatty acid profiles. The meat samples were then individually vacuum packed in plastics and preserved in a cooler box with ice and immediately transported to the laboratory for the determination of colour and pH.

6.2.6.1. pH Measurements

A Jenway pH/mV/ Temperature bench meter (Model 3510) with a glass covered combination pH electrode (924 005) and ATC probe (027 500) was used to measure ultimate pH (pH₂₄) and temperature of the chevon samples 24 hours after slaughter. Calibration with standards of pH 4; 7 and 10 was done according to the user guide recommendations of the instrument.

6.2.6.2. Determination of Colour

The determination of chevon colour coordinates (L*= Lightness; a*= redness and b*= yellowness) [Commission International De I' Eclairage, (1976)] was done using a Minolta colour guide 45/0 BYK Gardener GmbH machine.

6.2.6.3. Determination of cooking loss and tenderness

6.2.6.3.1. Cooking loss

Determination of cooking loss was done preceding the evaluation of tenderness (WBSF). Briefly, the frozen chevon samples from the *Muscularis longissimus thoracis et. Lumborum* (LTL) and *Triceps brachii* (TB) muscle were thawed, dried with thick absorbent multi-wipe paper towel then weighed. The chevon samples were then put in individual plastics and placed in a common water bath, for cooking, immersed in water whose temperature had been raised and maintained at 72 °C, for 45 minutes. After the 45 minute cooking time, the samples were then removed from the plastics and allowed to drain off excess water and lightly dried with multi-wipe industrial paper towel and reweighed. Cooking loss was then computed as the difference in weight between the thawed weight and the cooked weight, expressed as a percentage, as shown in Equation [6.1]

$$CL\% = [(Thawed\ weight) - (Weight\ after\ cooking)] / (Thawed\ weight) * 100\ \% \dots \text{Equation [6.1]}$$

6.2.6.3.2. Determination of tenderness

Tenderness of the chevon samples from the *Muscularis longissimus thoracis et. Lumborum* (LTL) and *Triceps brachii* (TB) was determined using the Instron- Warner Bratzler Shear Force (WBSF) machine (Model 3344). Three sub samples per each cooked chevon sample were obtained by coring a 10 mm meat rode along the meat grain. The 10 mm chevon core samples were then cut across the direction of the muscle fibres using a shearing device of the Instron Warner Bratzler Shear Force machine. The shearing speed was 400 mm per minute per chevon core at a time.

6.3 Statistical analysis

The effect of grazing management practice (T vs H), floor type (EF vs SF) and muscle cut (LTL vs TB) on physico- chemical properties of chevon was analysed using the General Linear models (GLM) procedure of SAS (2003). The SAS (2003) GLM procedure was also used to determine effects of grazing practice and floor type on activity of CK and cortisol concentration. Significant differences between least square group means were compared using Tukey's Studentized Range (HSD) test. Pearson's correlation coefficient among physico- chemical properties of chevon: L*, a*, b*, pH24, CL% and WBSF were determined using SAS (2003). The statistical models used were as shown in model [6.1] and [6.2] below:

$$Y_{ijkl} = \mu + G_i + H_j + (GH)_{ij} + E_{ijk} \quad \text{Model..... [6.1]}$$

Where,

Y_{ijk} = Response variable (e.g. CK, cortisol or physico- chemical property),

μ = overall mean,

G_i = effect due to grazing practice (i = tethering or herding),

H_j = effect due to floor type (j = slated or earth floors),

$(GH)_{ij}$ = interaction of grazing practice and housing floor type,

E_{ijk} = random residual error distributed as $\sim N(0; I\delta e^2)$.

$$Y_{ijkl} = \mu + G_i + H_j + C_k + (GH)_{ij} + (GC)_{ik} + (HC)_{jk} + (G*H*C)_{ijk} + E_{ijkl} \quad \text{Model.. [6.2]}$$

Where,

Y_{ijkl} = Response variable (e.g. physico-chemical parameter),

μ = overall mean,

G_i = effect due to grazing practice (i = tethering or herding),

H_j = effect due to floor type (j = slatted or earth),

C_k = effect due to muscle cut on carcass (k = LTL or TB),

$(GH)_{ki}$ = interaction of grazing practice and housing floor type,

$(GC)_{il}$ = interaction of grazing practice and muscle cut from carcass,

$(HC)_{jk}$ = interaction of floor type and muscle cut from carcass,

$(GHC)_{ijk}$ = interaction of grazing practice, housing floor type and muscle cut from carcass, and

E_{ijkl} = random residual error distributed as $\sim N(0; I\delta e^2)$.

6.4 Results

The mean monthly temperatures recorded in the study area from January to May 2015 were as shown in Section 3.3, Figure 3.1. There was a gradual decrease in mean monthly temperature from 23°C in January to 15.5 °C in May.

6.4.1 Serum cortisol concentration

There were no significant differences ($P > 0.05$) in least square mean (\pm SEM) nmol/L cortisol concentration between T and H goats. The hormone concentration was also similar between goats accommodated in EF and those in SF. There was month x floor type interaction effect on cortisol concentration. Figure 6.1 shows the monthly concentration of cortisol per floor type. The concentration of serum cortisol in HE and TS goats both peaked in February followed by a decline. On the other hand, there was a general increase in cortisol concentration in HS goats while that in TE group maintained a constant range.

6.4.2 Physico- chemical properties of chevon and activity of CK

Housing floor type only significantly ($P < 0.05$) affected pH_{24} . Earth floors promoted higher pH_{24} of 6.14 ± 0.330 compared to the pH_{24} of 6.03 ± 0.036 observed in meat from goats accommodated in slatted floors. There was a significant ($P < 0.001$) positive correlation of +0.39 between L^* and CL. Significant ($P < 0.05$) negative correlations of -0.28 were observed between a^* and L^* ; -0.22 for pH_{24} and WBSF (N); and -0.29 for CK and CL %.

Table 6.1 shows the effect of tethering and herding on activity of CK and physico chemical properties of chevon. Chevon lightness (L^*) and cooking loss % (CL) were higher ($P < 0.05$) in T than in H goats. The post slaughter chevon temperature, measured after 24 hours of chilling at 4 °C, was significantly lower ($P < 0.05$) in T compared to H goats. There was no effect ($P > 0.05$) of grazing management practice on a^* , b^* , pH_{24} , tenderness and CK. Table 6.2 shows the influence of muscle cut on the physico- chemical characteristics of chevon. Chevon cut from the *triceps brachii* (TB) showed more redness (a^*) and pH_{24} ($P < 0.0001$) than the LTL cuts. Meat from the TB muscle was more tender and had higher ($P < 0.05$) cooking loss than that from the LTH. There was no effect of muscle cut on b^* and L^* .

Table 6.2 shows the influence of muscle cut on the physico- chemical characteristics of chevon. Chevron cut from the *triceps brachii* (TB) showed more redness (a^*) and pH_{24} ($P <$

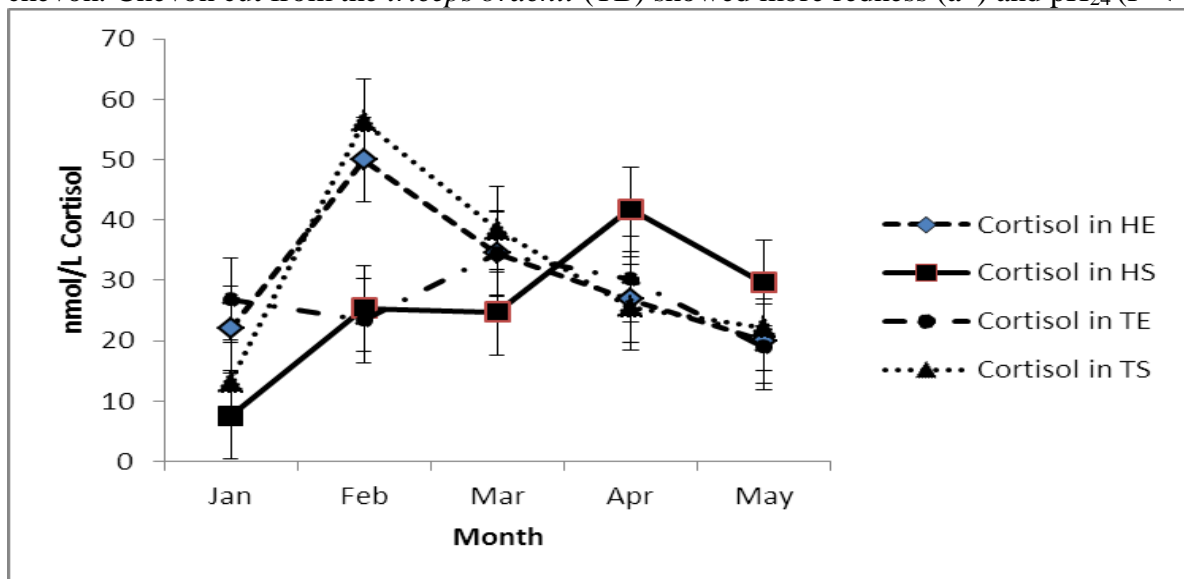


Figure 6.1: LS Mean (\pm se) nmol/L cortisol level as influenced by the interaction of month by management by floor type.

HE = herded goats penned on earth floor; HS = herded goats on slatted floors; TE = tethered goats on earth floors; TS = tethered goats on slatted floors

Table 6.1LSMean (\pm SEM) of physico- chemical properties of chevon from tethered and herded goats

	Grazing practice		Level of significance
	Herding	Tethering	
L*	36.20 ^a \pm 0.356	37.48 ^b \pm 0.322	*
a*	13.24 ^a \pm 0.255	13.68 ^a \pm 0.248	NS
b*	10.74 ^a \pm 5.117	18.66 ^a \pm 4.989	NS
pH₂₄	6.09 ^a \pm 0.035	6.08 ^a \pm 0.034	NS
WBSF (N)	27.10 ^a \pm 1.438	27.22 ^a \pm 1.402	NS
CL %	23.31 ^a \pm 0.560	25.50 ^b \pm 0.542	*
CK	414.33 ^a \pm 38.079	472.64 ^a \pm 36.585	NS
Temperature	8.31 ^b \pm 0.300	7.19 ^a \pm 0.292	*

L* = Lightness, a* = redness, b* = yellowness, pH₂₄ = meat pH at 24 hours post slaughter, CL = Cooking Loss, WBSF = Warner Braztler Shear Force. LSM means with different superscripts in same row indicate significant (P < 0.05) difference. Significant difference: * (P < 0.05); ** (P < 0.001); NS = No significant difference

Table 6.2

LSMean (\pm SEM) of physico- chemical properties of chevon from LTL and TB muscle of Nguni goats

	Muscle type		Level of significance
	LTL	TB	
L*	36.47 ^a \pm 0.323	37.21 ^a \pm 0.320	NS
a*	12.74 ^a \pm 0.229	14.18 ^b \pm 0.229	***
b*	17.83 ^a \pm 5.060	11.57 ^a \pm 5.060	NS
pH₂₄	5.98 ^a \pm 0.030	6.190 ^b \pm 0.030	***
WBSF (N)	30.06 ^b \pm 1.348	24.26 ^a \pm 1.348	*
CL %	23.35 ^a \pm 0.538	25.45 ^b \pm 0.537	*

L* = Lightness, a* = redness, b* = yellowness, pH₂₄ = meat pH at 24 hours post slaughter, CL = Cooking Loss, WBSF = Warner Braztler Shear Force, LTL = *Muscularis longissimus thoracis et. Lumborum*; TB = *Triceps brachii*; LSM means with different superscripts in the same row indicate significant (P < 0.05) difference.

Significant difference: * (P < 0.05); ** (P < 0.001); *** (P < 0.0001) NS = No significant difference

6.5 Discussion

6.5.1 Serum Cortisol concentration

The herded goats that were accommodated on earth floors (HE) had a similar general trend of cortisol concentration to that of tethered goats that were housed on slatted floor (TS). The cortisol concentration of HS showed a general increase whereas that in TE was within a constant range. Cortisol concentrations have been reported to become elevated in response to stress or increase in temperature in cattle, sheep (Wise *et al.*, 1988) and goats (Kaushish *et al.*, 1997; Nazifi *et al.*, 2003). However in the current study, the recorded temperatures fell within the optimum levels that can be tolerated by goats i.e. mean monthly temperature range of 15.5 to 23.2°C recorded during the study period. Therefore, the high cortisol concentration could not be attributed to extreme temperatures. The observed surge in the initial cortisol concentration followed by a decline for the HE and TS treatments could have been an adjustment phase which maybe similar to the observations of Moolchandani *et al.* (2008) in restraint and isolation studies. The lack of constant concentration of cortisol in the herded and tethered goats of the current study may be due to the high sensitivity of the hormone to stress. The observation confirms that goats are highly fearful animals (Forkman *et al.*, 2007) and are susceptible to sporadic surges in cortisol concentration in response to stressors that may make it difficult to offer coherent explanation in longitudinal studies. Moolchandani *et al.* (2008) attributed surges in cortisol concentration to the immediate activation of the adrenal cortical axis by the stressor leading to elevated concentration of cortisol. However, the authors explained that as the animals adjusted to the stressor, the cortisol concentration would fall. In accordance with Moolchandani *et al.* (2008), the TS, HE and TE goats appeared to have acclimatised to the stressor. However, it could not be explained why the HS goats showed susceptibility to stress throughout the monitoring period. Hooda and Upadhyay (2014) found

a jump in cortisol concentration when cross bred Alpine x Beetle goats were subjected to thermal stress and feed restriction.

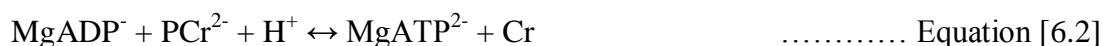
6.5.2 Creatine Kinase (CK)

The activity of CK obtained in this study was high but similar between the T vs H and EF vs SF treatments. Activity of creatine kinase is a reliable indicator of the extent of muscle activity or injury (Wilson *et al.*, 1990) especially that experienced by goats during loading, transportation and offloading (Kannan *et al.*, 2000). The activity of CK is high in muscle tissue where there is high requirement to maintain a balance of energy in the form of ATP to sustain muscle activity (Wallimann *et al.*, 1992; Dieni and Storey, 2009). The goats in the current study were loaded, transported, offloaded and put in lairage for the first time since their birth. This could have presented a novel environment and anxiety in the goats making them hyperactive thereby increasing activity of CK (Zimermana *et al.*, 2011). The goats further went through a period of 24 hours lairage with access to water but deprived of feed. In accordance to Kannan *et al.* (2002) high CK levels are attributed to anxiety and restlessness associated with feed deprivation in lairage. Kannan *et al.* (2007) also found heightened activity of CK (range: 130.2 to 197 IU) during transportation which remained high through overnight lairage fasting. Kannan *et al.* (2007) postulated that the elevated CK activity in other studies was a result of the high temperament of the breeds. The Nguni goat breed that was used in the current study has a fair temperament. However, there were some occasional episodes of aggression and or playful fights that were observed in the current study that could have resulted in fear, muscle injury and promoted CK activity. The range of CK activity values in the current study concur with those obtained by Nazif *et al.* (2003) in Iranian fat tailed sheep exposed to 21°C. However, the same breed of sheep when subjected to 4 °C and

40 °C gave very high CK activity of 126.89 and 95.90, respectively. The responsiveness of CK activity to heat extremes suggests that the enzyme activity can be used as an indicator of thermal stress on animals.

The activity of CK obtained in this study was double the activity range of 206- 276 U/L) obtained by Zimermana *et al.* (2011). In their trial, Zimermana *et al.* (2011) took blood samples from goats immediately after they had been subjected to exercise. The authors highlighted that there is a need for a lag period for there to be peak CK activity. In the current study blood samples were collected after 24 hours of lairage time which could have given sufficient time for peak CK activity to occur. Chulayo and Muchenje (2013) found much higher (723.3 ± 77.75 and 1026.3 ± 105.06 U/L) in studies done with sheep. The authors attributed the higher activity of CK they obtained in summer to increased physical activity respiratory rate, which they postulated lead to fatigue and muscle damage.

Chulayo and Muchenje (2013) postulate that increased CK activity could be due to elevated demands of ATP in order to hasten metabolic rate and respiratory activity associated with loading, transportation and offloading stress. The ATP is generated through the phosphorylation of Magnesium Adenosine Diphosphate (MgADP⁻) from phosphocreatine (PCr) in the presence of CK to yield magnesium Adenosine triphosphate (MgATP²⁻) as depicted in the following Equation [6.2] (Wallimann, 1992):



According to (Meyer *et al.*, 2006), the formation of complexes of CK with Cr or ATP or ADP presents three respiratory states that prevent the production of reactive oxygen species such as hydrogen peroxide (H₂O₂). In that regard, CK functions as an antioxidant against oxidative

stress through ADP recycling mechanisms, but the property largely depends on the phosphocreatine (PCr) to Cr ratio (Meyer *et al.*, 2006).

6.5.3 Meat quality parameters

6.5.3.1 pH

High mean pH values were obtained in the current study with 83.33 % of the pH readings being above 6. Meat with pHu values above 5.9 is classified as dark, firm dry (DFD), due to its dark red colour, has a shorter shelf life, high water holding capacity, is less tender, and has inferior palatability scores (Ferguson and Warner, 2008; Muchenje *et al.*, 2009b). The pH values obtained in the current study were higher than those obtained by Kadim *et al.* (2008) (pH range: 5.65 to 5.81) from heat stress studies on Omani and Somali goats. Lomiwes *et al.* (2014) categorised meat pH into three compartments namely: 5.4- 5.8 (described as low pH), 5.8- 6.2 (referred to as intermediate) and >6.2 (ranked high pH or otherwise DFD meat). The three compartments were apportioned quality scores in terms of tenderness as: tender meat (low pH), inconsistency in tenderness (intermediate pH), and tender meat associated with microbial contamination DFD and poor flavour (high pH), respectively (Lomiwes *et al.*, 2014).

The results from the current study would have fallen in the (Lomiwes *et al.*, 2014)'s intermediate pH category characterised by inconsistency in tenderness. Vimiso and Muchenje (2013) described such meat with high pH as of inferior quality referred to it as DFD in beef. The EF promoted higher chevon pH than SF. The higher pH observed in chevon from goats accommodated on earth floor was attributed to fatigue from standing within the pens. It was observed that during some periods of the study, there was heavy accumulation of urine in the

earth floors that made manure conditions muddy and forced the goats on EF to spent significant time standing than lying down to rest. The long hours of standing in the EF could have caused leg muscle fatigue and stressed the goats, unlike in the SFs which were dry all the time. Exhaustion from long hours of standing and the associated energy required for the standing posture, in the damp pens, could have contributed to depletion of glycogen reserves, leading to possible low post slaughter lactic acid production and resultantly high chevon pH_{24} (Veiseth- Kent *et al.*, 2010).

Higher pH values were obtained from samples taken from the TB muscle compared to those from the LTH. It was assumed that the standing during transportation and the continuous disturbance by the novel environment activities of lairage could have put a strain on the *triceps brachii* muscles leading to high pH. Further, standing in the pens at the farm during overnight accommodation could also have strained the TB muscle. Kadim *et al.*, (2003) observed that the LTL muscle had the lowest pH among the muscles measured in their study. According to Kadim *et al.* (2003), pH variations across muscle types may be due to the differences in the ratio of white and red fiber types which dictate the energy metabolism in the pre and post slaughter.

The pH_{24} value of the current study are slightly higher than those obtained by Zimmerman *et al.* (2011) (range 5.61- 5.66) measured at meat temperatures of 7.2- 7.6°C. The findings in this study are consistent with the review observation of Webb *et al.* (2005) who noted a pH range of 5.5- 6.83 which was skewed to the high values. The authors attributed the high pH values of chevon to goats being inherently susceptible to stress. Hopkins and Fogarty (1998) offers a genetic explanation to the high pH in chevon by stating that it is probable that goats

carry and inherently easily excitable gene that makes them prone to stress. It is possible that the novel process of vehicle transportation over the 120 km to the abattoir coupled with the strange environment in lairage stressed the goats that depleted their glycogen reserves. In a review, Muchenje *et al.* (2009a) explained that grass fed cattle that experienced less handling on range were badly affected by pre-slaughter stress as demonstrated by high ultimate pH compared to feedlot steers. Despite frequent on-farm handling of both tethered and herded goats, in the current study, the prior experience of human contact may not have been sufficient to reduce the fear of unfamiliar personnel and abattoir environment as both groups exhibited high pH.

Muchenje *et al.* (2009a) highlighted that pre- slaughter stress, especially emanating from loading, transportation, aggressive handling, heightened temperatures can cause an animal to deplete its glycogen reserves pre slaughter. Additionally, animal handling before loading, even at gathering stage from the paddocks, loading and offloading all constitute sources of stress. In the current study, there were no differences in pH of chevon from goats that were tethered or herded. However, both the two management practices resulted in chevon of high pH. The pH values obtained in the current study are consistent with the values obtained by Simela *et al.* (2004a) for South African indigenous goats. In the current study the goats were loaded at their housing facility suggesting that the high pH was probably due to the tethering and herding management practices, loading, transportation, offloading, and novel environment of the lairage. However, the distance that the goats were transported to the abattoir in the current study was short (~ 120 km) and was not expected to heighten the pH₂₄.

Vimiso and Muchenje (2013) suggested that rough handling at loading and offloading

constituted stress that adversely affects pH and colour. In the current study, it appears that the management of the goats and the novelty of being put on board a vehicle for the first time and the unfamiliar surroundings of the abattoir environment could also have contributed to stress and high pH. There was a lot of urination and defaecation by the goats aboard the trailer in transit to the abattoir, as well as a lot of bleating by the goats in lairage. According to a review by Forkman *et al.* (2007), urination, defaecation and bleating are an indication of fear that has been substantiated in literature by tests such as the novel arena test and has high repeatability in trials. In view of such display of behaviour and fear related excretion, it can be fairly assumed that the goats in the current study experienced fear stress in transit and in lairage.

6.5.3.2 Colour

6.5.3.2.1 Lightness

Chevon lightness (L^*) was only affected by grazing management practice and was higher in tethered goats compared to those that were herded. Lightness (L^*) values which are ≤ 33 indicate meat of dark colour (Vimiso and Muchenje, 2013). This implies that chevon in the current study was on the lighter side of the lightness scale. The L^* values obtained in this study were, however, lower than those obtained by Zimmerman *et al.* (2011) (range: 41.45-43.13) for goats subjected to fasting, exercise and fear. The L^* values obtained by Chulayo and Muchenje (2013) in sheep were lower than those obtained in this study. According to Babiker *et al.* (1990), the lower intramuscular fat content of chevon makes goat meat darker and more red than mutton. The occurrence of high L^* values simultaneously with high pH in the current study could not be explained. Zhang *et al.* (2005) observed high pH being associated with low L^* values and subsequently the meat appeared darker. The L^* values

obtained in this study were above 36.20 in all treatments. Vimiso and Muchenje (2013) state that stress factors that lead to depletion of glycogen resources result in high pH and tend to lower the L* values. According to Muchenje *et al.* (2009a), depletion of glycogen reserves that occurs in the pre- slaughter period results in less lactic acid production in the post mortem phase and leads to high meat pH. Meat with high pH is dark in colour, not very palatable, is shunned away by consumers, is susceptible to microbial growth and has shorter shelf life (Muchenje *et al.*, 2009a).

6.5.3.2.2 Redness (a^*)

Chevon redness (a^*) in this study was only influenced by muscle type, with *triceps brachii* (TB) having a higher mean score than LTH meat. However, in comparison with other studies the a^* values of the current study were lower than those obtained by Zimmerman *et al.* (2011) (range 18.55- 19.43) in fasted goats; (~ 16.3) obtained by Chulayo and Muchenje (2013) in sheep studies and the 18.48- 23.04 values (Kadim *et al.*, 2008) in sheep and much lower than the measurements by Kadim *et al.* (2008) from meat of Omani (20.89 and 24.78) and Somali (20.20 and 23.63) goats. Webb *et al.* (2005) explained that generally the redness of goat meat is not as pronounced as of mutton. It is possible that the lack of supplementing of veld forages with improved feeds to goats in the current study coupled with fasting from extended periods of everyday penning and lairage pre-slaughter could have contributed to the low a^* values. Ryan *et al.* (2007) found that supplementing basal diet of confined Boer goat with concentrates improved a^* and b^* values compared to the un- supplemented ones. Higher a^* and b^* values correspond to meat of desirable redness and yellowness, respectively.

6.5.3.2.3 Yellowness

Yellowness (b^*) values obtained in this study were not different between treatment (T vs H), (EF vs SF) and were not influenced by muscle cut (LTH vs TB). The b^* values obtained in this study were much higher than the 3.07- 4.12 range found by Kadim *et al.* (2008), 7.40- 7.84 by Zimmerman *et al.* (2011). Chulayo and Muchenje (2013) found similar results as in the current study but Kadim *et al.* (2008) got much lower b^* values for Somali sheep (3.57- 4.26) and Merino (2.8- 3.20). There is lack of consistence on effect of temperature on b^* values in literature with Chulayo and Muchenje (2013) reported higher b^* in summer but Kadim *et al.* (2008) reported lower yellowness in the hot season.

6.5.3.3 Cooking loss (CL) %

Cooking loss % was affected by management being higher in T than in H goats. The TB muscle also had higher CL (%) compared to LTH. Webb *et al.* (2005) highlighted that the relevancy of cooking loss in meat is that the amount of water that remains in a cooked piece is the primary contributor to the juiciness experienced by the consumer. Therefore, the usually high CL % loss in goat meat is thought make the meat less juicy and has reduced tenderness than other meats (Jama *et al.*, 2008). According to Jama *et al.* (2008), high cooking loss is undesirable since it leads to loss of essential mineral and vitamins from the meat. Low cooking loss obtained in H goats and for the LTL muscle was desirable. Generally, the CL (%) losses obtained in this study are on the lower side of the range (20- 35 %) that is normally observed in goats (Kadim *et al.*, 2003; Webb *et al.*, 2005). The CL (%) obtained in the current study (range 23.31 to 25.50 %) are comparable to those obtained for mutton (20.74 %) and goat chevon (22.67) by Sen *et al.* (2004).

Safari *et al.* (2011) found low CL (%) and attributed it to high ultimate pH observed in their

study. According to Huff- Lonergan and Lonergan (2005) high pH causes increased water holding capacity which leads to low drip loss and cooking loss. Huff- Lonergan and Lonergan (2005) further explain that high pH promote higher net charges and larger space between myofilaments that contribute to increased water holding capacity which translates to low CL %. Kadim *et al.* (2006) observed that transportation stress on goats prior to slaughter negatively affected cooking loss, WBSF values and colour coordinates (L*, a* and b*). Agbeniga *et al.* (2013) got CL% values for conventionally slaughtered beef (22.1 %) that are similar to those of the current study. The authors explained that pre- slaughter stress caused redirection of blood flow to skeletal muscle which led to high cooking loss. It is necessary to consider increasing ageing of goat carcasses post slaughter as a way to increase disintegration of myofibrillar proteins, increase water holding capacity, thereby, reducing cooking loss (Jama *et al.*, 2008).

6.5.3.4 Tenderness

The muscle cut significantly affected the WBSF values of the chevon. *Triceps brachii* cuts were tenderer than the samples obtained from the LTL. Nguni goats predominantly browsed during their allocated foraging time. The goats assumed a bi-pedal stance during browsing and it appears the posture strained and exercised the LTL more, thereby, making it less tender. Management and floor type did not affect the chevon tenderness. Generally, the meat cuts from this study were more tender (24.26 to 30.06 N) than those (range 29.8 to 35.6 N) of Marume (2010), (29.8 to 32.6 N) of Moyo *et al.* (2013) and lower than the standard reference of 55 N for tough meat (Mushi *et al.*, 2009) and much lower than the results obtained by Simela *et al.*, (2004) who got 78.8 N and 66.9 N for South African indigenous goats; 54.1 N and 60.4 N obtained by Schönfeldt *et al.* (1993). Almost all the WBSF values obtained in this

study were less than the (29.43 N= 3kg shear force) referred by Watanabe *et al.* (1996) as the limit for acceptable tender lamb meat. Compared to beef tenderness, the values obtained for WBSF in the current study rated between the limit for acceptably tender beef (19.62 N= 2kg shear force) and moderately acceptable (47.08 N= 4.8kg shear force) by Australian- New Zealand consumers (Daly, 2000). Webb *et al.* (2005) explained that WBSF results are affected by pre- slaughter handling of the animal, management of the carcass post slaughter as well as the muscle cut on the carcass. Despite the differences in grazing practice (T vs H), the herded goats foraged within the vicinity of tethered goats and did not drift away from their counterparts on leashes during foraging. Therefore, the tenderness results suggest that the goats were almost subjected to similar forages and comparable levels of activity hence the same magnitude of meat tenderness.

The goats used in this study were slaughtered at a young age ~ 12 months. The obtained lower WBSF (N) values for TB cuts could be explained by the young age at which the goats were slaughtered despite the higher (6.19 ± 0.030) pH. Further, the pH range obtained in this study conforms to the pH values that Lomiwes *et al.* (2014) ascribed to cause inconsistency in tenderness values. The category of inconsistency in tenderness is when low WBSF values can be obtained when pH values are high (Lomiwes *et al.*, 2014). It was also hypothesised in the current study that the bi- pedal stance assumed by the goats as they, predominantly, browsed put a strain on the LTH muscles hence made them tougher than the TB. The observation of there being no relationship between pH and WBSF conforms to the findings of Muchenje *et al.* (2008). However, this is a departure from the observation by Simela *et al.* (2004b) who reported that lower pH were associated with lower WBSF values, longer sarcomere length post chilling, higher energy values and ultimately more tender. Webb *et al.*

(2005) reported that goat meat is generally less tender than mutton. The observation is ascribed to less back fat thickness of goat carcasses, relative to sheep, which when chilled too quickly, the chevon is predisposed to cold shortening hence becomes less tender than mutton (Webb *et al.*, 2005). Additionally, goat meat has been reported to have more connective tissue in the form of collagen, which is less soluble, and has broader myofibrils than mutton which confers toughness to chevon relative to mutton (Gaili and Aili, 1985; Schönfeldt *et al.*, 1993).

The pH range of values obtained in the current study (5.98- 6.19) vis-à-vis meat tenderness was referred to as intermediate pH (5.8- 6.2) by Lomiwes *et al.* (2014) which they said gave rise to inconsistency in tenderness. Additionally, the authors indicated that tender meat had pH_u of either ≤ 5.79 or ≥ 6.2 . The weak negative correlations between pH and WBSF obtained in this study appear to agree with the compartmentalisation of pH noted by Lomiwes *et al.* (2014) i.e. inconsistency of tenderness at that pH range, especially when viewing muscle cut pH vs WBSF.

6.6 Conclusions

High pH, cortisol concentration and activity of CK observed in tethered and herded goats indicated that the animals were stressed. Tethering caused higher L^* and cooking loss than herded goats. However, the rest of the other physico-chemical parameters were similar between tethered and herded goats. Slatted floors lowered chevon pH and improved the welfare of goats. It was concluded that there was no difference in a^* , b^* and pH between tethered and herded goats. However, goat farmers need to be advised that body weights and body condition scores in tethered goats are less than in the herded ones. It is recommended to

herd goats as it gave desirable CL %, BCS and live weights. Further, provision of goat houses with SF is encouraged since it improved the welfare of goats and resulted in low chevon pH.

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CHAPTER 7: Effects of grazing management and floor type on fatty acid profiles of Nguni goat meat

Abstract:

The objective of this study was to determine the effect of grazing management (tethering vs herding) and floor type (earth vs slatted) on fatty acid composition of chevon from tethered and herded Nguni goats. Forty eight 6-7 months-old Nguni goats, at approximately 22 kg body weight, were randomly assigned to tethering (T) and herding (H) grazing treatments. Grazing treatments were imposed daily from 0800 to 1300 hrs for five months. The goats were then slaughtered at a commercial abattoir and meat samples were taken from the *m. longissimus thoracis et lumborum* (LTL) and *triceps brachii* (TB) muscles for fatty acid analysis. Floor type had no effect on fatty acid composition. Oleic, stearic, palmitic and linoleic were the major fatty acids. Chevon from tethered goats had higher ($P < 0.05$) proportions of long chain polyunsaturated fatty acids (PUFAs): eicosapentaenoic, docosapentaenoic, docosahexaenoic, conjugated linoleic acid (CLA) and more total SFA, total PUFA, total Omega- 6 and total omega 3 fatty acids than herded goats. On the other hand, chevon from herded goats had more ($P < 0.05$) C18:1c9, C18:2t9, 12 (n-6), C20:3c11, 14, 17 (n-3) and total MUFA than tethered goats. However, there was no difference ($P > 0.05$) in the PUFA: SFA and n-6/n-3 fatty acid ratios between the herded and tethered goats. It was concluded that tethering promoted higher proportions of beneficial PUFAs which were more in TB than LTH muscle. Goat farmers can consider tethering management practice to enhance harnessing of desirable health effects from chevon fatty acid profiles.

Key words: PUFA; SFA; tethering; herding; Nguni goats

7.1 Introduction

Animal feeding system has been named as one of the forces that influence dietary fatty acids and subsequently their incorporation into meat (Rhee *et al.*, 2000). Mapiye *et al.* (2011) demonstrated that supplementing *Acacia* leaves to beef cattle influenced their fatty acid profiles. Similarly, the extent to which goats access *acacia* leaves and other browse species is postulated to influence composition of ingested feed, dietary fatty acid profiles and their incorporation into body fatty acid. It appears that the diet selected by goats, their foraging behaviour and probably fatty acid profiles are influenced by grazing practice (tethering or herding) and the comfort accorded by type of overnight housing. Further, the grazing practice and housing floor type is postulated to determine the utilisation of body fat reserves as well as composition of fat in different muscles. Goats accommodated in muddy floors are that to utilise more body fat reserves for generation of energy required for standing long hours. Despite such possible influences, the effect of grazing management of goats and type of housing floor on chevon fatty acid profiles has been skirted in literature.

Tethered goats are limited in choice to the type of herbage available in the radius permitted by the leash. Free ranging or herded goats have shown preference to browse than grass species (Mugabe and Munthali, 1998; Bakare and Chimonyo 2011). Browse species have been reported to contain tannins (Mhlambo and Mapiye, 2015). Tannins when present in the diet bind to microorganisms responsible for biohydrogenation and hence protect the unsaturated fatty acids and make them available in the lower gastro-intestinal tract (GIT) (Banskalieva *et al.*, 2000). Poly unsaturated fatty acid have been demonstrated to have health beneficial effects to consumers (Banskalieva *et al.*, 2000; Muchenje *et al.*, 2009b).

The majority of goats kept by smallholder farmers are accommodated in a variety of shelter, that include earth floor houses and slatted floors (Chikwanda *et al.*, 2013). Earth floors sometimes become muddy and tend to soften the hooves and predispose them to foot rot. Affected feet may get inflamed, develop pain and are too painful for the goats to forage, worse still to assume the bipedal stance necessary to access overhead browse species. The affected goats may, therefore, be limited to predominantly graze and occasionally browse on the few low lying tree leaves. The type of fatty acids that are dominant in grass species are the MUFAs and PUFAs (Wood *et al.*, 2008). It may, therefore, be postulated that type of floor and or grazing management practice affects fatty acid profiles. Slatted floors minimise contact of goats and damp manure and are assumed to maintain healthy hooves and promote normal foraging behaviour, i.e. browsing (Mugabe and Munthali, 1998; Bakare and Chimonyo, 2011) in goats. In addition, goats that are accommodated on slatted floors are expected to have adequate rest during penning unlike those on earth floor that may spend whole nights standing avoiding to lie down on damp manure. It is hypothesised that fatigue resulting from inadequate rest during overnight penning may limit time spent foraging and dietary selection in the veld.

There is scant literature on the effect of feeding programmes (Rhee *et al.*, 2000) or traditional goat management practices i.e. tethering and herding on fatty acid profiles, fatty acid ratios and fatty acid indices of chevon. Various researchers have also lamented on the scarceness of studies on MUFA and PUFAs in goat muscles despite the undisputed fact that unsaturated fatty acids (Banskalieva *et al.*, 2000), lean chevon and its nutritive value (Talpur *et al.*, 2008) are very important to human health. The objective of this study was, therefore, to evaluate how grazing management (tethering vs herding) and type of housing floor (earth vs slatted)

and muscle type (LTL vs TB) influence affect fatty acid profiles of chevon.

7.2. *Materials and methods*

7.2.1. Study site

The experimental trial was done at the University of Fort Hare, Research Farm which was described in Section 3.2.1.

7.2.2 Study animals

Forty eight clinically healthy castrated Nguni goats aged between 6-7 months were randomly selected from about 120 weaners at average weight of 22 kg, ear tagged for identification and used in this trial. The management of the study animals was as described in Section

7.2.3. Design of the study

The study was a 2 X 2 factorial arrangement of treatments in a Completely Randomised Design (CRD) where the factors were two grazing practices (tethering and herding) and two house floor treatments (earth and slatted). The goats under each management practice were randomly assigned to 3 pens with slatted floors and 3 pens with earth floors at the rate of 4 goats per pen.

7.2.4. Goat transportation to abattoir and slaughter

At the end of the monitoring period, the 48 Nguni goats were taken to a commercial abattoir and slaughtered. The transportation and slaughter procedures were as described in Section 5.2.7.

7.2.5 Fatty acid profile determination

Total lipid from the goat meat samples was quantitatively extracted as described by Folch *et al.* (1957), using chloroform and methanol at a ratio of 2:1. An antioxidant, butylated hydroxytoluene was added at a concentration of 0.001 % to the chloroform: methanol mixture. A rotary evaporator was used to dry the fat extracts under vacuum and the extracts were dried overnight in a vacuum oven at 50°C, using phosphorus pentoxide as moisture adsorbent. Total extractable intramuscular fat was determined gravimetrically from the extracted fat and expressed as % fat (w/w) per 100 g tissue. The fat free dry matter (FFDM) content was determined by weighing the residue on a pre-weighed filter paper, used for Folch extraction, after drying. After determining the difference in weight, the FFDM was expressed as % FFDM (w/w) per 100 g tissue. The moisture content of the muscle was determined by subtraction (100% - % lipid - % FFDM) and expressed as % moisture (w/w) per 100 g tissue. The extracted fat from muscle was stored in a polytope (glass vial, with push-in top) under a blanket of nitrogen and frozen at -20°C pending fatty acid analyses.

A lipid aliquot (20 mg) of muscle lipid was converted to methyl esters by base-catalysed transesterification, in order to avoid CLA isomerisation, with sodium methoxide (0.5 M solution in anhydrous methanol) over 2 hours at 30 °C, as proposed by Alfaia *et al.* (2007), Kramer *et al.* (2002) and Park *et al.* (2001). The fatty acid methyl esters (FAMES) from muscle were quantified using a Varian 430 flame ionization GC, with a fused silica capillary column, Chrompack CPSIL 88 (100 m length, 0.25 mm ID, 0.2 µm film thicknesses). Analysis was performed using an initial isothermic period (40°C for 2 minutes). Thereafter, temperature was increased at a rate of 4°C per minute to 230°C. Finally an isothermic period of 230°C for 10 minutes followed. FAMES *n*-hexane (1µl) was injected into the column using

a Varian CP 8400 Autosampler. The injection port and detector were both maintained at 250°C. Hydrogen, at 45 psi, functioned as the carrier gas, while nitrogen was employed as the makeup gas. Galaxy Chromatography Software recorded the chromatograms.

Fatty acid methyl ester (FAME) samples were identified by comparing the retention times of FAME peaks from samples with those of standards obtained from Supelco (Supelco 37 Component Fame Mix 47885-U, Sigma-Aldrich Aston Manor, Pretoria, South Africa). Conjugated linoleic acid (CLA) standards were obtained from Matreya Inc. (Pleasant Gap, Unites States). These standards included: *cis*-9, *trans*-11; *cis*-9, *cis*-11, *trans*-9, *trans*-11 and *trans*-10, *cis*-12-18:2 isomers. All other reagents and solvents were of analytical grade and obtained from Merck Chemicals (Pty Ltd, Halfway House, Johannesburg, South Africa). Fatty acids were expressed as the proportion of each individual fatty acid to the total of all fatty acids present in the sample. Determination of marbling %, fat free dry matter (FFDM) % and moisture content was done on the chevon samples according to the Association of Analytical Chemists (AOAC), (2003) procedures. The following fatty acid combinations were calculated: omega-3 (*n*-3) fatty acids, omega-6 (*n*-6) fatty acids, total saturated fatty acids (SFA), total monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), PUFA/SFA ratio (P/S), *n*-6/*n*-3 ratio, Atherogenicity Index (AI) and Thrombogenicity index (IT). The AI described the relationship between the total of the major saturated fatty acids and the main unsaturated fatty acids (Garaffo *et al.*, 2011; Nantapo *et al.*, 2015). Equation [7.1] and [7.2] show the computation of AI and IT (Garaffo *et al.*, 2011; Nantapo *et al.*, 2015; Średnicka-Tober *et al.*, 2016).

$$AI = [(4 \times C14:0) + C16:0 + C18:0] / [\Sigma MUFA + \Sigma PUFA- n6 + \Sigma PUFA- n3]..Equation [7.1]$$

$$IT = [C14:0 + C16:0 + C18:0] / [(0.5 \times MUFA) + (0.5 \times PUFA- n6) + (3 \times PUFA- n3) + (PUFA- n3/PUFA- n6)] \quad \dots \text{Equation [7.2]}$$

7.2.6 Statistical analysis

The effect of management practice (T vs H), floor type (EF vs SF) and muscle cut (LTL vs TB) on fatty acid profiles was analysed using the General Linear models (GLM) procedure of SAS (2003). Significant differences between least square group means were compared using Tukey's Studentized Range (HSD) test. The statistical models used were as shown in model [7.1] and [7.2] below:

$$Y_{ijk} = \mu + G_i + H_j + (G*H)_{ij} + E_{ijk} \quad \dots \text{Model [7.1]}$$

Where,

Y_{ijk} = Response variable (e.g. fatty acid, fatty acid ratio or fatty acid index),

μ = overall mean,

G_i = effect due to grazing practice (i = tethering or herding),

H_j = effect due to floor type (j = earth or slated floor),

$(GH)_{ij}$ = interaction of grazing practice and housing floor type,

E_{ijk} = random residual error distributed as $\sim N(0; I\delta e^2)$.

$$Y_{ijkl} = \mu + M_i + H_j + (M*H)_{ij} + E_{ijkl} \quad \dots \text{Model [7.2]}$$

Where,

Y_{ijk} = Response variable (e.g. fatty acid, fatty acid ratio or fatty acid index),

μ = overall mean,

M_i = effect due to muscle (i = LTL or TB),

H_j = effect due to floor type (j = earth or slatted),

$(MH)_{ij}$ = interaction of effect of muscle and housing floor type,

E_{ijk} = random residual error distributed as $\sim N(0; I\delta e^2)$.

7.3 Results

Fatty acid composition, ratios and indices

There was no effect ($P > 0.05$) of floor type, and no interaction effect of muscle by grazing practice on fatty acid profiles, fatty acid ratios, Atherogenicity Index (AI) and Thrombogenicity Index (IT). Chevron cuts from LTL had higher ($P < 0.05$) marbling percentage (IMF) and fat free dry matter (FFDM) compared to that from TB as shown in Table 7.1. On the other hand, cuts from the TB muscle had higher moisture content ($P < 0.05$) compared to LTL cuts. Herding management promoted more ($P < 0.05$) marbling of chevon than tethering Table 7.2. Generally, the major fatty acids from chevon of Nguni goats from both the management and muscle type perspective were oleic (C18:1c9), stearic (C18:0), palmitic (C16:0) and linoleic acid (C18:2c9, 12(n-6), in decreasing order.

Table 7.3 shows the least square means (\pm SEM) of fatty acids as affected by muscle type (LTL versus TB). Chevron from the LTL muscle had higher proportions of C10:0 ($P < 0.01$) and MUFA ($P < 0.0001$) compared to that from TB. On the other hand, the TB muscle had higher proportions of: Pentadecylic (C15:0), Pentadecenoic (C15:1c10), Margaric (C17:0), Linoleic (C18:2c9,12(n-6), Arachidic (C20:0), α -Linolenic (C18:3c9,12,15(n-3), Conjugated linoleic acid (CLA) [C18:2c9,t11 (n-6) (CLA)], Erucic (C22:1c13), Arachidonic [(C20:4c5,8,11,14 (n-6)], Docosapentaenoic [C22:5c7,10,13,16,19 (n-3)], Docosahexanoic [C22:6c4,7,10,13,16,19 (n-3)], total poly unsaturated fatty acids, total omega- 6 fatty Acids,

Table 7.1

Least square means (\pm SEM) for the chemical composition of chevon from cuts from the LTH and TB muscle.

Parameter (%)	Muscle		SEM	Level of significance
	LTH	TB		
Intramuscular fat (Marbling)	2.19 ^b	1.95 ^a	0.084	*
FFDM	21.07 ^b	19.43 ^a	0.437	*
Moisture	76.74 ^a	78.63 ^b	0.453	*

Means with different superscripts for management or muscle type were significantly different ($P < 0.05$). LTL = *Muscularis longissimus thoracis et. Lumborum*; TB = *triceps brachii*; FFDM = Fat free dry matter.

Significant difference: * ($P < 0.05$)

Table 7.2

Least square means (\pm SEM) for the chemical composition of chevon from herded and tethered Nguni goats.

Parameter (%)	Muscle		SEM	Level of significance
	H	T		
Intramuscular fat (Marbling)	2.22 ^b	1.92 ^a	0.085	*
FFDM	19.99 ^a	20.52 ^a	0.453	NS
Moisture	77.80 ^a	77.57 ^a	0.474	NS

Means with different superscripts for management or muscle type were significantly different ($P < 0.05$). H = Herded; T = tethered; FFDM = Fat free dry matter
Significant difference: * ($P < 0.05$), NS = No significant difference

Table 7.3

Least square means (\pm SEM) of fatty acid composition expressed as percentage of weight of total named fatty acids from the LTH and TB muscle of Nguni goats

Fatty acid (% total fatty acid)		Muscle			
Common Name of fatty acid	Abbreviation	LTH	TB	SEM	Level of significance
Capric	C10:0	0.03 ^b	0.01 ^a	0.003	**
Lauric	C12:0	0.02 ^a	0.02 ^a	0.004	NS
Myristic	C14:0	1.04 ^a	1.00 ^a	0.059	NS
Myristoleic	C14:1c9	0.01 ^a	0.01 ^a	0.004	NS
Pentadecylic	C15:0	1.03 ^a	1.21 ^b	0.084	*
Pentadecenoic	C15:1c10	0.07 ^a	0.11 ^b	0.007	**
Palmitic	C16:0	19.76 ^a	19.48 ^a	0.204	NS
Palmitoleic	C16:1c9	0.87 ^a	0.86 ^a	0.034	NS
Margaric	C17:0	1.01 ^a	1.11 ^b	0.019	**
Heptadecenoic	C17:1c10	0.24 ^a	0.27 ^a	0.015	NS
Stearic acid	C18:0	23.59 ^a	23.97 ^a	0.375	NS
Elaidic	C18:1t9	0.19 ^a	0.13 ^a	0.021	NS
Oleic	C18:1c9	38.52 ^b	32.43 ^a	0.734	***
Linolelaidic	C18:2t9,12 (n-6)	0.10 ^a	0.11 ^a	0.006	NS
Linoleic	C18:2c9,12 (n-6)	4.17 ^a	7.06 ^b	0.201	***
Arachidic	C20:0	0.09 ^a	0.11 ^b	0.004	**
α -Linolenic	C18:3c9,12,15 (n-3)	2.61 ^a	3.97 ^b	0.116	***
Conjugated linoleic acid (CLA)	C18:2c9,t11 (n-6) (CLA)	0.44 ^a	0.48 ^b	0.014	*
Conjugated linoleic acid (CLA)	C18:2c9,c11 (n-6) (CLA)	0.14 ^a	0.16 ^a	0.010	NS
Eicosatrienoic	C20:3c8,11,14 (n-6)	0.01 ^a	0.01 ^a	0.002	NS
Erucic	C22:1c13	0.19 ^a	0.24 ^b	0.014	*
Eicosatrienoic	C20:3c11,14,17 (n-3)	0.01 ^a	0.01 ^a	0.002	NS
Arachidonic	C20:4c5,8,11,14 (n-6)	2.37 ^a	2.99 ^b	0.175	*
Tricosanoic	C23:0	0.01 ^a	0.01 ^a	0.004	NS
Docosadienoic	C22:2c13,16 (n-6)	0.00 ^a	0.00 ^a	0.002	NS
Eicosopentaenoic	C20:5c5,8,11,14,17 (n-3)	1.64 ^a	1.94 ^a	0.113	NS
Docosapentaenoic	C22:5c7,10,13,16,19 (n-3)	1.62 ^a	2.01 ^b	0.112	*
Docosahexanoic	C22:6c4,7,10,13,16,19 (n-3)	0.20 ^a	0.29 ^b	0.019	*
Fatty Acid Ratios:					
Total Saturated Fatty Acids	(SFA)	46.58 ^a	46.93 ^a	0.449	NS
T. Mono Unsaturated Fatty Acids	(MUFA)	40.10 ^b	34.05 ^a	0.735	***
T. Poly Unsaturated Fatty Acids	(PUFA)	13.31 ^a	19.02 ^b	0.684	***
Total Omega- 6 Fatty Acids	(n-6)	7.23 ^a	10.81 ^b	0.357	***
Total Omega- 3 Fatty Acids	(n-3)	6.09 ^a	8.21 ^b	0.335	***
PUFA:SFA		0.29 ^a	0.41 ^b	0.016	***
n-6/n-3		1.22 ^a	1.32 ^b	0.019	**
Fatty acid Indices					
Atherogenicity Index	AI	0.90 ^a	0.91 ^a	0.020	NS
Thrombogenicity Index	IT	1.06 ^b	0.95 ^a	0.027	*

Means with different superscript under management or muscle were significantly different ($P < 0.05$); SEM = standard error of the mean; LTL = *Muscularis longissimus thoracis et. Lumborum*; TB = *triceps brachii*; Significant difference: * ($P < 0.05$), *** ($P < 0.001$), NS = No significant difference

total omega- 3 fatty Acids, PUFA to SFA ratio, n-6/n-3 ratio and Thrombogenicity index. However, there were no differences ($P > 0.05$) in Atherogenicity Index between chevon cuts from the LTL compared to that from the TB. Further, there was no difference ($P > 0.05$) in the following fatty acids between the LTL and TB cuts: C12:0; C14:0; C14:1c9; C16:0; C16:1c9; C17:1c10; C18:0; C18:1t9; C18:1c9; C18:2t9,12 (n-6); C18:2c9,c11 (n-6) (CLA); C20:3c8,11,14 (n-6); C20:3c11,14,17 (n-3); C23:0; C22:2c13,16 (n-6); C20:5c5,8,11,14,17 (n-3) and total SFA.

Table 7.4 shows the least square means (\pm SEM) of chevon fatty acids as affected by tethering or herding of goats. The herding of goats promoted higher proportions of: Oleic (C18:1c9), Linolelaidic [C18:2t9, 12 (n-6)] and total mono unsaturated fatty acids. On the other hand, tethering of Nguni goats promoted higher proportions of: Pentadecylic (C15:0), Pentadecenoic (C15:1c10), Margaric (C17:0), Heptadecenoic (C17:1c10), Stearic acid (C18:0), Arachidic (C20:0), Conjugated linoleic acid (CLA) [C18:2c9,t11 (n-6) (CLA)], Conjugated linoleic acid (CLA) [C18:2c9,c11 (n-6) (CLA)], Eicosatrienoic [C20:3c8,11,14 (n-6)], Eicosatrienoic [C20:3c11,14,17 (n-3)], Arachidonic [C20:4c5,8,11,14 (n-6)], Eicosopentaenoic [C20:5c5,8,11,14,17 (n-3)], Docosapentaenoic [C22:5c7,10,13,16,19 (n-3)], Docosahexanoic [C22:6c4,7,10,13,16,19 (n-3)], total saturated fatty acids, total poly unsaturated fatty acids, total omega- 6 fatty acids, total omega- 3 fatty acids and Atherogenicity Index. However, there was no difference ($P > 0.05$) in the PUFA: SFA and n-6/n-3 fatty acid ratios and Thrombogenicity Index between the herded and tethered goats.

Table 7.4

Least square means (\pm SEM) of fatty acid composition expressed as percentage of weight of total named fatty acids of chevon from herded and tethered Nguni goats

Fatty acid (% total fatty acid) Common Name of fatty acid		Abbreviation	Muscle			Level of Significance
			H	T	SEM	
Capric	C10:0	0.02 ^a	0.02 ^a	0.004	NS	
Lauric	C12:0	0.02 ^a	0.03 ^a	0.004	NS	
Myristic	C14:0	0.98 ^a	1.07 ^a	0.058	NS	
Myristoleic	C14:1c9	0.01 ^a	0.01 ^a	0.004	NS	
Pentadecylic	C15:0	0.99 ^a	1.25 ^b	0.049	**	
Pentadecenoic	C15:1c10	0.07 ^a	0.10 ^b	0.008	*	
Palmitic	C16:0	19.38 ^a	19.85 ^a	0.201	NS	
Palmitoleic	C16:1c9	0.90 ^a	0.83 ^a	0.034	NS	
Margaric	C17:0	1.01 ^a	1.11 ^b	0.020	**	
Heptadecenoic	C17:1c10	0.23 ^a	0.28 ^b	0.014	**	
Stearic acid	C18:0	22.53 ^a	25.02 ^b	0.370	***	
Elaidic	C18:1t9	0.15 ^a	0.18 ^a	0.021	NS	
Oleic	C18:1c9	38.62 ^b	32.33 ^a	0.852	***	
Linolelaidic	C18:2t9,12 (n-6)	0.12 ^b	0.09 ^a	0.006	*	
Linoleic	C18:2c9,12 (n-6)	5.26 ^a	5.96 ^a	0.296	NS	
Arachidic	C20:0	0.08 ^a	0.12 ^b	0.005	***	
α -Linolenic	C18:3c9,12,15 (n-3)	3.09 ^a	3.49 ^a	0.153	NS	
Conjugated linoleic acid (CLA)	C18:2c9,t11 (n-6) (CLA)	0.43 ^a	0.48 ^b	0.014	*	
Conjugated linoleic acid (CLA)	C18:2c9,c11 (n-6) (CLA)	0.13 ^a	0.16 ^b	0.011	*	
Eicosatrienoic	C20:3c8,11,14 (n-6)	0.01 ^a	0.01 ^b	0.002	*	
Erucic	C22:1c13	0.20 ^a	0.24 ^a	0.015	NS	
Eicosatrienoic	C20:3c11,14,17 (n-3)	0.01 ^a	0.01 ^b	0.002	*	
Arachidonic	C20:4c5,8,11,14 (n-6)	2.31 ^a	3.05 ^b	0.178	*	
Tricosanoic	C23:0	0.01 ^a	0.01 ^a	0.004	NS	
Docosadienoic	C22:2c13,16 (n-6)	0.00 ^a	0.001 ^a	0.002	NS	
Eicosopentaenoic	C20:5c5,8,11,14,17 (n-3)	1.59 ^a	1.99 ^b	0.113	*	
Docosapentaenoic	C22:5c7,10,13,16,19 (n-3)	1.61 ^a	2.02 ^b	0.114	*	
Docosahexanoic	C22:6c4,7,10,13,16,19 (n-3)	0.21 ^a	0.28 ^b	0.020	*	
Fatty Acid Ratios:						
Total Saturated Fatty Acids	(SFA)	45.03 ^a	48.48 ^b	0.445	***	
T. Mono Unsaturated Fatty Acids	(MUFA)	40.18 ^b	33.97 ^a	0.851	***	
T. Poly Unsaturated Fatty Acids	(PUFA)	14.78 ^a	17.55 ^b	0.801	*	
Total Omega- 6 Fatty Acids	(n-6)	8.27 ^a	9.76 ^b	0.445	*	
Total Omega- 3 Fatty Acids	(n-3)	6.52 ^a	7.78 ^b	0.367	*	
PUFA:SFA		0.33 ^a	0.37 ^a	0.018	NS	
n-6/n-3		1.28 ^a	1.27 ^a	0.020	NS	
Fatty acid Indices						
Atherogenicity Index	AI	0.84 ^a	0.97 ^b	0.020	***	
Thrombogenicity Index	IT	0.98 ^a	1.03 ^a	0.028	NS	

Means with different superscript under management or muscle were significantly different ($P < 0.05$); SEM = standard error of the mean; H= herding; T= tethering. Significant difference: * ($P < 0.05$), *** ($P < 0.001$), NS = No significant difference

7.4 Discussion

The results obtained in the current study of high levels of palmitic (C16:0), oleic (C18:2), stearic (C18:0) and linoleic (C18:2) in chevon from goats that were tethered or herded were in accordance with observations in other red meats (Banskalieva *et al.*, 2000; Rao *et al.*, 2003). The lack of differences in C16:0 proportions between the treatment groups in the current study are consistent with observations by Rhee *et al.* (2000). Goats that have more access to dietary C16:0 tend to synthesize less of the fatty acid, *in vivo*, due to inhibitory feedback mechanisms (Rhee, 1992). However, ruminants with less dietary C16:0 tend to synthesize more of the fatty acid thereby bringing the available proportions of C16:0 to the same level as that of goats that have access to abundant dietary C16:0. The goats in the current study foraged in the same area and are thought to have consumed similar dietary source of C16:0. The myristic (C14:0) and palmitic (C16:0) levels obtained for Nguni goats in the current study were lower than those obtained for Nguni steers by Mapiye *et al.* (2011). High levels of C14:0 and C16:0 are otherwise linked to biosynthesis of, and laying down of cholesterol (Talpur *et al.*, 2008) which is associated with cardiovascular problems in humans and is, therefore, a health risk and a cause of concern (Garaffo *et al.*, 2011).

Oleic acid (C18:1c9) was the main fatty acid in the current study for both LTH and TB as well as for the T and H treatments. The finding was consistent with observation in other studies cited in a review by Banskalieva *et al.*, 2000. Oleic was significantly higher in herded goats and in the LTL muscle. Oleic acid (C18:1c9) is an important fatty acid that helps to reduce blood cholesterol content (Bonanome and Grandy, 1988). The C18:1c9, therefore, has opposing effects on cholesterol to those displayed by C16:0. Oleic thus reduces the risk of cardio vascular ailments (Garaffo *et al.*, 2011). Rhee *et al.* (2000) also observed high levels

of C18:1 and similar levels of C16:0 to those of the current study. However, despite the apparent high differences in total unsaturated fatty acid between diets fed to goats in the studies by Rhee *et al.* (2000), the authors found small differences in the intramuscular fat, which they attributed to hydrogenation of fatty acids in the feed by rumen microbes e.g. of C18:2 and 18:3 to 18:1 and 18:2 as well as the *in vivo* synthesis through elongation of e.g. C16:0 to 18:0 to bridge the gap in dietary fatty acid differences. Chevron from tethered goats had higher proportions of long chain fatty acids such as conjugated linoleic acid (CLA) [C18:2, C20:4c5,8,11,14 (n-6)], conjugated linoleic acid (CLA) [C18:2c9,c11 (n-6) (CLA)C20:5(n-3); C20:3c8,11,14 (n-6); C20:3c11,14,17 (n-3); C20:4c5,8,11,14 (n-6); C20:5c5,8,11,14,17 (n-3); C22:5c7,10,13,16,19 (n-3) and C22:6c4,7,10,13,16,19 (n-3), total SFA, total PUFAs, total Omega- 6; total Omega- 3 and Atherogenic Index (AI) compared to that from herded group. The improvement in the levels of eicosapentaenoic [C20:5c5,8,11,14,17 (n-3)], docosapentaenoic [C22:5c7,10,13,16,19 (n-3)], docosahexaenoic [C22:6c4,7,10,13,16,19 (n-3)], conjugated linoleic acid and AI just by simply tethering goats is an important innovation strategy to increase essential fatty acids. Decreasing cardiovascular ailments or anti- thrombogenic effects, promotion of foetal brain and visual development and the proper function of neural and sight tissues are among some of the beneficial effects of C20:5c5, 8,11,14,17 (n-3) and C22:6c4, 7, 10,13,16,19 (n-3) (Garaffo *et al.*, 2011; Nantapo *et al.*, 2015; Scollan *et al.*, 2006; Ulbricht and Southgate, 1991).

Linoleic acid and α -Linolenic acid are critical precursors in the production of prostaglandins and other long chain PUFAs (Gogus and Smith, 2010). The presence of higher levels of the essential fatty acid C20:4c5, 8, 11, 14 (n-6) in the tethered goats was probably due to the occurrence of higher levels of C18:2 and C18:3c9, 12, 15 (15-3) in that treatment group. α -

Linolenic is a precursor to C20:4c5, 8, 11, 14 (n-6) and its presence will promote synthesis of the later fatty acid. It appears that tethering of the goats restricted the animal to either browsing the leaves of the bush to which it was attached to or the grass within the radius permitted by the tether, whereas the herded goats had unlimited access to many browse bushes at any given time. Bakare and Chimonyo (2011) observed that Nguni goats that were unrestricted on foraging spent more time browsing than grazing. The observation in the current study, of higher PUFAs in tethered goats that were forced by the tether to either browse one bush or graze grass at any one point in time, is in accordance to the findings in studies where ruminants fed grass or grass silages showed higher levels of n-3 polyunsaturated fatty acids (Warren *et al.*, 2003). Noci *et al.*, 2005) noted that increased duration of feeding on grass forage diets was positively correlated to the levels of PUFAs. Scollan *et al.* (2006) explained that grasses contained 50- 75 % of fatty acids in the form of C18:3c9,12,15 (n-3) and the feeding of grass to ruminants increased n- 3 polyunsaturated fatty acid [C20:5c5,8,11,14,17 (n-3); C22:5c7,10,13,16,19 (n-3) and C22:6c4,7,10,13,16,19 (n-3)] in their intramuscular fat through elongation of the precursor fatty acid. The high total mono unsaturated fatty acids observed in chevon from herded goats were reported to be important in reducing the risk of coronary heart disease (Garaffo *et al.*, 2011). Both tethering and herding practices promoted optimum n- 6/n-3 ratio that is within the accepted range of below five. According to Garaffo *et al.*, 2011 and a review by Nantapo *et al.* (2015), the acceptable n- 6/n-3 ratio is ≤ 5 but can be as low as 1.

The conjugated linoleic acid (CLA) C18:2c9, t11 (n-6) was higher in the tethered goats compared to herded group, a situation which presents a lot of beneficial health and physiological effects to consumers (Pariza *et al.*, 2001). The c9, t11 CLA isomer stops

carcinogenesis, improves: immune response, growth and feeding efficiency by reducing fat deposition and has anti diabetic and has opposing atherogenic properties (Pariza *et al.*, 2001; Scollan *et al.*, 2006). The biohydrogenation of linoleic acid also yields C18:2c9, t11 (n-6) (CLA) as an intermediate product. Todaro *et al.* (2004) obtained lower CLA values (0.31 to 33 %) in Nedrodi goats compared to those that were found in the current study. It is probable that the tethering management systems modified the diet normally selected by goats in the current study. Banskalieva *et al.* (2000) highlighted that different nutritional conditions can alter the fatty acid composition of muscle as well as the omega 6: omega 3 PUFA ratios. Further, the proportions of the C20:5(n-3) and C22:6(n-3) obtained for tethered goats are even higher than those obtained for Nguni steers by Mapiye *et al.* (2011).

According to Mapiye *et al.* (2011), the long chain n-3 PUFA are important in averting the occurrence of, as well as critical for the treatment of: cardiovascular challenges, hypertension, rheumatoid arthritis, nervous disorders, asthma, and many forms of cancer. An increase in the long chain fatty acid and specifically eicosapentaenoic acid [C20:5c5,8,11,14,17 (n-3)] in chevon simply by tethering goats in the same veld as herded goats, as observed in the current study, may contribute to cost effective method of protecting goat meat consumers against colorectal cancer (Nkondjock *et al.*, 2003). Further, eicosapentaenoic acid that was promoted in chevon simply by tethering goats, is also important in that it is a precursor for the omega- 3 eicosanoids (Chen *et al.*, 1995). Additionally, the docosohexaenoic (DHA) that was promoted in higher amounts by tethering reduces the concentration of low density lipoprotein cholesterol in blood of consumers (Childs *et al.*, 1990). The observation of increased PUFAs by tethering may support recommendations by Molendi- Coste *et al.* (2011) who advocated for the consumption of the

C22:5(n-3), C22:6(n-3) PUFA at levels between 200- 600 mg per day, by humans in order to reduce deficiency challenges. A reduction in the incidence of such diseases, to a population, can bring down the health allocation portion of a national budget that would otherwise be set aside for such ailments.

The range of IM fat obtained in the current study (1.92- 2.21 %) were comparable to the (1.94 to 2.16 %) reported by Talpur *et al.* (2008) and that of 1.3 to 2.5 % by Bas *et al.* (2005). However, much higher levels (4.97%) of IM fat have been reported for Boer goats (Lee *et al.*, 2006). The higher intramuscular fat content in chevon from herded goats did not necessarily translate to higher 14:0 or 16:0 proportions as was obtained by Mapiye *et al.* (2011) for steers supplemented with sunflower cake. In the current study, there were no differences in 14:0 and 16:0 proportions despite the observation that herded goats had higher intra muscular fat. Chevon from herded goats had higher intra muscular fat but conversely contained lower total PUFA concentration than tethered goats. The higher intramuscular fat in herded goats was in agreement with higher body weights and body condition scores obtained in the same longitudinal study (unpublished data) for the goats under the herding management practice. It appears the herded goats were able to freely select forages that promoted live weight gains. It is possible that tethered goats that were attached to trees containing anti nutritional factors (condensed tannins) were forced to consume the foliage that was available to them.

The herded Nguni goats in the current study had higher (40.18%) levels of MUFA compared to tethered group (33.97 %) and also higher than the average of 31.10 % obtained by Talpur *et al.* (2008) and 33 % by Rao *et al.* (2003). The results obtained on MUFA concentration in the current study appear to support assertions by Talpur *et al.* (2008) that the management of

goats post weaning contributes to differences in MUFA levels. Further, the high intramuscular fat in herded goats promoted an increase in the total SFA and total MUFA at the expense of total PUFA level. Conversely, chevon from tethered goats had lesser marbling, showed reduced proportions of total MUFA, an increase in total PUFA and total SFA compared to their levels in chevon of herded goats. The relationship between total MUFA, PUFA, SFA and marbling observed in the current study are in agreement with the reports by De Smet *et al.* (2004) that fatness increases relative proportions of total MUFA and total SFA but reduces total PUFA.

In the current study, an average of 45.07 and 48.45 % concentration of SFA; 54.93 and 51.55 % unsaturated fatty acids were obtained from chevon of previously herded and tethered goats, respectively. This observation was in agreement with the proportions compiled in a review by Banskalieva *et al.* (2000) for goat muscles from various studies as well as the findings of Mahgoub *et al.* (2002). According to Grundy *et al.* (1990), high levels of SFA such as C12:0, C14:0 and C16:0 have a danger of increasing plasma cholesterol levels in contrast to high levels of PUFA and MUFA. The high level of C16:0 (range: 19.40 to 19.85 %) that was obtained in the current study is a cause of concern since the fatty acid is undesirable and is attributed to raising plasma cholesterol level. However, the notably high levels of oleic acid (C18:1c9) range (32.33 to 38.62) may act as a counter that reduces blood cholesterol level (Bonanome and Grundy, 1988).

Tethering promoted higher SFA, total PUFA, total omega- 6 and total omega- 3 and Atherogenicity index. However, the PUFA: SFA and n-6/n-3 ratios were not different between tethered and herded goat. SFA have been linked to increased risk of cardio vascular

disease (CVD) in people. However, the observed higher proportions of total PUFA, omega-6 and omega-3 in tethered goats tend to reduce the risk of CVD (Średnicka-Tober *et al.*, 2016). Średnicka-Tober *et al.* (2016), further stated that the very long chain fatty acids ($\geq C20$) such as the Docosapentaenoic and Docosahexanoic that were found in higher proportions in tethered goats are the main n-3 fatty acids that reduce CVD, high blood pressure, arrhythmias and inflammation in consumers. Further the VLC fatty acids enhance foetal brain development. The n-6/ n-3 ratios were similar and within the optimum levels of less than five as recommended by Garaffo *et al.* (2011) and Nantapo *et al.* (2015). Herded goats had a desirable lower Atherogenicity Index compared to tethered goats. According to Garaffo *et al.* (2011) and Nantapo *et al.* (2015) the AI gives the relationship between the main classes of saturated fatty acids (enumerator) to unsaturated fatty acids (denominator). The SFA are reported to be pro- atherogenic meaning that they promote the adhesion to circulatory system and immunological cells thus impairing the function of blood vessels and immune system (Garaffo *et al.* 2011). On the other hand the unsaturated fatty acids are anti-atherogenic. The occurrence of lower AI index in chevon from herded goats was possibly a result of a high proportion of MUFA that was higher than that of tethered goats by ~ 6.21 %. Thrombogenicity index (IT) was low and similar between tethered and herded goats. The low Thrombogenicity Index is desirable in that it is a reflection of reduced propensity to form clots within blood vessels (Garaffo *et al.*, 2011).

The PUFA/SFA ratios obtained in TB muscles in the current study were the only ones that met the desired level of above 0.4 required to prevent development of cardiovascular challenges and reduce risk of cancer (Higgs, 2002). Tethering or herding as management practices and chevon cuts from the LTL muscle promoted PUFA/SFA ratios below 0.4. However, in general the PUFA/SFA ratio of chevon obtained in this study (0.29 to 0.41 %) fall within the range (0.13- 0.49 %; median 0.320) for goats and higher than the (0.07- 0.26

%; median 0.19) for sheep and (0.11- 0.40 %; median 0.25) for beef but on the lower side of the 0.30- 0.65 for pork compiled in a review by Banskalieva *et al.* (2000). Muchenje *et al.* (2009) obtained higher (range: 0.45- 0.52) PUFA: SFA ratio in Nguni, Bonsmara and Angus steers raised on natural pasture. Generally, ruminants have lower PUFA: SFA ratio due to rumen microbial biohydrogenation of ingested unsaturated fatty acids (Jenkins *et al.*, 2008). Therefore, according to Higgs (2002) the range of PUFA:SFA in most available literature for beef, mutton, chevon as well as those obtained in the current study, with the exception of lean pork, are not sufficient to eliminate the risk of cancer and cardiovascular challenges in humans. Rhee *et al.* (2000) observed that raising goats on range with numerous species of grasses and forbs resulted in more saturated fatty acid than those raised on concentrates. The authors further observed that forage plants from the range had more saturated fatty acids than grain. It is, therefore, possible that the PUFA:SFA ratios obtained in the current study that were less than the minimum recommended threshold of 0.4 (Higgs, 2002) was a consequence of range being the sole source of goat diet in the current study, as multi species range forages promoted more SFA (Rhee *et al.*, 2000). Webb *et al.* (2005) explained that the inclusion of both meat and fat in the computation of the PUFA/ SFA ratio tended to lower the values.

The PUFA/MUFA ratios obtained in the current study (range: 0.331 to 0.559) for tethered and herded goats were higher than the range of 0.062 to 0.79 % and 0.047 to 0.080 % for goats and sheep, respectively (Tshabalala *et al.*, 2003). The n-6/n-3 values obtained in the current study (range 1.27 to 1.28) were much lower than the (3.34- 3.42 %) and (3.58- 4.15 %) by Talpur *et al.* (2008) and Todaro *et al.* (2004), respectively. A low ratio of the n- 6/ n-3 might be a result of low proportion of the n- 6 or high proportion of the n- 3. Nantapo *et al.*

(2015) recommend n-6/n-3 ratio of below 5 as necessary for the prevention of cardiovascular diseases. The authors further state that a ratio of n-6/n-3 as low as 1 was still acceptable. In the current study, tethered goats appeared to have both higher proportions of n- 6 and n- 3 compared to herded goats. According to Gogus and Smith (2010), raising n- 6 omega polyunsaturated fatty acids coupled with decreasing n- 3 PUFAs in the human diet increases the susceptibility of the populace to inflammation of the colon. The condition is treated by improving dietary n- 3 fatty acids floor to affected persons. Similarly, Nitenberg and Raynard (2000), suggest that n-3 omega poly unsaturated fatty acid reduce the chance of thrombogenesis and inflammation that is promoted by n-6 polyunsaturated fatty acids.

In the current study, the n-6/n-3 ratios for chevon from herded and tethered goats were similar and in accordance with the recommendations of Raes *et al.* (2004) who stated that the ratio should be below 4.0 to reduce the risk of development of cancer and cardiovascular ailments. It is postulated that the within acceptable range of n- 6/ n- 3 omega fatty acid ratio in chevon may be beneficial in the diet of patients when incorporated in the post and pre-surgical operation period. Gogus and Smith (2010) explain that administration of adequate n- 3 omega PUFAs improves the body immune system and work against inflammatory response. The higher n- 6/n- 3 ratios of TB cuts compared to the LTL cuts was probably a result of the higher level of total omega- 6 fatty acids observed in TB.

7.5 Conclusions

Floor type had no effect on fatty acid profiles. Tethering promoted higher levels of most PUFAs which are desirable for reducing risk of cardiovascular challenges and some forms of cancer as well as enhancing immune response. Higher levels of PUFA and desirable

Thrombogenic Index were obtained in TB than LTL muscle. Consumption of meat from TB muscle may, therefore, be recommended as supportive nutrition therapy for people with high susceptibility of clot formation in their blood. There is need to consider some dietary strategies aimed at increasing MUFAs in chevon from tethered goats so that the atherogenicity and thrombogenicity indices are improved. Such strategies may involve reducing biohydrogenation in the rumen. It was concluded that goat farmers that are constrained on labor can, therefore, safely tether their goats, a grazing management practice which yields desirable fatty acid composition in chevon that has good health effects to consumers.

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CHAPTER 8: General discussion, conclusion and Recommendations

8.1 Discussion

The main objective of the study was to evaluate the effects of grazing and housing management systems on greenhouse gas emissions, blood profiles, physico-chemical characteristics and fatty acid profiles of meat from Nguni goats. The main hypothesis tested was that there are no effects of grazing and housing management system on greenhouse gas emissions, blood metabolite profiles, physico- chemical characteristics and fatty acid profiles of meat from Nguni goats. Prior to implementing the study, a goat housing facility was designed and constructed. The housing facility had some compartments with slatted floors and others with earth floors. The Nguni goats were acclimatised for two weeks to their respective housing compartments and the grazing treatments.

The hypothesis tested in Chapter 3 was that there is no effect of grazing and housing management system on CH₄, CO₂ and N₂O emissions. However, the results obtained demonstrated that CH₄ flux was influenced by management system, floor type as well as the combined effects of grazing management system and floor type. Manure of herded goats on earth floors (HE) emitted the highest methane. Faeces of herded goats that were penned on earth floors (HE) became saturated with urine and this created anaerobic conditions that were conducive for methane production. The wetness of manure of HE was postulated to be a result of excretion of more volumes of urine due to unlimited access of herded goats to water during foraging. In addition, compaction by the force of weight of goats exerted on hooves

could also have prevented urine to percolate through the earth floor. The wet manure and compaction are presumed to have been favourable for methanogenesis. It is further possible that diet composition could also have contributed to more methane in herded goats than tethered. It is assumed that goats that were tethered to *acacia* bushes were limited mainly to browse whereas herded goats had access to both grass and browse. Benchaar *et al.* (2001) stated that grass diets resulted in more CH₄ emission than legumes based forages. Browse species contain CTs that hinder methanogenesis by decreasing the amount of H₂ produced by protozoa (Mhlambo and Mapiye, 2015) or reduce the population of cellulolytic bacteria (Animut *et al.*, 2008).

The manure of goats that were herded and were kept on slatted floors (HS) emitted the highest carbon dioxide followed by that of tethered goats in slatted floors (TS). The high emission of carbon dioxide in the slatted floors was ascribed to aerobic conditions that were thought to exist between the intact, distinct faecal pellets underneath the slats that permitted aerobic degradation of the manure. The slatted floors prevented compaction of the faeces since the goats and the manure were at separate levels. Compaction reduces aerobicity in manure heaps and lowers the rate of aerobic decomposition of the manure (Chadwick, 2005). The carbon dioxide levels obtained in the current study were lower but comparable to those in other ruminant studies by Adviento- Borbe *et al.* (2010) and Borhan *et al.* (2011). The observation was ascribed to possible effect of CTs postulated to have been present in browse species foraged on by the goats (See Section 3.2.1).

Nitrous oxide emitted from manure of herded goats on earth floors was very low and it was ascribed to damp conditions that were postulated to prevent ureolysis i.e. conversion of urea

to the ammonium ion (NH_4^+) which is a critical step preceding nitrification (Chadwick *et al.*, 1999). Nitrification and denitrification are aerobic and anaerobic processes, respectively, that emit nitrous oxide as an intermediate product. Tethered goats had less access to water during foraging time and their pen floors were comparatively less wet than those of herded goats. The initial high emission of N_2O in HS was thought to be a result of them accessing nutritious herbage whose protein was easily digested and converted to urea. Nitrogen in urea is easily converted to NH_4^+ ion which is then subjected to nitrification to release more N_2O . The TS later assumed high production of N_2O in the second half of the monitoring period and it is thought that there could have been some catabolism of muscle in tethered goats that lead to more serum urea as observed in Chapter 5,. The herded goats appeared to have continued to have access to nutritious forages as demonstrated by the better BCS and live weights obtained in Chapter 5, and more intra muscular fat obtained in Chapter 7. The results suggest that GHG gas emission from goat manure is influenced by type of grazing practice and type of housing floor. It may be beneficial for the farmers to consider harvesting methane for use as a fuel.

Chapter 4 was done to investigate the effect of disused and occupied goat pens on GHG emission. The study was motivated by the observation that some goat pens in the smallholder are abandoned, especially, when they become too saturated with moisture and fresh pens are constructed to accommodate the goats. The abandoned pens remain with manure and this study was conducted in order to investigate the contribution of manure in disused and occupied pens to GHG emission. The hypothesis to the chapter was that there is no effect of pen use (disused vs occupied), floor type (earth vs slatted) on the emission of CH_4 , CO_2 and N_2O emissions. Generally manure in occupied pens emitted the highest greenhouse gases.

Occupied pens with earth floors (OPEF) were found to emit the highest methane whereas occupied pens on slatted floors (OPSF) emitted the highest carbon dioxide and nitrous oxide. Continued occupation of the pens, by goats, allowed excretion of faeces, urine and the resultant compaction of manure created anaerobic conditions necessary for methane emission. Further, the deposition of urine and faeces provided the necessary substrate for decomposition (i.e. urea, undigested feed remains, and endogenous protein) and the microbes and enzymes required for the degradation processes that yield the GHG. Despite emitting comparatively lower GHG, the disused pen continued to release CO₂, CH₄ and N₂O and thus remain an important but neglected source of greenhouse gases. There is need to remove manure from the goat pens either for use in bio-digesters or for incorporation in the soil as organic fertiliser for sequestration of nitrogen and carbon by plants.

The study in Chapter 5 was done to determine the effect of grazing system (tethering vs herding), floor type (earth vs slatted) on blood profiles, growth performance and carcass characteristics of Nguni goats. The hypothesis that was tested was that there is no effect on grazing management and floor type on blood profiles, growth performance and carcass characteristics. It was postulated at the beginning of the study that tethered goats are limited in forage selection by length of the tether. On the other hand herded goats were thought to be free to select sites to forage and plant parts they desired. The type of housing floor was thought to influence the extent of rest and comfort experienced by the goat that would determine their capacity move around in search of forages. Generally goats that were herded had higher body weights and BCS than tethered goats. However, there was no relationship between grazing practice and carcass characteristics. Urea was higher in tethered goats indicating possible catabolism of protein which could have resulted in the observed

comparatively lower BCS and weights. Higher glucose concentration in herded goats indicates that they were able to select nutritious herbage which provided the energy yielding monosaccharide for metabolism. High globulin concentration in tethered goats indicated possible subclinical cases of infection. It appears the wide spatial foraging space for herded goats improved their immunity as demonstrated by lower globulin concentration and high A:G ratio.

The objective in Chapter 6 was to determine the effect of grazing system and floor type on cortisol concentration, activity of creatine kinase and physico-chemical characteristics of meat from Nguni goats. In addition, the physico-chemical characteristics of chevon from LTL and TB muscle were compared. High chevon pH was generally observed in the study but was consistent with studies cited in a review Webb *et al.* (2005). Higher pH was observed in goats that were on earth floors compared to those on slatted floors. The finding was ascribed to unnecessary expenditure of energy and possible utilisation of glycogen reserves due to long hours of standing by the goats on EF. The goats on EF avoided to rest on the wet manure but opted to stand which could have depleted glycogen reserves and caused low post-mortem lactic acid production and high meat pH (Veiseth- Kent *et al.*, 2010). The L* values obtained in this study were higher than the 33 threshold below which meat is referred to as dark cuts (Muchenje *et al.*, 2009). Tethered goats gave L* values that were higher than herded goats. *Triceps brachii* muscle was observed to have a desirable redder colour and more tender than the LTH muscle. It is possible that the LTL was strained on assuming the bipedal stance as goats browsed making it tougher and darker than TB. However, most of the meat quality parameters were similar for T vs H goats and EF vs SF. The study demonstrated that chevon pH can be lowered by providing pens with slatted floors. Improvements in meat

pH ordinarily results in a cascade of benefits including better visual appeal, tenderness and shelf life (Muchenje *et al.*, 2009a). Further, the *triceps brachii* muscle appears to yield better quality meat that could be sold at a premium and earn goat farmers more revenue.

In Chapter 7 the hypothesis that there is no effect of tethering, herding of goats as well as site of muscle cut [*m. longissimus thoracis et lumborum* (LTL) and *Triceps Brachii* (TB)] on fatty acid profiles, fatty acid ratios and fatty acid indices was tested. The major fatty acids in tethered and herded goats as well as between muscle cuts were oleic, stearic, palmitic and linoleic acid in decreasing order. Tethered goats had higher levels of PUFAs, stearic and linoleic acid. Tethering also promoted more cis- 9 and trans 11 CLA which are important for preventing cancer. The observation of increased proportions of eicosapentaenoic, docosapentaenoic, docosahexaenoic, conjugated linoleic acid and Atherogenicity index just by simply tethering goats is an important strategy to increase essential fatty acids. The n-6: n-3 ratio for both tethered and herded goats was within the accepted range of below 5 that promotes good health among meat consumers (Nantapo *et al.*, 2015).

8.2 Conclusions

It was concluded that goat manure is an important source of greenhouse gases (methane, carbon dioxide and nitrous oxide). High methane emission came from manure of herded goats on earth floors. More carbon dioxide and nitrous oxide were produced in herded goats on slatted floors. Manure in vacated pens emitted quantifiable levels of greenhouse gases and, therefore, remain an important but neglected source of greenhouse gases. Physico-chemical characteristics were similar between tethered or herd goats. Slatted floors promoted low chevon pH. Herding grazing management system resulted in better live weights and body

condition scores of goats. Tethering practice was seen to promote higher proportions of desirable fatty acids than herded flocks.

8.3 Recommendations

The following are recommendations that came out of the study:

Manure of indigenous tethered or herded Nguni goats that is excreted on earth and slatted floors is an important but neglected source of greenhouse gases. There is need to discourage the practice of abandoning goat pens and leaving them with manure. It is recommended to consider research aimed at using goat manure in bio-digesters to generate methane that can be used as a cooking or lighting gas. Herding of goats can yield desirable live weights and BCS, therefore, farmers who dispose their goats through market channels that pay based on weights are encouraged to herd their goats in order to realise bigger margins. Small holder farmers who live in communities where there is high susceptibility to cardiovascular challenges and colo-rectal cancer may tether their goats and sale the chevon to patients as nutritive supportive therapy. *Triceps brachii* from indigenous goats maybe considered to be sold as prime cuts due to their tenderness and redder colour which are desirable physico characteristics. Further studies may be carried out to determine ammonia and particulate matter from goat houses.

8.4 References

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Appendix 1: Goats in slatted floor compartments



Manure collects in bottom compartments and static chambers placed as in Appendix 3

Gates on bottom compartments prevent goat entry

Appendix 2: Goats in earth floor compartment

Goats accommodated in earth floor compartment are in direct contact with the their manure

Appendix 3: Computer carbinate fan for homogenising head space gas during chamber deployment



The red septum is the point of gas collection

Appendix 4: Static chambers being deployed under slates for gas measurements



White cables are connected to homogenising fans inside the static chambers and are powered by 18U PSU 12VOLT POWER SUPPLY 18 WAY.

The gates on manure section are closed when gas sampling session has been completed

Appendix 5: Gas sample collection with 20 ml plastic syringes connected to 20 gauge needles through the air tight septum

