Methane and nitrous oxide emissions from pen surfaces in a commercial beef feedlot in South Africa

by

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Abbreviations

ADF	Acid detergent fibre
CH_4	Methane
CO_2	Carbon dioxide
CP	Crude protein
CRDS	Cavity ring-down spectroscopy
CRLAS	Cavity ring-down laser absorption spectroscopy
CSFC	Closed static flux chamber
DM	Dry matter
ECD	Electron-capture detector
EF	Emission factor
FID	Flame ionization detector
GC	Gas chromatography
GHG	Greenhouse gas
GHGs	Greenhouse gasses
IPCC	International panel on climate change
K	Kelvin
LFC	Landfill gas
MCF	Methane conversion factor
MEF	Methane emission factor
N	Nitrogen
NH_3	Ammonia
NH_4	Ammonium
N_2O	Nitrous oxide
NO_2^-	Nitrite
NO_3^-	Nitrate
NDF	Neutral detergent fibre
O_2	Oxygen
OM	Organic matter
OP- TDLAS	Open-path tunable diode laser absorption spectroscopy
OP-FIR	Open-path fourier-transform infrared spectroscopy
PIMA	Photo-acoustic infrared multi-gas analyser
PPM	Parts per million
SE	Standard error
SFC	Static flux chamber
SOC	Soil organic carbon
UNFCC	United Nations framework convention on climate change

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Declaration

I, Kirsty Lynch, declare that the dissertation, which I hereby submit for the degree MSc (Agric) Animal Science: Animal Nutrition at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Signature: 

Miss. K. Lynch

Date: 05/10/2019

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Executive summary

Methane and nitrous oxide emissions from pen surfaces in a commercial beef feedlot in South Africa

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The aim of the study was to determine methane (CH_4) and nitrous oxide (N_2O) emissions from beef feedlot pen surfaces, as influenced by diet and seasons, and from back grounding operations as well as manure management systems across different seasons at a commercial beef feedlot in Mpumalanga, South Africa. The closed static chamber method was used for measuring CH_4 and N_2O emissions from the feedlot.

Feedlot surface parameters such as temperature, pH, moisture, ash, nitrogen (N), neutral detergent fibre (NDF) and acid detergent fibre (ADF) concentrations all observed differences ($P<0.05$) in set seasons between treatments.

Methane and N_2O emissions from feedlot pen surfaces were influenced by different feedlot diets fed. Within the feedlot, the grower diet observed the highest overall CH_4 and N_2O emissions over the measured seasons, whilst the starter treatments observed the lowest CH_4 and N_2O emissions over the measured seasons. The seasons that experienced, on average, higher CH_4 and N_2O emissions were the dry and hot season and the wet and hot season, which indicated that temperature and moisture had an effect on CH_4 and N_2O emissions from manure and feedlot surfaces.

Methane and N_2O emissions from the manure management practices were affected by season, with the wet and hot season having the highest CH_4 emission for both the effluent dam and manure piles, which indicated that available substrate, through rainfall wash off into the dam, and adequate moisture, though rainfall, in the piles allowed favourable conditions for CH_4 production to occur. The N_2O emissions from the effluent dam were lowest in the wet and hot season and highest in the dry and cold season, whilst for the manure piles it was lowest in the dry and cold season and highest in the wet and hot season.

Manure characteristics differed between seasons as a result of different feedlot diets, including rangeland grass and supplement fed. This could have affected the rate of CH_4 and N_2O emissions from the manure as a result. The gas emissions observed did show a trend between diets fed within the feedlot, with the manure management areas (pile and effluent dams) recording the highest CH_4 emissions over each of the measured seasons. The CH_4 emissions between seasons within the feedlot and manure management practices, observed significant differences for certain treatments and seasons, as well as certain manure characteristics which observed significant differences. The N_2O emissions observed showed no set trend

between areas measured on the feedlot. The varying values, and negative values obtained may indicate a general uptake of N by soil or microorganisms (Chantigny *et al*., 2007; Li *et al*., 2011).

Chadwick *et al.* (2011) described how farm management decisions interact with environmental controls, such as temperature and water availability to influence key microbial processes, which ultimately affects the magnitude of emissions from each stage of the manure management continuum. In this trial, environmental conditions could have influenced the manure composition at different sites within the feedlot across the different seasons. Although the CH_4 and N_2O emissions from a commercial beef cattle feedlot in the present trial did differ between seasons, only the grower treatment observed significant differences for CH_4 emissions from feedlot pens surfaces. Rangeland observed significant differences between the dry and cold season and dry and hot season as compared to the wet and hot season for both CH_4 and N_2O emissions. This was different for the manure piles, N_2O emissions, which observed no differences ($p>0.05$) between seasons, and the effluent dam, CH_4 emissions, which observed a significant difference between the wet and hot season as compared to the dry and hot season and dry and cold season. The piles CH_4 emissions observed a difference between the dry and hot season as compared to both the dry and cold season and wet and hot season.

Within the present trial the highest emissions within the feedlot pens were recorded during the dry and hot season for the grower treatment and the dry and cold season for CH_4 and N_2O respectively. The highest recorded emissions for CH_4 in the management systems were in the hot and wet season for both the effluent dam and manure pile system. The highest N_2O emissions were observed during the dry and cold and wet and hot seasons for effluent dams and manure piles respectively.

The results of the present trial suggests that the difference between the seasons, and manure composition, based on diet fed, impacted on the feedlot pen surface parameters, and ultimate CH_4 and N_2O production from beef cattle manure.

Chapter 1

Globally greenhouse gasses (GHGs) have become an increasing environmental concern. Greenhouse gases have the potential to absorb and emit infrared radiation that increases the earth's temperature. This increases the environmental temperature above the naturally occurring rate and is classified as global warming (IPCC, 2001). Two of the main GHGs associated with livestock production are methane (CH_4) and nitrous oxide (N_2O) (Du Toit *et al*., 2013). There are international protocols to calculate the concentration of CH_4 and N_2O produced by various activities, which allows for the comparison of emissions between different countries. This is set out by the International Panel on Climate Change (IPCC). There are 3 Tier's to the IPCC methodology to calculate GHG emissions. Tier 3 requires direct measurements of gas emissions and is the most accurate representation of emissions from an activity and area. Quantifying direct CH_4 and N_2O emission from commercial beef feedlot pen surfaces, will allow South Africa to move towards an IPCC Tier 3 approach in reporting national livestock emissions as required by the IPCC and United Nations Framework on Climate Change (UNFCC).

1.1 Aim

The aim of the study was to determine CH_4 and N_2O emissions from beef feedlot pen surfaces, between prominent seasons and diet fed, from rangeland manure between the prominent seasons experienced, and between manure management systems between the prominent seasons experienced, at a commercial beef feedlot in Mpumalanga, South Africa, as influenced by diet and season.

1.2 Objectives

The objectives of the study were to:

1. Quantify CH_4 emissions from manure located in rangeland from manure, on feedlot pen surfaces and from manure management practices at a commercial beef feedlot as influenced by different seasons and feedlot cattle diet composition.

2. Quantify N_2O emissions from manure located in rangeland from manure, on feedlot pen surfaces and from manure management practices at a commercial beef feedlot as influenced by different seasons and feedlot cattle diet composition.

1.3 Hypothesis

1: Manure and feedlot pen surface CH_4 emissions will differ according to diet composition.

2: Manure and feedlot pen surface CH_4 emissions will differ between seasons.

3: Manure and feedlot pen surface N_2O emissions will differ according to diet composition.

4: Manure and feedlot pen surface N_2O emissions will differ between seasons.

5: Manure management practices will influence CH_4 and N_2O production according to season.

6: Manure management practices will not influence CH_4 and N_2O production according to season.

Chapter 2

2. Literature review

2.1 Introduction

Methane (CH_4) and nitrous oxide (N_2O) gasses are important greenhouse gases (GHGs), along with carbon dioxide (CO_2) and fluorinated gases. Methane, N_2O and CO_2 are the GHGs most commonly referred to by Vac *et al.* (2013), and are the major GHGs (Owen & Silver, 2015; Philipp & Nicks, 2015; Gautem *et al*., 2016) emitted from livestock production systems (Gonzalez-Avalos & Ruiz-Suarez, 2007; Du Toit *et al*., 2013). The agricultural industry contributes a significant proportion to global CH_4 emissions. Jiang *et al.* (2011) stated that it was estimated that 80% of N_2O and 40% of CH_4 emitted globally are from agriculture activities. Scholtz *et al*. (2013) reported a recent global figure of 5% to 10% for GHG emissions from livestock, with South Africa having a similar value. Du Toit *et al*. (2013) reported that livestock contributed 4.9% to GHG, corrected for carbon sinks values, in South Africa, with approximately 27% of the national CH_4 emission being through enteric methane from ruminants. Methane is one of the most important GHGs with the ability to trap heat up to and greater than 25 times more effectively than CO_2 (Ramaswamy *et al*., 2001; Lassey, 2007). Nitrous oxide is a by-product of the formation of nitrogen (N) gas. The atmospheric lifetime of the above mentioned CH_4 and N_2O, is 10 years for CH_4 and 130 years for N_2O (Houghton *et al*., 1990). The atmospheric lifetime of CH_4 and N_2O has since been adjusted by the IPCC to 12.5 years (Blasing, 2016) for CH_4 and 113 years for N_2O (IPCC, 2017). Recently the EPA (Blasing, T. J., online accessed 2018) listed that the global warming potential (GWP) of CH_4 is 28-36 over 100 years and N_2O GWP is 265-298 times that of CO_2 for a 100-year timescale. Wang *et al*. (2018) reported the most recent CO_2 equivalent values of 28 for CH_4 and 265 for N_2O.

Animal manure is an important source of anthropogenic GHGs, such as CH_4, N_2O and CO_2, and livestock, as a whole, contributes 37% of global CH_4 emissions, according to Vac *et al.* (2013). USEPA (2006) and Montes *et al*. (2013), reported CH_4 emissions, from manure management, of 470 Mt CO_2/yr in 2010 with an expected increase of 11% by 2020. The same authors also suggested a N_2O value of 2,482 Mt CO_2/yr in 2010, with an increase of 18% by 2020 from manure management globally. Clemens *et al.* (2006) and Montes *et al.* (2013) observed that raw cattle manure can release between 160 to 3,600 g/m^3/year of CH_4 and 38 to 57 g/m^3/year of N_2O in summer and winter respectively.

Methane and N_2O emissions have not been measured from manure sources in South Africa (Du Toit *et al*., 2013), but manure management contributes an estimated 6.86% of total GHG emissions from agriculture according to Vac *et al.* (2013). As quoted directly from Chadwick *et al.* (2011a) farm management decisions interact with environmental controls such as temperature and water availability of key microbial processes (i.e. nitrification, denitrification, methanogenesis, and CH_4 oxidation), affecting the magnitude of emissions from each stage of the manure management continuum. Scholtz *et al*. (2013) also described how ruminants on extensive systems may have a lower carbon footprint compared to ruminants in grain-fed systems, such as feedlots. Extensively raised ruminants result in a higher carbon footprint in terms of emissions/final kg product produced (Rotz *et al*., 2019).

With climate change becoming a more prominent aspect in everyday life, accurately quantifying GHG emissions is becoming more important. According to Wuebbles & Hayhoe (2002) atmospheric CH_4 concentrations have more than doubled since the 1700's. It is important to establish how much of the increase is due to agricultural practices and livestock activities. Globally the livestock sector has increased in size, and production, with an increase in intensive animal farming practices (Muir, 2011; Costa Junior *et al*., 2012). The increase in intensive farming of beef cattle in feedlots is due to the increasing external protein demand (Millen *et al*., 2011; Costa Junior *et al*., 2012). In Brazil, Costa Junior *et al*. (2012) stated that beef cattle fed in feedlots had more than doubled since 2012. Verge *et al.* (2008) alluded to the fact that this increase was driven by both population increases and the increased demand for higher protein human diets. This increase in feedlot cattle production has also been observed by the IPCC where a 1.4-fold increase of cattle and buffalo, sheep and goats, and a 1.6 and 3.7 fold increases for pigs and poultry globally have taken place since the 1970's (Smith *et al*., 2014). The concern of the carbon footprint in agricultural practices, including livestock production, has resulted in more comprehensive research into accurately determining the

amount that livestock contribute towards GHG emissions. However, Monteny *et al.* (2001) stated that many authors described how GHG emission factors, from various sources, are greatly uncertain. Stevens *et al.* (2016) described a contribution of 40% by anthropogenic activities to the increase in CO_2 levels since the 1700's. The Kyoto protocol, which was the international treaty brought forward by the United Nations to commit state parties to reduce GHG emissions based on scientific research and global warming, was in response to the global carbon footprint concern. The Kyoto protocol came into effect in 2005 (Ellis *et al.*, 2007). In 2018 the Paris climate agreement replaced the Kyoto protocol.

Accurately quantifying GHG emissions is important to determine and monitor the contribution of livestock towards global GHGs concentrations. Similarly, it is important to evaluate possible mitigation measures to practically reduce the impact of livestock production on the environment.

Enteric CH_4 emissions is the most recorded source of GHG emission sources in animal agriculture and contributes 45% of total GHG emissions from agriculture globally, according to Vac *et al.* (2013). In South Africa, the enteric methane production in beef cattle was estimated to be 72.6% of the total South African livestock GHG emissions as described by Du Toit *et al.* (2013). Feeding practices to reduce enteric CH_4 production, such as modifying rumen microbial populations by vaccinations and bacteriocins, or addition of feed additives, such as tannins, fats, oils, and enzymes, have been explored as described by Kruezer & Hindrichsen (2006).

In the past studies and trials, emissions were calculated via the IPCC Tier 1 methodology based on the equation that Bingemer & Crutzen established in 1987 (Bingemer & Crutzen, 1987). This method allocates fixed values per animal specie in different regions of the world. Bingemer & Crutzen (1987) divided the world into 4 regions consisting of the Organisation for Economic Co-operation and Development (OECD), Union of Soviet Communist country (USSR) and Eastern Europe, which are known as industrialized countries. The fourth region is allocated to developing countries. South Africa falls under the developing country region. However, the IPCC Tier 1 methodology does not allow for animal specie variation, or variation between production systems. South Africa has a range of beef production systems such as communal beef systems (none intensive), extensive beef production (semi-intensive) systems and commercial beef production (intensive) systems (such as feedlots) (Du Toit *et al.*, 2013). The amount of gas produced per animal specie, consisting of enteric gas production and external gas production from manure, has been established in some countries, and thus a more accurate estimate of gas production in the country can be obtained. The IPCC Tier 2 methodology allows for cattle type and geographical region to be accounted for (Muir, 2011), and is based on statistical and mathematical models. The IPCC Tier 3 approach involves all the above-mentioned aspects for Tier 1 and Tier 2 approaches, as well as added data from direct measurements (IPCC, 2006). The Tier 3 methodology is more accurate and specific to certain areas in the 4 regions, and would require a direct measurement of the gas emissions from the different species of animals, as well as from the different animal production systems to be obtained. The IPCC encourage countries to adapt a Tier 3 methodology for international reporting. All equations and guidelines for the IPCC Tier 1, Tier 2 and Tier 3 methodologies can be seen in Volume 4 of the Agriculture, Forestry and Other Land Use (AFOLU) draft 2006 IPCC guidelines for national greenhouse gas inventories (IPCC, 2006).

Methane and N_2O emissions from beef cattle manure are dependent on a variety of factors. These factors include seasonal factors, such as temperature and rainfall, the type of feed used, cattle water intake, and most importantly, the method of manure waste management on the farm (Chadwick, 2004). Diet composition can affect rumen pH, carbon:nitrogen ratio, nutrient composition of manure, odour and gaseous emissions from the manure system according to Bouwman & Van Vuuren (1999); Mirabelli *et al.* (2006); and Gautam *et al.* (2016). In beef cattle feedlots, the most common manure practice is dry manure piling (where manure is collected from the pens frequently and piled together in a manure heap) to be later used as fertilizer. In rangeland manure management, the manure is usually left on the rangeland to decompose uninterrupted. Emissions from rangeland manure are dependent on soil microbial processes (Gallardo, 2013). These soil microbial processes, such as nitrification, denitrification, methanogenesis and respiration according to Hou *et al.* (2000); Li *et al.* (2012b); Gallardo (2013), are regulated by interactions of soil reduction-oxidation (redox) potential, pH, carbon (C) content, temperature, water content, oxidants, such as oxygen (O_2), nitrate (NO_3^-), manganese (Mn^{4+}), iron (Fe^{3+}), sulphate (SO_4^{2-}), carbon dioxide (CO_2) and hydrogen (H_2). Manure emissions from rangeland are currently not reported for livestock emissions but are allocated to soil emissions according to IPCC guidelines (IPCC, 2006).

Methane is produced under oxygen limiting/anaerobic conditions whereas N_2O is produced when sufficient oxygen/aerobic conditions are available as described by Montes *et al.* (2013). However, Mathot *et*

al. (2011) reported that through the weak diffusion of oxygen within the manure heap, which may be due to limited air space between manure particles, this would considerably reduce the nitrification and the N_2O emissions, thus also reducing the potential emissions of N_2O through denitrification.

Estimated CH_4 and N_2O emissions from manure have extensively been calculated through equations and models which are not representative of all production systems and parameters (Muir, 2011) to estimate emissions. Recent developments have allowed researchers to directly measure emissions from manure by techniques such as the closed chamber method (Rodhe *et al*., 2012).

2.2 Formation of greenhouse gases

The greenhouse gases effect is due to the absorption of solar infrared radiation by gases and the earth's surfaces, which are heated and then re-emit infrared (IR) radiation at low frequency with high absorption power, as explained by Moss *et al.* (2000).

The burning of fossil fuels and solid waste produces CO_2 as described by Marland & Rotty (1984). Methane is emitted as a natural gas through the production of coal and oil. Emissions also occur from livestock and agricultural practices, and by the fermentation and decay of organic waste in municipal solid waste landfills. Below, Equation 1 depicts the formation of CH_4 by Kovács (2001). Agricultural and industrial activities also emit N_2O during the combustion of fossil fuels and solid waste. Fluorinated gases are produced mainly from industrial processes. Hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride are examples of fluorinated gases (Vac *et al*., 2013).

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$$

Equation 1 The formation of methane adapted from Chemical equations online, 2015, http://chemequations.com/en/?s=CO2+%2B+H2+%3D+CH4+%2B+H2O&red=vr&k=1. Accessed 3 April 2015)

Nitrous oxide forms mainly from the microbial process in the soil through nitrification, denitrification and respiration as shown in Figure 1 by Lawrence (1989). Lawrence (1989) showed how nitrification and denitrification occur within the nitrogen cycle. This process occurs in manure by free nitrogen from protein (exogenous or endogenous) or from ammonia present in the manure, being oxidized to nitrite (NO_2) and then to nitrate (NO_3) by nitrifying bacteria. This is the process of nitrification. The nitrates produced by microbes are either assimilated and incorporated into plants or undergo the denitrification process by denitrifying bacteria and get converted into nitrogen (N) that is released and incorporated into atmospheric nitrogen, as depicted in Figure 1 (Lawrence, 1989).

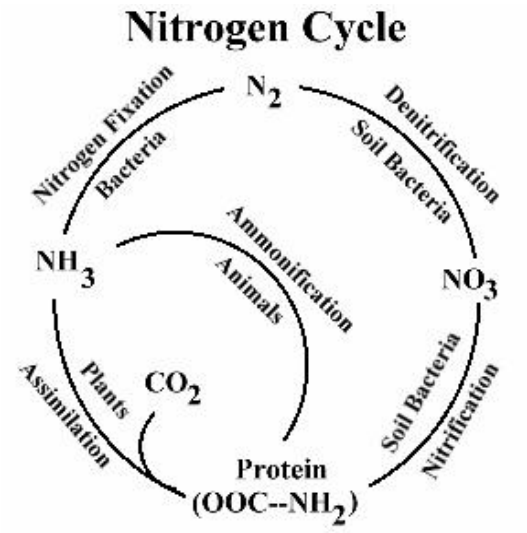


Figure 1 The nitrogen cycle adapted from Lawrence, E., 1989. Henderson's Dictionary of Biological Terms (10th Edition). Longman Scientific and Technical, Harlow, UK. 637

2.2.1 Livestock methane

Methane production occurs in many industries, such as the transport industry, the mining industry and the livestock industry (Monteny *et al*., 2001). In the livestock industry, and more specifically, the cattle industry CH_4 production can occur from two sources, directly from the cattle as a result of enteric CH_4 production, or as a by-product in the degradation of cattle manure as exogenous CH_4 production.

2.2.1.1 Enteric methane

Methane that is produced inside the ruminant is known as enteric CH_4 and it is produced mainly in the reticulo-rumen and to a lesser extent in the large intestine (Hegarty, 1999). Enteric CH_4 is mainly released through eructation as described by Murray *et al.* (1976) and Lassey *et al.* (2007). Methane production within the rumen represents an energy loss to the ruminant, and it is the most prominent hydrogen sink available in the ruminant which is important for microbial feed degradation and utilization. Hydrogen (H_2) is produced as a by-product of fermentation by cellulolytic bacteria (Muir, 2011). Free hydrogen is readily used by methanogens, which are methane-producing bacteria, in the production of CH_4. A few CH_4 producing bacteria that occur within the rumen of grazing cattle are *Methanobacterium fomicium*, *Methanobacterium mobile*, and *Methanosarcina barkeri* (Jarvis *et al*., 2000). The process of CH_4 production within the rumen occurs to avoid excess free hydrogen accumulating in the rumen and decreasing rumen pH (Muir, 2011). Thus, rumen pH and environment has to be maintained for optimal feed degradation by rumen microorganisms (Muir, 2011).

Enteric CH_4 emission can be reduced by decreasing the production of hydrogen as a by-product. This can be done by feeding practices that decrease acetic acid production and increase propionic acid production. Acetic acid is one of the main sources of hydrogen in the rumen (Van Soest, 1982; Boadi, 2003), whilst propionic acid production is a 'net proton-using reaction'. Hegarty (1999) and Moss *et al.* (2000), report that propionate production favours competitive pathways for H_2 use in the rumen and would therefore decrease overall CH_4 production. The role of acetic acid in the production of CH_4 is depicted in Figure 2, adapted from the FAO (1997). The fermentation ability to produce CH_4 is dependent on the rumen ecology, and rumen ecology in turn is dependent on the ruminal species of microorganisms and their ultimate concentration. Krehbiel *et al*. (2003) stated that rumen microflora, such as microbial species and their concentration, affects volatile fatty acid proportions that occurs within the rumen. Enteric CH_4 production is thus related to the microbial fermentation of hydrolysed carbohydrates, and CH_4 emissions increased as

digestibility of feed decreased (Johnson & Johnsons, 1995; Kriehbel *et al*., 2003; Todd *et al*., 2014). Van Soest (1994) described decreased acetate: propionate ratio which is accompanied with a decrease in CH_4 production according to the stoichiometric laws of chemical balance due to the availability of substrate (acetic acid) for CH_4 production decreasing.

Short-term practices to decrease enteric CH_4 production include feeding strategies that alter rumen microorganism populations, to cause the methanogenic bacteria and protozoal populations to decline. This can be accomplished by increasing the concentrate proportion of the ruminant diet and decreasing the roughage portion of the diet to favour propionic acid production over acetic acid production. Altering the rumen microflora is also achieved by using feed additives such as ionophores, organic acids, yeasts, enzymes, bacteria and probiotics, as described by Moss *et al.* (2000). Todd *et al.* (2014) observed that cattle that graze or consume forage produced more CH_4 than cattle on a more concentrated, grain-based diet. According to the IPCC (2006) and Verge *et al.* (2008) feedlot cattle have a lower CH_4 emission intensity (MEI= unit CH_4 /kg product) compared to cattle on pasture. Ionophores such as monensin can reduce ruminal CH_4 production by decreasing the acetate to propionate ratio. This can decrease the output of CH_4 by approximately 21% (Van Vugt *et al*., 2002). Propionate was increased by 17% in dairy cattle according to Ipharraguerre & Clark (2003) when monensin was fed, whilst Russel (2002) observed that cattle that were fed monensin consumed less feed and had a 6% greater feed efficiency compared to grazing cattle. According to Russel (2002) who reported a decline of 30 to 50% in CH_4 production, monensin's action on bacteria increases propionate production and concentration, which increases the H_2 sink in the rumen thereby reducing CH_4 fermentation.

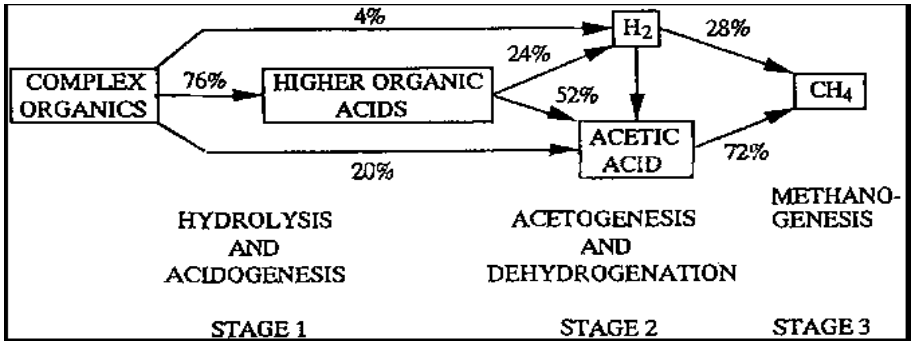


Figure 2 The formation of methane in the ruminant adapted from FAO,1997. Renewable Biological Systems for Alterative Sustainable Energy Production (FAO Agricultural Services Bulletin-128). Agriculture and Consumer Protection. Osaka Uni.

2.2.1.2 Exogenous methane

Methane is produced from cattle manure when the components within the manure (water and the volatile solids portion), which are dependent on livestock type and diet, undergo anaerobic fermentation (Costa Junior *et al*., 2012). Manure consists of organic matter (OM) containing minor minerals that once excreted undergoes a series of reactions in which the three GHGs, CH_4, N_2O and CO_2, can be produced (Li *et al*., 2012a). Methane is formed by the anaerobic bacterial decomposition of organic matter (Steed & Hashimoto, 1994). During anaerobic fermentation volatile acids are produced by acid producing bacteria. Methane producing bacteria utilize the volatile acids under anaerobic conditions to produce CH_4, as described by Chadwick *et al.* (2011). The main components of volatile solids (VS) are fats, proteins and carbohydrates, with most of the carbohydrate fraction being very resistant to degradation. Kreuzer & Hinderichsen (2006) refer to organic carbon sources in excreta as the volatile soilds. The degradable carbohydrate fraction consists of the non-lignin OM. Lodman *et al*. (1993) reported that anaerobic lagoons may ferment almost all of the non-lignin OM into potential CH_4, whilst manure produced by grazing cattle on a pasture may produce virtually no CH_4. This is described by Kreuzer & Hinderichsen (2006) and Muir (2011)

where CH_4 emissions from a dung patch on pasture are often considered negligible, but emissions from manure stored under anaerobic conditions can produce 7 to 20% of total CH_4 emissions from ruminants. Methane production from a fresh manure pile will not occur instantly, but it will increase until it slows as aerobic decomposition commences (Saggar *et al*., 2004; Lassey, 2007; Muir, 2011).

2.2.2 Nitrous oxide

Nitrous oxide (N_2O), as well as nitric oxide (NO) are both produced through the processes of denitrification and nitrification (Chadwick *et al*., 2011). Nitrous oxide emissions associated with manure composting have been reported from the two processes mentioned above (Dytzcak *et al*., 2008; Maeda *et al*., 2010; and Gallardo, 2013). Nitrous and nitric oxide are both potent GHGs, with nitric oxide being involved in the production and destruction of the tropospheric ozone, and its contribution to the formation of acid rain as described by Paul *et al.* (1993). Nitrous oxide was recorded to have the ability to trap heat 298 to 310 times more effectively than CO_2 (FAO, 2006; IPCC, 2006), with the most recent GWP value from the EPA being adjusted to 265 to 298 times that of CO_2 in its atmospheric life time as research into N_2O continues. The presence of nitrifying and denitrifying bacteria in manure, or in soil the manure is present on, is important for the production of N_2O. The presence of organic matter (ammonia, or nitrogen for ammonia to be produced) is required as a source of nitrogen for N_2O production. The schematic representation of N_2O production by Chadwick *et al*. (2011) is shown in Figure 3 and illustrates the relationship between nitrification and denitrification, in the production of N_2O. Chadwick *et al.* (2011) stated that the transformation from ammonium to nitrate (NO_3^-) via nitrification is a source of N_2O and produces NO_3^- which is a source of N for denitrification. As the biological reduction of NO_3^- to N_2 gas occurs, N_2O is produced as a result of incomplete denitrification (Chadwick *et al*., 2011). Most of the N present in cattle manure is due to unabsorbed N from feed, present as N itself or as a protein, as well as endogenous protein from the animal (Chadwick *et al*., 2011).

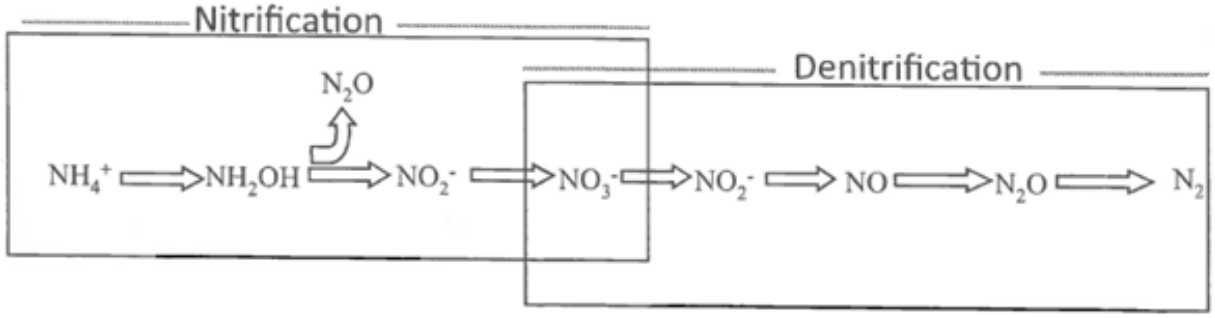


Figure 3 Schematic chemical representation of two processes responsible for nitrous oxide production adapted from Chadwick, D., Sommer, S., Thorman, R., Fangueiro, D., Cardenas, L., Amon, B. & Misselbrook, T., 2011. Manure management: Implications for greenhouse gas emissions. Anim. Feed. Sci. & Tech. 166-167, 514-531.

2.3 Factors affecting greenhouse gas emissions from manure

The drier the manure, either from feeding practices, temperature, or low rainfall, the less it is able to be fermented which results in less CH_4 being produced from the manure. However, an increase in CH_4 and N_2O can be observed when the manure has been decomposed and degraded, provided sufficient moisture is available for microbial activity (Murwira *et al*., 1990). Moisture content of the manure will also affect the amount of oxygen that is available to microbes in the manure by preventing oxygen penetration of the heap as described by Huston (1994) and Mathot *et al.* (2011). If the manure is saturated and less oxygen is available to microbes, the resultant anaerobic process of CH_4 production will dominate in the manure. However, if the manure is more porous due to lower water content, more oxygen is able to enter the manure which increases the aerobic process, and results in N_2O production, provided there is enough water in the manure to prevent complete drying out and for microbial activity to occur.

2.3.1 Methane

2.3.1.1 Temperature

Methane production in manure is dependent on the activity of methanogens which are affected by temperature. Stevens & Schulte (1979) stated that CH_4 production decreased significantly at low ambient temperatures. However, methanogenesis has been reported at temperatures as low as 4°C ambient (Stevens & Schulte, 1979). Based on temperature alone, Hillorst *et al.* (2001) predicted a 66% reduction in CH_4 emission whenever the temperature decreased from 20°C to 10°C. The manure CH_4 production rate from a 45°C fermenter was faster than a 35°C fermenter, but the total production of CH_4 at long fermentation times was ultimately similar, according to Hashimoto *et al.* (1981). Methane production was therefore accelerated at higher temperature, but the total yield was the same over total time intervals at different temperatures. This shows how susceptible CH_4 production in liquid manure is to temperature.

Temperature effects on solid manure are more complex. The process of fermentation occurs within the manure pile and produces heat as a by-product. Dustan (2002) described how the different methane-producing microorganisms operate at different temperature levels within, and on, the manure. The process of fermentation, within manure, can raise the core temperature of manure to above that of the external temperature (Dustan, 2002) which would make external temperature have less of an effect on manure piles and resulting gaseous emissions (Dustan, 2002). In the areas of the solid manure that was supplied with oxygen, not much CH_4 production occurred (Dustan, 2002) as methanogenesis is an anaerobic process. Climate does tend to influence CH_4 production, as explained by Parker *et al.* (2002b) who observed that between the temperature range of 8 to 30°C, a 1°C rise in temperature increased the CH_4 yield by 0.009 m^3 per kg of volatile solids. The following CH_4 producing bacteria operate at the following temperatures.Thermophilic bacteria operate in the range 45-60°C, mesophilic bacteria in the range 20-45°C and psychrophilic bacteria below 20°C (Dustan, 2002). This shows the wide range of manure temperatures at which CH_4 can be produced by the relative methanogenic bacteria.

The humidity (moisture content) and temperature would therefore affect how quickly the manure pile dries out, which affects the CH_4 emission from the manure pile. A more humid/higher moisture content environment would result in the manure pile taking longer to dry out. A higher atmospheric temperature would result in a quicker drying rate of the manure pile. However, it appears that temperature affects the rate at which CH_4 is produced (possibly due to an effect on microbial activity) but does not increase the amount of CH_4 that can be produced from a unit of substrate (Hashimoto *et al.*, 1981; Muir, 2011).

2.3.1.2 Water

When cattle manure is wet and compacted, as in feedlot pen conditions, anaerobic methanogenesis occurs, and once the manure dries, it becomes more porous and the temperature increases, which is indicative of composting (Dustan, 2002). Methane flux is the net rate of CH_4 exchange between an ecosystem and the atmosphere (Zhu *et al.*, 2010). Gallardo (2013) observed no CH_4 flux on dry and loose manure, but a mean CH_4 flux of 7.4 $mg/m^2/h$ and a peak of 28.5 $mg/m^2/h$ during a time period of 13.51 minutes was observed for manure that was moist and loose after water application, whilst for the same time period a mean of 5.1 $mg/m^2/h$ and a peak of 21.7 $mg/m^2/h$ for moist and compacted manure was observed after water application. Gallardo (2013) also observed CH_4 fluxes over a longer period of time after water application. No CH_4 flux was reported for dry loose manure used as a control with no water application. For the moist and loose manure Gallardo (2013) observed a mean of 0.29 $mg/m^2/h$ and a peak of 1.33 $mg/m^2/h$ over 146 hours following water application, and for moist and compacted manure a mean of 0.89 $mg/m^2/h$ and a peak of 4.51 $mg/m^2/h$ was observed over a similar time period (7 days) following water application.

Manure water concentration can be dependent on elements such as animal diet (Sakirkin *et al.*, 2011), water intake and rainfall. A more fibrous diet would lower the moisture concentration of the manure and the more concentrated the diet, the higher the water concentration of the manure is, as described by Sakirkin *et al.* (2011). Mean environmental temperature would also affect water intake by the animal and ultimately manure water concentration, with water intake being higher in hot temperatures, and lower in cold temperatures, as described by Arias & Mader (2010).

Weather related water effects include rain. Rainfall would increase the water saturation level of manure on the ground, thus increasing CH_4 production by the formation of an anaerobic environment. This is described by Todd *et al*. (2014) who reported an interaction between CH_4 emissions and water availability following two large rainfall events that created an anaerobic condition, due to air being displaced by water between soil particles, which enhanced microbial fermentation of manure organic matter. Miller & Berry (2005) reported variation with soil manure and moisture concentration on GHGs fluxes, with the largest fluxes occurring at moderate to high moisture concentrations, depending on the manure concentration present on the soil.

2.3.1.3 Feed intake and feed digestibility

Manure composition and N availability are dependent on the diet composition and digestibility (Sørensen *et al*., 2003). Manure contains substantial quantities of nitrogen with the majority of the nitrogen being inorganic (Amon *et al.* 2001; Chadwick *et al*., 2011).

When ruminants were given *ad lib* diets rich in starch or infused with a single dose of soluble carbohydrate (glucose), propionate production increased (McAllister *et al*., 1996). Increased fermentation rates favour propionate production over acetate production which would decrease the acetate: propionate ratio (McAllister *et al*., 1996). Propionate production resulted in less CH_4 being produced as it serves as a H sink as described by Muir (2011). Diets high in starch or soluble carbohydrates resulted in a decreased rumen pH compared to the rumen pH when feeding roughage diets (Todd *et al*., 2013). A decrease in pH and increased fermentation rates may inhibit methanogenic bacteria and rumen ciliates, and increase propionate production (McAllister *et al*., 1996).

Readily fermentable carbohydrate feeds are mainly cereal grains for ruminants, which increase propionate production in the rumen as explained. Most of the roughage component in feeds consists of forages such as grasses (DeRasmus *et al*., 2003). Forages fed to cattle result in an increase in acetate production in the rumen as described above by Todd *et al*., (2014). Based on the ration consumed by the cattle it will favour either propionate or acetate production and this will have an impact on gas production within the rumen and feed particles within the excreted manure which in turn would affect the substrate available to microbes for gas production (Chadwick *et al*., 2011) in manure.

The quantity and quality of a ration consumed is an important determinant of the daily CH_4 emission of livestock, with increased intake supplying increased substrate for ruminal fermentation according to Hegarty *et al.* (2007). Thus, more hydrogen (H_2) is produced and results in increased methanogenesis and more CH_4 being produced. This affects enteric CH_4 production. Whilst the amount of fermentable organic matter present in manure, as well as the physical form of the manure deposit, climatic and soil conditions as well as time the manure pile is intact, before decomposing, will affect the amount of CH_4 produced from the manure pile (Lassey. 2007), exogenous CH_4 production.

Seasonal effects such as temperature, rainfall and humidity will affect manure gas emissions by affecting the rate the manure is fermented and decomposed once excreted. Seasonal effects will also affect the consistency of manure excreted from the animal by affecting the animal's overall feed intake and water consumption (Olkowski, 2009). This in turn would then determine the animal's rumination and fermentation processes. During high temperatures, cattle tend to decrease feed intake to maintain a thermo-neutral internal environment to avoid heat stress, since heat is produced from the rumination fermentation process (Blackshaw & Blackshaw, 1994). A decrease in forage intake is most drastic during hot weather and concentrate feed intake is decreased to a lesser extent (Beede & Collier, 1985). Rumination frequency declines due to lower roughage intake; therefore less saliva is incorporated into the rumen as a buffer and the rumen pH declines slightly during rumination, as described by Bailey & Balch (1961). Baily & Balch (1961) observed that the lowest secretion rates of saliva were found in silage whilst a grass (hay) diet evoked the highest rate of secretion of saliva, with intermediate levels of saliva secretion for the diets that contained some concentrates. A lowered rumen pH, due to high concentrate diets, according to Nagaraja & Titgemeyer (2007), resulted in an increase in lactic acid producing bacteria, which is capable and adapts quickly to the shift in rumen pH and is associated with an increased feed flow through the digestive tract. This results in more feed particles and water being present in the manure, which would directly affect microbial nutrient supply for gaseous production of the manure (Chadwick *et al*., 2011). During cold weather feed intake can increase or stay constant, thus rumination frequency is maintained, and feed is digested

more efficiently and less feed particles are found in the manure. The manure water content is also reduced due to the more effective fermentation occurring within the rumen (Blackshaw & Blackshaw, 1994). Jarvis *et al.* (1995) stated that cattle consuming high forage diets produce manure with a higher content of partially digested cell wall material, which is more resistant to microbial degradation and subsequent release of manure carbon, as compared to cattle consuming high grain diets. In general, CH_4 production increases with the organic matter (volatile solids) content of the excreta (Monteny *et al*., 2001). The change in feed components, specifically the amount of nitrogen and carbon that passes the digestive tract and ends up in the manure will influence the CH_4 gas production of the manure (Boadi *et al*., 2004). Diets high in concentrates are though to decrease CH_4 production through increasing propionate production (endogenous) (DeRasmus *et al*., 2003) however, an increase in CH_4 production from manure was observed in diets mainly composed of concentrates as compared to only roughage by Kreuzer & Hinderichsen (2006) and Lodman *et al*., (1993). According to Lodman *et al*., (1993) this is due to more readily fermentable carbohydrates present in the manure of cattle fed a concentrated diet. Jarvis *et al*., (1995) observed the opposite effect with the manure from cattle on a roughage diet emitting more CH_4 as compared to manure from cattle on a concentrate diet.

In total, the altered feed intake and water intake, due to environmental conditions such as temperature, will alter the animal's final manure composition and available substrate for microbial processes to occur within the manure. Methane production, enteric and exogenous, is affected by diet (Gonzalez-Avalos & Ruiz-Suarez, 2007).

2.3.1.4 Manure concentration and soil type characteristics

The amount of manure present within and on a piece of soil would affect external CH_4 production by influencing the amount of substrate that is available from the manure to the CH_4 producing microbes (Chadwick, *et al.,* 2011). The higher the concentration of manure, and ultimate substrate, within and on soil, the larger the production of CH_4 from microbes, provided that there is adequate moisture, temperature and limited oxygen supply for optimal methanogenic activity to occur (Chadwick *et al*., 2011). Li (2007) described how when anaerobic conditions were sustained for a few days, all oxidants were depleted and H_2 became an electron acceptor which resulted in CH_4 production. However, according to Ellert & Janzen (2008), GHG emissions from irrigated cropping soils, as influenced by manure and synthetic fertilizer applications, resulted in increased emissions of CO_2 after manure application, whilst CH_4 emissions were negligible. Muir (2011) explained that on a feedlot surface there is considerable spatial variation in manure composition (moisture, manure thickness, fresh/older deposits), and the variation in composition resulted in considerable differences in manure CH_4 emission potential of feedlot pen surfaces.

Soils act as a source and sink for GHGs for CH_4 and N_2O (Oertel *et al*., 2016). The type of soil will affect CH_4 production from manure by affecting the quantity of microbes present for methanogenesis to occur once manure is applied to the soil (Muir 2011). The soil pores will affect the amount of available oxygen to the feedlot surface of the manure patty and will affect how quickly the manure is able to dry out (O'Geen, 2013). Soil GHG emissions are dependent on microbial activity in the soil and the substrate availability (Gautam *et al*., 2016), such as carbon and a protein substrate, from the soil or manure particles that mix within the soil (Amon *et al*., 2006). The compaction of the soils, as influenced by soil particle size, would affect the amount of air and water that is able to penetrate the soil feedlot surface (Chadwick, 2004) and would affect overall gaseous emissions.

2.3.1.5 Manure management

Manure management consists of manure accumulation and collection in buildings, storage, processing, and application to cropland as well as being deposited on pastures and rangelands in grazing systems (Montes *et al*., 2013). For grazing cattle in South Africa there is no manure management in extensive systems where the manure is left on the rangeland. In intensive production systems, such as feedlots, the common manure management practice is dry stock-piling (Scholtz *et al*., 2013). The manure is collected (via scraping the feedlot surface) from the pens, generally once the cattle have been removed from the pen (occurring after each cycle and feeding change which can vary from a 3 to 4-week period). The manure is piled on the area of the farm designated for the manure waste. At the site manure is composted

and used as fertilizer on the farms. Most of the CH_4 emissions from manure are produced under anaerobic conditions during storage with very little CH_4 emissions following land application of manure (Montes *et al*., 2013).

The piling of manure allows for conditions to develop that favour internal fermentation and heat production. Piling will also create anaerobic conditions in which methanogenesis can occur, and for ultimate composting to result within the manure (Kebreab *et al*., 2006). However, factors such as the age of manure before pen collection, the water content of manure, and seasonal factors such as rainfall and temperature, would also affect the ability of manure to ferment during storage (Chadwick *et al*., 2011). Solid storage tends to retain moisture better and allows better anaerobic conditions to develop as stated by Steed & Hashimoto (1994). The degree of contamination with inorganic materials (such as dirt and stones) affects ultimate CH_4 yield from the stored manure by diluting the manure concentration (Steed & Hashimoto, 1994) and the substrate for fermentation.

Most beef cattle feedlots have dams that collect water runoff during rainfalls. These dams are similar to a slurry system, except that the manure concentration included into the system is relatively small, usually rain water runoff, contaminated with manure particles, and the dams are not covered. Methane conversion factors for various manure management systems at similar temperature regions are depicted in Figure 4 (Steed & Hashimoto, 1994). It is important to point out that the dam collection of manure would not have such a high CH_4 production as compared to a liquid slurry treatment due to the concentration of manure being lower from the feedlot as water incorporated into the dam consisted of water run off contaminated with manure from the feedlots after rainfall.

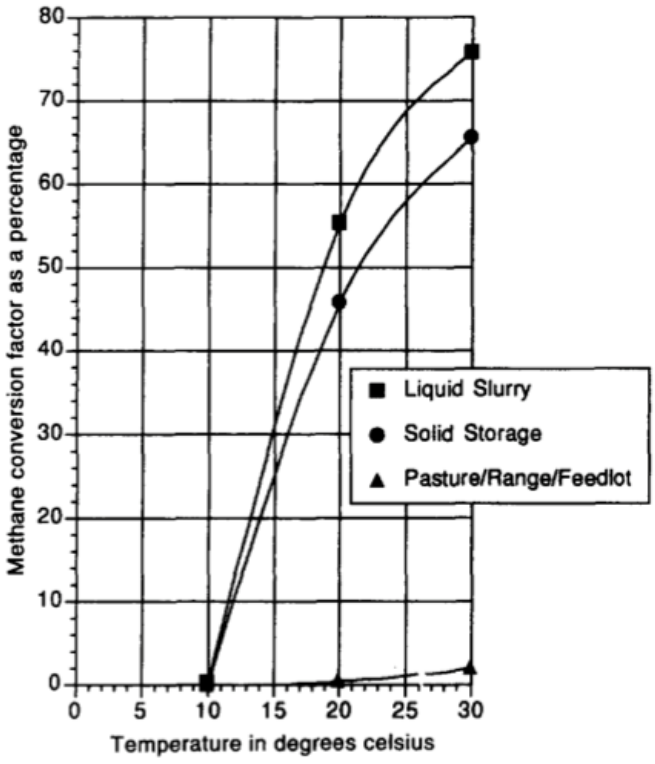


Figure 4 Methane conversion factor (MCF) for various treatments adapted from Steed, J.Jr. & Hashimoto, A. G., 1994. Methane emissions from typical manure management systems. Dept. of Bio-resource engineering, Oregon State Univ. Corvallis, USA.

2.3.2 Nitrous Oxide

2.3.2.1 Temperature and water content

Atmospheric temperature affects soil water content by affecting the rate at which water is evaporated from the soil and the manure (Ahmad & Rasul, 2008). During the rainfall season, the soil and aged manure is saturated sufficiently to avoid drying for a period following a rainstorm, and fresh manure is kept saturated for an extended period of time (Jarvis *et al*., 1995; Muir, 2011). The higher the soil and manure moisture content, the higher the N_2O emission rate according to Paul *et al*. (1993), provided adequate oxygen is available to microbes in the saturated soil. According to Granli & Bøckhman (1994) and Dustan (2002), the denitrification process continues at temperatures as low as -4 °C, but temperatures above 5 °C are required for rates of nitrification to be significant, and therefore during the warm and wet seasons, an increase in N_2O emission from manure on soil can be expected. However, Gallardo (2013) observed that under very high atmospheric temperature conditions a decrease in N_2O emission flux from feedlot surfaces with temperatures greater than 30°C can occur. Gallardo (2013) reported that this was due to the high feedlot surface temperatures resulting in the loss of NH_4^+ to the air in the form of NH_3 as observed by the inverse relationship between the soil temperature and NH_4^+.

Due to soil water content and temperature affecting the rate of decomposition of soil organic matter, these factors also affect the N_2O emission flux (Lee *et al*., 2009; Gallardo, 2013). Nitrous oxide may only be produced under conditions of adequate oxygen availability, as a consequence of reduction of oxidized nitrogen compounds in the nitrification part of the nitrogen cycle (Monteny *et al*., 2001). Rahman *et al. (*2013) observed an increase in N_2O emissions through facilitating aerobic nitrification. Gallardo (2013) observed an increase in N_2O flux following water application on moist and loose manure with a mean of 29.3 mg/m^2/h and a peak of 99.2 mg/m^2/h at 15 minutes and for moist and compacted manure a mean of 19.3 mg/m^2/h and a peak of 75.4 mg/m^2/h over the same time period. Gallardo (2013) also observed that the N_2O flux decreased for moist and loose manure to a mean of 2.60 mg/m^2/h with a peak of 6.83 mg/m^2/h at 5 days after water application, as well as for moist and compacted manure a decrease flux to a mean of 4.33 mg/m^2/h with a peak of 17.2 mg/m^2/h at 17 days after water application. Gallardo (2013) observed that the application of water to manure resulted in short term peaks of GHG emissions a few minutes after water application. Gallardo (2013) also calculated the following mean N_2O gas flux results: for moist/muddy manure a value of 2.03 mg/m^2/h, for dry and loose manure a value of 0.16 mg/m^2/h, for dry and hard manure a value of 0.13 mg/m^2/h, and for flooded manure a value of 0.10 mg/m^2/h 15 minutes after water application. The value of the flooded manure being the lowest supports the fact that fully saturated manure has less oxygen available for the aerobic process of N_2O production. Rahman *et al. (*2013) observed highly variable N_2O concentrations or flux rates within and among months resulting in a high standard deviation in the result published by the authors. There is a water requirement for optimal microbial activity as seen after application of water by Gallardo (2013), but not when the application rate was high enough to create an anaerobic environment in the soil. Thus temperature, adequate oxygen and moisture are required for N_2O production to occur. Von Essen & Auvermann (2005) and Gallardo (2013) noted that N_2O emissions from cattle feedlot pens were episodic and related to rainfall events and warm temperatures.

2.3.2.2 Manure concentration

Agricultural soils amended with manure are known to increase N_2O emissions because of the enhanced nitrification and denitrification processes associated with the increased nitrogen availability to microbes from manure (Ryals & Silver, 2013). Tisdale *et al.* (1993) and USEPA (2010) described how most of the N_2O resulting from manure is produced in manure-amended soils through microbial nitrification under aerobic conditions, and partial denitrification under anaerobic conditions. This is due to the increased availability of nitrogen present for denitrification with the increase in manure content in a patch of soil. Chadwick *et al.* (2011) described how the application of manure to soil allows manure ammonia to be subjected to aerobic processes such as nitrification for soil nitrate generation. Rochette *et al*. (2008) found that N_2O emissions resulting from liquid or solid manure application to lands showed no clear difference between treatments. Ellert & Janzen (2008) and Gallardo (2013) stated that soil N_2O emissions were remarkably variable among treatment replicates, and duplicated sample sites a few meters apart within the same plots.

2.3.2.3 Soil type and characteristics

The type of soil present in the area where manure occurs affects N_2O emission by affecting the amount of oxygen present in the soil (Niera *et al*., 2015). Uchida *et al.* (2008) described the important factors that contribute towards anaerobic soil conditions which promote N_2O production. These factors were soil respiration rates, soil aggregation and degree of soil compaction. Bouwman *et al.* (2002) stated that soil organic carbon (C) content, pH, texture and drainage have significant influence on N_2O emissions. Clay soils have a very fine pore size, and have a high water holding capacity, as compared to sandy soils, which have a larger pore size and a lower water holding capacity. Therefore, the water holding capacity and organic matter content of clay soils, as compared to sandy soils, tends to result in higher N_2O emissions following manure application, according to Van Groenigen *et al.* (2004). Agricultural fields with high N inputs (such as manure and urine) and poor soil drainage show higher denitrification values because the condition of the soil is commonly anaerobic, with a high organic C content as described by Hofstra & Bouwman (2005). Lee *et al.* (2009) reported limited N_2O emission flux from soils with temperatures higher than 35°C. Microbial activity is markedly increased when water is added to dry soil, with the microbes becoming active within minutes according to Davidson (1992). Ellert & Janzen (2008) reported that no significant relationship between N_2O flux and soil water content and temperature in the top 5-cm soil layer occurred, contrary to Gallardo (2013). Soil pH affects soil interactions such as denitrification. It was reported by Hofstra & Bouwman (2005) that soil pH was the only soil property with a significant influence on denitrification, with alkaline conditions favouring it. However, Hou *et al.* (2000) reported that a pH of 7 (neutral) is favourable for N_2O and CH_4 emissions. The presence of water within, or added to, the soil would fill up the soil air spaces, therefore displacing and decreasing the amount of O_2 present in the soil for aerobic processes. Gallardo (2013) explained how after water application the O_2 in the soil feedlot surface is displaced by water that goes into the porous spaces of the soil.

2.3.2.4 Manure management

In solid manure waste management/dry landfill, both aerobic and anaerobic conditions are supplied to microorganisms, and so production of N_2O can occur (Chadwick *et al*., 2011). Emission of N_2O is typically <1% to 4.2% of the total N measured in stored cattle and pig farmyard manure (FYM) heaps, but N_2O emissions as high as 9.8% have been reported from stored farmyard manure (Webb *et al*., 2012).

With slurry systems, the layer of slurry that is exposed to the environment experiences aerobic conditions, but under the top layer the condition is primarily anaerobic, and thus the production of N_2O is small, unless an increase in oxygen supply via a treatment occurs (Béline *et al*., 1998).

2.4 Greenhouse gas sampling and measuring techniques from soil and manure

Greenhouse gas emissions from soil and manure sources can be measured and quantified through several different techniques. Gas emissions can be estimated or measured using a backward langrangian stochastic model, as applied by Flesch & Wilson (1994); Laubach & Kelliher (2005); Flesch *et al.* (2007); Todd *et al.* (2014). Open-path laser spectrometers are used in an inverse dispersion model to calculate the CH_4 concentration via a three-axis sonic anemometer as described and utilized by Todd *et al.* (2014).

Micrometeorological techniques for measuring gas concentration and changes include photo-acoustic infrared multi-gas analysers (PIMA). This method is commonly used to measure concentrations in air and stack emissions of almost any gas that absorbs infrared radiation (Gallardo, 2013).

Additional methods include open-path tunable diode laser absorption spectroscopy (OP-TDLAS) which uses wavelengths to determine gas concentration; open-path Fourier-transform infrared (OP-FIR) spectroscopy which uses a beam of light that uses different wavelengths to determine gas concentration (Gallardo, 2013); and cavity ring-down spectroscopy (CRDS) otherwise known as cavity ring-down laser absorption spectroscopy (CRLAS) which is a laser-based absorption spectroscopy technique (Wheeler *et al*., 1998).

Gas collected from trials can be analysed on a gas chromatography (GC) instrument or by infrared (IR) techniques. The GC instrument contains different detectors to analyse for various GHG (Hensen *et al*., 3013). It is easy to use, affordable, and collected gas in a vial can be transported to a suitable GC instrument (Hensen *et al*., 2013). The disadvantage of using a GC is the continuous supply of highly purified carrier gas that is used for gas detection. Gas chromatography techniques can also be less sensitive at gas detection than IR techniques (Hensen *et al*., 2013).

The IR techniques use the relative gases ability to absorb infrared light as set wavelengths to determine which gas is present and the quantity of the gas (Hensen *et al*., 2013). Infrared techniques include the fourier transform infrared spectrometers (FTIR), photo-acoustic instruments and laser based instruments such as tunable diode laser (TDL), Quantum cascade laser (QCL) spectrometers and CRDS (Hensen *et al*., 2013). Infrared (IR) techniques are more accurate and sensitive than a GC instrument, however IR techniques are more expensive than the GC instrument and require experienced maintenance (Hensen *et al*., 2013). Advantages and disadvantages of various gas measuring techniques from literature is depicted in Table 1. Each measurement technique has its own unique advantages and disadvantages.

Table 1 Advantages and disadvantages of various gas measuring techniques from literature

Sampling techniques	Advantages	Disadvantages	Reference
Static closed chamber	Ability to collect smaller concentrated gas emissions from a set area. Used to measure soil respiration. Frequently used. Easy to apply. Static chamber- does not interfere with soil processes.	With closed chambers disturbance to soil external environment inside the chamber is observed. Gas has to be stored and analysed later.	Muir (2011) Gallardo (2013) Hensen *et al*. (2013) Rapson & Dacres (2014)
Eddy covariance, Eddy accumulation/ Relaxed eddy accumulation (REA) method, Flux gradients methods, Mass balance Integrated horizontal flux, Backward lagrangian stochastic(bLs) dispersion technique, Moving platforms/ Boundary layer budget approach	Considered most adequate for measuring emission fluxes from soils. Does not interfere on the measurement being made. Non-intrusive.	Requires substantial experimental infrastructure Qualified personnel Expensive equipment	Muir (2011) Gallardo (2013) Hensen *et al*. (2013) Rapson & Dacres (2014)
Reverse dispersion modelling Inverse dispersion modelling	Non-intrusive. Non-labour intensive. Can be calculated at short time intervals over a long period of time.	Requires in-situ weather information. GHG concentrations upwind and downwind of the source. Cannot be partitioned into sources.	Muir (2011) Gallardo (2013)
PIMA	Can be equipped with several optical filters for measuring up to five gases plus water vapour.	Limitation due to cross interference among gases and water vapour.	Muir (2011) Gallardo (2013)
OP-TDLAS	Does not require calibration.	Expensive.	Muir (2011) Gallardo (2013)
OP-FTIR	Real time identification and quantification of atmospheric contaminants. Quick and versatile. Reliable data quality. No calibration required.	Significant resources. Highly trained operator.	Muir (2011) Gallardo (2013)
CRDS/CRLAS	High sensitivity. High throughput.	Spectra cannot be acquired quickly. Analyses are limited by availability of tunable laser light and availability of high reflectance mirrors. Expensive.	Muir (2011) Gallardo (2013)
Mass Balance and plume methods	Several equations are used to compute N intake, N of feed refusal, net protein and net energy. Low cost.	Does not distinguish among several N gases. Requires detailed information on feedlot configuration. Requires meteorological instrumentation.	Muir (2011) Gallardo (2013) Hensen *et al*. (2013) Rapson & Dacres (2014)

PIMA (photo-acoustic infrared mutli-gas analyser), *OP-TDLAS* (open-path tunable diode laser absorption spectroscopy), *CRDS/CRLAS* (cavity ring-down spectroscopy/cavity rind-down laser absorption spectroscopy)

2.4.1 Closed static flux chamber

The use of chambers to measure CH_4 and N_2O from agricultural systems gives increased sensitivity compared with open-path measurements (Muir, 2011). Kelliher *et al.* (2008) described how the closed chamber methods have an advantage of being able to assess spatial variability.

Measuring CH_4 and N_2O directly is important, according to Costa Junior *et al.* (2015) for developing and verifying the empirical, as well as the process- based, modelling approaches that provide emissions and data for modelling (Sagger *et al*., 2004, 2007; Sagger, 2010) and up-scaling (Giltrap *et al*., 2010) of CH_4 and N_2O emissions from animal production systems.

Closed static flux chambers (CSFC), due to their low cost and ease of operation (Healy *et al*., 1996; Gallardo, 2013) have been widely used in measuring gas emissions from soils. Gas can be directly measured from manure using a closed static flux chamber (SFC) method (Muir, 2011; Rodhe *et al*., 2012; and Gallardo, 2013). Closed static flux chambers are frequently used in the field to estimate trace gas fluxes (Boadi *et al*., 2004; Costa Junior *et al*., 2013) such as CH_4 and N_2O gases. The gases are then detected on the GC with a flame ionization detector (FID) (Rodhe *et al*., 2012). The gas fluxes are calculated by linear regression or a non-linear (diffusion) model (Kreuzer & Hinderichsen, 2006; Muir, 2011; and Gallardo, 2013) from the concentration changes over time. Averaging the flux between two adjacent sampling points and multiplying by the number of days between sampling occasions will calculate cumulative emissions of N_2O and CH_4 (Rodhe *et al*., 2012). Adding these calculated emission rates should allow the total cumulative emissions rate to be determined (Rodhe *et. al.,* 2012) within an area.

With the CSFC method, chamber design and soil seal is important as described by Rochette *et al.* (2008). Rochette *et al.* (2008) stated that using the correct methodology is important in obtaining gas concentrations from the CSFC. The CSFC needs to be insulated to both trap gas within and prevent external gas from entering the chamber (Rochette *et al*., 2008). The chamber is also required to allow some gas to escape for adequate gas production to still occur within the chamber by the soil over a short period of sampling time. Rochette *et al.* (2008) stated that a minimum insertion depth of 5cm is necessary to have adequate depth for the chamber on soil sealing, but enough chamber headspace to allow for gas escape, for a more accurate gas collection within the chamber. A static flux chamber is shown in Figure 5.

The use of pressurized fixed-volume containers of known efficiency for air sample storage (i.e. avoid plastic syringes) (Rochette *et al*., 2008), such as 5ml vacuumed glass vials are suitable for gas storage prior to sample analysis. For gas sampling a minimum of three discrete air samples during deployment are required, including one at time zero, and one to test nonlinearity of changes in headspace concentration with time for estimating gas concentration over measuring time at time zero (Rochette *et al*., 2008). However, the delayed response in results that have to be run at a later time after sampling on a gas chromatograph instrument results in this method being expensive and time-consuming (Gallardo, 2013).

Figure 5 A static flux chamber head and base (Online: Chamber Picture, https://3c1703fe8d.site.internapcdn.net/newman/gfx/news/hires/2013/2-1-battlingclim.jpg, accessed 10 Feb. 2017)

Emission fluxes can be calculated through linear or nonlinear equations. Most of the equations available to determine gas concentrations from manure are derived from slurry-based systems, which must be adapted accordingly to be suitable for use in a beef feedlot management system where dry piling is the main storage system for the manure (Pattey *et al.*, 2005).

The linear model equation shown in Equation 2, by Gallardo (2013), is used for SFC gas collection from soil for short time intervals of less than 40 minutes.

Equation 2 Linear model equation for static flux chamber gas collection adapted from Gallardo, O.A.A., 2013. Measurement and control of greenhouse gas emissions from beef cattle feedlots. Thesis, Kansas State Univ. (Online) Available at: http://krex.k-state.edu/dspace/handle/2097/15167. (Accessed on 4th May 2015).

$$F = [(V/A)(\Delta C/\Delta t)]\ k$$

Where

F : gas emission rate (μg/m^2 /h)
V : volume of air within the chamber (m^3)
A : the feedlot surface area of soil within the chamber (m^2)
$\Delta C/\Delta t$: the gas concentration gradient with time within the chamber (ppm/h)
k : conversion factor for gas concentration from ppm to μg/m^3

The linear equation is used when short time intervals of gas sampling occur. This model is used to correlate the observed SFC headspace gas concentration and time (Gallardo, 2013). Short sampling times are essential to avoid significant non-linearity due to different soil conditions, which vary from sampling site to sampling site (Gallardo, 2013).

The non-linear model equation, Equation 3, by Gallardo (2013), is used to correct for the decreasing concentration gradient within the SFC headspace based on diffusion theory (Gallardo, 2013). The non-linear model equation is used for SFC on soil for gas collection. This method can only be used when there are set periods of sampling times of the same length, with the initial gas sample taken as the chamber is placed on the feedlot surface at T_0 and for 2 other set gas sampling times whilst the chamber is sealed on the ground. Ginting *et al. (*2003) explained that three gas samples from the SFC headspace are needed for accurate flux determination (0 minutes, 15 minutes and 30 minutes). The non-linear equation is shown in Equation 3.

Equation 3 Non-linear model equation for static flux chamber gas collection adapted from Gallardo, O.A.A., 2013. Measurement and control of greenhouse gas emissions from beef cattle feedlots. Thesis, Kansas State Univ. (Online) Available at: http://krex.k-state.edu/dspace/handle/2097/15167. (Accessed on 4th May 2015).

$$F = kd\,(273/T)(V/A)(\Delta C/\Delta t)$$

Where

F : gas emission rate (mass/ha/d)
k : unit conversion factor
d : gas density (g/cm^3) at 273 K
T : air temperature within the chamber (K)
V : volume of air within the chamber (cm^3)
A : area of soil within the chamber (cm^2)
ΔC : gas concentration difference (ppm)
Δt : sampling interval (15 min)

Costa Junior *et al. (*2012) used the following equation, Equation 4, to calculate gas concentrations over time for the resulting gas flux for CH_4 and N_2O using the closed chamber method of gas collection.

Equation 4 Gas flux equation adapted from Costa Junior, C., Sagger, S., Giltrap, D. & Cerri, C.C., 2012. Nitrous oxide and methane emission from a beef cattle feedlot pen in Brazil: Chamber measurement and DNDC modelling approaches. (Online). Available at: http://www.agrisus.org.br/arquivos/relatorio_final_PA1023_trabalho.pdf (Accessed 9th July 2017)

$$F = p(V/A)(\Delta C/\Delta t)[273/(T+273)]$$

Where

F : the gas flux (mg/m^2/hr)
p : the density of the gas (kg/m^3)
V : the volume of the chamber (m^2)
$\Delta C/\Delta t$: the average rate of change of concentration with time (ppmv/h)
T : the temperature in the chamber (°C)
A: area of chamber (m^2)

It is similar to Equation 3 (Gallardo, 2013) for non-linear equation taking into account volume of the chamber as well as the gas concentration change over time. The non-linear equation from Equation 3 would be the most suited to quantify emissions from beef feedlot pen surfaces using set periods, during the same time interval, being measured.

2.5 Current state of knowledge on greenhouse gas emissions from feedlot surface soils, manure and feedlot operations

Du Toit *et al.* (2013) calculated manure CH_4 and N_2O emission factors for beef cattle in South African feedlots as 0.012-0.022 kg CH_4/h/yr and 0.46 kg N_2O/h/yr respectively. Other values from literature for CH_4 and N_2O are shown in Table 2 and Table 3 respectively. The IPCC allocated a manure management emission factor (EF) for non-dairy cattle of 1 kg/head/yr (Jun *et al*., 1996).

Table 2 Manure and feedlot pen surface methane emission values reported in literature

Comparative Literature	Substrate Type	Author of Article
11.0±1.90 g CH_4/pen/day	Low grain: forage	Steed & Hashimoto (1994)
17.7±19.0 g CH_4/pen/day	High forage: grain	Steed & Hashimoto (1994)
0.96 g CH_4/day/cow	Urine and dung on grazing pasture	Steed & Hashimoto (1994)
1.5-2 g CH_4/animal/day	58kg of manure per 1000kg of live weight	Ghafoori *et al.* (2006)
0.7-1.2g CH_4/ animal/day	Manure pack	Ghafoori *et al.* (2006)
1.0g CH_4/head/day	Manure pack	Ghafoori *et al.* (2006)
2.3 kg CH_4/m^2/year	Stacked manure	Ghafoori *et al.* (2006)
38 g CH_4/head/day	Pen feedlot surface in beef feedlot	Montes *et al.* (2013)
160 g CH_4/m^3	Winter compositing raw manure	Montes *et al.* (2013)
3600 gCH_4/m^3	Summer composting raw manure	Montes *et al.* (2013)
0.14 g CH_4/kg DM	Compost	Montes *et al.* (2013)
2.85 g CH_4/ kg DM	Stockpile	Montes *et al.* (2013)
9.78 g CH_4/kg DM	Slurry	Montes *et al.* (2013)
15.15 g CH_4/kg DM	Slurry (5 months)	Montes *et al.* (2013)
0.012-0.022 kg CH_4/head/year	Beef cattle	Du Toit *et al.* (2013)
132(±2.3 SE) g CH_4/animal/d	Pens	Bai *et al.* (2015)
22(±0.7 SE) g CH_4/animal/d	Manure stockpile	Bai *et al.* (2015)
<100 mg CH_4/m^2/d	Solid Manure	Arriaga *et al.* (2017)

The manure measured in Table 2 was beef cattle manure within a beef feedlot, unless stated otherwise in the substrate type column. When manure was spread on rangeland, the overall CH_4 emission calculated, in the different units measured, showed a trend of a lower measured value than manure that was allowed to stay in the feedlot, stored in a stockpile as well as being allowed to turn into compost.

Table 3 Manure and feedlot pen surface nitrous oxide emission values reported in literature

Comparative Literature	Substrate Type	Author of Article
0.162g N_2O/kg DM	Compost	Pattey *et al.* (2005)
0.034 g N_2O/kg DM	Stockpile	Pattey *et al.* (2005)
0.017 g N_2O/kg DM	Slurry	Pattey *et al.* (2005)
0.017 g N_2O/kg DM	Slurry (5 months)	Pattey *et al.* (2005)
3.8 g N_2O/head/day	Pen feedlot surface in beef feedlot	Montes *et al.* (2013)
38-57 g N2O/m3 of N2O	Winter compositing raw manure	Montes *et al.* (2013)
40-76 g N2O /m3 of N2O	Summer composting raw manure	Montes *et al.* (2013)
0.457 kg N2O/h/year	Beef cattle	Du Toit *et al.* (2013)
0 g N_2O/animal/d	Pens	Bai *et al.* (2015)
2 (± 0.2 SE) g N_2O/animal/d	Manure stockpiles	Bai *et al.* (2015)
<50 mg N2O/m2/d	Baseline N_2O	Arriaga *et al.* (2017)
500 mg N2O/m2/d	Maximum rates after manure turning	Arriaga *et al.* (2017)
43.08 ± 0.89 mg N2O/m2/hr	Moist manure	Parker *et al.* (2017b)
0.025 ± 0.0016 mg N2O/m2/hr	Dry manure	Parker *et al.* (2017b)
10 mg N2O/m2/hr (average 4.8 mg/m2/hr)	Open lot beef feed yards	Waldrip *et al.* (2017)
200 mg N2O/m2/hr	After rainfall feedlot manure	Parker *et al.* (2017a)

Nitrous oxide values from beef cattle manure reported in Table 3 show how N_2O emissions are higher in composting manure as compared to manure stored in stockpiles and within slurry systems.

2.6 Mitigation of greenhouse gas emissions from manure and manure management systems

The mitigation of GHGs from agriculture has produced more research of late due to global warming concerns. The IPCC (2006), as quoted, explained that "the main mitigation options within the Agriculture, Forestry and Other Land Use (AFOLU) section involve the following strategies: reduction/prevention of emissions to the atmosphere by conserving existing carbon pools in soil or vegetation that would otherwise be lost or by reducing emissions of CH_4 and N_2O". Muir (2011) described how mitigation options to reduce feedlot emissions need to be applied to both enteric CH_4 and N_2O gas emissions and emissions from manure management. Liao *et al*. (2018) describes how implementing certain mitigation practices can cause inverse effects on different target gases, specifically removing manure may decrease CH_4 emission but may increase NH_3 emissions due to artificial disturbance and an in indirect GHG through NH_3 in the N_2O production pathway. Decreasing CH_4 and N_2O emissions from cattle manure can be achieved in 2 ways - through manure management or through selective breeding and feeding practices (Montes *et al*., 2013; Cai *et al*., 2017). Li *et al.* (2012a) described technical potentials to mitigate GHGs and NH_3 emissions from animal farms through animal physiology selection. The animal physiology includes breeding cattle for better food utilization, lower enteric methane production, and utilization of feed additives such as ionophores, antibiotics, vaccines and tannins to reduce GHG emissions from enteric CH_4 and manure CH_4 (Li *et al*., 2012a). Li *et al.* (2012a) also described how altering the rumen microbial population, as well as microbial metabolism, to produce alternative substrates, for microbial use, can ultimately decrease CH_4 production. This is done through altering the feed composition fed as described earlier, and is dependent on the manure management practiced, being stock piling or slurry. Liao *et al*. (2018) researched the application of hydroquinone and dycyandiamide to feedlot pen surfaces to decrease GHG emissions with dycandiamide reducing GHG by 60.3%. Figure 6 adapted from Montes *et al*. (2013) shows the various ways to mitigate GHG emissions from livestock manure.

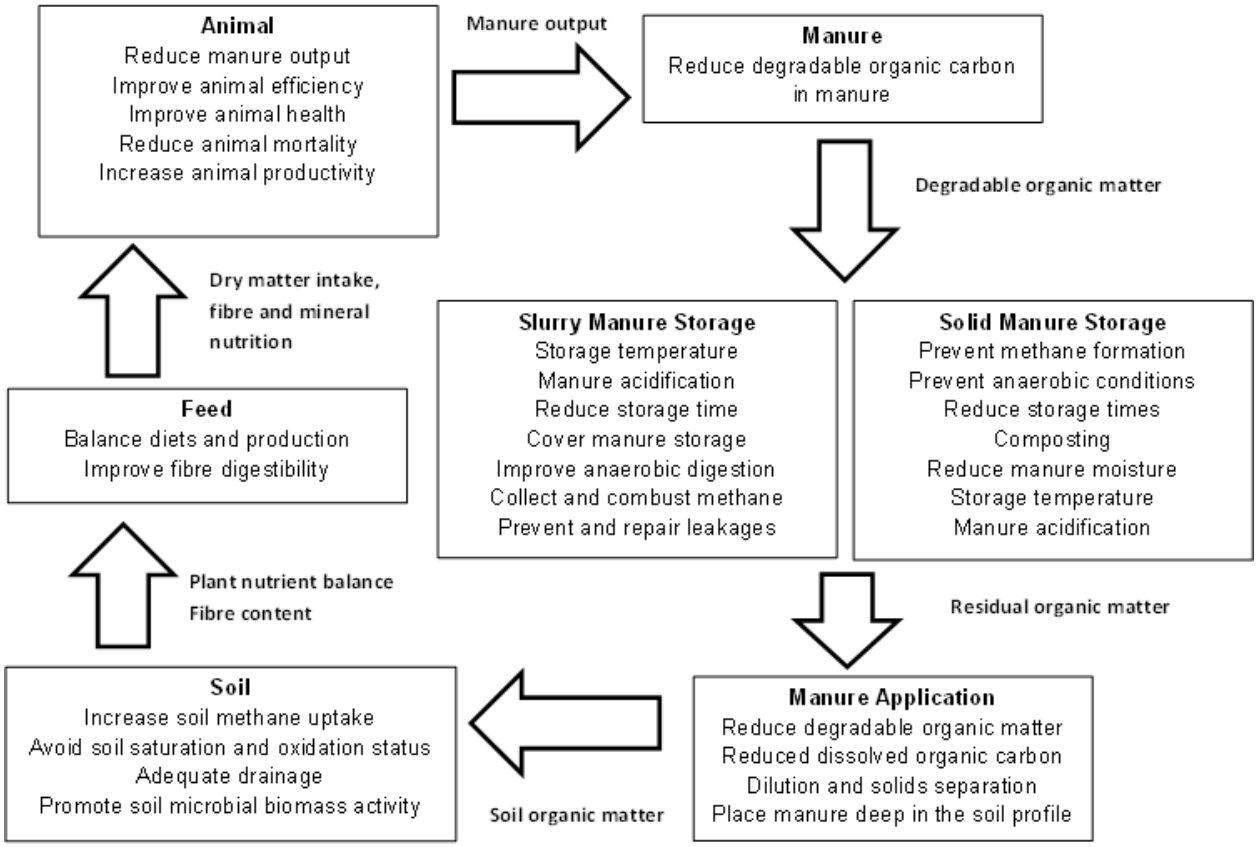


Figure 6 Opportunities to mitigate methane emissions from livestock manure adapted from Montes, F., Meinen, R., Dell, C., Rotz, A., Hristov, A.N., Oh, J., Waghorn, G., Gerber, P.J., Henderson, B., Makkar, H.P.S. & Dijkstar, J., 2013. Special Topics- Mitigation of methane and nitrous oxide emissions from animal operations: II. A review of manure management mitigation options. J Anim. Sci. 91, 5070-5094.

From Figure 6, for manure management, getting the manure to compost quicker or acidifying the manure would be a method to decrease CH_4 production (Montes *et al.*, 2013).

The amount of oxygen available to the microbes within the manure can inhibit or promote CH_4 and N_2O production (Chadwick *et al.*, 2013). According to Pelser *et al.* (2012) manure carbon may increase microbial respiration rates in the soil, which would cause oxygen to be depleted and thus anaerobic conditions would occur, which are required for denitrification. Soil amended with livestock manure has more available carbon and nitrogen which can lead to an increase in soil N_2O emission compared to soils amended with mineral fertilizers (Montes *et al.*, 2013; Oertel *et al.*, 2016). Figure 7, adapted from Montes *et al.* (2013), shows the various ways one can mitigate N_2O production from livestock manure.

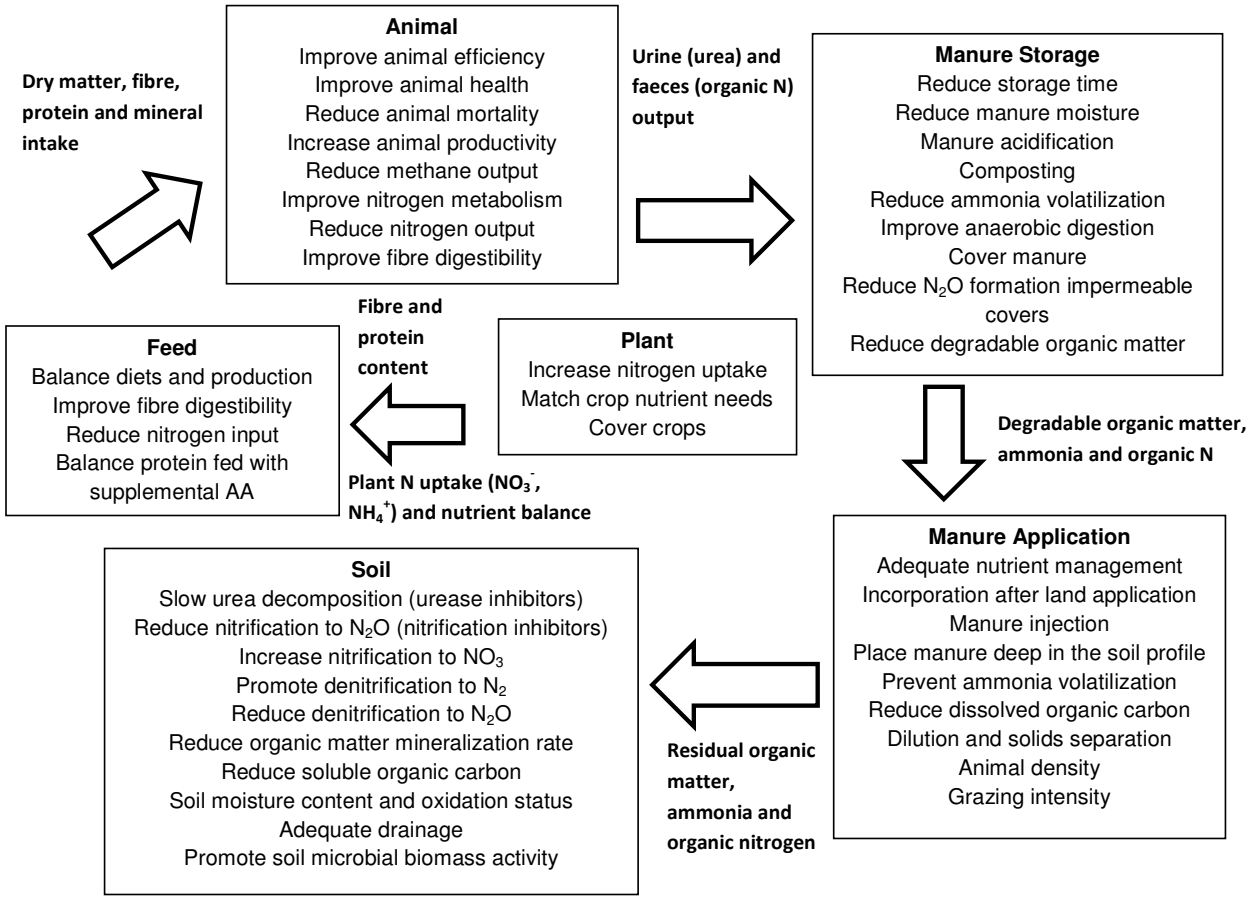


Figure 7 Opportunities to mitigate nitrous oxide emissions from livestock manure adapted from Montes, F., Meinen, R., Dell, C., Rotz, A., Hristov, A.N., Oh, J., Waghorn, G., Gerber, P.J., Henderson, B., Makkar, H.P.S. & Dijkstar, J., 2013. Special Topics- Mitigation of methane and nitrous oxide emissions from animal operations: II. A review of manure management mitigation options. J Anim. Sci. 91, 5070-5094.

Chadwick (2004) observed that compacting and covering beef cattle manure heaps helped decrease N_2O production, and a decrease in CH_4 was observed following compaction in the second storage period (90 days), however, an increase was observed after compaction with the third storage period (109 days). Compacting and covering would therefore not affect the CH_4 yield of the manure in general (Chadwick, 2004).

The trend towards environmentally friendly and sustainable energy has resulted in alternative avenues in generating fuel and electricity. Bio-fuel, manufactured using grown crops has been a clean alternative to using petrol and diesel, whilst the use of electronic cars, created as hybrid cars, are some examples of how going green is becoming a daily occurrence. Harvesting the CH_4 to use in combustion to generate heat to electricity is another practice one can explore to mitigate CH_4 from livestock manure (Voermans, 1985; Montes *et al*., 2013). The use of gas, such as CH_4, to generate power and electricity, is another alternative to coal powered and nuclear-powered electricity (Ghafoori *et al*., 2006). This is reiterated by Voermans (1985) who stated that biogas (such as CH_4) can be used as a substitute for natural gas for heating and producing electricity. The use of bio-digestors to collect gas production of CH_4 for beef cattle manure has been utilized (Mullo *et al*., 2018). The waste recovered from the bio-digestor has been full composted and can then be utilised on agricultural land as a safer alternative to chemical fertilizers (Pertiwiningrum *et al*., 2016). Thus fully integrating the feedlot system.Kumar *et al*. (2004) explained how landfill CH_4 emissions are measured as landfill gas (LFG) with regards to its potential utilisation as a renewable source of energy. Adapting this to agricultural animal waste as a means of waste management could be a great source of energy production due to the natural production of animal waste in the process of animal farming.

2.7 Summary

Greenhouse gas emissions have contributed to concerns about global warming and climate change and have thus become a significant environmental concern. The accurate determination of the GHGs produced from livestock and livestock waste has become critical. The majority of the current values for GHGs such as CH_4 and N_2O have been obtained indirectly through estimating amounts of gasses produced in livestock production systems. This is known as the IPCC Tier 2 methodology. A step towards the IPCC Tier 3 methodology, as required by countries with international agreements in place, is necessary to improve the accuracy of GHGs emission values, and more accurate country specific emission factors. This step requires measuring actual values and concentration of gasses produced from certain activities and calculating the total GHGs emission per activity to obtain a national average.

Decreasing GHG emissions from cattle can be achieved by altering and adding inhibiting additives to the animal feed. This however only causes a decrease in enteric CH_4 production and will only cause a decrease in exogenous CH_4 if excreted manure contains a significantly lower amount of protein (endogenous and exogenous) and metabolisable carbohydrates. Soil factors, such as moisture, temperature, and soil type will affect CH_4 and N_2O emissions. Manure factors such as moisture concentration and organic matter concentration will also affect CH_4 and N_2O emissions, along with seasonal effects. Gas emissions will depend highly on microorganism activity, which depends on having favourable conditions for the microorganisms. Microorganisms require a certain amount of moisture, temperature range and organic matter for optimal function, and ultimate gas production from manure on soil.

Atmospheric conditions contribute towards CH_4 and N_2O emissions directly and indirectly - directly through affecting feed and water intake, and indirectly through manure water concentration and rate of drying. Soil conditions will affect gas emissions by affecting the amount of oxygen available to the manure patty through the soil, which is influenced by soil particle size. The soil will also affect gas emissions by its water holding capacity and factors such as how long it can stay saturated and keep the manure saturated. Manure conditions, as depicted by the abovementioned factors, contribute towards CH_4 and N_2O production from the manure.

There are a variety of methods to measure CH_4 and N_2O gas emissions from soil and manure. Each method has its own advantages and disadvantages. The closed static flux chamber method is the most accurate method of measuring gas emissions from beef cattle manure and feedlot pen surfaces. The chamber method allows measurements to occur directly and a gas emission flux can be calculated within 30 minutes of application. Multiple chambers can be deployed to measure gas emissions from an area more accurately as well as being a more cost-effective method to apply and use (Rochette *et al*., 2008; Collier *et al*., 2014).

Chapter 3

3. Research methodology

3.1 Ethical approval

The experimental procedures and all associating materials for this study were approved by the animal ethics committee of the University of Pretoria - Project number: ec076-15.

3.2 Experimental site

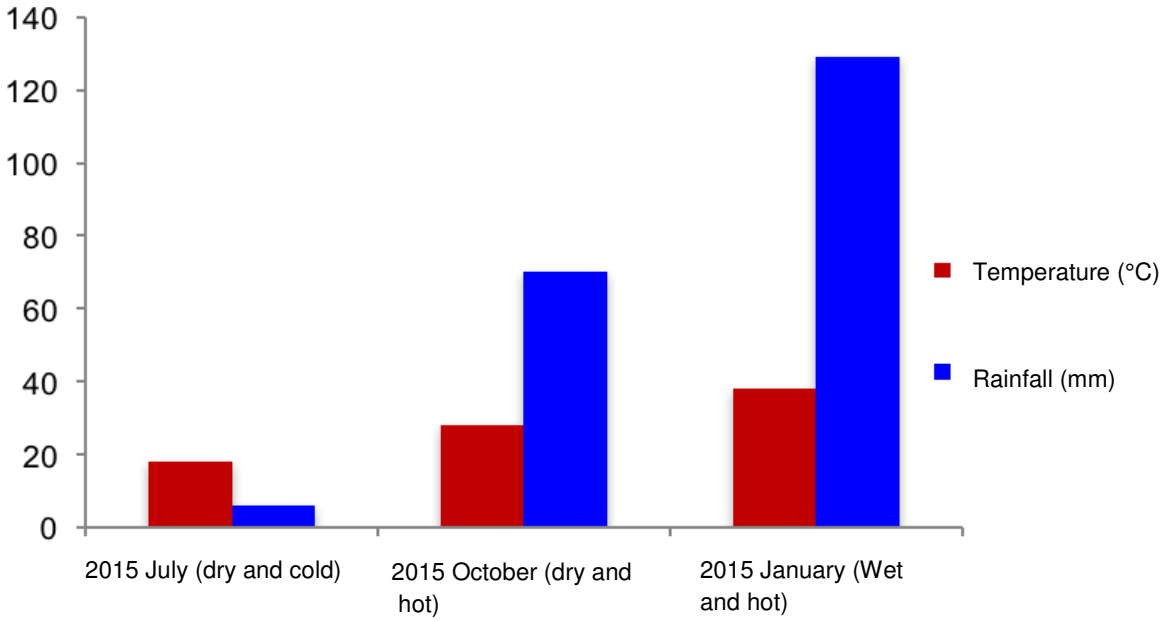
3.2.1 Feedlot description

The trial was conducted during 2015 and 2016 with sampling occurring during the dry and cold (July 2015), dry and hot (October 2015) and wet and hot (January 2016) season, on the farm Boschkop, Bronkhorstspruit, 1020 (-25.917551, 28.597891) in Mpumalanga South Africa.

Average rainfall in the area during the sampling months was 6 mm for July 2015, 70 mm for October 2015, and 129 mm for January 2016 according to climate data (Online: South African weather service, 2016). Figure 8 depicts the seasonal average temperature and rainfall during each sampling season.

The trial was conducted on a commercial beef feedlot situated near Bronkhorstspruit, Mpumalanga, South Africa. The feedlot operates on a total area of 1700 ha, including rangeland, feedlot pens and infrastructure. The feedlot pens present in the feedlot, are shown in Figure 9 (Online: Google Maps, 2017), and are approximately 25m x 50m per pen.

There were three diets fed in the feedlot, a starter feed (pens situated with an A), a grower feed (pens situated with a B) and a finisher feed (pens situated with a C). Cattle coming into the feedlot that are below 240kg, are put onto the rangeland and supplemented with a back-grounding supplement and additional hay, if grazing were insufficient in the rangeland. Feedlot manure management practices includes pen manure cleaning (using front end loaders), which occurred approximately once every three weeks. The manure was then dry piled, and stored until the manure was collected for use on pastures. The feedlot pens occupied by cattle were cleaned using front end loaders, every 3 weeks, and the manure collected is transported and placed in manure piles. Location of the manure piles is depicted by a red E in Figure 9. The manure from the manure piles is transported off to various farms to be used as fertilizer after compositing. Three dams are located on the farm, depicted by green D's in Figure 9, catches rain runoff water contaminated with cattle manure.



Seasonal average temperature and rainfall at the experimental site

Figure 8 Average maximum temperature on site and monthly rainfall during the sampling seasons (Online: South African weather service, 2016)

Figure 9 Outlay of feedlot (Online: Google Maps, available at: https://www.google.com/maps/place/Beefcor,+Bronlhorstspruit/@-25.9133316,28.5991995,17z/data=!4m2!3m1!1s0x1e954bf222f98f2d:0x762aa8c10770cca2 (Accessed 18 July 2017) A: Starter pens, B: Grower Pens, C: Finisher pens, D: Effluent dams, E: Manure piles

3.2.2 Experimental design

The aim of the experiment was to measure the amount of CH_4 and to calculate CH_4 flux, and the amount of N_2O and to calculate N_2O flux emitted from manure and feedlot pen surfaces in a commercial beef feedlot at each respective diets fed within the feedlot, and for the respective manure management systems employed at the feedlot during the prominent seasons experienced in Mpumalanga, South Africa. Closed static chambers were used for gas collection from feedlot pen surfaces, rangeland manure and from manure management practices employed at the feedlot. Measurements for the feedlot diets fed were divided into backgrounding and feedlot diets fed, which consisted of a starter, grower and finisher feed. Backgrounding was for the calves that were purchased for the feedlot and weighed less than 240 kg. They were placed onto the rangeland near the feedlot and fed once a day with concentrates and supplemented with *Eragrostis curvula* hay when grazing availability was low due to limited grass growth in winter. The feedlot pen surface experiment was designed as a randomized block design with 3 treatments and 3 replicates per treatment. Three measurements per pen, and three pens per diet fed, were measured to obtain the overall CH_4 and N_2O fluxes at the end of each season measured at the feedlot. The rangeland had CH_4 and N_2O fluxes calculated from dry manure and wet manure over a 3-week measurement period for each season. Table 4 gives an outlay of the sampling/collection fields and collection days that occurred within each season at the feedlot.

Table 4 Depicting collection fields on collection days during the experimental period

	Day 1	Day 3	Day 5	Day 8	Day 15
Measured first	Rangeland	Rangeland	Rangeland	Rangeland	Rangeland
Measured second	Starter pen	Effluent dam		Starter pen	Starter pen
Measured third	Grower pen	Manure Piles		Grower pen	Grower pen
Measured fourth	Finisher pen			Finisher pen	Finisher pen

3.3 Materials and methods

3.3.1 Sampling procedure

Materials used in the trial consisted of twelve closed static chambers, three closed static buckets modified for gas collection, soil and manure thermometer, atmospheric temperature and humidity gauge, plastic syringes, needles, three-way stop valves, vacuumed glass vials, sample bags, latex gloves, and hammer and chisel.

The static flux chambers were constructed out of polyvinyl chloride (PVC) piping, 38 cm diameter and 0.5cm thickness (Rochette & Eriksen-Hamel, 2008). The chamber head was covered with reflective tape that extended 0.5 cm down the side of the chamber head. This was to reflect external heat to avoid the chamber heating up from external parameters that would inhibit or aid in gaseous production (Figure 10) (Rochette & Eriksen-Hamel, 2008; Gallardo, 2013; Butterbach-Bahl *et al*., 2016). The base had a height of 10.5 cm, including the lip of the base that was tapered for 0.5 cm from the bottom of the base, to assist with ground penetration as observed in Figure 11. The closed static chamber head had an injection port (approximately 1.5 cm diameter) where gas was collected. The closed static chamber port can be seen in Figure 12. A permanent needle (needle size 22 G x 1 ¼") stayed in the injection port, and there is a permanent vent of 4mm in diameter, on the lid of the chamber, to allow small gas fluxes. This gas release was to decrease the effect of the chamber on the soil gas flux rate (Rochette & Eriksen-Hamel, 2008). The chamber head had a height of 20.4 cm, and a combined height of 31 cm when assembled. The chamber head and base were held together using a rubber band with a width of 7 cm and a thickness of 0.2 cm as seen in Figure 13. The whole closed static chamber (head and base) had a total volume of 0.035 m^3. Figures 10, 11, 12 and 13 show the closed static chamber head with injection port; the closed static chamber head and base; the underside of the closed static chamber head displaying the air vent; and the joined closed static chamber head and base.

Manure was randomly collected from the rangeland (rangeland divided into quarters and 4 random manure samples taken from each quarter) to form a homogenised composite sample, and the gas emission was measured over a period of three weeks to obtain the rangeland manure CH_4 and N_2O fluxes. Measurements within the feedlot were based on ration fed and were divided into three treatments, starter, grower and finisher. The treatments were measured once a week, on the same day at midday, over a 3-week period. Due to the cattle, still being present in the pens, a constant measuring site could not be obtained and a random feedlot surface spot was chosen via a randomized block design. With the cattle still present in the pens, the feedlot pen surface manure present in each block changed each measurement due to cattle movements and defecation patterns. Due to the feedlot pen surface manure amount and type changing consistently, the feedlot pen measurements were described as feedlot pen soil surface emissions. The change that occurred with the feedlot surface manure in the pens included the manure volume (using height within the camber to calculate), age and quantities one would observe when placing down the chamber base for gas collection.

Gas measurements were taken once during the measurement seasons from the piles and effluent dams. Four manure pile chambers were placed randomly on manure piles for gas measurements and the average CH_4 and N_2O fluxes were calculated for the piles from each season. For the dams, three buckets of water were collected per dam, by throwing a bucket into the catchment dam and letting it sink just below the

surface of the dam and pulling the bucket out with the rope attached to the handle, then transferring the collected dam water into a gas collection bucket and collecting the gas samples over a 30-minute interval as described below. The gas sample results were combined per dam and per season to obtain the average CH_4 and N_2O fluxes. Atmospheric temperature and humidity were obtained during each collection day by a Kestrel 4000 Pocket Weather Tracker, otherwise known as a Kestrel 4000 Weather Meter (Animal Gear, sales@animalgear.co.za, 012 300 4031).

Figure 10 Closed static chamber head with injection port and reflective tape

Figure 11 Closed static chamber head and base on their sides

Figure 12 Underneath the closed static chamber head displaying the air vent

Figure 13 A joined closed static chamber head and base making up the closed gas chamber for gas collection

The closed static chamber buckets, used for effluent dam manure samples, were 22 cm in diameter and 25 cm high. The buckets were 5 litre (l) buckets and had a volume of 0.035 m^3 and an area of 380.13 cm^2. The lid of the bucket was fitted with a 1.5 cm diameter injection port for gas collection, and a permanent vent of 4mm in diameter (the same as the gas chamber described above for the PVC chamber heads). When the lids were sealed onto the bucket an airtight seal was achieved. The bucket design was designed through personal communication between the author and Dr. Luanne Stevens (luanne@jacali.net).

Syringes used were 20 ml plastic syringes, replaced before the start of each trial period. During each trial period three 20 ml syringes were used, and therefore a total of nine syringes were used for the three trial periods. Each syringe was fitted with a three-way valve to trap gas collected inside the syringe before transferring the gas to 5 ml vacuum vials (Labco, Unit 3, Pont Steffan Business Park, Lampeter SA48 7EA, United Kingdom). Before each sample was taken the syringe was flushed out several times, with ambient air, to remove any residual sample gas from the previous sampling (Collier *et al.*, 2014). Gas stored in the glass vials was analysed 24 to 72 hrs after collection (Rochette & Eriksen-Hamel, 2008), on a GC instrument. For the gas collection 20ml of gas was collected at each sample time, and when transferred across to the 5ml vacuum vials, as much of the collected gas as possible was injected into the vials. This was done to ensure that if a leak occurred the sample gas would not be contaminated with the atmospheric gas (Rochette & Eriksen-Hamel, 2008). The vials were then placed into a cold bag (temperature under 10°C) and then stored in the fridge at the University of Pretoria, at 3.5 °C, for 24 to 72 hours, until analysis on the GC instrument (Dr. Luanne Stevens, 2014, Pers. Comm., luanne@jacali.net).

Four gas samples were taken per chamber measurement. According to Rochette & Erikson-Hamel (2008) a recommended minimum of at least three air samples per chamber are needed to increase the accuracy of determination of the linear gas increase. Gas samples were taken over a period of 30 minutes. Time zero (T_0) as chamber head is attached, T_{10} occurring ten minutes following chamber head and base assembly, T_{20} occurring twenty minutes after chamber head and base assembly, and lastly T_{30} occurring thirty minutes after chamber head and base were assembled. The sampling times were described by Rochette & Eriksen-Hamel (2008) and Gallardo (2013).

Sample bags of 17.7 cm x 20.3 cm were used to store feed samples collected per diet fed: starter, grower and finisher, as well as a grass sample for the back-grounding cattle's feed. Additional sample bags were used to store manure samples obtained per pen per diet fed on the sample days. A manure sample was also taken from the manure piles and stored in sample bags. Feed samples were collected by taking a handful of feed, at the centre of the feed bunker, at various depths, every 4 meters along the feeding bunker for each pen in a treatment level, until a representative sample of the feed was obtained (Herman, 2001). Approximately 2.0 kg of feed sample (Herman, 2001) was collected per season measured. Grass samples from the rangeland were collected by taking a handful of grass every 10 steps in the paddock, using scissors to cut the grass approximately 5 cm above the ground, until approximately 2 kg (Herman, 2001) of sample was collected. One feed and grass sample were collected per season for each treatment. Manure samples were collected after gas collections were complete from the manure found within the closed static chamber bases. This was for the feedlot pen measurements per treatment level and manure samples were taken after every gas collection day for every chamber. On the rangeland a composite aged manure sample and a composite fresh manure sample were collected at the beginning of the season from manure left over after manure placement into the closed static chamber bases. All feed, grass and manure samples were dried in an oven to determine moisture concentration and analysed for parameters described in 3.4.2.

Manure and soil temperatures were obtained using a Soil Test by Hanna (Hanna Instruments (Pty) Ltd, 6 Vernon Road, Morninghill, Bedfordview). Soil temperature was taken by inserting the tip of the Soil Test Hanna into the ground, approximately 2 cm deep, and temperature was recorded in °C. For the manure, the temperature was taken just before sampling by placing the tip of the Soil Test by Hanna into the manure and the temperature was recorded after each measurement (Dr. Luanne Stevens, 2014, Pers. Comm., luanne@jacali.net).

Initial manure moisture content was estimated by manure scoring and was recorded as 1. Runny, 2. Loose, 3. Soft, 4. Dry and hard. Manure scoring was adapted from Ireland-Perry & Stallings (1992). Runny manure was manure that had no distinct definition of a manure patty and contained a lot of water. Loose manure had a regular patty shape to the manure. Soft manure had a distinct patty shape, and dry manure was manure that had a distinct patty shape that was noticeably dry or had been disturbed out of its original patty shape due to the manure drying out and cattle traffic (Ireland-Perry & Stallings, 1992).

Feedlot soil surface samples were collected by using a hammer and chisel. This was to aid in getting enough depth into the ground to collect a representative soil sample. The depth achieved was between 5 to 10 cm deep (Dr. Luanne Stevens, 2014, Pers. Comm., luanne@jacali.net and taken from right next to the gas sampling site on the rangeland, and within the feedlot pens as described. Due to the compaction of organic matter that occurred within the feedlot pens a screw drill was used to obtain a soil sample situated beneath the organic matter layer present, due to the hardness of the ground.

Animal number per pen and average feed intake per animal was obtained from the feedlot's own recorded data for each pen and rangeland for each of the seasons measured. This data is shown in Table 8.

3.3.2 Rangeland measurement procedure

Rangeland measurements were taken on days 1, 3, 5, 8 and 15 of the sampling period for each season as described. The average of the sampling days was then calculated and the flux for the measurement period was determined.

Before starting rangeland measurements, atmospheric temperature and humidity were taken using a Kestrel 5500 hand held weather meter (Futurama, Shop 4, the Flags@Circle 5 centre, corner Centenary Drive and Reese Road, Somerset West, Cape Town, 7130) and recorded in °C. Four chamber bases were then inserted to a depth of approximately 5 cm (Rochette & Eriksen-Hamel, 2008). Manure was randomly collected from the rangeland paddock. Eight aged manure samples, which were dry and cold to the touch, were combined and homogenised to make up a composite sample (Dr. Luanne Stevens, 2014, Pers. Comm., luanne@jacali.net). From the composite sample a manure sub-sample was taken and placed within a chamber base until a height of 5 cm was reached. The same occurred for the fresh manure, which was collected in the same way as the aged manure and placed in two chamber bases. The one chamber base (Base 1) was left empty as a control measurement. Manure initial wetness was estimated as described earlier, and a sub-sample, of approximately 2kg (Herman, 2001), from both the composite aged and composite fresh manure was collected and placed in separate sample bags and stored in a fridge, at 3.5 °C, at the University of Pretoria. After analysis was run on the wet and dry manure an average for the manure parameters was calculated to give a representative value of rangeland manure.

The chamber heads were placed on top of the chamber bases and secured using a rubber band. As each chamber head was placed, a gas sample was taken at time zero (T_0). Gas measurements were then taken at ten minutes (T_{10}), twenty minutes (T_{20}) and thirty minutes (T_{30}) after chamber assembly as described earlier (Rochette & Eriksen-Hamel, 2008).

Manure temperatures were taken at placement of the chamber bases and recorded in °C as described. An atmospheric gas sample was taken by standing upright and taking a gas sample at the sampling site. Twenty ml of atmospheric gas was collected and then transferred into the relevantly labelled 5ml vacuum vial via injection. The vial was placed into a cold bag until it could be stored in a fridge at the University of Pretoria at 3.5 °C.

After gas samples were taken, the chamber head was removed from the chamber base, and the chamber base removed from the ground. Soil samples were obtained from three areas around the chamber bases as described above. The back-grounding supplement sample was obtained as described above as well as the composite grass sample (Dr. Luanne Stevens, 2014, Pers. Comm., luanne@jacali.net).

The manure measured after day 1 was left in the same spot and the same manure was measured over a period of 3 weeks. On sampling days 3, 5, 8 and 15 the base chambers were placed in the same spot and contained the same manure sample as on day 1.

3.3.3 Feedlot pen measurement procedure

Pen measurements were taken on days 1, 8 and 15 of the trial period for each season measured. The days were labelled as 1, 2 and 3 for feedlot pens. The average of each pen sampled was calculated and an average flux was calculated for each feedlot ration for the measurement period.

At the start of each pen measurement day atmospheric temperature and humidity were taken and recorded as described. With two helpers, the three pens per diet were measured at the same time during the day. Each pen was divided into 3 regions and a static flux chamber was randomly placed in each third of the feedlot pen. Temperatures of the pen surface were taken and initial pen surface moisture estimated. Soil temperature was taken at three points next to each chamber base and an average temperature was calculated per pen. The temperature readings were averaged to estimate the overall temperature for each diet fed. A top soil sample was taken at each chamber base as deep as was possible (5 to 7cm). Three samples per pen and three pens per diet fed were combined to obtain a composite organic matter (OM) sample per diet per day. This was repeated for each measured on the day and for each measured day in the season.

Atmospheric gas was collected (in the same manner as described above) and transferred into the 5ml vacuum vial. Manure and feed samples were collected as described from each pen. Chambers were assembled and gas samples collected in each pen according to the sampling protocol described.

3.3.4 Effluent dam measurement procedure

Effluent dam measurements were taken on day 3 of the sample period for each season measured.

Atmospheric temperature and humidity were taken prior to effluent dam water collection and recorded as described. Effluent dam water was collected using a bucket with rope tied to the bucket handle. The bucket was thrown into the catchment effluent dam and allowed to sink just below the dam surface and slowly pulled out of the dam. A 700 ml sample of water was transferred to the closed static bucket and the lid of the bucket was closed and sealed (Dr. Luanne Stevens, 2014, Pers. Comm., luanne@jacali.net). Gas samples were taken at T_0, T_{10}, T_{20} and T_{30} (Rochette & Eriksen-Hamel, 2008). Gas collected was transferred to 5ml vacuum vials as described. There were 3 main effluent dams on the feedlot and 3 representative samples of effluent dam water were obtained and measured. All measurements from each dam were combined for an average flux value for the effluent dam (Dr. Luanne Stevens, 2014, Pers. Comm., luanne@jacali.net).

3.3.5 Manure pile measurement procedure

Manure pile measurements were taken on day 3 of the sample period for each season measured. The manure piles on the feedlot were located North to the back right of the feedlot. Starting from West to East 4 manure piles were chosen as follows: the first manure pile of the line, the second manure pile of the line, the fifth manure pile of the line and the sixth manure pile of the line per season measured. The closed static chamber base was inserted as high as possible onto the manure pile's side, and to a depth of 5cm (Rochette & Eriksen-Hamel, 2008). The temperatures of the manure piles were taken, by inserting the tip of the Soil Test by Hanna probe, approximately 2 cm into the manure pile within the chamber base and the temperature was recorded (Dr. Luanne Stevens, 2014, Pers. Comm., luanne@jacali.net). Atmospheric gas samples were collected as described above in the rangeland. Closed static chamber heads were connected to chamber bases and gas samples taken at T_0, T_{10}, T_{20} and T_{30}. Gas samples were taken and transferred into the 5ml vacuum glass vials as described above (Rochette & Eriksen-Hamel, 2008). Closed static chamber heads were removed from their bases once gas measurements were complete. Manure samples were taken from inside the chamber bases, approximately 5 cm deep by hand, and placed into sample bags and stored in the fridge, at 3.5 °C, at the University of Pretoria. Bases were removed from the piles until the next sampling period.

3.4 Sample analysis

3.4.1 Gas sample analysis

Gas samples collected from the feedlot were analysed 24-72 hours following collection on a GC instrument. The GC instrument was a SRI 8610c Gas Chromatograph instrument equipped with electron-capture detector (ECD) and a flame ionisation detector (FID). Using a HayeSep D stainless steel packed GC column for CH_4 and N_2O detection respectively. The carrier gases were nitrogen (N) and hydrogen (H2). Spancan calibration gas, 100 ppm and 300 ppm CH_4 gas and a 100 ppm N_2O standard gas by Praxair were used for instrument calibration. The temperature of the instrument was set to run at 100°C. Figure 14 shows the GC instrument used to analyse the gas samples. Figure 15 shows the GC instrument underneath the lid and Figure 16 shows the HaySep loops used to detect CH_4 and N_2O.

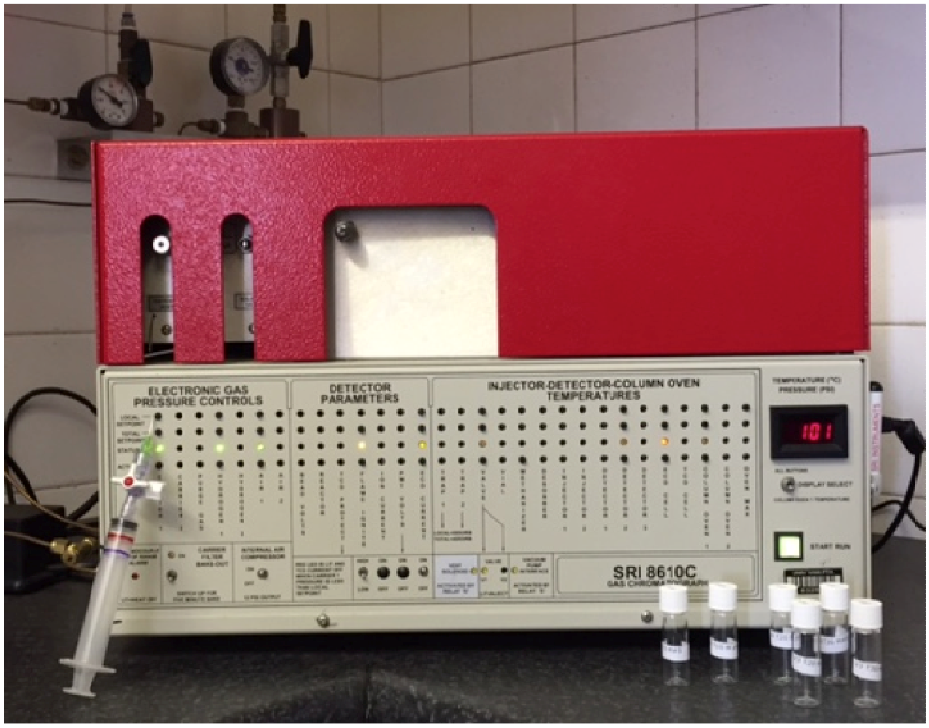


Figure 14 Gas chromatograph instrument at the University of Pretoria with 5ml vacuumed vials in front of the gas chromatography at the bottom right

Figure 15 Beneath the gas chromatograph lid

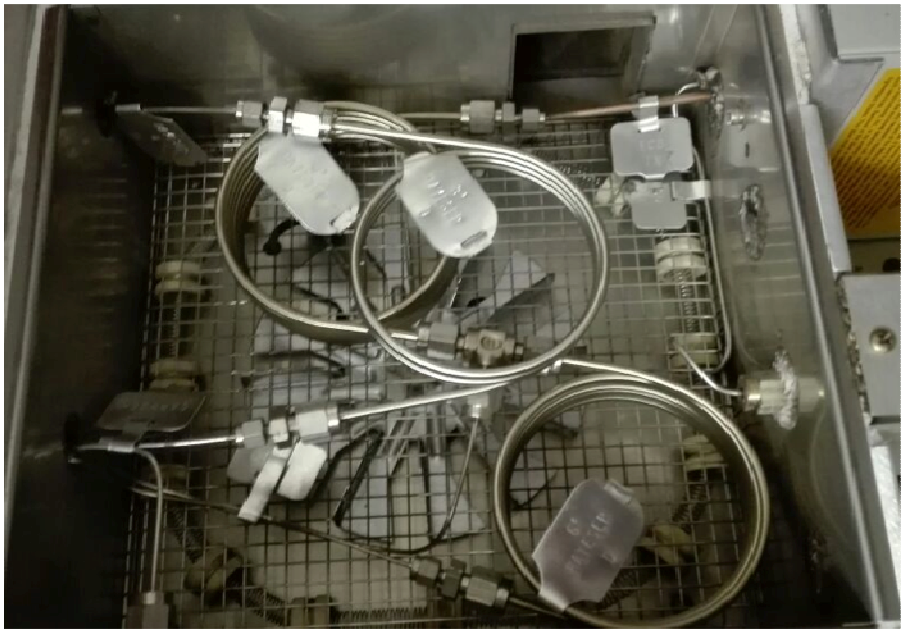


Figure 16 Displaying the HayeSep D packed stainless steel columns in the gas chromatograph instrument

The GC instrument was switched on 24 hours prior to gas sampling and a bake out was initiated to clean out any leftover sample gasses prior to the start of gas analysis for the trial. A 100 ppm and 300 ppm CH_4 gas and a 100 ppm N_2O standard gas was run at the start and end of each day that gas analysis occurred (Dr. Luanne Stevens, 2014, Pers. Comm., luanne@jacali.net).

The sample run time was 8 minutes (Rapson & Dacres, 2014) in which the results for CH_4 and N_2O were recorded. Two ml of gas (standard gases at the start of the day and the sample gases thereafter) was pulled into a 5ml syringe fitted with a three-way stop valve to lock the gas within the syringe. A short needle (26G x 5/8") was used to inject 2 ml of the gas into the injection port and the sample was run. Once the gas was injected into the GC instrument a four-port valve diverted the gas to the FID for CH_4 detection, and then the gas passes through an ECD for N_2O analysis (Rochette & Ericksen-Hamel, 2008). The software used for the GC instrument was the PeakSimple for Windows software (Alltech, tech_service@alltechemail.com).

The CH_4 and N_2O flux was calculated as described by Li *et al.* (2011a). The gas flux values ($mg/m^2/hr$) of CH_4 and N_2O was then converted to g/head/d for the feedlot. This was calculated as follows: $mg/m^2/hr$ was multiplied by the conversion factor of mg/hr to g/d value of 0.024 to get $g/m^2/d$. The $g/m^2/d$ value was then multiplied by the total area for a pen in the feedlot which is $1250m^2$. This calculated the emission value in g/pen/d. The g/pen/d was then divided by the number of cattle present in each treatment level, displayed in Table 8, to calculate the g/head/d value.

3.4.2 Soil and manure analysis

3.4.2.1 Soil and feedlot pen surface analysis

Soil samples obtained from the rangeland paddock per season were sent for analysis to NviroTek lab (Unit No. 6, Nviro Business Hub, Die Ou Wapad St, Ifafi, Hartebeespoort, 0260) for soil texture (clay, silt, sand), carbon concentration (by the Walkley black method), nitrate (NO_3^-) and ammonia nitrate (NH_4^+). The N concentration was obtained by using potassium sulphate to extract the extractable nitrogen (Kjeldahl, AOAC official method 199.04) in the soil samples analysed by NviroTek.

3.4.2.2 Manure and effluent dam water analysis

Manure samples collected from rangeland and from feedlot pen surfaces were analysed for moisture (AOAC official method 934.01), ash (AOAC official method 942.05), pH (AOAC official method 981.12), neutral detergent fibre (NDF) (Ankom method, Accessed 2016), acid detergent fibre (ADF) (Ankom method, Accessed 2016), and nitrogen (N) (AOAC official method 990.03) according to the AOAC (2000). Samples collected from effluent dams were analysed for pH, moisture and ash according to the AOAC (2000).

3.4.2.3 Pasture and feedlot ration analysis

Feed samples and grass samples collected were analysed using the same methods as described above for DM, Ash, ADF, NDF and N. Ether extract was conducted according to the AOAC (2000) official method of analysis 920.39. Starch was analysed by the South African Grain Laboratory (477 Witherite Road, The Willows, Pretoria, 0040). The starch method used was the SAGL's in-house method 019.

3.4.3 Statistical analysis

Data was analysed statistically as a randomized block design with the general linear model (GLM) of SAS (Littell, 2014) for the average effects. Means and standard errors were calculated per manure characteristic, seasons and gas emissions. Significance of difference ($P<0.05$) was calculated between means using the Fischer's test (Samuals, 1989). Equation 5 depicts the linear model used for statistical analysis in the trial.

Equation 5 The linear model used for statistical analysis adapted from Samuals, M.L., 1989. Statistics for the Life Sciences. Collier MacMillan Publishers, London.

$$Y_{ij} = \mu + T_i + S_j + TS_{ij} + e_{ij}$$

Where

Y_{ij} = variable studied during the period
μ = overall mean of the population
T_i = effect of the i^{the} treatment
S_j = effect of the j^{the} season
TS_{ij} = effect of the ij^{the} interaction between treatment and season
e_{ij} = error associated with each Y

Chapter 4

4. Results and discussion

4.1 Feedlot

4.1.1 Atmospheric conditions and feedlot pen soil composition

The average environmental conditions, such as ambient temperature, ambient humidity and rainfall per season (the entire season) are shown in Table 5. Seasons measured were dry and cold (July 2015), dry and hot (October 2015), and wet and hot (January 2016).

Table 5 Average ambient weather conditions at the study site per season (Online: South Africa weather service, 2016) on the sampling days

Season	Ambient temperature °C	Ambient humidity (%)	Rainfall (mm)
Dry and cold	16.9	37.0	6.0
Dry and hot	31.4	31.6	70.0
Wet and hot	31.6	45.2	129.0

The rainfall experienced per season during the trial, was below annual averages (Online: South African weather service, 2016). This was due to a drought that South Africa, and thus Mpumalanga, was experiencing at the time of the trial.

The feedlot soil composition situated under the OM layer in the treatment pens was relatively similar as seen in Table 6. This should minimize the effect of soil composition on the gas emissions from the feedlot pen surfaces (Chadwick *et al.*, 2011) for the different diets fed in the feedlot.

Table 6 Feedlot pen surface composition

Ration	Clay %	Silt %	Sand %
Starter pen	29	24	47
Grower pen	34	35	31
Finisher pen	27	27	46

The layout of the feedlot was situated on a gentle slope. The starter pens were situated at the lowest part of the slope with the grower pens situated on the middle of the slope and the finisher pens at the top of the slope. Soil composition was similar between the starter and finisher pens, with the clay percentage and silt percentage being lower compared to the sand and clay percentages. Grower pen soil varied with sand being the lowest percentage. The grower pen clay and silt had percentages that were close to each other. Due to the composition of the soil at the feedlot pen surfaces, no statistics were done on the soil textures, as the effect from the feedlot pen surface composition on gas emissions should be too small to have any noticeable effect (Chadwick, 2004). The compaction of the manure on top of the soil, and the compaction of the soil beneath the manure made the feedlot surface very hard. Compaction affects soil and manure emissions by decreasing the water and air penetration into the feedlot surface (Chadwick, 2004), which

decreases overall gas emissions. The type of soil should have affected the water holding capacity and the oxygen availability for the relative microbial activity and gas production (Uchida *et al.,* 2008; Gallardo, 2013).

4.1.2 Feedlot diets fed during the different growth phases and cattle information per season

Table 7 shows the treatment rations fed per season in the feedlot pens.

Table 7 Nutrient composition of the diet rations fed (100% DM basis) during the different seasons

Season	Diets	Ash (%)	CP (%)	Starch (%)	Ether extract (%)	NDF (%)	ADF (%)
Dry and cold	Starter	6.3	12.4	26.9	12.2	44.7	23.6
	Grower	8.2	12.5	30.4	9.3	36	17.2
	Finisher	7.7	11.6	47.4	9	33.2	15.9
Dry and hot	Starter	6.6	15.1	32.4	12.2	30.3	15.1
	Grower	7.1	13.9	43.4	4.9	28.5	13
	Finisher	7.3	13.9	44.4	5.4	27	14.3
Wet and hot	Starter	6.5	16	31.4	11.5	34.1	20.6
	Grower	6.4	14.5	40.3	5.2	28.5	16.3
	Finisher	6.2	14.4	55.6	5.9	29.5	16.1

CP (crude protein), *ADF* (acid detergent fibre), *NDF* (neutral detergent fibre)

Each diet fed, such as starter, grower and finisher, showed changes in the feed nutrient composition between seasons, although not statistically analysed, with the crude protein varying the most between seasons, followed by the NDF and ADF concentrations of the feed. The variations observed between the seasons may be due to random sampling and variation in raw feed material composition between seasons. The crude protein % observed in Table 7 for each of the diet fed were fairly similar to the grower and finisher diets observed by Gautam *et al*. (2016), in the range of 13.7% to 17.6% CP, with the higher CP observed by Gautam *et al*, (2016) belonging to the grower diets. The CP results obtained from the analysis were supported by the diet formulations used at the feedlot (Ruben Gouws, 2016, Pers. Comm., ruben@beefcor.com, Bronkhorstspruit, 1020). The difference in starch values observed between the diets, specifically the dry and hot finisher diet compared to the dry and cold, and the wet and hot finisher diet starch values was unexpected. The same may be applied to the observed ADF and NDF concentrations observed in the dry and hot season for each treatment compared to the treatments in the dry and cold, and the wet and hot seasons. Scholtz *et al*. (2009) recorded ADF values in the range of 21.26 to 47.28 % and NDF values in the range of 28.89 to 65.93% for *Medicago sativa* hay. Even though the concentrate to roughage ratio is 80:20, *Medicago sativa* hay is the most common hay included into TMR as a roughage source for cattle in South Africa (Scholtz *et al*., 2009). Going on the lower range being a representative of young hay the NDF values observed in the present diets fall into the range. However the ADF values were higher than observed in the present trial.

Table 8 shows the average number of cattle within each of the diets fed at the time of this study. The average feed intake, as well as target animal weight (kg) per treatment level in each of the measured seasons, is also depicted in Table 8. Information was obtained from data supplied by the feedlot (Ruben Gouws, 2016, Pers. Comm., ruben@beefcor.com, Bronkhorstspruit, 1020).

Table 8 Average seasonal dry matter intake (kg/head), animal numbers per pen, total animal number in back grounding phase and animal live weight during the different seasons

Season	Diets	Daily feed intake, DMI (kg)	Average animal numbers	Target animal mass (kg)
Dry and cold	Back ground	3.4	18069*	210
	Starter	8.2	111	240
	Grower	9.6	158	310
	Finisher	9.3	196	450
Dry and hot	Back ground	5.2	17734*	210
	Starter	10.3	158	240
	Grower	10.3	212	310
	Finisher	10.8	169	450
Wet and hot	Back ground	5.9	4394*	210
	Starter	14.5	148	240
	Grower	14.6	206	310
	Finisher	14.9	211	450

* Total number of animals in the back grounding phase

The average number of cattle per diet fed was determined by data obtained from the feedlot. The cattle number per diet fed fluctuated based on feed costs at the time, which were higher in winter and lower in summer due to feed raw material availability, and holiday times of the year which affected consumer consumption of meat. Intake values reported by the feedlot manager falls out of the range of 2.7-3% liveweight as reported by the ARC (1996). The variation in feed intake per cattle head observed between the diets over the three seasons may be due to weather related instances (Rahman *et al*., 2013). Rahman *et al.* (2013) stated that "cold ambient temperatures increase maintenance energy needs and feed intake in most ruminants", however this was not observed in the data provided by the feedlot with regards to daily feed intake per feed as seen in Table 8 and the weather (ambient temperature, humidity and rainfall) recorded per season in Table 5. Feed intake increased in the wet and hot season as compared to the average daily feed intake in the dry and cold season as seen in Table 8. Feedlot intake data was sourced from feedlot management records during the trial period (Ruben Gouws, 2016, Pers. Comm., ruben@beefcor.com, Bronkhorstspruit, 1020). Even though DMI of the cattle was not measured in the present trial, the low intake (DMI/kg body weight) in the backgrounding group on the dry and cold season, and the high intake in the starter treatment in the wet and hot season, according to feedlot records, was unexpected.

4.1.3 Feedlot pen surface parameters per season

Table 9 consists of the feedlot pen surface parameters measured for seasons and treatments, on an "As is'' basis. The feedlot pen surface sampling sites ranged from containing small amounts of manure, to a whole manure pile, depending on the manure deposited by cattle and spread via trampling, and random sampling sites.

Table 9 Feedlot pen surface parameters between diets fed and seasons in the feedlot (DM basis)

		Seasons			
Feedlot surface parameter	Diets	Dry and cold	Dry and hot	Wet and hot	SE
Temperature (°C)	Starter	$18.1^{c}{}_{1}$	$24.0^{b}{}_{3}$	$29.6^{a}{}_{1}$	1.2
	Grower	$15.9^{c}{}_{3}$	$31.7^{a}{}_{2}$	$29.5^{a}{}_{1}$	1.2
	Finisher	$17.3^{c}{}_{2}$	$33.7^{a}{}_{1}$	$29.6^{b}{}_{1}$	1.2
	SE	0.67	0.67	0.67	
pH	Starter	$7.1^{a}{}_{1}$	$7.1^{a}{}_{2}$	$6.5^{b}{}_{2}$	0.2
	Grower	$6.7^{b}{}_{2}$	$7.3^{a}{}_{1}$	$6.5^{b}{}_{2}$	0.2
	Finisher	$6^{c}{}_{3}$	$7.1^{a}{}_{2}$	$6.7^{b}{}_{1}$	0.2
	SE	0.12	0.12	0.12	
DM (%)	Starter	$46.4^{b}{}_{2}$	$40^{a}{}_{2}$	$38.8^{a}{}_{2}$	3.4
	Grower	$53.4^{b}{}_{3}$	$37.9^{a}{}_{2}$	$35.5^{a}{}_{1}$	3.4
	Finisher	$41.7^{b}{}_{1}$	$35.5^{a}{}_{1}$	$33.5^{a}{}_{1}$	3.4
	SE	1.95	1.95	1.95	
Ash (%)	Starter	$5.9^{a}{}_{1}$	$4.6^{b}{}_{2}$	$6.1^{a}{}_{1}$	0.7
	Grower	$5.3^{b}{}_{2}$	$6^{b}{}_{1}$	$7.1^{a}{}_{1,2}$	0.7
	Finisher	$5.6^{b}{}_{1,2}$	$5.9^{ab}{}_{1}$	$6.6^{a}{}_{2}$	0.7
	SE	0.41	0.41	0.41	
N (%)	Starter	$2.39^{c}{}_{3}$	$2.54^{b}{}_{3}$	$2.77^{a}{}_{2}$	0.065
	Grower	$2.54^{c}{}_{2}$	$2.71^{b}{}_{2}$	$2.80^{a}{}_{1,2}$	0.065
	Finisher	$2.63^{c}{}_{1}$	$2.81^{b}{}_{1}$	$2.84^{a}{}_{1}$	0.065
	SE	0.037	0.037	0.037	
NDF (%)	Starter	$50.9^{a}{}_{1}$	$41.8^{c}{}_{2}$	$46.5^{b}{}_{1}$	1.5
	Grower	$47.2^{a}{}_{2}$	$44.5^{b}{}_{1}$	$46.5^{a}{}_{1}$	1.5
	Finisher	$45.4^{a}{}_{3}$	$37.5^{b}{}_{3}$	$45.7^{a}{}_{1}$	1.5
	SE	0.89	0.89	0.89	
ADF (%)	Starter	$31.8^{b}{}_{1}$	$28.3^{c}{}_{1}$	$35.4^{a}{}_{1}$	1.3
	Grower	$32.2^{a}{}_{1}$	$28.4^{b}{}_{1}$	$33.1^{a}{}_{2}$	1.3
	Finisher	$28.1^{b}{}_{2}$	$26.5^{b}{}_{2}$	$36.2^{a}{}_{1}$	1.3
	SE	0.77	0.77	0.77	

$^{*a, b, c}$ Means in a row with different superscripts differ (P<0.05), $_{1, 2, 3}$ Means in a column with different subscripts differ (P<0.05) *DM* (dry matter), *N* (nitrogen), *ADF* (acid detergent fibre), *NDF* (neutral detergent fibre), *SE* (standard error)

Manure scoring, based on the 4-point visual scoring system according to Ireland-Perry & Stallings (1992), resulted in the dry and hot season obtaining a manure scoring of 2. According to Kebreab *et al.* (2006) manure that was fresh and contained enough moisture was less susceptible to atmospheric temperature due to the piling effect. This could explain why the manure temperature in the dry and hot season recorded a higher temperature than in the hot and wet season, in the grower and finisher pens, due to enough water being present and being less susceptible to atmospheric temperature. The manure measured in the wet and hot season may have been influenced more by atmospheric temperature due to the random sampling procedure applied to the trial. This can be seen in Table 5 with manure temperature in the dry and hot season and in the wet and hot season being similar to atmospheric temperature recorded in those seasons respectively.

The feedlot pen surface temperature differed ($P<0.05$) for each diet in the dry and cold and the dry and hot season. No difference ($P>0.05$) was observed for feedlot pen surface temperature between diets in the wet and hot season. The highest temperature was recorded in the dry and hot season finisher diet (33.7°C), followed by the dry and hot season grower diet (31.7°C) and the lowest temperature was recorded in the dry and cold grower diet (15.9°C). Both the grower and finisher diets recorded the highest surface temperature in the dry and hot season, 31.7 °C and 33.7°C respectively, then followed by the wet and hot season for the starter and finisher diets both recording 29.6 °C. The coolest temperature recorded was in the dry and cold season, 15.9°C and 17.3°C for the grower and finisher diets respectively. The temperature range observed in the cold and dry season was 15.9 to 18.1 °C, in the dry and hot was 24.0 to 33.7 °C and in the wet and hot 29.5 to 29.6°C. The temperature range observed in each season corresponds with the recorded ambient temperature, 16.9 °C for the dry and cold season, 31.4 °C for the dry and hot season and 31.6 °C for the wet and hot season as seen in Table 5. Thus the temperature change observed between the seasons was due to the time it took to sample within the sampling day. Ambient temperature has an impact on soil temperature (Gallardo, 2013), the higher the ambient temperature results in a higher soil temperature (Gallardo, 2013).

Feedlot pen surface pH observed differences ($P<0.05$) in the starter diet between the dry and cold, and the dry and hot (pH value of 7.1 for both) seasons, compared to the wet and hot season (pH value of 6.5). The grower diet observed differences ($P<0.05$) between both the dry and cold season (pH 6.7) and the wet and hot season (pH 6.5) compared to the dry and hot season (pH 7.3) for feedlot pen surface pH. No difference ($P>0.05$) was observed between the dry and cold season (pH 6.7) to the wet and hot season (pH 6.5) for the grower diet for feedlot pen surface pH. The finisher diet observed differences ($P<0.05$) between each of the seasons measured for feedlot pen surface pH, with a pH of 6 for the cold and dry season, a pH of 7.1 for the dry and hot season and a pH of 6.7 for the wet and hot season respectively. Within the dry and hot season the starter (pH 7.1) and finisher (pH 7.1) diet observed differences ($P<0.05$) compared to the grower (pH 7.3) diet for feedlot pen surface pH. No difference ($P>0.05$) was observed between the starter and finisher diets within the dry and hot season for feedlot pen surface pH. Within the wet and hot season the starter (pH 6.5) and grower (pH 6.5) diets observed a difference ($P<0.05$) compared to the finisher (pH 6.7) diet for feedlot pen surface pH. No difference ($P>0.05$) was observed between the starter and grower diets within the wet and hot season for the feedlot pen surface pH. Within the dry and cold season differences ($P<0.05$) were observed between each diet level for the feedlot pen surface pH, starter, grower and finisher had pH values of 7.1, 6.7 and 6 respectively. All diets in the dry and hot season recorded the highest pH value in the range of 7.1 to 7.3. The lowest pH was observed in the finisher diet in the dry and cold season with a value of 6. The lower pH observed, especially in the wet and hot season in all seasons, and the grower and finisher pens in the dry and cold season, can be explained by Blackshaw & Blachshaw (1994) that during high temperatures, cattle tend to decrease feed intake to maintain a thermo-neutral internal environment to avoid heat stress, since heat is produced from the rumination fermentation process. A decrease in forage intake occurs, especially during hot weather, whilst concentrate intake remains relatively constant (Beede & Collier, 1985). This decrease in forage intake results in a decrease in rumination frequency, which results in a lowered rumen pH (Bailey & Balch, 1961). A lowered rumen pH, due to high concentrate diets, according to Nagaraja & Titgemeyer (2007), resulted in an increase in lactic acid producing bacteria, and an increased feed flow through the digestive tract with a lower overall pH. Redding *et al*. (2015) observed that the pH decreased with higher moisture content of the manure, possibly as a result of decreased oxygen diffusion and supply. This should explain the decrease in pH observed in the wet and hot season in the present trial.

Feedlot pen surface DM observed differences ($P<0.05$) in the starter, grower and finisher diets between the dry and cold season (46.4%, 53.4% and 41.7% respectively) as compared to the starter, grower and finisher diets in the dry and hot (40%, 37.9% and 35.5% respectively) and the wet and hot (38.8%, 35.5% and 33.5% respectively) seasons respectively. No difference ($P>0.05$) was observed between the dry and hot, and the wet and hot seasons for the starter, grower and finisher diets for feedlot pen surface DM. Within the dry and cold season differences ($P<0.05$) were observed between each diet for feedlot pen surface DM. In the dry and hot season a difference ($P<0.05$) between the finisher diet compared to the grower and starter diets was observed for feedlot pen surface DM. No difference ($P>0.05$) between starter and grower diets were observed within the dry and hot season for feedlot pen surface DM. Within the wet and hot season the starter (38.8%) and finisher (33.5%) diets observed a difference ($P<0.05$) compared to the grower (35.5%) diet for the feedlot pen surface DM. Feedlot surface DM is related to rainfall occurring within each season. This is shown in Figure 8 with the rainfall being lowest in the dry and cold season, then increasing slightly in the dry and hot season and the highest in the wet and hot season. This is shown in the surface DM values which are lowest in the dry and cold season, and highest in the wet and hot season for all the diets fed. Olkowski (2009) observed that the intake of fed by cattle was lower during the hot season and water intake higher as compared to the cold season. Thus seasonal effects will also affect the consistency of manure excreted (Olkowski, 2009). Nardone *et al*. (2010) also explained how water intake by cattle is lower in cold temperatures and higher in hot temperatures; this would ultimately affect defecated manure DM content and so would also affect the surface DM content. Liao *et al*. (2018) explained how soil surface composition affected manure moisture content, in a relatively new surface there was a faster decline of manure DM due to a greater soil hydraulic conductivity which was indicated by higher soil porosity as compared to an established surface. This can come into effect after pen cleaning in the feedlot with a recently cleaned pen having higher soil porosity due to the limited layer of manure present.

The ash concentration of the feedlot pen surface observed differences ($P<0.05$) in the starter diet between the dry and hot season (4.6%) as opposed to the dry and cold (5.9%) and the wet and hot (6.1%) seasons. No difference ($P>0.05$) was observed between the dry and cold, and the wet and hot seasons for the starter diet for the feedlot pen surface ash concentration. With the grower diet, a difference ($P<0.05$) was observed between the dry and cold (5.3%) and the dry and hot (6%) seasons as compared to the wet and hot (7.1%) season. No difference ($P>0.05$) was observed between the dry and cold, and the dry and hot seasons for the grower diet for the feedlot pen surface ash concentration. For the finisher diet, a difference ($P<0.05$) between the dry and cold (5.6%) season and the wet and hot (6.6%) season was observed. The dry and hot season (5.9%) observed no difference ($P>0.05$) to both the dry and cold, and the wet and hot seasons for the finisher diet for feedlot pen surface ash concentration. Within the dry and cold season, a difference ($P<0.05$) was observed between the starter and grower diet for the feedlot pen surface ash concentration. There was no difference ($P>0.05$) observed between the starter and finisher diets and the grower and finisher diets for feedlot pen surface ash concentration within the dry and cold season. Within the dry and hot season, a difference ($P<0.05$) was observed for the starter diet as compared to both the grower and finisher diets. No difference ($P>0.05$) was observed for the grower and finisher diets within the dry and hot season for feedlot pen surface ash concentration. Within the wet and hot season, differences were observed between the starter and finisher diets measured for the feedlot pen surface ash concentration, but not between the starter and grower diets and not between the grower and finisher diets. the ash concentration in the feedlot manure is lower than observed by Font-Palma (2019) who recorded feedlot manure low ash of 13.85% DM basis. Font-Palma (2019) recorded a manure ash range of 13.58% for low ash manure to 45.23% for feedlot manure high ash. The increase ($P<0.05$) in ash, from starter to finisher diets, concentration can be explained based on temperature effects as described for feedlot surface temperature. Higher ambient temperature should have caused a decrease in feed intake. This results in less rumination occurring and more feed particles escaping digestion and ending up in the manure according to Muir (2011). Thus, if more feed particles are escaping digestion and ending up in the faeces the inorganic content of the manure will increase (Amon *et al*. 2001), thus so will the ash concentration. This can be seen as temperature increases in each season for the grower and finisher diets. However, the ash concentration of the soil surface gives an indication on the amount of soil present in the sample along with manure, with the higher ash value indicating more soil content in the sample taken (Von Eman *et al*., 2016).

For feedlot pen surface N concentration, differences ($P<0.05$) were observed for each diet fed between each season measured. The wet and hot season recorded the highest N values for each diet, 2.77% for starter, 2.80% for grower and 2.84% for finisher as compared to the same diets in the dry and cold season with 2.39% for starter, 2.54% for grower and 2.63% for finisher, and the dry and hot season with 2.54% for starter, 2.71% for grower and 2.81% for finisher, seasons respectively. Sørensen *et al*. (2003)

explained that the amount of N in the manure is affected by diet, feed digestibility and endogenous N. Manure contains substantial quantities of nitrogen with the majority of the nitrogen being inorganic (Amon *et al.* 2001; Chadwick *et al*., 2011). In Table 7 the CP values for the diet feeds, as supplied by the feedlot, were higher in the wet and hot season compared to the other seasons. This may be due to the quality of raw materials available during that season. The N concentration varied slightly between feedlot pen surface manure due to the sampling method being random, and the base of the chamber being placed on an area within the pen that had a low concentration of manure present (Gautam *et al*., 2016). It might also be due to the different CP levels in the different diets fed as shown in Table 7. The amount of N deposited, from manure and urine patches, even though not measured in the present study, and thus available on the sample site, is affected by diet, feed digestibility and endogenous N (Sørensen *et al*., 2003).

Feedlot pen surface NDF concentration observed a difference ($P<0.05$) in the starter diet between each season measured. Both the grower and finisher diets observed differences ($P<0.05$) between the dry and cold season (47.2% for grower and 45.4 % for finisher) and the wet and hot season (46.5% for grower and 45.7% for finisher) as compared to the dry and hot season (44.5% for grower and 37.5% for finisher) for feedlot pen surface NDF. No difference ($P>0.05$) between the dry and cold season, and the wet and hot season for the grower and finisher diets was observed for feedlot pen surface NDF concentration. Within the dry and cold season (starter 50.9%, grower 47.2% and finisher 45.4%) and the dry and hot season (41.8% starter, 44.5% for grower and 37.5% for finisher) differences ($P<0.05$) between each diet level were observed for the feedlot pen surface NDF concentration. Within the wet and hot season (starter 46.5%, grower 46.5% and finisher 45.7%) no difference ($P>0.05$) was observed for each diet level measured for the feedlot pen surface NDF concentration. The NDF concentration of the manure indicates the fraction of lignin, cellulose and hemicellulose (Von Eman *et al*., 2016). The NDF level for feed is used to measure forage intake. A decrease in forage intake at higher temperatures will result in a lower expected NDF value in the manure. This is observed in the hot seasons (dry and hot and wet and hot seasons) in the trial as presented in Table 9 when comparing within each diet fed in the dry and cold season. However the lowest NDF value for each diet was observed in the dry and hot season and then the wet and hot season. However, in the present trial a decrease in feed intake was not observed in the hot seasons with the wet and hot season having the highest average feed intake.

Feedlot pen surface ADF concentration observed differences ($P<0.05$) in the starter diet between each season measured (31.8% for dry and cold, 28.3% for dry and hot and 35.4% for wet and hot). The grower diet observed a difference ($P<0.05$) in the dry and cold (32.2%) season and the wet and hot (33.1% receptively) season as compared to the dry and hot (28.4%) season. The finisher diet observed a difference between the wet and hot season (36.2%) compared to the dry and cold (28.1%) season and the dry and hot (26.5%) season. Within the dry and cold season, and the dry and hot season, differences ($P<0.05$) between the finisher diets as compared to the grower and starter diets were observed for feedlot pen surface ADF concentration. Within the wet and hot season, a difference ($P<0.05$) between the grower diet compared to the starter and finisher diets was observed for feedlot pen surface ADF concentration. No difference ($P>0.05$) was observed within the wet and hot season between the starter and finisher diets for feedlot pen surface ADF concentration. The ADF concentration of the manure indicates the lignin and cellulose fraction (Von Eman *et al*., 2016). Cellulose and hemicellulose are partly broken down to a certain extent by the microbes in the rumen where lignin is not degraded at all. If a decrease in digestion occurs, due to an increase passage or decrease in intake, one can expect a higher proportion of ADF and NDF in the manure. Working on the assumption that what is consumed and excreted are in relative proportions intake can be expected to increase from the starter ration to the finisher ration for the dry and cold and the wet and hot seasons, this is shown in Table 8. The dry and hot season had a lower starter NDF to grower NDF concentration. The ADF concentration would suggest that in each season the availability of nutrients in the diet, as seen in Table 7, or the cattle's ability to digest the concentrate fed (as rumen microbial populations establish to digest the high concentrate diets) (Krehbiel *et al*., 2003), increased from starter to finisher diets.

The differences observed overall, for most of the pen surface parameters, were directly related to the season and the presence of manure in the sampling area in each pen, as described. This suggests that the difference between the seasons played an important role on the feedlot pen surface parameters as depicted in Table 9 and described by Uchida *et al.* (2008).

4.1.4 Seasonal feedlot methane and nitrous oxide emissions per diet

The CH_4 and N_2O emissions recorded from the feedlot pen surfaces are depicted in Table 10.

Table 10 Feedlot pen surface methane and nitrous oxide emissions between diets fed and seasons in the feedlot

Feedlot surface parameter	Diets	Dry and cold	Dry and hot	Wet and hot	SE
CH_4 (mg/m^2/hr)	Starter	1.1_2	2.1_2	2_2	1.5
	Grower	$0.5^b{}_3$	$4.9^a{}_1$	$4.6^a{}_1$	1.5
	Finisher	2.7_1	2.8_2	2.7_2	1.5
	SE	0.87	0.87	0.87	
N_2O (mg/m^2/hr)	Starter	0.7 x 10^{-2}	0.4 x10^{-2}	0.3 x10^{-3}	0.65
	Grower	0.4x 10^{-1}	0.8x 10^{-3}	0.2 x 10^{-3}	0.65
	Finisher	0.2 x 10^{-1}	0.2 x 10^{-2}	0.7 x10^{-3}	0.65
	SE	0.37	0.37	0.37	

*[a, b, c] Means in a row with different superscripts differ (P<0.05), [1, 2, 3] Means in a column with different subscripts differ (P<0.05), *CH_4* (methane), *N_2O* (nitrous oxide), *SE* (standard error)

Feedlot pen surface CH_4 emissions observed a difference (P<0.05) in the grower diet between the dry and hot season (4.9 mg/m^2/hr) and the wet and hot season (4.6 mg/m^2/hr), compared to the dry and cold season (0.5 mg/m^2/hr). Within the dry and cold season, differences (P<0.05) were observed between each of the diets (starter 1.1 mg/m^2/hr, grower 0.5 mg/m^2/hr and finisher 2.7 mg/m^2/hr). Within the dry and hot season, and the wet and hot season, a difference between the starter (2.1 mg/m^2/hr for dry and cold and 2 mg/m^2/hr for wet and hot season) and finisher (2.8 mg/m^2/hr for dry and hot and 2.7 mg/m^2/hr for wet and hot season) diets as compared to the grower diet (4.9 mg/m^2/hr for the dry and hot and 4.6 mg/m^2/hr for the wet and hot season) was observed. No differences (P>0.05) were observed for N_2O between seasons, and between diets within seasons.

Feedlot pen surface CH_4 flux values for the diets fed and seasons resulted in the highest CH_4 value of 4.9 mg CH_4/m^2/hr from the grower pens in the dry and hot season. The second highest CH_4 value was observed in the grower pens occurring in the wet and hot season with a CH_4 flux value of 4.6 mg CH_4/m^2/hr. In the dry and cold season the lowest recorded CH_4 flux, in the grower, with a value of 0.5 mg CH_4/m^2/hr was observed. According to Chadwick (2004) CH_4 and N_2O emissions from beef cattle manure are dependent on a variety of factors including seasonal factors, type of feed fed to cattle, water intake of cattle and the most important factor being waste management. For all the seasons, the finisher pens had similar CH_4 flux values that were recorded as the second highest in the seasons, of 2.7 mg CH_4/m^2/hr for dry and cold, 2.8 mg CH_4/m^2/hr for dry and hot and 2.7 mg CH_4/m^2/hr for wet and hot respectively. The starter pens had the lowest recorded CH_4 flux values in the dry and hot, and the wet and hot season. The starter pens in the dry and cold season recorded a value of 1.1 mg CH_4/m^2/hr which was higher than the grower pens within the same season. Starter CH_4 in the dry and hot season was 2.1 mg CH_4/m^2/hr, and in the wet and hot season it was 2.0 mg CH_4/m^2/hr. The variation observed between diets, starter, grower and finisher diets, may be due to the different CP values fed in each diet, as shown above in Table 7. Montes *et al.* (2013) reported that diet affects manure CH_4 emissions. Decreasing the dietary protein concentration resulted in an increase in the fermentable carbohydrates portion in the diet, which resulted in an increase in CH_4 production from excreted manure (Montes *et al*., 2013). However this was not observed with the grower diets in the present trial as seen in Table 10. A decrease in CP was observed between the trial diets as seen in Table 7. The starter diets had the highest CP values in each season, followed by the grower diets and the finisher diets having the lowest CP values. Boadi *et al.* (2004) stated that a higher dietary N content resulted in a greater release of CH_4 from manure. This was not seen in the present trial with the grower pens resulting in larger CH_4 production except in the dry and cold season. In the diet rations, in Table 7, the higher CH_4 flux, in the

grower pens between seasons, can be explained by the grower surface having a slightly higher N concentration in the dry and cold season, and the wet and hot season as compared to the dry and cold season as seen in Table 9. However, the small difference observed between the grower and finisher surface N concertation values does not fully explain the CH_4 values observed for those diets in each of the seasons. In Table 9 the feedlot pen surface N concentration for the finisher diet was the most consistent ranging between 2.63 to 2.84%, whilst the starter diet ranged from 2.39 to 2.77% and the grower 2.54 to 2.80%.

Boadi *et al.* (2004) recorded values of 11.0 and 17.7 g CH_4/pen/day. Converting the largest CH_4 flux observed from the pens measured in the present trial, it would be the 4.9 mg CH_4/m^2/hr, which would result in a value of 147 g CH_4/pen/day, using a pen size of 1250m^2. The value obtained from the trial was higher than observed by Boadi *et al.* (2004). This may be due to the different environmental conditions experienced between Canada and South Africa, such as temperature, atmospheric moisture, as well as a difference in pen size, 685 m^2 for Boadi *et al*. (2004) as compared to 1250m^2 in the present trial, and cattle stocking rate per pen, 14 animals/pen for Boadi *et al*. (2004) as compared to a range of 113-237 animals/pen in the present trial. When comparing the pen sizes between Boadi *et al*. (2004) and in the present trial the present trial had more space available per animal than Boadi *et al*. (2004) which may have influenced gas emissions by decreasing animal trampling of manure in the larger pen's, providing a more suitable environment for CH_4 emissions as the manure was not aired by foot traffic. Boadi *et al*. (2004) described how the thicker portions of manure packs have the most favourable conditions for microbial decomposition of organic matter to CH_4. This explains the difference observed in gas emissions due to the quantity of manure that the chamber base landed on in the measurement period. However, if one factors in the pen space per cattle for Boadi *et al*. (2004), with 14 animals in 685 m^2, one would get a stocking rate of 49m^2/animal. In the present trial with 113 to 237 animals in 1250m^2 pens the stocking rate varied from 5.3 to 11 m^2 /animal. Thus, a factor of 4.5 or 9, depending on animal numbers, between Boadi *et al*. (2004) and the present trial is calculated. This converts to a data range of 80 to 156 g CH_4/pen/day as reported by Boadi *et al*. (2004). Thus the recorded value of 147 g CH_4/pen/day in the present trial falls within the range calculated from Boadi *et al*. (2004) when space per animal is factored in.

The N_2O flux, depicted in Table 10, for the diets in the dry and cold season was as follows. In the starter diet a flux of 0.7 x 10^{-2} mg/m^2/hr, 0.4 x 10^{-1} mg/m^2/hr for the grower diet and 0.2 x 10^{-1} mg/m^2/hr for the finisher diet respectively. In the dry and hot season the starter diet had a N_2O flux of 0.4 x 10^{-2} mg/m^2/hr, the grower diet observed a N_2O flux of 0.8 x 10^{-3} mg/m^2/hr and the finisher diet observed a N_2O flux of 0.2 x 10^{-2} mg/m^2/hr. In the wet and hot season a N_2O flux of 0.3 x 10^{-3} mg/m^2/hr for the starter diet was observed, 0.2 x 10^{-3} mg/m^2/hr for the grower diet was observed and 0.7 x 10^{-3} mg/m^2/hr for the finisher diet was observed. Although no difference ($P>0.05$) were recorded within and between diets and seasons there was an indication that the dry and cold season had the highest N_2O flux for the starter and finisher pens, whilst the grower pen in the dry and hot season had the highest flux recorded overall all the diets and seasons measured. Gallardo (2013) described how soil water content and temperature affect the rate of decomposition of soil organic matter which affects ultimate N_2O emissions by supplying adequate moisture and temperature for N_2O production. In Table 9 the manure DM percentage per diet and season is shown. The recorded manure moisture and resulting N_2O flux does not support Gallardo's data. This may be due to the N_2O flux being very small. Boadi e*t al*., (2004) recorded a N_2O emission rate of 0.134 mg N_2O/m^2/hr. The value is much higher than was recorded in the present trial. Parker *et al.* (2017b) observed a N_2O value of 0.025 $\pm$ 0.0016 mg/m^2/hr, which is lower than Boadi's *et al*. (2004) results, but in the region of 0.04 mg/m^2/hr and 0.02 mg/m^2/hr observed in the dry and cold season grower and finisher diets respectively. Liao *et al*. (2018) recorded N_2O emission from a feedlot, with high dung frequency, of 0.03 to 0.77 mg/m^2/hr which is close to the grower and finisher diet N_2O emission in the cold and dry season in the present trial. Nitrous oxide emissions from open feedlots are generally smaller than those obtained from agricultural soil according to Waldrip *et al.* (2016). The difference observed between the present trial and Boadi *et al.* (2004) is more likely to be the result of differing atmospheric conditions between Canada and South Africa, as well as pen size, cattle number and manure pack depth (Boadi *et al*., 2004), whilst the difference observed between Parker *et al*. (2017 b) and the present trial overall (excluding the grower and finisher diet N_2O fluxes in the dry and cold season) could be as a result of atmospheric conditions, however the panhandle in Texas USA had dusty and dry conditions, which would be similar to conditions experienced in the present trial. The differences observed between Parker *et al*. (2017 b) and the present trial may be due to the random sampling procedure followed in the present trial, and the trial followed by Parker *et al*. (2007 b) in which water was added to dried manure to determine N_2O production whilst in the present trial the N_2O production was calculated from manure already present in the pens with no additional water added unless through climatic conditions. Redding *et al*. (2015) observed that the higher moisture content of manure/soil is

associated with decreased emissions, possibly as a result of decreased oxygen diffusion and supply. This explains the lower N_2O emission in the wet and hot season as compared to the two dry seasons measured as seen in Table 10. This is supported in Table 9, with an overall higher moisture concentration for the pen/manure surface.

The carbon and nitrogen content of the soil could contribute towards available substrate and microbial activity available for gas production (Ryals & Silver, 2013). Liao *et al.* (2018) observed that established feedlot pen surface soils usually have a greater N and C content, with feedlots being important sites for GHG production, particularly N_2O, through the process of nitrification and denitrification due to the high concentrations of N (Liao *et al.*, 2018).

4.1.5 Feedlot methane and nitrous oxide emission per head per day per season

Using the average number of animals per diet level and season, depicted in Table 8, as well as the average CH_4 and N_2O emissions per diet level, depicted in Table10, and the average pen size (m^2), the following CH_4 and N_2O emissions (g/head/d) were estimated as shown in Figure 17 and Figure 18 respectively. Figure 17 and Figure 18 show the feedlot pen surface CH_4 and N_2O emissions in grams per head per day (g/head/d) observed per diet level in the feedlot.

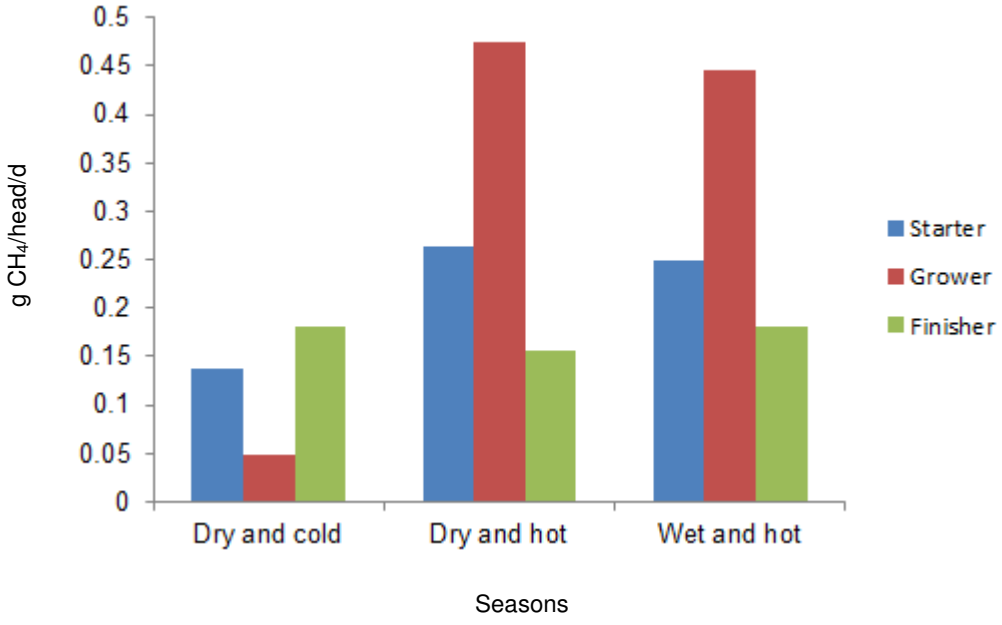


Figure 17 Methane emissions (g/head/d) for feedlot pen surfaces for each respective season

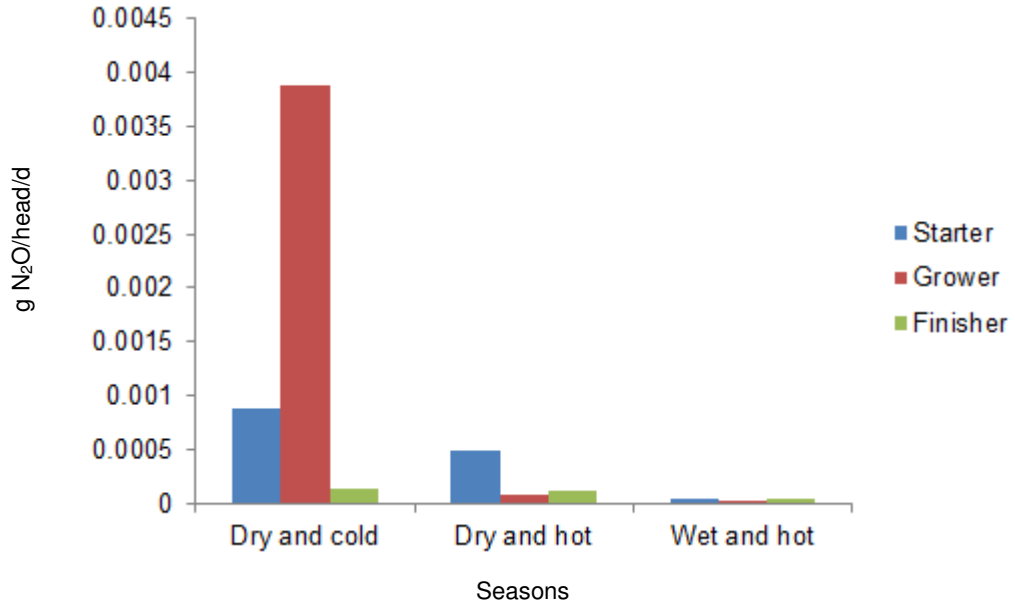


Figure18 Nitrous oxide emissions (g/head/d) for feedlot pen surfaces for each respective season

Using the average number of animals per diet level and season, depicted in Table 8, as well as the average CH_4 and N_2O emissions per diet level, depicted in Table10, and the average pen size (m^2), the following CH_4 and N_2O emissions (g/head/d) were estimated as shown in Figure 17 and Figure 18 respectively. Feedlot pen surface CH_4 emissions per head for the dry and cold season were as follows, starter diet was 0.138 g/head/d, grower diet 0.048 g/head/d, and finisher diet 0.18 g/head/d. Feedlot pen surface CH_4 emissions for the dry and hot season were 0.26 g/head/d for starter, 0.47 g/head/d for grower and 0.16 g/head/d for finisher diets respectively. Methane emissions for the wet and hot season were 0.25 g/head/d for starter diet, 0.45 g/head/d for grower diet and 0.18 g/head/d for the finisher diet level. Du Toit *et al*. (2013) estimated a CH_4 flux for beef cattle manure of 0.87 kg/head/yr, which converts into 2.38 g/head/d. This value is higher than the CH_4 values recorded in g/head/d for CH_4 in the present trial. Du Toit *et al*. (2013) estimated emissions for manure. In the present study, the emissions were measured from feedlot pen surfaces in which the amount of manure within sample sites varied. This could explain the lower CH_4 emissions reported for the present trial compared to Du Toit *et al.* (2013). Montes *et al.* (2013) observed a feedlot pen surface CH_4 emission of 38 g/head/d which is much higher than observed in the present trial but there is a large variation in climatic conditions, such as temperature and rainfall, between New Zealand and South Africa, and differences in diet may also have contributed to the variances between the two countries. New Zealand diets are predominantly silage-based diets (White *et al*., 2010) as compared to the maize based diets used under South African conditions. Ghafoori *et al*. (2006) reported CH_4 values of 0.7 to 1.2 g/animal/day and 1.5 to 2 g/animal/day, which is larger than the values calculated in this trial. Ghafoori *et al*. (2006) trial was based in North America. The North American climate is cooler and annual rainfall larger than that experienced in South Africa, as well as the quantity of manure present in the chamber bases through the random sampling procedure followed in the present trial, as compared to values extrapolated from individual dung pats in Ghafoori *et al*. (2006) trial. This would have contributed to the difference observed in the present trial data as compared to data reported by Ghafoori *et al*. (2006).

Nitrous oxide emissions, shown in Figure 18, for the dry and cold season were 0.87×10^{-3} g/head/d for starter diet level, 0.39×10^{-2} g/head/d for grower diet level and 0.13×10^{-3} g/head/d for finisher diet level. During the dry and hot season the starter diet level produced 0.5×10^{-3} g/head/d of N_2O emissions, 0.77×10^{-4} g/head/d for grower diet level and 0.11×10^{-3} g/head/d for finisher diet level. The wet and hot season produced N_2O emissions of 0.38×10^{-4} g/head/d for starter diet, 0.19×10^{-4} g/head/d for grower diet and 0.47

x 10^{-4} g/head/d for finisher diet. Du Toit *et al.* (2013) estimated a N_2O value, for manure, of 0.457 kg/head/yr for South African feedlot cattle, which converts into 1.25 g/head/d N_2O, which is higher than the N_2O emissions observed for the diets in each season measured in the present trial. This N_2O value differs with the observed values from the present trial with the highest N_2O value observed being 189.1 mg/head/d in the dry and cold season's starter diet. Montes *et al*. (2013) reported a value of 3.8 g N_2O/head/day, which converts to 3800 mg N_2O/head/day, which is much larger than reported values in the present trial for feedlot pen surfaces in each diet level. This is more likely due to the climatic differences between New Zealand and South Africa as described for CH_4 emissions. Boadi *et al.* (2004) recorded N_2O emissions of 2.2 and 2.4 g/pen/d, which according to Muir (2011) equates to 0.15 g/head/d. This value is lower than data from Muir (2011) who reported 7.0 and 5.4 g/head/d. Muir (2011) described how the difference observed was due to the cool climate that Boadi *et al*., (2004) was conducted in. Values obtained by Boadi *et al*. (2004), although lower than Muir's, were still larger than observed N_2O values obtained in this trial. The varying N_2O emission rates from feedlot pen surfaces may be due to sampling differences but there is a pattern observed in Figure 18 in the hot and dry, and hot and wet seasons with the starter diets in each season having a higher N_2O flux, followed by the grower diets, with the finisher diets having the lowest N_2O flux out of all the seasons although not significant ($P>0.05$). The cold and dry season differed from the pattern observed in the other seasons with the starter diet having a much larger overall N_2O flux value compared to the other seasons' diets, followed by the finisher diets, and then the grower diets. Montes *et al*. (2013) described how N_2O emissions are as a result of microbial processes, and were thus highly variable and influenced by environmental and metabolic factors. Chantigny *et al*. (2007) and Li *et al*. (2011) described how N can be taken up by soil or microorganisms which would explain how the N_2O fluxes were so low for each diet level in the relative seasons in the present trial, although this was not evaluated in the present trial.

4.2 Rangeland

4.2.1 Rangeland soil, grass nutrient and backgrounding feed composition

The rangeland soil composition during each season is reported in Table 11.

Table 11 Seasonal rangeland soil composition

Season	Clay %	Silt %	Sand %	Carbon %	NO_3-N mg/kg	NH_4-N mg/kg
Dry and cold	21	22	57	7.7	150	26.8
Dry and hot	21	22	57	6.3	118.8	22.8
Wet and hot	21	22	57	6.6	180.3	13.9

*NO_3-N (nitrate nitrogen), NH_4-N (ammonium nitrogen)

Although not statistically analysed the rangeland soil composition did not differ with regards to the soil texture over the different seasons. However, soil N concentrations did seem to vary across the seasons. This may have been due to seasonal changes in soil organic matter, C and N concentration, at the rangeland sample sites due to increased manure deposition (Chadwick *et al.,* 2011), or different rates of manure decomposition based on environmental effects (Arifin *et al*., 2018). Table 12 reports the nutrient concentration of rangeland grass and backgrounding supplement during background operations across the different seasons.

Table 12 Rangeland and supplement nutrient composition offered to cattle under backgrounding operations (100% DM)

Season	Ration	Ash %	CP %	Starch %	Ether Extract %	NDF %	ADF %
Dry and cold	Background supplement	10.2	15.4	14	6.2	29.3	13.5
	Rangeland grass	6.7	3.5	4	3.3	75.2	45.2
Dry and hot	Background supplement	7.6	15.9	14.9	5	43.2	26.5
	Rangeland grass	4.7	7.8	3	1.4	55.2	43.4
Wet and hot	Background supplement	8.1	16.7	18.8	5.5	36.2	24.5
	Rangeland grass	7.2	8.4	8.6	3.4	51.9	30.6

CP (crude protein), *ADF (*acid detergent fibre), *NDF* (neutral detergent fibre)

According to Meissner (1997) South African grasses mainly fall into the subtropical zone. Although not statistically analysed, the rangeland grass showed the highest variation in nutrient concentration between seasons. There was a noticeable change in quality of rangeland as it matured (Smart *et al*., 2012). Weinmann (1940) explained how total carbohydrates and sugars accumulated in grass roots as grass matured, and how sugars and carbohydrates decreased in roots during spring when the grass is sprouting and growing. This indicates that when the grass is growing it has a higher sugar and soluble carbohydrate portion in the grass stems and leaves than when the grass is mature. Spring in the present trial is in the dry and hot season going into the wet and hot season. The dry and cold season is the winter season.

The highest CP % was observed in the wet and hot season with a value of 8.4%, with the dry and cold season having the lowest CP percentage with a value of 3.5%. Meissner (1997) described how low CP was observed in the dry season of sour-veld areas in South Africa. The high CP value for rangeland grass in the wet and hot season was due to the grass having young green leaves, and may be due to the supplementation of manure over time which has resulted in a well fertilized soil to grow in with adequate watering, as a result of the rainy season, can be seen in Table 11 in the increase in NO_3-N mg/kg observed over the seasons. The varying NDF and ADF portion, as seen in Table 12, of the rangeland grass collected in each season may be due to the physiological stages of grass growth, as well as the variation within, and between seasons. According to Meissner (1997) intake by animals is generally limited above NDF concentrations of 550 to 600g/kg DM but not below those concentrations. Meissner (1997) reported that most subtropical grasses at time of grazing would contain NDF concentration above this indicator level. The CP % of the backgrounding concentrate was higher than observed values in the grower and finisher rations of Gautam *et al.* (2016), as shown in Table 12. This is to be expected as it is a supplement feed fed to the backgrounding cattle to assist cattle growth. The CP value of the rangeland grass in the dry and hot season, and the wet and hot season were within the range observed in the mixed hay in Gautam *et al*. (2016), who observed a value of 7.42% CP. The ether extract value in the dry and cold season rangeland grass is higher than observed in the dry and hot season, and the wet and hot season. The NDF concentration for the background supplement in the dry and hot (43.2%) season observed a higher value compared to the other seasons (29.3% for the dry and cold season and 36.2% for the wet and hot season). The NDF concentration in the wet and hot season was also higher than expected for the backgrounding supplement. For rangeland grass the NDF concentration observed was 75.2% for the dry and cold season, 55.2% for the dry and hot season, and 51.9% for the wet and hot season. Raffrenato *et al*. (2018) observed NDF concentration of 59.2% for eragrostis species. This is more in line with the NDF concentration obtained from the rangeland grass, with the wet and hot season's grass being in line with the ryegrass, and the dry and cold and dry and hot falling between the ryegrass and Eragrostis concentrations observed by Raffrenato *et al*. (2018). The concentrations reported by Raffrenato *et al.* (2018) are for 24 Eragrostis samples collected in South Africa harvested at various vegetative states to increase variability. Du Toit (2017) recorded NDF values of 68.09% for *cenchrus ciliarus* (dhaman grass), 69.33% for *chloris gayana* (rhodes grass), 59.73% for *digitaria erianthra* (digit grass) and 64.84% for *panicum maximum* (guinea grass) with 0 N kg/ha fertilizer application. In the present trial the closest NDF value was to *digitaria erianthra* with a value of 55.2 % in the dry and hot season. Du Toit (2017) recorded a NDF value of 73.04 % for *cenchrus ciliarus* (dhaman grass) with a fertilizer application rate of 50 N kg/ha. This value is similar to the rangeland NDF value in the dry and cold season. With respect to the obtained ADF concentrations, the ADF concentrations for the rangeland grass in

the dry and cold season was lower than expected, with a concentrations of 43.4% as this is when the grass has matured and an increase in ADF is expected in related to grass age. Raffrenato *et al*. (2018) observed ADF concentrations of 31.7% in Eragrostis grass. Du Toit (2017) recorded ADF values of 40.49% for *cenchrus ciliarus* (dhaman grass), 35.53% for *chloris gayana* (rhodes grass), 35.02% for *digitaria erianthra* (digit grass) and 36.03% for *panicum maximum* (guinea grass) with 0 N kg/ha fertilizer application. These concentrations are lower than observed in the present trial for the dry and cold season and dry and hot season, and higher than the value recorded in the wet and hot season. This may be due to the varying grass species in the rangeland in the present trial and the conditions that the rangeland grass grew under.

4.2.2 Rangeland manure methane and nitrous oxide emission and composition per season

The manure composition and CH_4 and N_2O emission fluxes from the backgrounding operation are reported in Table 13

Table 13 Rangeland manure parameters between seasons (as is basis)

	Seasons			
Manure parameter	Dry and cold	Dry and hot	Wet and hot	SE
CH_4 (mg/m^2/hr)	5.2^a	1.1^b	1.1^b	1.7
N_2O (mg/m^2/hr)	0.2^a	0.1 x10^{-1b}	0.9 x10^{-2b}	0.4 x10^{-1}
Temperature (°C) of manure	6.1^c	28.2^b	33.6^a	1.2
pH	9.1^a	8.1^b	8^b	0.1
DM (%)	22.2^a	24^b	31.9^c	1
Ash (%)	2.8^b	2.6^b	8.3^a	0.5
N (%)	1.86^b	1.86^b	1.96^a	0.09
NDF (%)	64.2^a	56.3^c	58.2^b	1.1
ADF (%)	50^a	37.6^c	48^b	1

*$^{a, b, c}$ Means in a row with different superscripts differ (P<0.05), *CH_4* (methane), *N_2O* (nitrous oxide), *DM* (dry matter), *N* (nitrogen), *ADF* (acid detergent fibre), *NDF* (neutral detergent fibre), *SE* (standard error)

Rangeland CH_4 from manure observed a difference between the dry and cold (5.2 mg/m^2/hr) season compared to both the dry and hot season (1.1 mg/m^2/hr), and the wet and hot (1.1 mg/m^2/hr) season. No difference (P>0.05) was observed for CH_4 between the dry and hot season as compared to the wet and hot season. Rangeland N_2O observed differences (P>0.05) between the dry and cold season (0.2 mg/m^2/hr) compared to the dry and hot and wet and hot seasons (0.1 x 10^{-1} mg/m^2/hr for the dry and hot and 0.9 x 10^{-2} mg/m^2/hr for the wet and hot season). The rest of the rangeland manure characteristics (temperature, pH, moisture, ash, N, ADF and NDF) showed differences (P<0.05) between the seasons as reported in Table 13. Rangeland manure temperature observed differences (P<0.05) between each season measured (6.1 °C for dry and hot, 28.2 °C for dry and hot, 33.6 °C for wet and hot). According to rangeland manure temperature data, displayed in Table 13, the rangeland manure temperature recorded temperatures closer to the recorded ambient temperature, as seen in Table 5. Rangeland manure pH observed a difference (P<0.05) between the dry and cold (pH 9.1) season compared to the dry and hot (pH 8.1) season, and the wet and hot (pH 8) season. No difference (P>0.05) was observed for rangeland manure pH between the dry and hot season, and the wet and hot season. Overall the DM concentration of rangeland manure in the wet and hot season was higher (P<0.05) than the other seasons. This may be a result of the lack of rain over the measuring period in the wet and hot season with the higher temperature aiding manure drying. Rangeland manure temperature was taken at the beginning of each gas sampling day and recorded. Rangeland manure

ash and N concentration observed differences ($P<0.05$) between the dry and hot season (2.6% ash and 1.86% N), and the wet and hot (8.3% ash and 1.96% N) season as compared to the dry and cold (2.8% ash and 1.86% N) season. Manure ash in the wet and hot season was very high in comparison to the other seasons; this may be due to the manure being contaminated with soil. No difference ($P>0.05$) was observed for rangeland manure ash and N concentration between the dry and cold season and the dry and hot season. Rangeland manure ADF concentration and NDF concentration observed differences ($P<0.05$) between all the seasons measured (50% ADF and 64.2% NDF for dry and cold, 37.6% ADF and 56.3% NDF for dry and hot and 48% ADF and 58.2% NDF for wet and hot). The difference between the rangeland manure chemical parameters measured would more likely be as a result of the change in the diet's nutrient composition (Boadi *et al*., 2004). This would be due to the change in nutrient composition of the rangeland grass over the seasons (Meissner, 1997), as well as the variation in supplement used in the different seasons of the year as reported in Table 12.

The CH_4 flux for the rangeland was 5.2 mg $CH_4/m^2/hr$ for the dry and cold season, 1.1mg $CH_4/m^2/hr$ for the dry and hot season and 1.1mg $CH_4/m^2/hr$ for the wet and hot season. A difference ($P<0.05$) was observed between the dry and cold season as compared to the dry and hot season, and the wet and hot season for CH_4. No difference ($P>0.05$) was observed for CH_4 flux between the dry and hot season, and the wet and hot season. The N_2O flux for rangeland was 0.2 mg $N_2O/m^2/hr$, 0.1 x 10^{-1} mg $N_2O/m^2/hr$ and 0.9 x 10^{-2} mg $N_2O/m^2/hr$ for the dry and cold season, the dry and hot season, and the wet and hot season respectively. A difference ($P<0.05$) was observed between the dry and cold season as compared to the dry and hot season, and the wet and hot season for N_2O. No difference was observed for N_2O emission between the dry and hot season, and the wet and hot season. The CH_4 flux calculated on the rangeland is much smaller than observed in literature with regards to feedlot pen results. However, none of the values displayed in Table 2 is specific for rangeland CH_4 fluxes as limited research has been done on extensive rangeland CH_4 emissions as influenced by beef cattle manure. Nichols *et al*. (2016) observed a net uptake of CH_4 from native rangeland. This was attributed to a lack of moisture to allow methanogenic activity to occur within the soil. The N_2O flux calculated for the rangeland in the present trial was small. Nichols *et al*. (2016) observed a range, on a plot of 1.26 to 1.27 kg N_2O-N/ha for native rangeland. In the present trial the CH_4 flux in the dry and cold season, 5.2 mg $CH_4/m^2/hr$, converts to 1.25 kg/ha, whilst the CH_4 values recorded for rangeland in the wet and hot and dry and hot season, 1.1 mg $CH_4/m^2/hr$, converts to 0.264 kg/ha. The N_2O flux recorded by Nichols *et al*. (2016) is similar to the recorded value in the dry and hot season in the present trial. The dry and cold season's N_2O flux in the present trial was larger than observed from Nichols *et al*. (2016). The larger flux of N_2O observed in the dry and cold season may be due to more favourable conditions experienced by the manure pile, such as adequate oxygen penetration into the pile and adequate moisture, as seen in Table 13, to allow N_2O production to occur at a larger rate than in the dry and hot season and the wet and hot season. The lower moisture content observed in the dry and hot season and wet and hot season may be due to the rate at which the manure dried out in the warmer atmospheric conditions, which may have affected the N_2O production. The small N_2O values calculated on the rangeland in the present trial may be due to N uptake by the soil as described by Chantigny *et al.* (2007) and Chapius-Lardy *et al*. (2007)

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4.3 Effluent dam and manure pile composition, methane and nitrous oxide emission per season

The effluent dam and manure piles were the two forms of manure management on the beef feedlot in the present trial. The manure piles were the main form of manure management, whilst the dams became types of slurry dams due to their function of catching runoff water after rain. Gas emissions from manure piles varied the most between the two management systems and this may be due to the fact that it was the main manure management system that was regularly cleared and replaced throughout the year. Table 14 shows the seasonal variation for manure parameters from the different manure management systems, dry piling and effluent dams

Table 14 Seasonal variation of manure parameters between different manure management systems across seasons (as is basis)

		Seasons			
Manure parameter	Diet	Dry and cold	Dry and hot	Wet and hot	SE
CH_4 (mg/m^2/hr)	Effluent dam	1.2^{b}	82^{b}	345.9^{a}	141.2
	Pile	115.9^{a}	9.2^{b}	249^{a}	122.3
N_2O (mg/m^2/hr)	Effluent dam	0.2^{a}	-0.3x10$^{-1\ b}$	-0.2x10$^{-2\ b}$	1.1
	Pile	-0.9x10$^{-1\ a}$	0.4x10$^{-2\ a}$	0.5x10$^{-2\ a}$	1
Temperature (°C)	Effluent dam	2.5^{c}	26^{b}	30^{a}	2.7
	Pile	42.5^{b}	32.9^{c}	46.8^{a}	2.4
pH	Effluent dam	7.3^{a}	7.5^{a}	7.6^{a}	0.3
	Pile	8.1^{a}	7.9^{a}	6.8^{b}	0.3
DM (%)	Effluent dam	0.5^{a}	3.3^{a}	19.3^{b}	5.1
	Pile	77.2^{b}	87.1^{c}	50.9^{a}	4.4
Ash (%)	Effluent dam	0.3^{a}	1.8^{a}	8.6^{a}	8.9
	Pile	28^{b}	55.7^{a}	12.5^{c}	7.7

*$^{a, b, c}$ Means in a row with different superscripts differ (P<0.05), *CH_4* (methane), *N_2O* (nitrous oxide), *DM* (dry matter), *SE* (standard error)

Due to the small portion of substrate obtained from drying the dam sample, only pH, moisture and ash was analysed for the manure parameters for the manure management systems. A difference (P<0.05) was observed in CH_4 emissions for the effluent dam between the dry and cold season, and the dry and hot season, as compared to the wet and hot season. Manure piles observed a difference (P<0.05) for CH_4 between the dry and hot season as compared to the dry and cold and wet and hot season. No difference (P>0.05) was observed between the dry and cold season, and the dry and hot season for the effluent dam and pile diets. The effluent dam N_2O emissions observed a difference (P<0.05) between the dry and cold season as compared to the dry and hot season, and the wet and hot season. No difference was observed between the dry and hot season, and the wet and hot season for N_2O flux for the effluent dam diet. No differences were observed for N_2O fluxes between seasons in the manure pile diet. Large variations were observed for gas measurements within seasons resulting in a large standard error value for both CH_4 and N_2O due to randomisation of sampling sites and the number of samples taken per site per season. Miller & Berry (2005) reported variation with soil manure and moisture concentration on GHGs fluxes, with the largest fluxes occurring at moderate to high moisture concentrations, depending on the manure concentration present on the soil which would explain that observed in the effluent dam and piles across the measured seasons in the trial.

The manure piles had the highest CH_4 yield (P<0.05) in the wet and hot season with 249 mg CH_4/m^2/hr and the dry and cold season with 115.9 mg CH_4/m^2/hr, as compared to the dry and hot season with 9.2 mg CH_4/m^2/hr. The lower value in the dry and hot season may be due to the manure pile's age being older and consisting of more inorganic material, which would explain the higher ash content, as well as higher DM content observed in the seasons' manure samples collected from the piles as shown in Table 14. Nitrous oxide for the piles was highest in the wet and hot season with 0.5x10^{-2} mg N_2O/m^2/hr, followed by the dry and hot season with 0.4x10^{-2} mg N_2O/m^2/hr and then lastly the dry and cold season with -0.9x10^{-1} mg N_2O/m^2/hr.

The effluent dam manure diet resulted in CH_4 emissions increasing from 1.2 mg CH_4/m^2/hr in the dry and cold season, to 82.0 mg CH_4/m^2/hr in the dry and hot season to the highest emission of 345.9 mg CH_4/m^2/hr in the wet and hot season. The N_2O production per season was highest in the dry and cold

season, 0.2 mg $N_2O/m^2/hr$, followed by a possible uptake of N_2O in the wet and hot season with $-0.2x10^{-2}$ mg $N_2O/m^2/hr$ respectively, and then the largest uptake of N_2O in the dry and hot season, $-0.3\ x10^{-1}$ mg $N_2O/m^2/hr$. Any increase in both CH_4 and N_2O emissions may be due to the increased availability of fresh manure substrate to the dams, following an influx of water following rain, which would increase the layer of organic matter. In turn, this could lower the anaerobic conditions in the dam through the increased water turbulence, as well as increasing the amount of top substrate which could be aerated by the influx of water flowing into the dam following rainfall, thus increasing N_2O production (Amon *et al*., 2006). The increased layer of OM would then form a crust, once the water flow into the dam slowed down, which could allow anaerobic conditions to then increase again and this would increase CH_4 emissions as well. This could explain the large standard error obtained for CH_4 and N_2O fluxes in the present trial. Amon *et al*. (2006) described how aerating the slurry system increased the N_2O emissions. The uptake/loss of N_2O in soils has been explained by Chantigny *et al*. (2007) and Chapius- Lardy *et al*. (2007); however in dams it has not been recorded, although limiting the production of N_2O through creating oxic and anoxic conditions in slurry was discussed by Molodovskaya *et al*. (2008). Leytem *et al*. (2011) recorded 103 g $CH_4/m^2/d$ and 0.49 g $N_2O/m^2/d$ from wastewater ponds in Idaho America. These values are larger than the highest recorded CH_4 (345.9 mg $CH_4/m^2/hr$ which converts to 8.3 g $CH_4/m^2/d$ for the dry and hot season) and N_2O (0.2 mg $N_2O/m^2/hr$ which converts to 0.0048 g $N_2O/m^2/d$ for the dry and cold season) in the present trial. Leytem *et al*. (2011) observed that wastewater pond CH_4 emissions increased as atmospheric temperature increased. This was observed in the present trial with atmospheric and water temperature increasing from 2.5 °C to 30 °C from the dry and cold to the wet and hot season respectively, and CH_4 emissions increased from 1.2 mg $CH_4/m^2/hr$ to 345.9 mg $CH_4/m^2/hr$ in the dry and cold season to the wet and hot season respectively. Leytem *et al*. (2011) observed the N_2O emission rates from wastewater pond tended to be low, although higher than recorded in the present trial. A 2-fold increase (Leytem *et al*., 2011) was observed in the spring as compared to the summer and fall in Idaho America. This increase was not observed in the present trial with N_2O emissions decreasing from winter (dry and cold) to spring (dry and hot) to summer (wet and hot) as seen in Table 14.

Manure temperature (°C) differed significantly between each season measured for the effluent dam (2.5 °C for the dry and cold season, 26 °C for the dry and hot season, 30 °C for the wet and hot season). This indicates that external temperature does have an effect on the effluent dam's water temperature with the highest temperature recorded in the wet and hot season, followed by the dry and hot season and then the lowest temperature recorded in the dry and cold season. This correlates to the ambient recorded temperatures in each season as seen in Table 5.

Manure DM for the effluent dam (top 20cm layer) showed differences ($P<0.05$) between the wet and hot (19.3%) season compared to the dry and cold season (0.5%), and the dry and hot (3.3%) season. No difference ($P>0.05$) was observed for effluent dam manure DM between the dry and hot season and the dry and cold season. During rainfall the top layer of sediment on the effluent dam could be saturated with moisture from rainfall, and disturbed from the runoff into the dam, which could then increase its overall solid top layer concentration and increasing the DM recorded.

Manure pH had no difference ($P>0.05$) between the seasons measured for the effluent dam (7.3 for dry and cold, 7.5 for dry and hot and 7.6 for wet and hot). Manure pH for manure piles had a difference ($P<0.05$) between the wet and hot (pH 6.8) season compared to the dry and cold season (pH 7.9), and the dry and hot (pH 8.1) season. No difference ($P>0.05$) was observed for manure pH between the dry and cold season, and the dry and hot season for manure piles. The degree of composting could have been accelerated due to the influx of water to the manure piles in the wet and hot season, thus providing optimal conditions for composting to occur (Chadwick, 2004). Whalen *et al*. (2000) observed a pH increase in acid soils amended with cattle manure so as cattle manure composts the pH increases, although this is not seen in Table 14 it is difficult to determine the degree of compositing occurring within the manure piles in the present trial.

Manure ash concentration had no differences ($P>0.05$) between the seasons for the effluent dam (0.3% for dry and cold, 1.8% for dry and hot and 8.6% for wet and hot). The increase in ash concentration, although not significant, as seen in Table 14, in the effluent dam in the wet and hot season could have been due to the increased soil runoff with rain water. The increased soil runoff could also cause disturbance within the dam resulting in more sediment being present in the water sample collected. This is confirmed by the lower ash concentration observed in the dry and cold season, and the dry and hot seasons' effluent water samples.

Temperature for manure piles differed ($P<0.05$) between each season measured (42.5 °C for dry and cold, 32.9 °C for dry and hot and 46.8 °C for wet and hot seasons). The piles had the highest temperature in the wet and hot season, and then followed by the dry and cold season and then the dry and hot season. The temperature difference observed between each of the seasons for the manure piles may be due to the level of decomposition present in the pile, with increasing levels of decomposition resulting in an increase in temperature in manure piles (Chadwick, 2004)

Manure DM concentration for manure piles had differences ($P<0.05$) between all the seasons measured (77.2% for dry and cold, 87.1% for dry and hot and 50.9% for wet and hot). Looking at the composting effect (Chadwick, 2004) of the manure piles the higher the moisture of the piles, the higher the recorded temperature was. The accumulation of manure, along with the soil composition and compaction, would result in moisture retention as the manure was still solid, and solid storage (unlike slurry) of manure retains moisture better (Steed & Hashimoto, 1994) as observed in the dry and cold season. This would allow adequate conditions for compositing to occur (Chadwick, 2004) as indicated by the higher temperature observed in the manure piles in the dry and cold season and wet and hot season as compared to the dry and hot season ($P<0.05$). The similar values observed in the two hot seasons would suggest that environmental temperature had an effect on the temperature of manure piles, as seen in Table 14, in that enough moisture was available in the piles, in both seasons, for sufficient composting to occur and an anaerobic condition to be achieved to allow N_2O production to occur (Chadwick, 2004). According to Kebreab *et al*. (2006) piling manure creates anaerobic conditions in which methanogenesis can occur as well as optimal composting. In the dry and cold season, it could be suggested that there was not enough moisture or a high enough temperature to allow adequate composting and N_2O production to occur. Steed & Hashimoto (1994) described how solid manure retained moisture better and thus allows for anaerobic conditions to occur.

Manure ash did have differences ($P<0.05$) between each season measured for manure piles (28% for dry and cold, 55.7% for dry and hot, and 12.5% for wet and hot). The differences in the ash concentration per season can be contributed to the amount of inorganic material, such as soil, that was scraped with the manure when the pens where cleaned out. The soil could have been slightly looser, due to rainfall, in the wet and hot season, which could explain why the ash content was higher in the piles in that particular season as compared to the dry and cold season and dry and hot season.

Bai *et al*. (2015) reported 3.9 g CH_4-C/m^2/d and 0.37g N_2O-N/m^2/d N_2O for beef cattle feedlot manures stockpiles, which converts to 162.5 mg/m^2/hr and 15.42 mg/m^2/hr for CH_4 and N_2O respectively. This is within the range reported for CH_4 in the present trial but not N_2O. The recorded manure pile CH_4 value was higher in the present trial in the wet and hot season than observed by Bai *et al*. (2015). Bai *et al*. (2015) reported a CH_4 emission value of 0.06 to 0.7 kg/hr, which converts to 60000 to 700000 mg/hr, with no obvious diurnal pattern for the gas emissions observed with regards to effluent dam emissions. The effluent dam in the present trial observed an increase in CH_4 gas emissions through the seasons as reported in Table 14, although the opposite was observed for N_2O gas emissions through the seasons. The increase in substrate, as described previously, could promote anaerobic conditions through the increase in substrate layer which would inhibit oxygen availability, would aid in CH_4 production and would hinder N_2O production (Chadwick *et al*., 2011).

4.4 Gas emission comparison between sites and manure management systems within the feedlot

Spatial variations, of manure and feedlot pen surfaces, in CH_4 and N_2O emissions observed after each measurement day is typical behaviour of emissions from animal systems where excretal inputs are deposited unevenly (Sagger, 2010 and Costa Junior *et al.*, 2015).

4.4.1 Methane emission fluxes

Methane emission (mg/m^2/hr) fluxes found between the feedlot pen sites, rangeland and manure management systems are depicted by line graph in Figure 19.

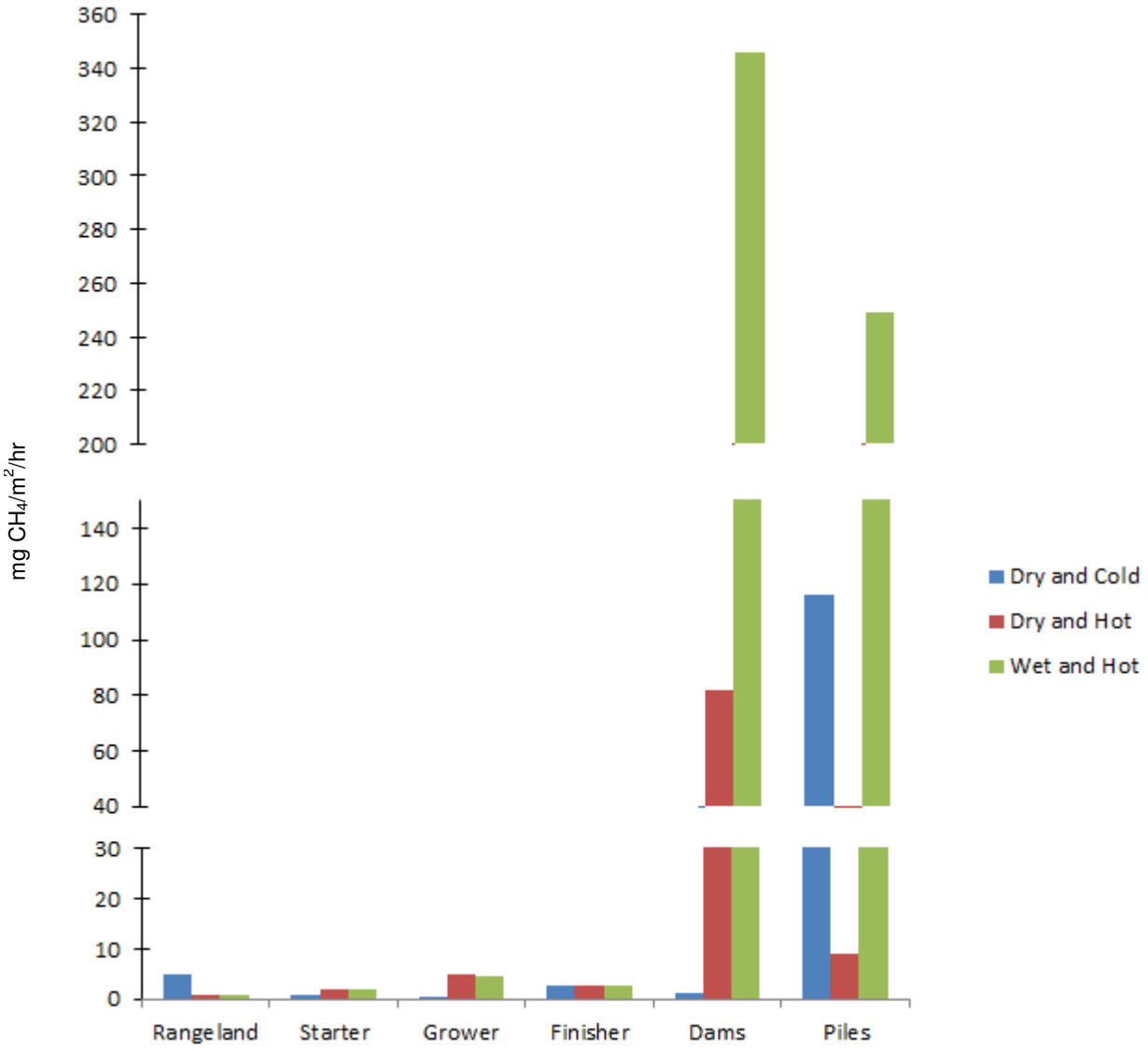

Figure 19 Methane emissions (mg/m^2/hr) for feedlot surfaces and manure management systems between seasons

The graph shows how the CH_4 emission flux (mg $CH_4/m^2/hr$) varied between the feedlot pen surfaces (starter, grower and finisher diets), the rangeland, and the manure management systems, effluent dam and manure piles. The CH_4 emissions in the wet and hot season and the dry and hot season showed the same graph trend for the rangeland and feedlot pens as shown in Figure 19. The graph trend, from highest to lowest, was the effluent dams, manure piles, grower pens, finisher pens, starter pens and rangeland. A change in the trend was observed with manure management, within the wet and hot season having a much larger CH_4 emission in both the effluent dams and manure piles, this can be linked to the increase in rainfall as observed in Table 5, which may have increased runoff of manure and organic matter into effluent dam supplying substrate for microbial gas production. The graph fluctuation of the effluent dams recorded a higher CH_4 emission flux in the wet and hot, and dry and hot seasons as compared to the piles. In the dry and cold season the general graph fluctuation differed from the other seasons by the rangeland recording a higher CH_4 emission flux, and the grower pens recording the lowest emission flux in the feedlot instead of the highest, as depicted in Figure 19. The change in CH_4 emissions would be due to the external environment's impact on the manure pile, or due to the random sampling process of the trial resulting in less manure being caught in the chamber base for measurement in the dry and cold season for the grower pens.

Surface CH_4 emission flux in the different diets (starter, grower and finisher) in the feedlot showed the same pattern for the dry and hot season, and the wet and hot season with the grower pens having the highest overall CH_4 flux of 4.9 mg $CH_4/m^2/hr$ for the dry and cold season and 4.6 mg $CH_4/m^2/hr$ for the wet and hot season, followed by the starter pens with 2.1 mg $CH_4/m^2/hr$ and 2.0 mg $CH_4/m^2/hr$ respectively as shown in Figure 19, and the finisher pens with values of 2.8 mg $CH_4/m^2/hr$ and 2.7mg $CH_4/m^2/hr$ respectively. The dry and cold season differed with the finisher pens having the highest overall CH_4 flux of 2.7mg $CH_4/m^2/hr$, followed by starter pens, 1.05 mg $CH_4/m^2/hr$, and then the grower pens, 0.5 mg $CH_4/m^2/hr$, as shown in Table 10.

Ghafoori *et al.* (2006) reported values ranging from 0.7 to 2 g/animal/d from manure packs/piles. This is slightly higher than the range for CH_4 emissions observed per head in the present trial with the dry and cold season ranging from 0.048 to 0.18 g/head/d, the dry and hot season with 0.16 to 0.47 g/head/d and the wet and hot season with 0.18 to 0.45 g/head/d as shown in Figure 17. The lower CH_4 emissions per head in the present trial as compared to Ghafoori *et al.* (2006) may be as a result of the different atmospheric conditions experienced in Northern America compared to South Africa.

Gallardo (2013) reported a value of 2.01 mg/m^2/hr for CH_4 on loose manure mixed with moist manure, which is similar to CH_4 emissions recorded in the finisher pens for the dry and cold season, the starter pens and finisher pens in the dry and hot season and for the starter and finisher pens in the wet and hot season in the present trial. The similar values for the diet levels observed between the dry and hot season, and the wet and hot season could be due to the higher atmospheric temperature and ultimate higher feedlot pen surface manure temperature in those seasons, as seen in Table 5 and Table 10 with the CH_4 emissions. Manure composition and nitrogen availability is dependent on diet composition and digestibility (Sørensen *et al.*, 2003). The manure N concentration per season is reported in Tables 9 and 13. The higher N value observed in the feedlot pen surface manure compared to the rangeland, along with the lower overall gas flux from the rangeland compared to the feedlot pens in the present trial was also observed by Sørensen *et al.* (2003). This can be explained by the low CP concentration of the rangeland and higher CP in the concentrate diets consumed as shown in Table 12. The grower pen surface contained higher water concentration, based on the manure sampled from the pens, in the hot and dry season, and the wet and hot season, and was rated as 1 and 2 on the manure scoring system used by Ireland-Perry & Stallings (1992), which indicated that the manure was more wet. This would have provided the feedlot pen surface microbes with adequate moisture for CH_4 production (Gallardo, 2013). Du Toit *et al.* (2013) reported a CH_4 emission factor of 0.457 kg/head/yr for feedlot cattle. This value correlates to 52.08 mg/head/hr, which is higher than the observed CH_4 flux values for the feedlot diet pens in the present trial, with the largest flux measuring 4.6 mg/m^2/hr in the grower diet in the wet and hot season, as shown in Figure 19. The difference between the present trial and Du Toit *et al.* (2013) data may be due to the difference in gas collection and analysis. Du Toit *et al.* (2013) used data provided by the IPCC to estimate a tier 2 value, whilst in the present trial actual gas was collected from the source and not estimated from values recommended by the IPCC.

For rangeland, Du Toit *et al.* (2013) calculated CH_4 emission factor for manure (MEF_{manure}) of 0.012 kg/head/year for beef calves and young oxen. This converts to a value of 1.37 mg/head/hr. Rangeland composite manure samples showed a general decreasing CH_4 emission value over the trial sampling period

of 3 weeks each season. The dry and cold season had the highest flux overall of 5.2 mg manure $CH_4/m^2/hr$, followed by the dry and hot season and wet and hot season both having a flux of 1.1mg manure $CH_4/m^2/hr$ for rangeland manure. The rangeland CH_4 flux value observed for the wet and hot season and the dry and hot season,1.1 $mg/m^2/hr$, are in range with Rahman *et al.* (2013) who reported an overall flux rate of 1.32 +/- 0.66 $mg/m^2/hr$, but the dry and cold season observed a higher CH_4 flux value of 5.2 $mg/m^2/hr$.

4.4.2 Nitrous oxide emission fluxes

The manure N_2O ($mg/m^2/hr$) flux on areas measured for rangeland, feedlot pens and feedlot manure management systems, manure piles and effluent dams, between seasons is displayed in Figure 20.

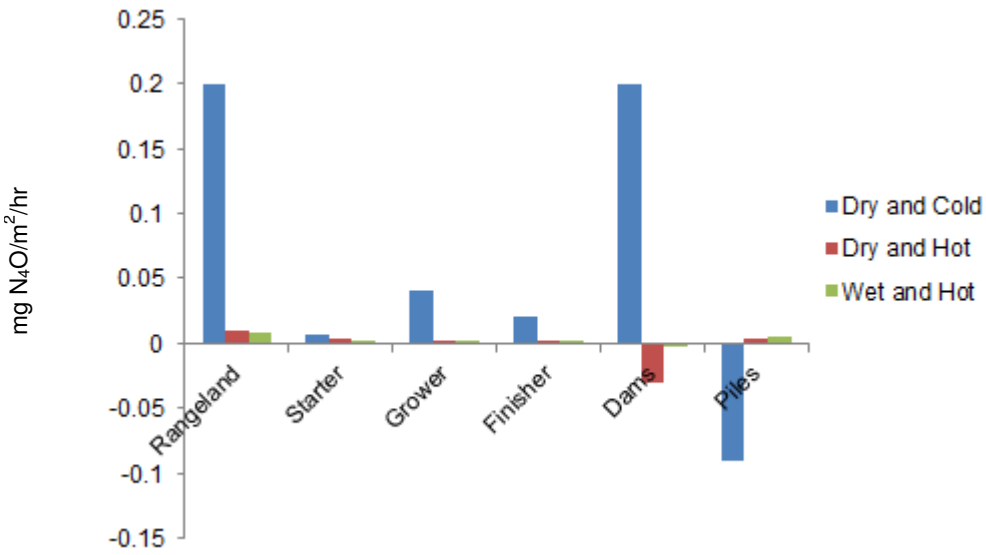

Figure 20 Manure nitrous oxide emissions ($mg/m^2/hr$) for feedlot surfaces and manure management systems between seasons

Manure and pen N_2O emissions from the rangeland, feedlot pens and manure management systems did not show any set pattern. The negative values obtained suggest a possible uptake of N_2O (Nicols *et al.,* 2016) occurred as there was no leakage detected with the CH_4 increasing in the same samples. The negative values recorded in the present trial can be explained by Chapius- Lardy *et al.* (2007) who stated that very low and negative N_2O fluxes are frequent and substantial and that the data should not be dismissed as experimental error or noise. Montes *et al.* (2013) described how N_2O from feedlot pen surfaces, of beef feedlot facilities, can be significant thus one can not ignore the low N_2O recorded in the present trial.

The range for the dry and cold season was -0.09 mg $N_2O/m^2/hr$ (piles), to 0.2 mg $N_2O/m^2/hr$ (dams). The dry and hot season had a range of -0.03 mg $N_2O/m^2/hr$ (effluent dams), to 0.004 mg $N_2O/m^2/hr$ (starter pens). The wet and hot season range was -0.002 mg $N_2O/m^2/hr$ (effluent dams), to 0.0002 mg $N_2O/m^2/hr$ (starter pens). The upper range observed in the present trial is similar to data reported by Parker *et al.* (2017b) who recorded a value of 0.025 ± 0.0016 mg $N_2O/m^2/hr$ from dry feedlot manure. The positive manure N_2O fluxes obtained from the present trial correspond to findings of Aguilar *et al.* (2014) on a Kansas feedlot of 0.0 to 41.4 mg $N_2O/m^2/hr$, although on the lower end of the results. Values obtained in the present trial was also lower than observed by Parker *et al.* (2017b), 43.08± 0.89 mg $N_2O/m^2/hr$ for moist manure and, 10 mg $N_2O/m^2/hr$ in open lot beef feedlots reported by Waldrip *et al.* (2017). Boadi *et al.* (2004) reported a value of 0.134 mg $N_2O/m^2/hr$ from manure packs. This is similar to the effluent dams N_2O flux calculated in the present trial, Table 14, but is larger than the manure piles N_2O flux, Table 14, and feedlot pens N_2O flux , Table 10, in the present trial. The negative values observed in the N_2O flux, in the present trial, may be due

to N uptake by the soil, which would decrease the amount of N available to microorganisms to produce N_2O (Chantigny *et al*., 2007).

The lower N_2O flux observed in the feedlot diet fed per pens, during the dry and hot season, could be due to higher atmospheric temperatures within that season which resulted in higher feedlot surface temperatures. The higher feedlot surface temperature, as explained by Gallardo (2013), could result in NH_4^+ loss to the air, and since NH_4^+ is part of the Nitrogen cycle a loss of it would decrease the amount of N available for N_2O production (Lawrence, 1989). Rahman *et al.* (2013) experienced a flux rate of 0.07g/m^2/d, which converts into 2.9 mg/m^2/hr, which is higher than the values obtained in the feedlot pens, the highest value being 0.04 mg/m^2/hr for the grower diet in the dry and cold season, in the present trial. This could be due to the different atmospheric conditions such as atmospheric temperature, rainfall and resulting humidity, Table 5, between the different experimental sites and the varying substrate composition, based on raw materials included in the final diet, as seen in Table 7, thus affecting final manure composition available at the sites based on diets fed.

Overall manure N_2O emission values observed in the present trial are on average lower than recorded by Pattey *et al.* (2005) who reported a flux of 0.03 g/m^2/d N_2O which is converted into 1.25 mg/m^2/hr N_2O, which is higher than observed in the present trial. The negative N_2O values obtained could have been due to unfavourable conditions on the feedlot pen surface for N_2O gas production, such as anaerobic conditions, limited or excessive moisture that would hinder microbial activity, or as described by Li *et al.* (2011), a negative N_2O flux that resulted in an uptake of N_2O by the soil microbial community. The uptake of N in soils is also reported by Chantigny *et al.* (2007) and Chapius-Lardy *et al*. (2007).

The variation in manure N_2O emissions values from the present trial may be due to feedlot pen surface manure accumulation, resulting in limiting N_2O production conditions (Chadwick *et al*., 2011). Du Toit *et al.* (2013) described how a high stocking density of animals situated in feedlots resulted in a build-up of manure, which may lead to the production of CH_4, particularly if the manure is wet. This would explain how the build-up of manure leads to oxygen limited conditions, suitable for CH_4 production and not N_2O production by nitrification. Rapson & Dacres (2014) explained how N_2O fluxes are episodic and demonstrated large temporal and spatial variations, which could also explain the lower N_2O emissions obtained in the present trial. Chapius- Lardy *et al*. (2007) reported that N_2O emissions are very variable between sites, sources and scientific reports.

4.4.3 Carbon dioxide equivalent

Feedlot pen surfaces occupied approximately 643558.50 m^2, 3.78%, of the feedlot. If one assumes that equal allocation of pens was allocated for the three different diets on the farm so an area of 214519.5 m^2 is allocated per diet in the feedlot. Feedlot dams occupied approximately 38326.50 m^2, 0.22%, of the feedlot. Feedlot piles occupied approximately 288.46 m^2, 0.002% of the total feedlot. Rangeland allocated to cattle was approximately 8560250 m^2, 50.35% of the total feedlot. The rest of the 1700 hectares of the feedlot contained the feedlots infrastructure and open land used for cultivating grass. Using a CO_2 equivalent of 28 for CH_4 and 265 for N_2O (Wang *et al*., 2018) the following results were obtained in the trial.

Feedlot starter pens in the dry and cold season had a total of 1.1 mg/m^2/d of CH_4, which converts into 0.69 t/season using 121.7 days per season and an area of 21459.5 m^2. For the starter pens in the dry and hot 2.1 mg/m^2/hr converts into 1.32 t/season, and in the wet and hot season 2 mg/m^2/hr converts into 1.25 t/season. The resulting CO_2 equivalent values obtained, using the conversion factor of 28, for the dry and cold season, the dry and hot season and the wet and hot season were 17.2 t/season, 32.9 t/season and 31.3 t/season respectively. This gives a total of 81.4 CO_2 t/year for the starter diet pens in the feedlot. The grower pens observed values of 0.5 mg/m^2/hr, 4.9 mg/m^2/hr and 4.6 mg/m^2/hr of CH_4 for the dry and cold season, the dry and hot season, and the wet and hot season respectively. This converts to a CO_2 equivalent of 7.8 t/season, 76.7 t/season and 72.1 t/season for the dry and cold season, the dry and hot season and the wet and hot season respectively. Giving the grower pens a total CO_2 equivalent value of 156.6 t/year. The finisher pens observed CH_4 values of 2.7 mg/m^2/hr, 2.8 mg/m^2/hr and 2.7 mg/m^2/hr for the dry and cold season, the dry and hot season and the wet and hot season respectively. This converts to a CO_2 equivalent value of 42.3 t/season for the dry and cold season, 43.9 t/season for the dry and hot season and 42.3 t/season for the wet and hot season. An overall CO_2 equivalent value for the finisher diet pens in the feedlot

of 128.5 t/year was calculated. Thus, from feedlot pens for the year a total CO_2 value of 366.54 t/year was calculated for CH_4 emissions

Feedlot effluent dams had an average CH_4 of 1.2 mg/m^2/hr for the cold and dry season, 82 mg/m^2/hr for the dry and hot season and 345.9 mg/m^2/hr for the wet and hot season which converted to 28.8 mg/m^2/d for the cold and dry season, 1968 mg/m^2/d for the dry and hot season, and 8301.6 mg/m^2/d for the wet and hot season. The average CH_4 emission for dams for the trial was 48.02 t/year. This converts to a CO_2 equivalent value of 1344.6 t/year.

Feedlot manure piles had an average CH_4 flux of 115.9 mg/m^2/hr for the dry and cold season, 9.2 mg/m^2/hr for the dry and hot season and 249 mg/m^2/hr for the wet and hot season. This converts to 2781.6 mg/m^2/d for the dry and cold season, 220.8 mg/m^2/d for the dry and hot season and 5976 mg/m^2/d for the wet and hot season. The average for the manure piles was 0.32 t/year for the trial for CH_4. This converts to a CO_2 equivalent of 8.8 t/year.

The N_2O emissions for feedlot starter pens in the dry and cold season, the dry and hot season and the wet and hot season were 0.007 mg/m^2/hr, 0.004 mg/m^2/hr and 0.0003 mg/m^2/hr respectively. This converts into a CO_2 equivalent value of 1.3 t/season, 0.7 t/ season and 0.5 x 10^{-1} t/season for the dry and cold season, dry and hot season and the wet and hot season respectively using a CO_2 conversion factor of 265 for N_2O. This calculates to an overall CO_2 equivalent value of 2.1 t/year for the starter pens in the feedlot. The grower pens observed the following N_2O emissions 0.04 mg/m^2/hr, 0.0008 mg/m^2/hr and 0.0002 mg/m^2/hr for the dry and cold season, the dry and hot season and the wet and hot season respectively. This converts into CO_2 equivalent values of 7.4 t/season, 0.1 t/season and 0.3 x 10^{-1} t/season for the dry and cold season, the dry and hot season and the wet and hot season respectively. An overall CO_2 equivalent value of 7.6 t/year was calculated for the grower pens in the feedlot. The finisher pens observed the following N_2O emissions 0.02 mg/m^2/hr, 0.002 mg/m^2/hr and 0.0007 mg/m^2/hr for the dry and cold season, the dry and hot season and the wet and hot season respectively. This converts in a CO_2 equivalent value of 3.7 t/season, 0.4 t/season and 0.1 t/season for the dry and cold season, the dry and hot season and the wet and hot season respectively. An overall CO_2 equivalent value of 4.2 t/year for feedlot finisher pens in the feedlot was calculated. Overall the CO_2 equivalent of 14 t/year was calculated for N_2O emissions from feedlot pen surface in the present study.

The feedlot effluent dams had N_2O emissions of 0.2 mg/m^2/hr for the dry and cold season, -0.03 mg/m^2/hr for the dry and hot season and -0.002 g/m^2/hr for the wet and hot season. Overall average N_2O emission value of 0.02 t/year was calculated for effluent dams in the present trial. The CO_2 equivalent for the effluent dams N_2O flux was 5 t/year.

Feedlot manure piles had N_2O fluxes of -0.0 9 mg/m^2/hr for the dry and cold season, 0.004 mg/m^2/hr for the dry and cold season and 0.005 mg/m^2/hr for the wet and hot season, with an average of -0.07 x 10^{-3} t/year for the present trial. The CO_2 equivalent for manure piles N_2O flux was –0.2 x 10^{-1} t/year.

For rangeland GHG emissions it was not possible to directly compare rangeland as a manure management system in the present trial. The calculated GHG emissions, CH_4 and N_2O, from the rangeland are just an estimated value as the manure was collected and placed in chamber bases. The resulting rangeland value was probably overestimated from the present trial due to the methodology employed compared to the feedlot pens and the manure management sites. According to the IPCC (2006) guidelines for national GHG inventories, manure emission from rangeland are not allocated to livestock emissions. Rangeland can also have a carbon sequestration effect (Silver *et al*., 2018) although this was not quantified during the present trial.

Chapter 5

5.1 Conclusion

Globally greenhouse gasses (GHGs) have become an increasing environmental concern. Greenhouse gases have the potential to absorb and emit infrared radiation that increases the earth's temperature and causes an increase in environmental temperature which, above the natural cycles, is classified as global warming (IPCC, 2006). The increase of GHGs has brought about rapidly changing climatic conditions throughout the world. Greenhouse gases are produced by various industry sectors and these sectors are being investigated, researched and laws put in place to limit the production of GHGs wherever possible. This includes the agricultural sector where extensive animal husbandry has increased the global carbon footprint and environmental pollution (Costa Junior *et al*., 2012). Global warming is a direct response to an increase in the concentration of atmospheric greenhouse gasses (Zhang *et al.,* 2016), and it has resulted in extreme weather phenomena occurring, as well as a rise in ocean level and temperature (Zhang *et al.,* 2016). Two of the greenhouse gasses associated with livestock production are methane (CH_4) and nitrous oxide (N_2O) (Du Toit *et al*., 2013). Globally the concentration of CH_4 and N_2O produced in regions around the world is calculated by set international quantification protocol, which allows for the comparison of emissions between different countries. This is set out by the International Panel on Climate Change (IPCC). The IPCC has three Tiers that are used to rate the reliability and methodological complexity of emission factors as well as activity data that is used to compile national inventories (IPCC, 2006).

Obtaining a Tier 3 value for gas emissions is required by countries who are signatories of the United Nations Framework Convention on Climate Change (UNFCC). For gas emissions from beef cattle manure, manure management and feedlot pen surfaces, the IPCC Tier 3 method would require direct measurement based on experimental data collected under country specific conditions. Due to the diversity of South African livestock production systems and regions, Du Toit *et al*. (2013) calculated livestock related emissions values based on a modified IPCC Tier 2 approach.

The use of closed static chambers has allowed for the development of Tier 3 emission factors for beef feedlot pen surfaces (Costa Junior *et al*., 2012). The IPCC (2006) has assigned a default value of 45kg CH_4/head/year for beef cattle manure in developing countries for manure emissions (Du Toit *et al*., 2013). South Africa currently falls within the bracket of developing countries. Du Toit *et al.* (2013) described how the CH_4 values, allocated by the IPCC, were lower in South Africa than originally observed by the IPCC for the various regions, with varying rainfalls and temperatures. The United Nation Framework on Climate Change stipulates that signatories are required to report on GHGs in the various sectors, such as Agriculture, every two years in national inventories (Stevens *et al*., 2016). The Kyoto agreement, stipulated by the Kyoto Protocol, emphasizes the need to reduce environmental pollution from nutrients, ammonia emissions, odour nuisance and GHGs, which will become important going forward, to meet integrated sustainability criteria (Monteny *et al*., 2001). Recently the Paris Climate Agreement, signed in April 2018, has taken over the Kyoto protocol, with 196 parties signing the Agreement (Fetchet, J., Online accessed 2018). Costa Junior *et al.* (2012) stated that "accurately quantifying CH_4 and N_2O gas emissions from beef feedlot pen surfaces is important for improving the accuracy of the GHG inventory and for assessing the effectiveness of GHG mitigating options". Quantifying direct CH_4 and N_2O emissions from beef feedlot pen surfaces will allow South Africa to move towards an IPCC Tier 3 approach in reporting national livestock emissions as required by the IPCC and the UNFCC.

At present in South Africa, these values are only roughly estimated and are only available as an IPCC Tier 2 value (Du Toit *et al*., 2013). Gaseous emissions from livestock waste, specifically beef cattle waste, are affected by a variety of external factors (atmospheric temperature, humidity, soil conditions, ration consumption and manure management practices) as well as internal factors, (ration digestibility, nutrient absorption and gut health). The objective of the study was to achieve an understanding of the gaseous emissions, specifically CH_4 and N_2O, from beef cattle feedlot pen surfaces, manure management practices and rangeland from a commercial beef feedlot in South Africa as influenced by diet and season, using the closed chamber method of gas collection over the three prominent seasons experienced in Mpumalanga, South Africa. The sampling of these various factors would lead to more accurate reporting, conforming to Tier 3 methodology requirements.

The differences observed, for most of the pen surface parameters, were directly related to the season and the presence of manure in the sampling area in each pen. This suggests that the difference between the seasons played an important role on the feedlot pen surface parameters as depicted in Table 9 and described by Uchida *et al.* (2008). The CH_4 and N_2O emission recorded from the feedlot pens are depicted in Table 10.

Feedlot pen surface CH_4 observed a difference ($P<0.05$) for the grower diet between the dry and hot (4.9 mg/m^2/hr) and the wet and hot (4.6 mg/m^2/hr) seasons, compared to the dry and cold (0.5 mg/m^2/hr) season. Within the dry and cold seasons differences ($P<0.05$) were observed between each of the diets (starter 1.1 mg/m^2/hr, grower 0.5 mg/m^2/hr and finisher 2.7 mg/m^2/hr). Within the dry and hot and the wet and hot seasons a difference between the starter (2.1 mg/m^2/hr for dry and cold and 2 mg/m^2/hr for wet and hot) and finisher (2.8 mg/m^2/hr for dry and hot and 2.7 mg/m^2/hr for wet and hot) diets as compared to the grower diet (4.9 mg/m^2/hr for the dry and hot and 4.6 mg/m^2/hr for the wet and hot) was observed.

No difference ($P>0.05$) was observed for N_2O flux in each season and between diets in each season measured. The N_2O flux, depicted in Table 10, for the diets in the dry and cold season were as follows, in the starter diet a flux of 0.7 x 10^{-2} mg/m^2/hr, 0.4 x 10^{-1} mg/m^2/hr for the grower diet and 0.2 x 10^{-1} mg/m^2/hr for the finisher diet respectively. In the dry and hot season the starter diet had a N_2O flux of 0.4 x 10^{-2} mg/m^2/hr, the grower diet a N_2O flux of 0.8 x 10^{-3} mg/m^2/hr and the finisher diet observed a N_2O flux of 0.2 x 10^{-2} mg/m^2/hr. In the wet and hot season a N_2O flux of 0.3 x 10^{-3} mg/m^2/hr for the starter diet, 0.2 x 10^{-3} mg/m^2/hr for the grower diet and 0.7 x 10^{-3} mg/m^2/hr for the finisher diet was observed. Overall the dry and cold season had the highest N_2O flux for the starter and finisher pens, whilst the grower pen in the dry and hot season had the highest flux for that diet between the seasons measured.

Rangeland CH_4 observed a difference ($P<0.05$) between the dry and cold (5.2 mg/m^2/hr) season compared to both the dry and hot (1.1 mg/m^2/hr) and the wet and hot (1.1 mg/m^2/hr) season. Rangeland N_2O observed differences ($P<0.05$) between the dry and cold season (0.2 mg/m^2/hr) compared to the dry and hot and the wet and hot seasons (0.1 x 10^{-1} mg/m^2/hr for the dry and hot and 0.9 x 10^{-2} mg/m^2/hr for the wet and hot season). Rangeland manure temperature observed differences ($P<0.05$) between each season measured (6.1 °C for dry and hot, 28.2 °C for dry and hot, 33.6 °C for wet and hot). Rangeland manure pH observed a difference ($P<0.05$) between the dry and cold (pH 9.1) season to the dry and hot (pH 8.1) season and the wet and hot (pH 8) season. The rangeland manure DM observed a difference ($P<0.05$) between all the seasons measured (22.2% dry and cold, 24% dry and hot, 31.9% for wet and hot). Rangeland manure ash and N observed differences ($P<0.05$) between the dry and hot (2.6% ash and 1.86% N) and the wet and hot (8.3% ash and 1.96% N) seasons as compared to the dry and cold (2.8% ash and 1.86% N) season. Rangeland manure ADF and NDF observed differences ($P<0.05$) between all the seasons measured (50% ADF and 64.2% NDF for dry and cold, 37.6% ADF and 56.3% NDF for dry and hot and 48% ADF and 58.2% NDF for wet and hot).

The CH_4 flux for the rangeland was 5.2 mg CH_4/m^2/hr, 1.1mg CH_4/m^2/hr and 1.1mg CH_4/m^2/hr for dry and cold, dry and hot and wet and hot seasons respectively. A difference ($P<0.05$) was observed between the dry and cold season as compared to the dry and hot and the wet and hot season for CH_4. The N_2O flux for rangeland was 0.2 mg N_2O/m^2/hr, 0.1 x 10^{-1} mg N_2O/m^2/hr and 0.9 x 10^{-2} mg N_2O/m^2/hr for dry and hot, dry and cold and wet and hot seasons respectively. A difference ($P<0.05$) was observed between the dry and cold season as compared to the dry and hot and the wet and hot seasons for N_2O.

For manure management, a difference ($P<0.05$) was observed for CH_4 for the effluent dam between the dry and hot season and the dry and hot season as compared to the wet and hot season. For manure piles a difference ($P<0.05$) was observed between the dry and hot as compared to the dry and cold and wet and hot seasons. The N_2O emissions observed a difference ($P<0.05$) for the effluent dam between the wet and hot season as compared to the dry and cold and the dry and hot season. No difference ($P>0.05$) was observed between the dry and hot and wet and hot seasons for N_2O flux for the effluent dam. No differences ($P>0.05$) were observed for N_2O fluxes between seasons for the treatment pile. Large variations were observed for gas measurements between seasons resulting in a large standard error value for CH_4 and N_2O.

The piles had the highest CH_4 yield in the wet and hot season with 249 mg CH_4/m^2/hr, followed by the dry and cold season with 115.9 mg CH_4/m^2/hr, and then the dry and hot season with 9.2 mg CH_4/m^2/hr. A difference ($P<0.05$) was observed between the dry and hot season as compared to the dry and cold season and wet and hot season. The lower value in the dry and hot season may be due to the manure pile's age

being older and consisting of more inorganic material, which would explain the higher ash content, as well as higher DM content observed in the seasons' manure samples collected from the piles as shown in Table 14. Nitrous oxide for the piles was numerically higher in the wet and hot season with $0.5x10^{-2}$ mg $N_2O/m^2/hr$, followed by the dry and hot season with $0.4x10^{-2}$ mg $N_2O/m^2/hr$ and then lastly the dry and cold season with $-0.9x10^{-1}$ mg $N_2O/m^2/hr$.

The effluent dam manure resulted in CH_4 emissions increasing from 1.2 mg $CH_4/m^2/hr$ in the dry and cold season, to 82.0 mg $CH_4/m^2/hr$ in the dry and hot season to the highest emission of 345.9 mg $CH_4/m^2/hr$ in the wet and hot season. The same was observed for the N_2O production with the dry and cold season, the results were $-0.3x10^{-1}$ mg $N_2O/m^2/hr$ for the dry and hot season, $-0.2\ x10^{-2}$ mg $N_2O/m^2/hr$ for the wet and hot season, and 0.2 mg $N_2O/m^2/hr$ for the dry and cold season.

The resulting CO_2 equivalents for the present trial from the areas measured were as follows. For CH_4, feedlot pen surfaces a CO_2 equivalent of 366.54 t/year was calculated, for effluent dams a CO_2 equivalent of 1344.6 t/year was calculated and for manure piles a CO_2 equivalent of 8.8 t/year was calculated. For N_2O, feedlot pen surfaces a CO_2 equivalent of 12.5 t/year was calculated, for effluent dams a CO_2 equivalent of 5 t/year g/d was calculated and for manure piles a CO_2 equivalent of -0.02 t/year was calculated. For CH_4 the largest flux was recorded by the effluent dam followed by the feedlot pens and then the manure pile. For N_2O the largest flux was recorded in the feedlot pens, with a CO_2 equivalent of 15 t/year, followed by the effluent dam with a CO_2 equivalent of 5 t/year, and then the manure piles with a CO_2 equivalent of $-0.2\ x\ 10^{-1}$ t/year.

Overall soil and manure characteristics were affected by feedlot diet and soil surface composition, which was as a result of the diet fed and climate differences between the seasons. However, the manure and soil characteristics only affected the gas fluxes of CH_4 in the grower diet between seasons ($P<0.05$). Rangeland observed differences ($P<0.05$) between the dry and cold season as compared to the and dry and hot season and the wet and hot season for both CH_4 and N_2O emissions, whilst for manure management the manure piles, N_2O emissions, and effluent dam, CH_4 and N_2O emissions, observed a significant difference between the wet and hot season as compared to the dry and hot season and dry and cold season. Potential ways to mitigate GHG emissions from feedlot pen surfaces and manure can occur in three ways. The first way is to feed a balanced diet that meets the cattle's production needs (Montes *et al*., 2013). The second is through genetics, to improve cattle's utilization of freed and resultant performance in production through selective breeding for improved efficiency (Li *et al*., 2012a). Increased feed utilization through feeding a balanced feed and better absorption of the nutrients from the feed, can decrease the amount of organic carbon passed in the manure, which would decrease the substrate available for microbes to produce GHG's (Montes *et al*. 2013). The third way to mitigate GHG emissions from manure is to ultimately collect the gasses and utilise them to generate heat and electricity in a bio-digester (Voermans., 1985). A combination of feeding cattle more efficiently, continually improving genetics for performance and utilising the manure to generate heat and electricity through a bio-digester are potential ways to mitigate GHG emissions from cattle manure.

In conclusion, it was found that manure characteristics are affected during the seasons and diets and this would affect the rate of CH_4 and N_2O emissions from the manure as a result. Manure characteristics are therefore mostly affected by the ration fed, and the environmental conditions.

5.2 Critical evaluation

The trial conducted was dependent on external atmospheric conditions. Potentially controlling the atmospheric conditions in which the trial was conducted, such as using a greenhouse, would allow gas emissions to show more of a trend, possibly even a significant trend. There were large variations in results obtained due to atmospheric variation, within which the atmospheric temperature and resulting feedlot surface and manure temperatures would play a part in CH_4 and N_2O emissions observed (Hashimoto *et al.,* 1981). The large variation in emissions measured in the present trial may be due to chamber bases not being able to be inserted and stay inserted in the pens' feedlot surface over the trial period due to the random sampling procedure used within the pens. This was necessary to not disturb the feedlot's routine. To implement this, one would have to fence off the area from cattle. Fencing off the area from cattle would however interfere with the cattle's placement of manure and urine. Fencing off the chamber bases would also interrupt the natural process of manure spreading in the pen via cattle movement. The hardness of the compacted soil in the feedlot pens also made the chamber base insertions difficult, and it was difficult to obtain the correct and consistent chamber base depth insertion. Increasing the number of chambers deployed in each pen, and increasing the number of pens measured per feed, would increase replication and repeatability, and may have aided in the increasing confidence of the results obtained. However, increasing the number of chambers does not reduce spatial variability in emission estimates from grazed pasture soils, but it does increase the confidence in mean value obtained (Sagger, 2010).

Sealing of the bases on the ground was an important aspect to consider for the lack of insertion depth. Adding a rubber apron onto the chamber base would have aided in sealing the base more effectively in very hard soils.

A controlled experiment under laboratory conditions would aid to determine the specific effects of manure parameters on manure GHG emissions. However, this would not represent a feedlot accurately due to no cattle defecating regularly and trampling of manure present, which would mix old and new manure samples together.

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