ASPECTS OF GEOPHAGIA AMONGST DAIRY CATTLE IN A FEEDLOT SYSTEM.

By

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CHAPTER 1

INTRODUCTION

CHAPTER 1: INTRODUCTION

Geophagy, the intentional intake of soil, is a common occurrence amongst various animal species animals including humans. Soil eating amongst humans has been well documented (Halsted 1968, Vermeer 1971, Dominy *et al*. 2004) and regarding animals, this behaviour has been documented in reptiles, birds and mammals (Kreulen and Jager 1984) as well as insects (Jain *et al.* 2008).

Despite the well documented instances of soil eating, the real motivation behind geophagy remains somewhat controversial. The debate around possible advantages of soil ingestion range from medicinal benefits such as the adsorption of plant phenols and secondary metabolites (Krishnamani and Mahaney 2000, Voigt *et al*. 2008, Chandrajith *et al*. 2009), counteraction of acidosis (Kreulen and Jager 1984, Abrahams 1999, Krishnamani and Mahaney 2000), act as an agent to counteract diarrhoea (Mahaney *et al*. 1990, Abrahams 1999, Krishnamani and Mahaney 2000) and even include the eradication or reduction of endoparasites (Kreulen 1985, Klaus *et al*. 1998, Krishnamani and Mahaney 2000). Other suggested explanations for geophagy include supplementation of microbial organisms in the stomach or possible digestive properties (Ketch *et al*. 2001), satiating olfactory senses, suppressing hunger (Krishnamani and Mahaney 2000) or might even serve no purpose at all (Krishnamani and Mahaney 2000).

Most contributions on the immediate cause of geophagy however, mention the mitigation of mineral deficiencies (Weir 1969, Langman 1978, Penzhorn 1982, Kreulen and Jager 1984, Krishnamani and Mahaney 2000, Mahaney and Khrishnamani 2003, Stephenson *et al*. 2010) and this explanation for geophagy became so accepted that most sites where geophagy is observed, are referred to as “mineral licks”, “salt licks” or “soil licks”. Various studies suggest that mineral supplementation might be the most likely cause for soil consumption. In a study done by Holdø *et al*. (2002), it was found that female elephants in the Hwange National Park in Zimbabwe consumed more mouthfuls of soil and spent a greater portion of their activity budget feeding on soil than males and therefore suggested that geophagy may be driven by a nutritional requirement, especially sodium. This might be because elephant cows probably had greater nutritional requirements than males because of pregnancy and lactation. According to Kreulen and Jager (1984) the use of lick sites in the southern Kalahari is mainly associated with mineral deficiencies and Eloff (1962) also commented that the availability of licks in the pans and riverbeds in the Kgalagadi Transfrontier Park is one of the most important factors in the habitat preference of gemsbok and thus also important in the ecology if these animals. According to Holdø, Dudley and McDowell (2002) geophagy may be driven by a nutritional requirement, especially sodium, due to the fact that females have greater nutritional requirements than males because of pregnancy and lactation. Robbins (1993), Kreulen and Jager (1984), Abrahams (1999), Atwood and Weeks (2003) and Brightsmith and Muṅoz-Najar (2004) all suggest that sodium is the desired mineral in geophagic soils. Knight (1991) also concluded that sodium from geophagy sites in the southern Kalahari was probably the desired mineral for gemsbok as sodium and its anions, sulphate and chloride, were present in significantly higher concentrations in geophagy soil than in the surrounding control sites. In contrast to sodium driven geophagy, Penzhorn (1982) and Langman (1978) suggested that calcium and phosphorus deficiency might be the motivation behind geophagy in Cape mountain zebras and giraffe respectively, while Krishnamani and Mahaney (2000), amongst others, suggested that soil provides extra iron for primates at high altitudes.

According to Wheeler (1980) large quantities of volatile fatty acids are produced in the reticulorumen as a result of feeding on high grain diets whilst several physiological abnormalities have been associated with acidic conditions in the reticulorumen. Kreulen and Jager (1984) suggested that nutrient minerals in general may not always be important in geophagy behaviour, since the soil may be sought after for its buffering effect. In this regard, Krishnamani and Mahaney (2000) explained that large quantities of volatile fatty acids could cause the stomach pH to decrease and cause acidosis, while Melendez *et al.* (2007) hypothesise that urine with a low pH can result in metabolic acidosis, and according to him, animals consequently consume alkaline soil to neutralise such internal acidic conditions. Knezevich (1998) brought attention to mineralogical similarities between ingested soils and pharmaceutical medication, which is commonly used for the cure or prophylaxis of gastrointestinal upset or diarrhoea in humans.

Despite the proposed advantages, geophagy also has several disadvantages. Animals that practice this behaviour must often travel long distances to reach geophagy sites and according to Stephenson *et al*. 2010), this ultimately leads to an energetic investment. In addition to the expenditure of energy, the eating of soil also causes teeth wear and an amplified risk of predation (Klaus *et al*. 1998) as well as toxification of prolonged utilisation of contaminated soils (Rich and Talent 2009, Kutalek *et al*. 2010) and fatalities due to sand impaction (Mushi *et al*. 1998, Abutarbush and Petrie 2006, Melendez *et al*. 2007). The possibility of fatal sand impaction depends on the amount of soil consumed by the animal as well as the rate at which consumed soil is excreted on a daily basis. Several cases of fatal sand impaction have been reported. Mushi *et al.* (1998) and Abutarbush *et al*. (2006) reported on ostriches and a one-month-old alpaca, respectively, that died of fatal sand impaction. Furthermore, Melendez *et al.* (2007) account for a case of sand impaction in dairy cows. In the latter two cases, authors stated that the major clinical signs associated with excessive geophagy include depression, either diarrhoea or lack of faecal passage as well as mild colic with mucosal damage. Regardless of the negative impact of geophagy to animals, this behaviour was reported from localities all over the world in areas ranging from deserts to rainforests. Geophagy must therefore, show rewards that outweigh the costs.

Though numerous research findings on geophagy have been published, almost all focused on geochemistry and only list the animals observed, while very few included behavioural aspects of the animals involved. Aspects on seasonal periodicity of geophagy by ungulates, for example, have mainly been carried out in North America (Kreulen and Jager 1984). Apart from those of Atwood and Weeks (2003) and Ping *et al*. (2010), reports on sex and age differences in geophagy represent nothing more than observational remarks.

Lactation stages

In order for milk production to commence, cows must calve. The period between one calving and the next is known as the lactation cycle. The gestation period of a jersey cow is roughly 283 days and the lactation cycle runs over an approximate 12 month period which comprises several phases (Figure 1.1). The first zero to 14 days after parturition is known as the fresh cow phase and during this time milk production of the cow starts. Early lactation constitutes the first 14 to 100 days after calving. During this phase, milk production will gradually increase and peak at 7 to 10 weeks after parturition. Feed intake at this phase is not optimal as the appetite and body capacity has not yet been restored to the full potential and body weight will decrease as the cow utilises body reserves for the increased milk production. Feed intake and body weight loss will stabilise after 10 to 12 weeks. Following peak milk yield, optimum feed intake must be achieved very early into the mid-lactation phase (day 100 to 200 after calving) in order to maintain high milk production. Body weight will increase but towards the end of this phase milk production and feed intake will decrease. The start of the mid-lactation phase is the optimal time for cows to start breeding again. During the late lactation phase (200 to 300 days after calving) milk yield and feed intake will continue to decline as lactation approaches an end and the foetus increase in size. Although protein and energy requirements are less during this period because of declining milk yield, sufficient energy is still needed for the growing foetus as well as the build-up of body reserves for the next lactation. The last phase is known as the dry phase in which milk production stop as the body gets ready for calving. It is important to maintain body reserves during the dry period to ensure that the individual has sufficient body reserves for early lactation (Anonymous 2015, Anonymous Undated a).

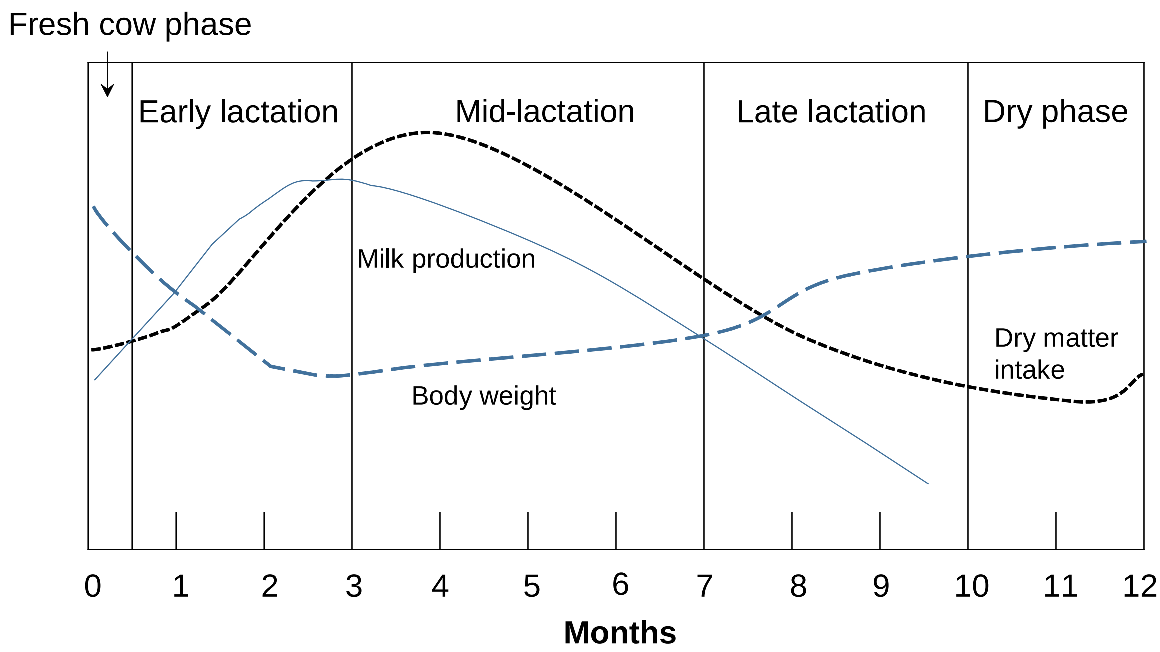

Figure 1. 1 Lactation cycle of a cow over a 12 month period. Modified from Anonymous (2015) and Anonymous (Undated a).

The use of a free-choice mineral experiment might therefore determine whether cows from different lactation stages would consume soil, mixed with calcium, calcium-phosphorus and sodium chloride, or a control soil at dissimilar amounts.

KEY QUESTION: What is the significance of geophagy at Amperplaas?

Objective 1

Determine peak times of mineral lick utilisation as well as geophagy hot spots amongst different lactation phases.

Questions:

1. Is there an increased incidence of soil ingestion during specific seasons at Amperplaas?
2. Is there a difference in the amount of soil ingested by cows in different lactation phases?
3. Is there a preferred time during a 24 hour period among the cows to consume soil?
4. Are there preferred areas in the encampments where geophagy is practiced?

Objective 2

Assess the risk of sand impaction.

Question:

1. When comparing the daily soil ingestion rate with the excretion rate, is there a risk of sand impaction among these dairy cows?

Objective 3

Do cows show a preference for certain elements?

Questions:

1. Are these individuals able to discriminate between different minerals?
2. Do cows from different lactation stages select different minerals as well as different amounts of these minerals?

CHAPTER 2

STUDY AREA

CHAPTER 2: STUDY AREA

The study was conducted at Amperplaas, a privately owned dairy farm, near Bloemfontein in the central Free State of South Africa. The farm was established in May of 1997 and is situated 13.5 km northwest of Bloemfontein (centered at 29°2'48.57" S, 26°5'52.09" E) (Figure 2.1). Amperplaas encompasses a surface area of 8.51 ha with an average elevation of 1 343 m above sea level. The surrounding area is predominantly used for agricultural purposes where farmers mainly farm with crops such as sunflower (*Helianthus annuus*), wheat (*Triticum aestivum*), maize (*Zea mays*) as well as livestock which include cattle (*Bos tuarus* and/or *B. indicus*), sheep (*Ovis aries*). On some farms other animals such as different game species as well as horses (*Equus caballus*) and goats (*Capra aegagrus hircus*) might also be present.

At this dairy farm, predominantly Jersey cattle (*B. taurus*) were kept for intensive milk production. At the start of the study, approximately 180 Jersey cows and two Jersey bulls were present at Amperplaas. Other livestock at the dairy farm included sheep and horses. Over the study period the number of cows fluctuated as deaths occurred and new individuals were added to the herd. In July 2013 two Holstein Friesian cows (*B. taurus)* were also added to the herd. The youngest individuals (9 – 18 months) were periodically moved to another farm in close proximity with natural feed.

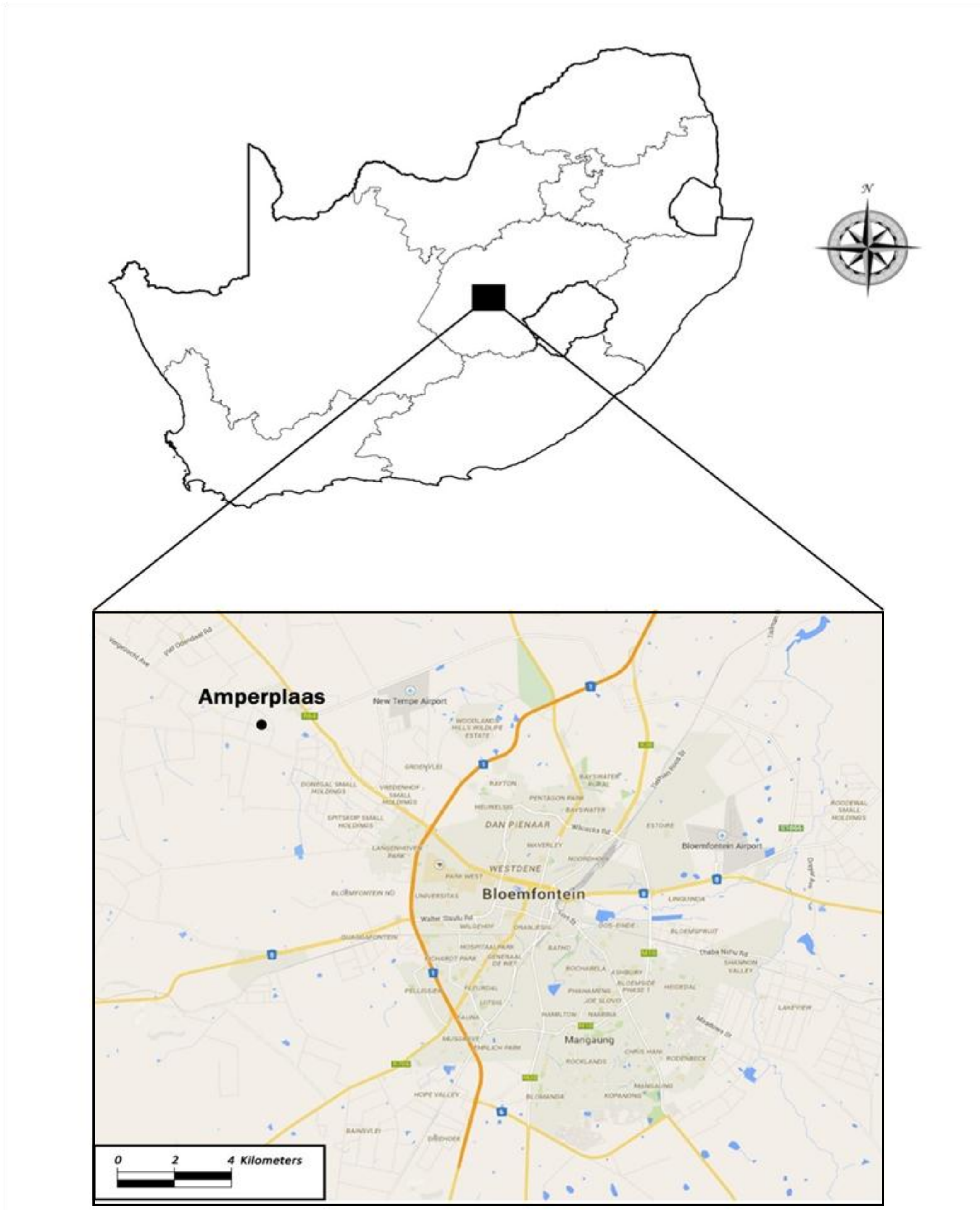

Figure 2.1 Location of Amperplaas dairy farm in the central Free State (South Africa). Modified from Google Earth Map Data © 2015 AfriGIS (Pty) Ltd.

2.1 Geology

Amperplaas is located in the Volksrust Subgroup (Figure 2.2) of the Beaufort Group which forms part of the Karoo sequence (Johnson *et al.* 2006). This area is underlain by basinal mudrocks with phosphatic/carbonate/sideritic concentrations and minor coals (Visser 1984). The Volksrust Formation is mainly a unit of the overlying Beaufort Group and underlying Vryheid Formation in which clay minerals are of secondary but significant component (Johnson *et al.* 2006). The formation consist of grey to black silty shale with thin, usually stirred by organisms, siltstone or sandstone bed deposits that is thick in the middle and tapers thin towards the edges. Thin phosphate and carbonate beds and hard compact masses of matter, which is formed by precipitation of mineral cement within spaces between particles, are commonly found (Johnson *et al.* 2006).

Tavener-Smith *et al* (1988) reported the presence of concretions of siderite ($FeCO_3$) up to 1.5 m in diameter and beds up to 0.75 m thick within this formation. Siderite is a mineral composed of iron (II) carbonate ($FeCO_3$). It is a valuable iron mineral, since it contains 48% iron and no sulphur or phosphorus. Zinc, magnesium and manganese commonly substitute for the iron resulting in solid solution series of siderite-smithsonite, siderite-magnesite or siderite-rhodochrosite (Anonymous Undated b).

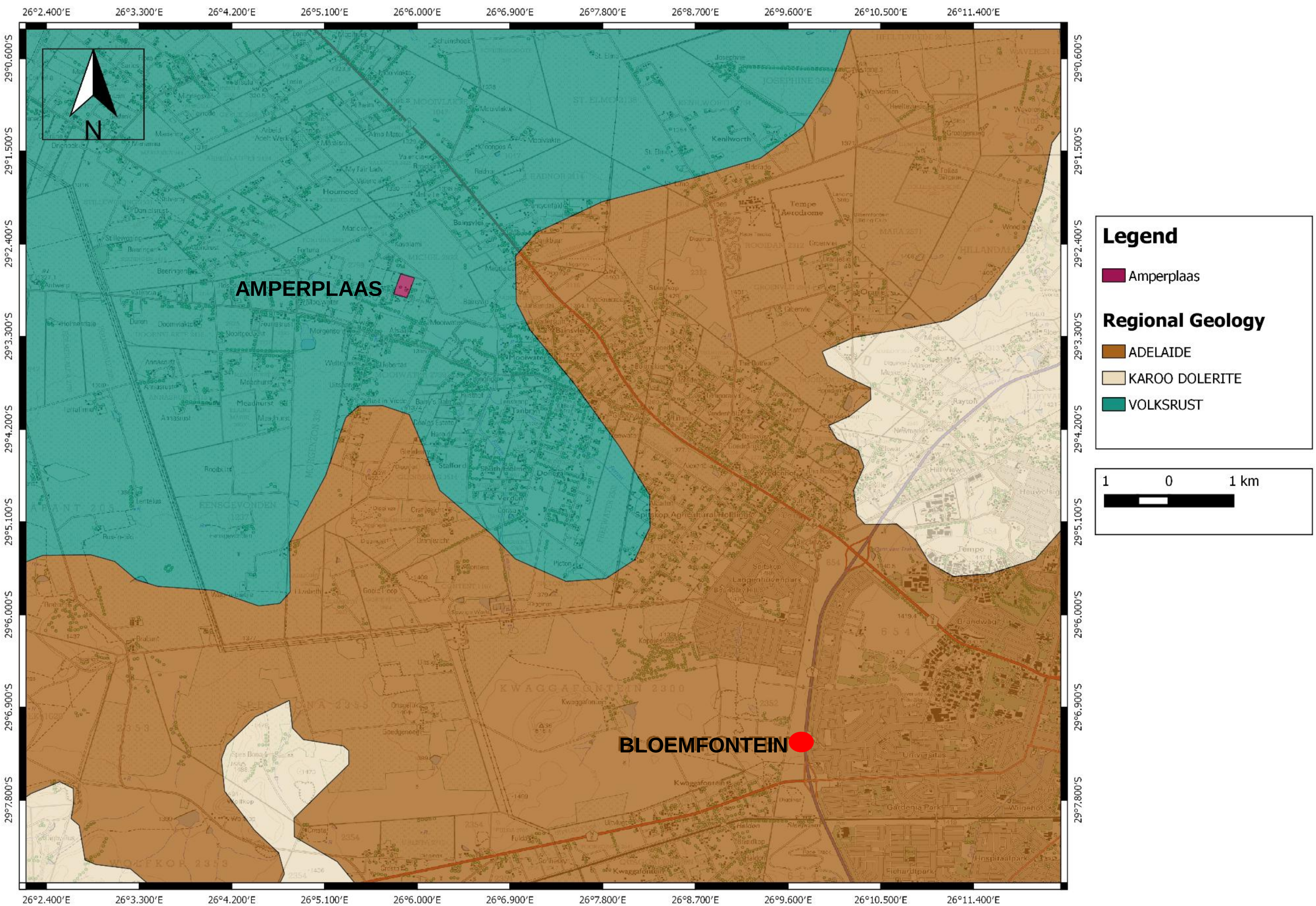

Figure 2.2 Regional geology surrounding the study area near Bloemfontein in the central Free State.

2.2 Vegetation

Amperplaas falls within the Grassland biome (O'Connor and Bredenkamp 1997) and more specifically in the Dry Highveld Grassland Bioregion which is dominated by Red grass (*Themeda triandra*) and Weeping lovegrass (also known as Oulandsgras) (*Eragrostis curvula*) grass species. As this farm is used for agricultural purposes, the natural vegetation has been removed in order to cultivate crops for additional feed for livestock. These additional feed include lucerne (*Medicago sativa*), radishes (*Raphanus sativus*) and teff (*Eragrostis teff*).

2.3 Climate

Amperplaas is situated in the summer rainfall region of South Africa which receives most of its rainfall from November to March (Figure 2.3). The mean annual rainfall for the period July 1999 to June 2016 was 534 mm. During the study period (July 2011 to June 2016) the mean annual rainfall was measured at 368 mm. The rainfall in the study area was below the average and irregularly distributed with the highest mean monthly rainfall recorded during December and February respectively. This farm falls in an area with a semi-arid climate and temperature extremes (Oliver 2007). Maximum temperatures can reach up to 37°C from November to February and temperatures as low as -8°C have been recorded from June to August. The average annual maximum temperature is 25°C and the annual average minimum temperature is 7°C.

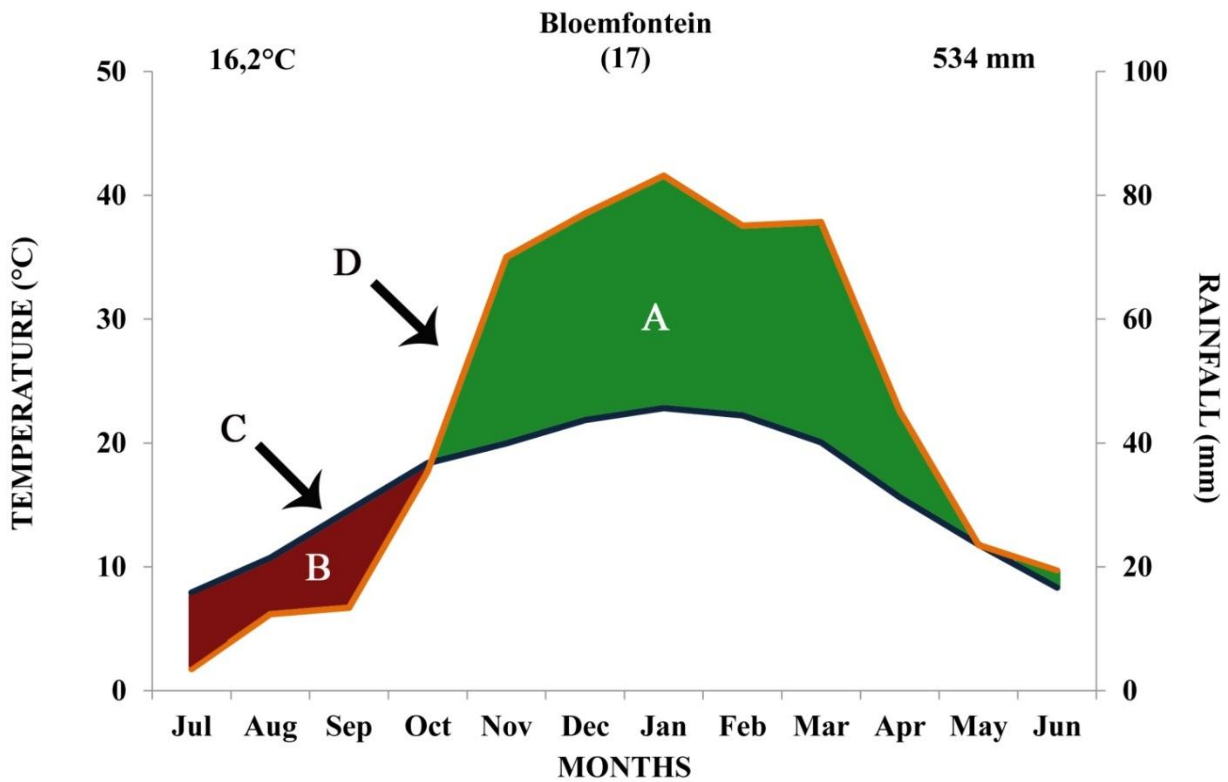

Figure 2.3 Climate diagram of Bloemfontein according to the method of Walter and Lieth (1964). Number between brackets indicates the number of years of observation. Mean annual temperature and rainfall are indicated in the top left and right corners respectively. **A**, wet season; **B**, dry season; **C**, average monthly temperature; **D**, average monthly rainfall. (Data source: South African Weather Service and Wunderground).

2.4 Encampments

The majority of the farm was divided into 13 camps of which six camps were exclusively utilized to hold livestock while the remaining camps were alternately used for temporary livestock holding pens and to grow feed (Figure 2.4). The encampments were of varying sizes ranging from 0.14 to 1.98 ha and camps which were not used for feed growing were predominantly bare soil with almost no plant cover (Figure 2.5). These holding pens had a varying number of geophagy lick spots where animals frequently consumed soil deliberately.

At the commencement of the study, only camps 1, 2, 5 and 6 held cattle, while camp 4 contained horses. During the study period the cows were moved between camps according to their respective lactation stage. Camps 1 to 6 were used to predominantly hold cattle, although camp 3 was empty with the onset of the study, it was however utilized as a holding pen later during the study. The remaining camps were used to plant additional feed (camps 7 to 9 and 12), to accommodate silage holes (camp 10), for training of horses (camp 11) or temporary holding pens for horses (camp 13).

Cows were grouped according to their different lactation stages. Individuals in the early lactation phase (milking group 1) were grouped together and at the commencement of the study, 36 cows were kept in camp 2. Milking group 2 consisted of the individuals on their last lactation (near dried up) and 15 cows of this late lactation group were kept in camp 6. Individuals in the first period of mid-lactation were regarded as milking group 3. Camp 3 held this first lactation group and at the commencement of observations 50 individuals were present in this camp. Milking group 4 consisted of the individuals on the second period of mid-lactation and these cows (47 in total) were contained in camp 5. Heifers (9 – 18 months of age) as well as dry individuals were not used for milk production. 16 Dry cows were kept in camp 1 while camp 4 held 49 heifers at the start of observations at this camp.

Figure 2.4 Layout of encampments at Amperplaas in the central Free State. Modified from Google Earth Map Data © 2015 AfriGIS (Pty) Ltd.

Figure 2.5 Encampments cleared of natural vegetation, of cows from different lactation stages at Amperplaas in the central Free State.

2.5 Operational system at Amperplaas

With the exception of small patches of kikuyu grass (*Pennisetum clandestinum*) in some camps, cattle at Amperplaas were kept in camps cleared of any natural vegetation. Feed was supplied once (11:00) or twice (11:00 and 16:00) daily, depending on the time of year and availability of feed, in steel or tyre feeding troughs (Figure 2.6). Feed consisted of either corn silage, baled Lucerne, turnips, maize plant residue, VOLMEL 15.5% (complete dairy feed) (AFGRI Animal Feeds, Bethlehem), scientific bovine semi complete (AFGRI Animal Feeds, Bethlehem), Farmix Complete Dairy Pellets or dairy meal (Lubern Veevoere, Hartswater) with Rumensin 200 supplements (ELANCO Animal Health, Bryanston). Self-filling water troughs were stationed at specific places in the encampments.

Cows were milked twice a day, usually at 04:00 in the morning and again at 16:00 in the afternoon, in sequence according to the different milking groups they belonged to. The individuals of one camp were driven out of the camp into the area in front of the milking stall before entering. The milking stall can hold 18 individuals at a time, after which they were driven out and back to their encampment.

Most individual cows could be identified by a number system. Some individuals were marked by a chain with a number around the neck while others were marked with ear tags. A few however remained unmarked but could easily be distinguished by coat patterns and skin markings. Records were kept of milk production of each individual cow.

Figure 2.6 Steel (left) and tyre (right) feeding trough used to place daily feed for individuals.

CHAPTER 3

METHODOLOGY

CHAPTER 3: METHODOLOGY

The behaviour of geophagy amongst dairy cattle was investigated by means of direct observations as well as with the aid of camera traps. Analysis of selected, ingested and excreted soil as well as milk from certain individuals was carried out to determine the chemical composition of soil and milk. As part of the study, selection of preferred minerals was tested by means of a cafeteria experiment.

3.1 Direct observations

The aim of direct observations was to indicate soil licks and identify the individuals that consume soil. The frequency of visits to soil licks and duration of soil consumption at licks was also recorded as well as general daily activities. General daily activities included lying, standing, drinking, feeding and geophagy.

Field observations were carried out over a four year period, from February 2012 until December 2015. Adjacent camps were alternately observed on a monthly basis. Camps on the southern side (1 to 4) were alternated with camps on the northern side (5 to 11) (*vide* Figure 2.3). Observations were done two to four days per week, from sunrise until sunset. Continuous observation was used to determine the incidence of geophagic events and the scan sampling method (Altmann 1974) was used to record the prevailing activity every 15 minutes for all individuals. During field observations, relevant information including date, time of day, individual number or characteristic of cow, ambient temperature and humidity at time of geophagic event, exact locality and duration of geophagic event was noted.

3.2 Camera traps

In order to maximize the documentation of geophagic events, camera traps were placed to record activity at the known licks at times, mainly during the night, when direct observations were not done. Two Bushnell® camera traps were used throughout the study; each was equipped with an 8 GB Kingston® Memory Card and rechargeable 12 V battery pack. Due to the setup of the camps at the farm, the only suitable locations for placement of camera traps were at the corners of each camp as well as the gate poles.

The quality of photographical data was influenced by weather conditions as well as the distance of individuals from the camera trap. In some instances the quality was affected by individuals licking the camera lens or rubbing against the camera trap, altering the original placement of the camera. In instances where the photograph was blurred due to dirt on the lens or the animal was too far away to recognize a number or coat patterns which distinguish it from other individuals, the event was only recorded as a geophagic event with a starting and ending time at a location. The delay time between photos was set to zero seconds in order to capture the initiation time as well as the end time of a geophagic event in order to determine the duration of such an event.

3.3 Soil collection

Soil was collected in order to establish the mineral content of the soil at the licks at Amperplaas. Mahaney and Krishnamani (2003) advise when soil is collected for analyses, the surrounding area must be properly described and samples should be collected from the exact spot of ingestion as well as surface soils or controls where no ingestion has occurred. Soil samples were collected at a few fresh, established and abandoned licks sites as well as sites, in close proximity of the geophagic site, where no soil ingestion has been recorded.

The samples were dried at 80 °C for 72 hours and stored in glass bottles for analyses. GPS coordinates of each sample location was recorded and plotted on a map. The collected soil was sent to the department of Geology at the University of the Free State to be analysed by means of X-Ray Diffraction as well as X-Ray Fluorescence.

3.4 Stomach content

Since March 2012 a few deaths occurred and in order to determine the amount of soil still present in the stomach, an arrangement was made with the owner to collect the stomachs of the dead individuals. Six stomachs were collected during the study period. When possible, the omasum, abomasum and reticulum were collected, but in three instances only the omasum and reticulum could be collected.

After collection, the stomach compartments were cut open and rinsed multiple times in either 45 litre plastic containers or a 100 litre metal drum filled with water (Figure 3.1A). All the material was scraped and rinsed from the stomach compartment linings (Figure 3.1B). The material collected from the stomach compartments were then continuously diluted with water, stirred and rinsed in order to separate and discard the floating plant material from the settled soil and gravel.

The remaining material at the bottom was rinsed through different sieves with decreasing mesh sizes in apertures of 1.4 mm, 1.25 mm, 0.85 mm, 0.5 mm, 425 μm and 150 μm. Plant particles that still remained after rinsing was manually removed using a pair of tweezers. The sifted soil and gravel was dried in an oven at 80 °C for 72 hours, weighed and analysed by means of X-Ray Diffraction as well as X-Ray Fluorescence by the department of Geology at the University of the Free State.

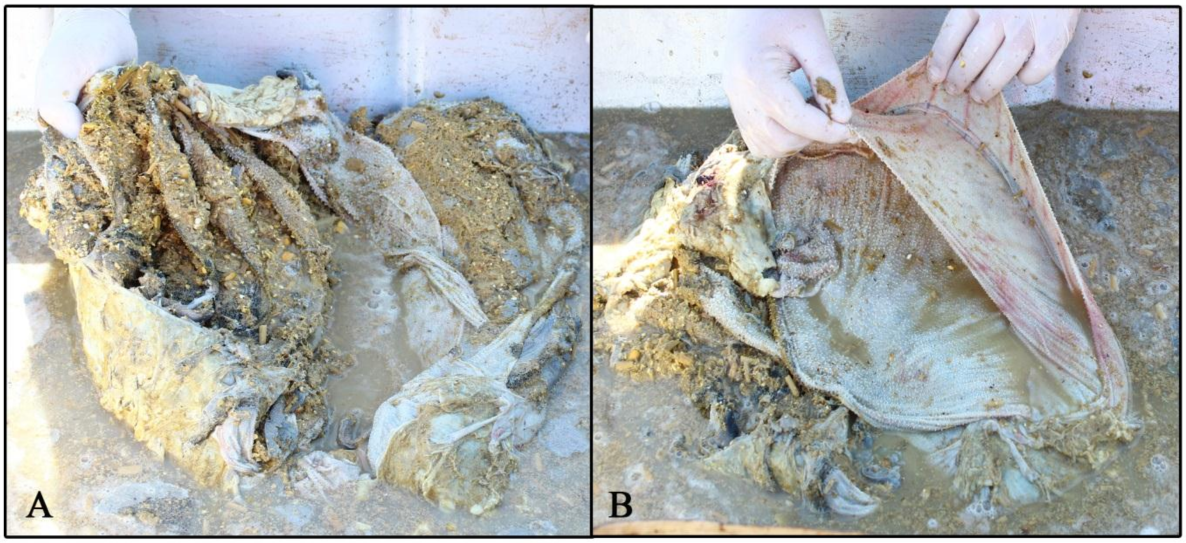

Figure 3.1 Omasum compartments prior to (**A**) and after (**B**) the removal of contents.

3.5 Faecal content

In order to evaluate the amount of soil ingested and excreted by dairy cows, an apparatus which enable the collection of faecal matter was adapted after the model of Kartchner and Rittenhouse (1979). The apparatus consisted of a canvas bag, several straps and a plastic bag (Figure 3.2). The canvas bag was 30 cm x 40 cm in size with a V-shaped cut on one side to fit the rear end (base of the tail) of the cow preventing the loss of faecal matter. The canvas bag had four attached straps, two at the top of the bag in order to keep the harness from sagging and two at the bottom of the V-shaped cut in order to hold the bag open to catch the faecal matter. These straps were secured to two anchor straps tied around the individuals' body; one around the neck and one just behind the front legs in order to secure the harness to the body (Figure 3.2). A thick plastic bag was inserted into the outside canvas bag so that faecal matter could be easily emptied into a sorting container.

Figure 3.2 Individual enclosed in milk stall, fitted with harness.

The harness could hold a cowpat of approximately 5 kg. During this study there was no need to separate the urine and faecal matter since the harness was quickly removed from the individual. The harness proved to only be successful when the individual was in a stationary position. The cows had a tendency to rub against the gate or wire around the camp to get rid of the harness and the harness would tear or move from the fitted position. Therefore an individual was herded into and enclosed in the milking stall, fitted with the harness and kept until a cowpat was excreted. The harness was then removed from the individual; the plastic bag emptied into a sorting container and the faecal matter diluted with water before the next individual was herded into the milking stall and fitted with the harness.

In order to establish dry mass, collected faecal matter was dried for 72 hours at 80°C in an oven where after it was weighed. Dried faecal matter was then submerged again in water and while it was stirred, the floating layer of plant material was discarded. The remaining water was decanted through sieves with progressively small mesh sizes. Large pieces of remaining plant material were removed using a pair of tweezers. After extraction, the collected soil was marked, dried in an oven at 80°C for 72 hours and weighed. Soil analysis was done by means of X-Ray Diffraction as well as X-Ray Fluorescence by the department of Geology at the University of the Free State.

3.6 Free-choice mineral selection

The use of a cafeteria experiment aimed to establish the preferred mineral intake by individuals. This experiment was carried out from April to August 2014 and comprised of an identical experimental procedure for groups of cows of three different lactation stages followed by a repetition for each group. During the cafeteria experiment, 29 individuals in the mid lactation stage, which at this time of the study was the highest milk producer group, 31 in their late lactation phase and seven dry individuals, were present.

At the start of the experimental procedure, soil was collected from the camp where the experimental procedure was to take place and dried at 80 °C for 72 hours. Four identical containers were planted each day at sunrise in holes, dug 1 m apart within a camp (Figure 3.4). Three of the containers were filled with three kilograms of the collected soil mixed with two kilograms of different minerals while a fourth container was filled with only soil collected from the camp with no added minerals and served as a control. One soil mixture was enriched with a high concentration of calcium. This mixture consisted of soil mixed with FEEDLIME consisting of a high calcium content as well as fluorine and aluminium of different concentrations. A second soil mixture containing calcium-phosphorus mineral mixture (KIMTRAFOS 12 Grande) consisted mostly of calcium and phosphorus with added iron and trace elements in various concentrations. A third mixture was made of soil and sodium chloride in the form of coarse salt.

The containers were removed at sunset and the remaining contents weighed. Containers were filled with 5 kg of soil mixtures and planted at sunrise the next day in a different order. The removal of the cafeteria containers was in order to observe specific individuals when consuming soil from these buckets. This procedure was repeated with all available lactation groups of cows.

As the amount of soil ingested by each individual cow could not be measured, the duration of soil eating, expressed in seconds, was recorded with the aid of a stopwatch for each geophagic event for each individual. As the containers with mineral mixtures were removed and weighed at the end of each day, it is accepted that the difference in weight was due to the eating of soil alone. In order to calculate the estimated amount of soil ingested by each individual cow, the amount of ingested soil was divided by the total time spent by all cows recorded at all the experimental containers. A calculated value of 3.16 gram/second was consequently used in the remaining study as a norm to express the amount of soil consumed.

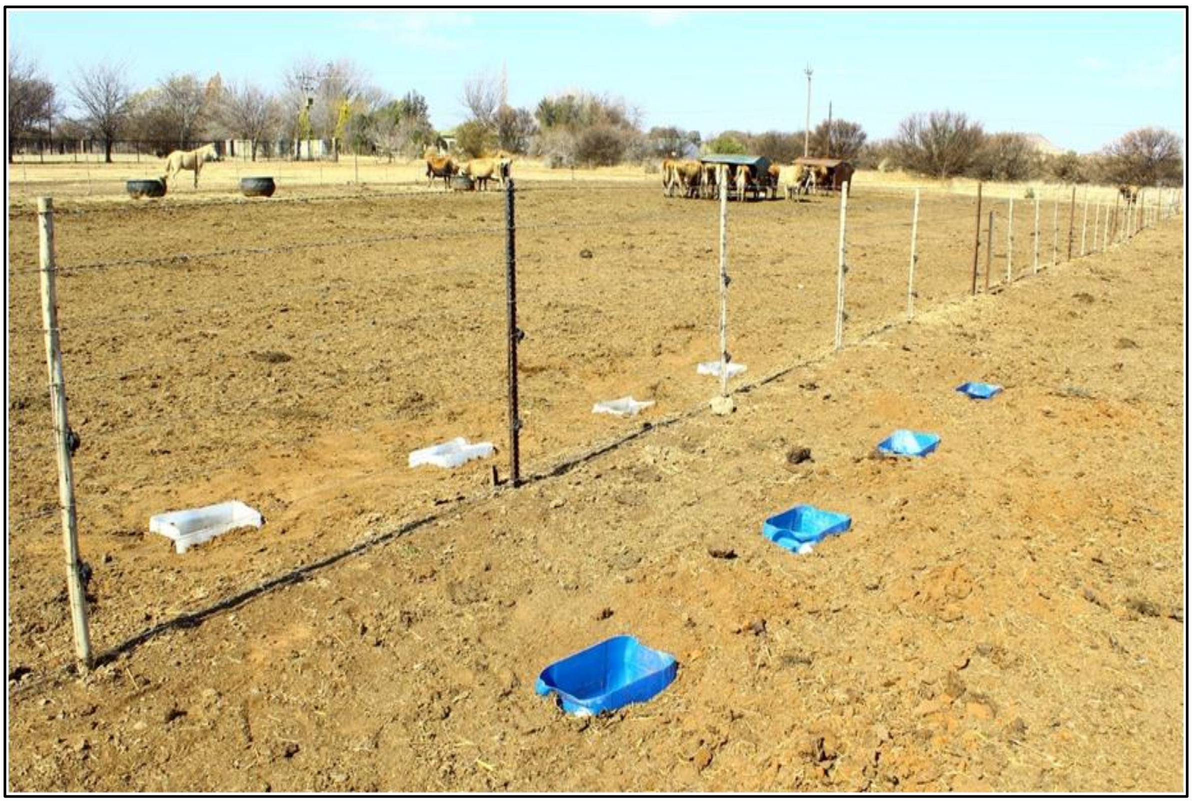

Figure 3.3 Containers containing mineral and soil mixtures, spaced 1 m apart, during cafeteria experiment performed in Camps 1 and 5 simultaneously.

3.7 Milk production and analysis

At Amperplaas, the milk production of all individuals was recorded on a standardized form by workers during the milking sessions. When possible, these milk production records were obtained. Milk samples were collected from selected individuals recorded to practice geophagia during the study period as well as from individuals with the lowest and highest milk yield together with their milk production records. The sampled milk was dry-ashed and analysed by the Department of Soil, Crop and Climate Sciences of the University of the Free State.

3.8 Data analysis

As the lactation phase of cows progress in a 12 month period, the lactation phase of individuals did not remain constant during the study period. Furthermore, the lactation phases of all the individuals were not synchronized and the cows were constantly moved to different groups as these phases changed. Wherever averages are calculated, the number of individuals for a specific lactation phase is provided. Microsoft Excel (Microsoft Office 2013) was utilised for all statistical analysis. All correlations were calculated using the Pearson Correlation Coefficient. Anova tests were used to calculate the difference of milk quality between different individuals of a specific lactation group. In all statistical analyses a 95% confidence level was used to determine significance.

CHAPTER 4

MINERAL LICKS AND GEOCHEMISTRY

CHAPTER 4: MINERAL LICKS AND GEOCHEMISTRY

Commonly known as salt licks, geophagy sites are often explained as areas where animals supplement their diets with sodium. The explanation for a salt deficiency, especially for herbivores, is because sodium act as the dominant cation in bodily fluids and with a diet depleted from sodium, might become sodium-deficient (Robbins 1993). Ungulates have a strong attraction to sodium salts and many studies have reported elevated concentrations of this element in the lick material (Hebert and Cowan 1971, Weeks and Kirkpatrick 1976, Fraser and Reardon 1980, Fraser *et al*. 1980, Tankersley and Gasaway 1983, Reisenhoover and Peterson 1986, Kennedy *et al*. 1995, Tracy and McNaughton 1995).

However, the commonly excepted hypothesis that the use of geophagy sites by ungulates can be explained only by the craving of sodium is disproved by results of geochemistry from other lick soils showing low sodium contents and the presence of other important elements (Heard and Williams 1990, Dormaar and Walker 1996). While it is difficult to target specific elements or minerals as stimuli for geophagy, it has been shown in many cases that sodium (as NaCl), which has commonly been cited as the stimuli for geophagy (Robbins 1993), is not always present in sufficient amounts to be the only reason for this behaviour. Although the presence of some elements in the soil may be linked to nutritional benefits, the presence of clay minerals appears to be a common and probably important factor (Mahaney *et al*. 1995). The observation of soil consumption by animals may therefore be related to the physical properties of the soils, elements in the contents, and/or to the presence and action of different clay minerals. Therefore, more correctly, such sites should rather be referred to as mineral licks.

Given the variation in chemical composition, geophagy sites may serve multiple functions for different species and sexes at different times of the year (Kreulen 1985). Atwood and Weeks (2003) reported that more female white-tailed deer (*Odocoileus virginianus*) used mineral licks with elevated concentrations of magnesium, calcium and phosphorous more often than they utilise salt licks. This discrimination by white-tailed deer was observed during the late gestation and early lactation phase (Atwood and Weeks 2003).

New evidence suggests that mineral supplementation is not the only reason for geophagic behaviour. According to Stephenson *et al*. (2010), natural licks are characterised by its moderate to high clay content and Jain *et al*. (2008) suggests that this may be a primary ingredient in soils which are selected. Elements other than sodium such as magnesium (Heimer 1988), buffering compounds such as carbonates (Kreulen 1985), and binding agents such as clays (Klaus and Schmid 1998) suggest multiple reasons for the use of licks by ungulates.

Deficiencies in macro- and trace elements are not necessarily a result of limited dietary intake, but can also be as a result of digestive disorders associated with the change in forge from winter to spring (Ayotte *et al*. 2006). A decrease in fibre and an increase in easily fermentable carbohydrates and proteins, as found in forage during springtime, can alter pH and weaken the functions of microbes in the rumen (Ayotte *et al*. 2006). Ruminants exposed to sudden drops in dietary fibre produce less saliva, which is high in bicarbonates (Kreulen 1985). With less saliva, the buffering capacity of the rumen is reduced (Church 1975) and can lead to a drop in pH below optimal conditions for rumen microbes, creating various intestinal ailments that reduce appetite and weight gain (Kreulen 1985, Klaus and Schmid 1998). The use of geophagy sites by many ungulates escalate during spring as there is an increase on the physiological demands of animals during lactation, growth or weight regain (Ayotte *et al*. 2006).

4.1 Results and Discussion

4.1.1 Mineral licks

Camp enclosures were constructed of wooden anchor posts and smaller wooden as well as iron droppers. Barbed wire was supported and spaced by these wooden anchor posts as well as wooden and iron droppers. With the exception of one mineral lick site, which was in a cleared, newly scraped open area in camp 2, where cows from the early lactation phase were kept, all mineral lick sites were positioned underneath the wire fence and around the wooden and iron poles. No specific preference for geographical position could be determined and it seemed that lick sites were established at random along the fences. Although all camps were scraped on a yearly basis, soil underneath the fences was not removed and therefore formed a small ridge which was elevated above the rest of the camp surface. These elevated, undisturbed ridges seemed to be the preferred areas where cows engaged in geophagy activity.

The size of mineral licks varied from a few centimetres in diameter (Figure 4.1A) to more than 4 m in length (Figure 4.1C). As mineral licks were often connected due to frequent utilisation, elongated sites resembling troughs were formed in the soil underneath fences. The depth of these geophagy sites ranged between 1 cm (Figure 4.1A) and 35 cm (Figure 4.1B) with typical depths of around 10 cm. The two largest licks were found in camp 5 and 6 with lick sites of two metres in length and width of about 40 cm that reached a depth of up to 35 cm. These geophagy sites were formed in camps where cows from the mid-lactation and late lactation were housed respectively.

Several licks were started and utilised only for a short period of time while some were continuously used for several years. A typical geophagy site will start with a small indentation (Figure 4.1A) and gradually increase in depth after which increasing in circumference as the site is continuously excavated. Certain times of the year geophagy sites will be filled with wind-blown top soil or sand washed in by rain water.

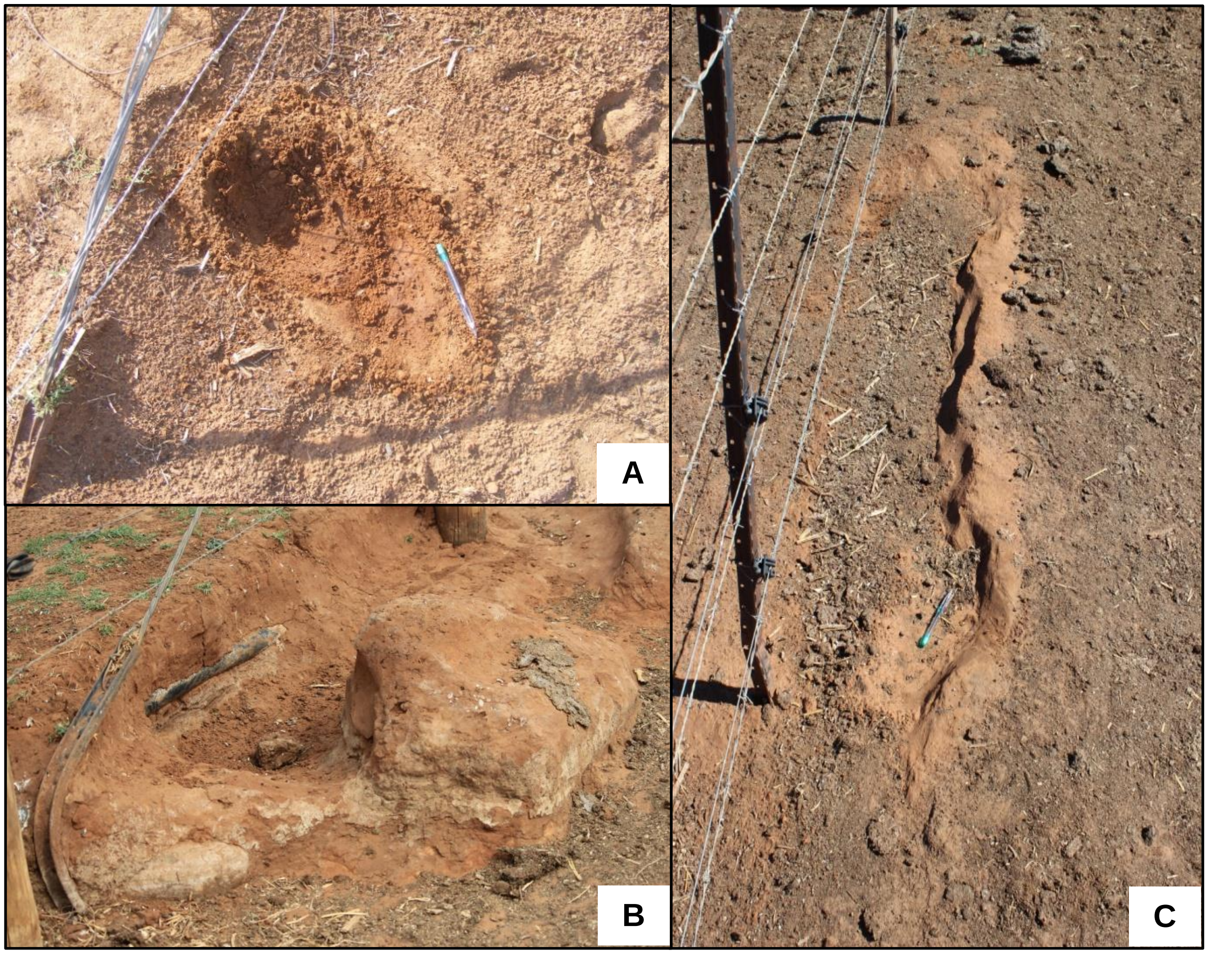

Figure 4.1 Geophagy sites alongside camp fences at Amperplaas dairy farm in the central Free State. Newly established lick (**A**), approximately 15 cm in diameter. Old established lick (**B**) with a depth of approximately 35 cm. Established lick (**C**) approximately 2 m in length.

4.1.2 Geochemistry

Although Mahaney and Krishnamani (2003) stated that geophagia sites are usually situated in mature landscape sites where weathering of parent material and soils over long periods have occurred, no evidence of weathered soil was visible at Amperplaas. The soil which is frequently consumed by dairy cows at Amperplaas can be described as alkaline with pH values ranging from 9.6 to 11.1. Texturally, the soil is classified as sandy clay loam (Figure 4.2) with contents of clay (33 – 35%), sand (68 –72%) and silt (65 – 72%). By using the Munsell System of Colour Notation, the soil can be described as 2.5 YR 6/6.

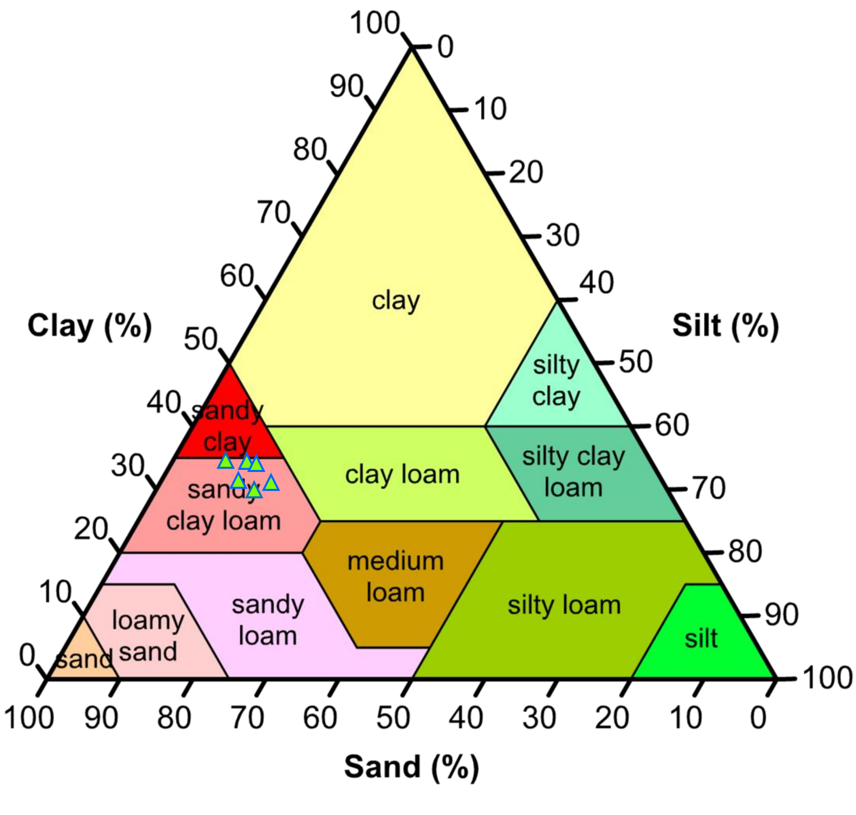

Figure 4.2 Textural classification of geophagy soil (green triangles) at Amperplaas near Bloemfontein in the central Free State.

Based on X-ray diffraction analysis Quartz, Plagioclase and K-Feldspar were identified in all the site samples while Ilmenite (Figure 4.3) was quantifiable in all samples except for Control 1 (Table 4.1). The majority of soil collected at Amperplaas consisted of Quartz, with the lowest concentration at the freshest site. With the exception of the freshly established site which showed elevated levels of Plagioclase and K-Feldspar compared to the other lick sites, comparable levels of Plagioclase, K-Feldspar and Ilmenite was present in all geophagy soil. One control sample as well as soil from an old site close to an iron pole was the only sites that showed evidence of Mica.

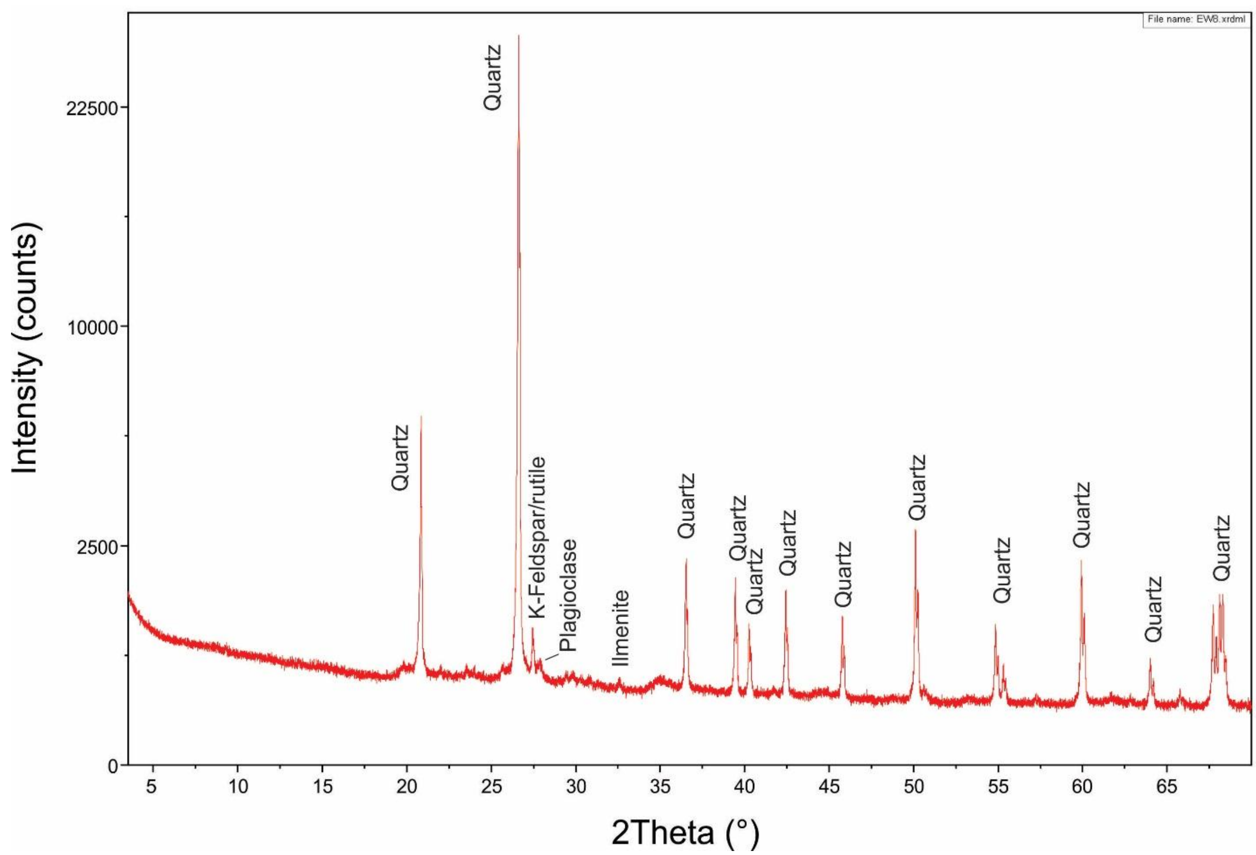

Figure 4.3 X-Ray diffractogram of clayey soil from the freshly established geophagy site at Amperplaas in the central Free State.

Table 4.1 Composition (%) of Quartz and clay components of mineral licks at Amperplaas near Bloemfontein in the central Free State.

	Control 1	Control 2	Abandoned site, beneath wire	Old Established site, wooden pole	Old Established site, iron pole	Newly established site, exposed soil	Newly established site, wooden pole	Fresh site, beneath wire
Quartz	81	84	84	87	77	87	86	69
Smectite								
Mica	7				8			
Plagioclase	5	6	6	5	5	5	5	10
K-Feldspar /Rutile	7	6	8	7	8	6	7	16
Ilmenite		5	2	2	2	2	2	4
Calcite								
Siderite								

The most abundant compound in the lick soil was silica (71.9 – 88.4%) (Table 4.2). The higher silica (SiO_2) and therefor Quartz content of the older established sites might be an indicator as to why these licks become less used or abandoned. As the mineral licks increase in size, these areas act as catchments for wind-blown top soil and debris which may be high in silica (SiO_2) which in turn can bring about an increased rate of tooth wear (Kaiser *et al.* 2009) in these animals if ingested continuously.

Furthermore soil collected from the freshly established site beneath the fence wire had the highest CaO, K_2O, Na_2O and P_2O_5 concentrations when compared to all the collected soil. When comparing only the lick sites, the fresh site beneath the fence wire also showed elevated Fe_2O_3 and MgO concentrations. According to Astera (2014) calcium, magnesium, potassium and sodium are all alkaline cations. Since clay particles are mostly negatively charged, the clay particles will attract and hold the positively charged nutrients. The calcium **:** magnesium ratio plays a role in the compactness of the soil. This in effect will determine the water and oxygen retention ability as well as the aerobic breakdown ability of the soil. Soil with higher magnesium content tends to be tighter, contain less oxygen and retain water more than soil with higher calcium content. With the exception of the freshest site, Table 4.2 shows that the other sites all had higher concentrations of magnesium than calcium.

Barium as well as zirconium were present in the highest concentration in the older mineral licks samples and were lowest at the newest lick site (Table 4.3). The concentrations of arsenic, bromine, cobalt, niobium, lead, scandium and yttrium present in the lick samples ranged between 2 - 20 mg/kg. The concentration of arsenic gradually increased as the utilization/age of a lick increased. The newest lick contained the highest concentration of bromine, cobalt, nickel, strontium as well as zinc. The concentration of chromium ranged between 80 and 97 mg/kg and except for control site 2, the highest concentration was present in the newest lick. Thorium was only quantifiable in the two control samples. The copper content ranged from 21 mg/kg at the newest lick to 44 mg/kg at the newly established licks at the wooden pole and exposed soil. The zinc concentration

Table 4.2 Composition (%) of major elements, in oxidation state, of soil collected at Amperplaas near Bloemfontein in the central Free State.

	Control 1	Control 2	Abandoned site, beneath wire	Old Established site, wooden pole	Old Established site, iron pole	Newly established site, exposed soil	Newly established site, wooden pole	Fresh site, beneath wire
SiO_2	87.0	84.6	84.0	88.3	85.0	88.4	86.0	71.9
TiO_2	0.6	0.6	0.5	0.6	0.6	0.6	0.6	0.5
Al_2O_3	4.2	5.3	3.9	4.2	4.4	4.0	4.3	3.9
Fe_2O_3	2.9	3.2	2.7	2.7	2.9	2.8	2.7	3.0
MgO	0.8	1.4	0.7	0.3	0.3	0.1	0.4	0.9
MnO	0	0	0	0	0	0	0	0
CaO	0.1	0.2	0.5	0.1	0.1	0	0.2	1.3
K_2O	1.0	0.9	0.8	0.7	0.7	0.8	0.7	1.4
P_2O_5	0.1	0.1	0.2	0	0.1	0	0.1	0.6
Na_2O	0.3	0.2	0.3	0.3	0.3	0.3	0.2	0.5
Loss on ignition	3.0	3.3	6.4	2.9	5.7	2.8	4.7	16.0
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

varied considerably between the site samples with extremely elevated concentrations occurring in the freshly established site. According to Schulte (2004) zinc as well as copper is held mainly as cations on the surface of clay minerals with the addition of zinc being bound by chelation, thus reducing zinc to leach as easily as other minerals would.

Table 4.3 Trace element content (mg/kg) of soil collected at Amperplaas near Bloemfontein in the central Free State.

	Control 1	Control 2	Abandoned site, beneath wire	Old Established site, wooden pole	Old Established site, iron pole	Newly established site, exposed soil	Newly established site, wooden pole	Fresh site, beneath wire
As	8	5	7	7	6	6	<4	4
Ba	709	661	578	656	628	666	648	562
Br	6	8	9	4	7	8	4	17
Co	6	6	6	5	7	6	8	9
Cr	83	97	81	80	87	81	87	89
Cu	24	32	42	30	33	44	44	21
Mo	<1	<1	<1	<1	<1	<1	<1	<1
Nb	5	4	4	5	4	5	4	3
Ni	21	21	20	19	21	21	20	25
Pb	8	8	9	9	8	9	8	7
Rb	39	43	36	35	37	34	37	38
Sb	61	59	57	60	59	58	60	57
Sc	4	4	2	3	5	4	5	<2
Sr	29	31	39	27	29	24	30	54
Th	3	3	<2	<2	<2	<2	<2	<2
V	79	73	69	79	78	81	76	66
Y	9	8	8	8	8	8	9	8
Zn	19	30	41	16	43	15	28	76
Zr	356	321	303	355	354	381	342	298

4.2 Conclusion

From the soil analysis results, soil collected at Amperplaas had relative low levels of clay and a relative high pH as it was classified as alkaline sandy clay loam. Even though literature reports that geophagic soil have high clay content, soil at Amperplaas was nonetheless consumed to a great extent as mineral licks were constantly utilised in the encampments. Based on the geology and soil geochemistry, soil that is consumed at Amperplaas contains macro as well as micro elements that might supplement the daily nutritional needs of dairy cows. It would appear that the newest established mineral licks was initiated for a trade-off between low silica, arsenic, lead, scandium as well as zirconium content with elevated levels of calcium, iron, potassium, magnesium and phosphorus as well as trace elements such as bromine, nickel, strontium and zinc.

CHAPTER 5

GEOPHAGIA

CHAPTER 5: GEOPHAGIA

Soil ingestion is a well-documented behaviour among various animals (Kreulen and Jager 1984). The consumption of soil varies greatly between species as well as within species due to different ages, gender, and time of year as well as the preference of certain soils or soil components (Abrahams 2011).

According to Weeks and Kirkpatrick (1976), Mahaney *et al*. (1995), Krishnamani and Mahaney (2000) as well as Atwood and Weeks (2003) a seasonal pattern can be discerned for the use of geophagy licks. Ping *et al.* (2010) suggests two reasons for this phenomenon: the first being that a greater amount of minerals is required when the chemistry of natural feed change in spring or wet season while the loss of sodium through body secretions is greater during this time (Langman 1978, Jones and Hanson 1985, Kreulen 1985, Heymann and Hartmann 1991). The second reason is that animals need different minerals during different life stages as more salt is required for lactation (Tracy and McNaughton 1995) and for bone growth (Henshaw and Ayeni 1971).

Frequency of lick use seems to range between daily utilisation and intervals of a few days (Henshaw and Ayeni 1971, Carbyn 1975, Seidensticker and McNeely 1975). The actual ingestion time per lick event has been recorded being more or less 30 minutes (Henshaw and Ayeni 1971, Fraser and Hristienko 1981, Redmond 1982).

5.1 Results and Discussion

5.1.1 Daily activities

Of all daily activities observed among individuals at Amperplaas, during the study period, standing was the most prevalent (38%) followed by feeding and lying (31% and 28% respectively). Water drinking and soil consumption made up 1.14% and 1.40% respectively of the total daily activity.

As can be expected from cows in a feedlot system where food is provided twice a day, all milk cows as well as heifers spent more time engaging in inactive behaviour which include standing and lying (Figure 5.1). The only exception to this tendency is during springtime when heifers, which was placed in a camp with natural growing grass, spent the majority of time (72%) on feeding and drinking water. All other lactation groups as well as heifers and dry cows spent the majority of time at inactive behaviour during all seasons.

An average of about 30% of daily activity was spent on digestive activities (feeding and water drinking) by the milk producing cows, leaving 70% of the day for inactive behaviour. The dry individuals displayed the highest percentage of inactive behaviour. During summer, dry cows were inactive for as much as 97% of the day while only 2.63% of the time was spent feeding and drinking water. This high percentage of inactivity among cows in which milk production has stopped is explainable as this stage is known for a decrease in dry matter intake (*vide* Figure 1.1).

According to Albright and Arave (1997), cattle in dry lot confinement display feeding behaviour different to that of free-ranging cattle as confined cattle feed when mangers are filled and feeding therefore is irrespective of photoperiod. Fraser (1983) stated that free ranging cattle display pronounced grazing peaks at sunrise and sunset. At Amperplaas, the feeding troughs were filled primarily at mid-day (11:00) and sometimes again in the late afternoon (16:00) (Figure 5.2). All feed was not always

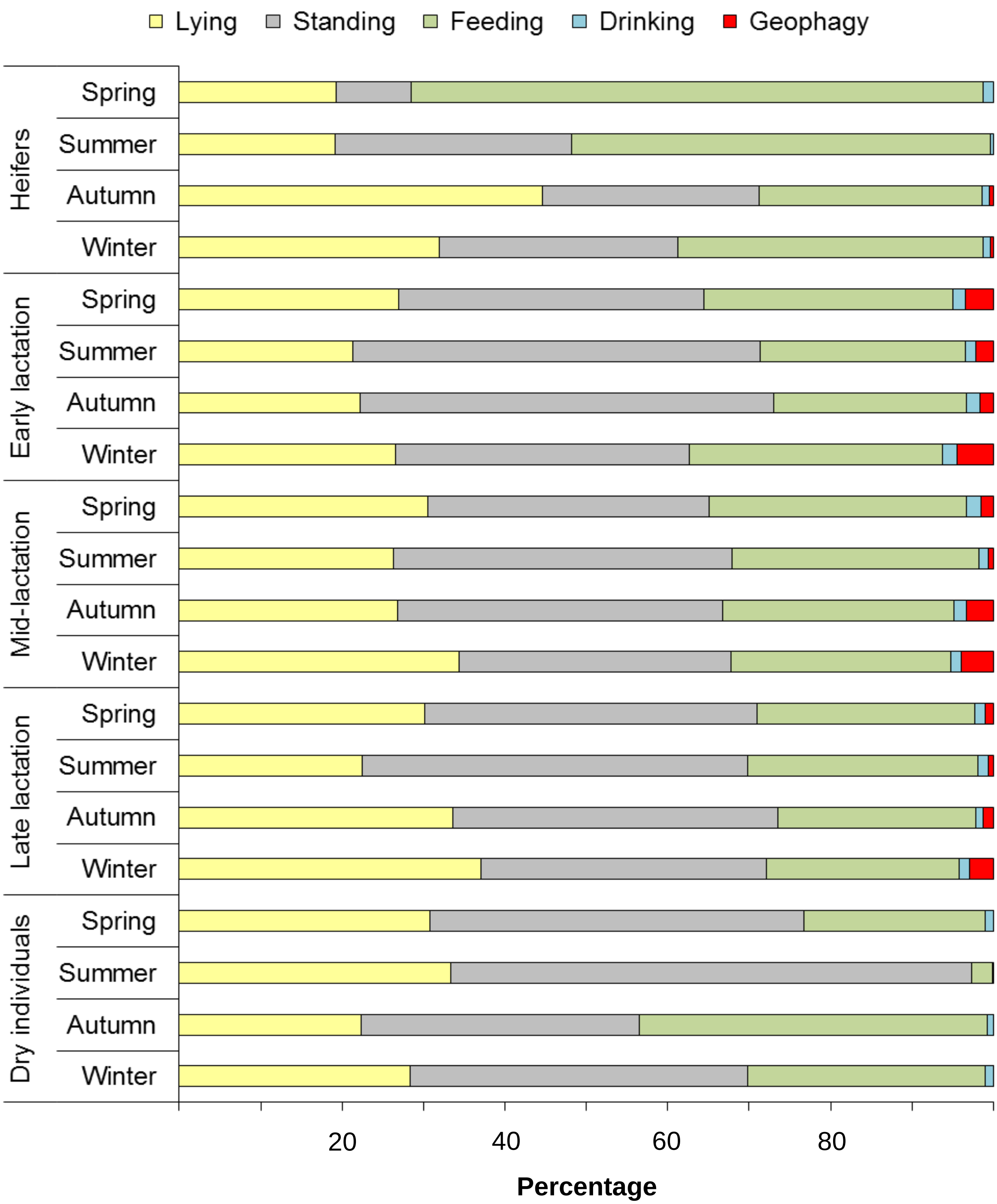

Figure 5.1 Frequency of daily activities during different seasons by cows of different lactation stages at Amperplaas. Heifers, n = 49, early lactation, n = 40, mid-lactation, n = 51, late lactation, n = 35, dry individuals, n = 51.

completely consumed during one day as some was often left in the troughs which indicate that more than enough feed was supplied. Feeding increased gradually from the last hour of the early morning period and morning hours and reached a peak at mid-day (12:00 until 13:00) after which it declined and stopped in the evening (20:00) (Figure 5.2).

Albright and Arave (1997) also states that cattle on pasture will drink less water less frequently than cattle in dry lot confinement which only have access to dry feeds. The activity of water drinking at Amperplaas increased during the early morning and morning periods and reached a peak at 12:00 after which it declined again before it ceased during the evening period (20:00) (Figure 5.2). A strong positive correlation was found between feeding and drinking ($R^2 = 0.91$). Nocek and Braund (1985) described a similar occurrence among cattle in dry lot confinement where an increase in water consumption was witnessed after dry matter intake.

Soil consumption by heifers constituted almost equal percentages of daily activity during autumn and winter while these individuals showed no soil ingestion during spring and summer (Figure 5.1). Among the lactating cows, the percentage of daily activity spent on geophagy was highest during the winter months. Cows in the early lactation phase spent the greatest part of the day ingesting soil during the winter months, after which the percentage of daily geophagy declined towards autumn. The mid-lactation group displayed little difference in daily geophagy during winter and autumn, while spending the smallest part of the day ingesting soil during the summer months. The late lactation cows displayed an increase of daily activity invested in soil consumption from spring towards winter time. The dry individuals, cows in which milk production has stopped, spent an negligeble percentage of the day on geophagy.

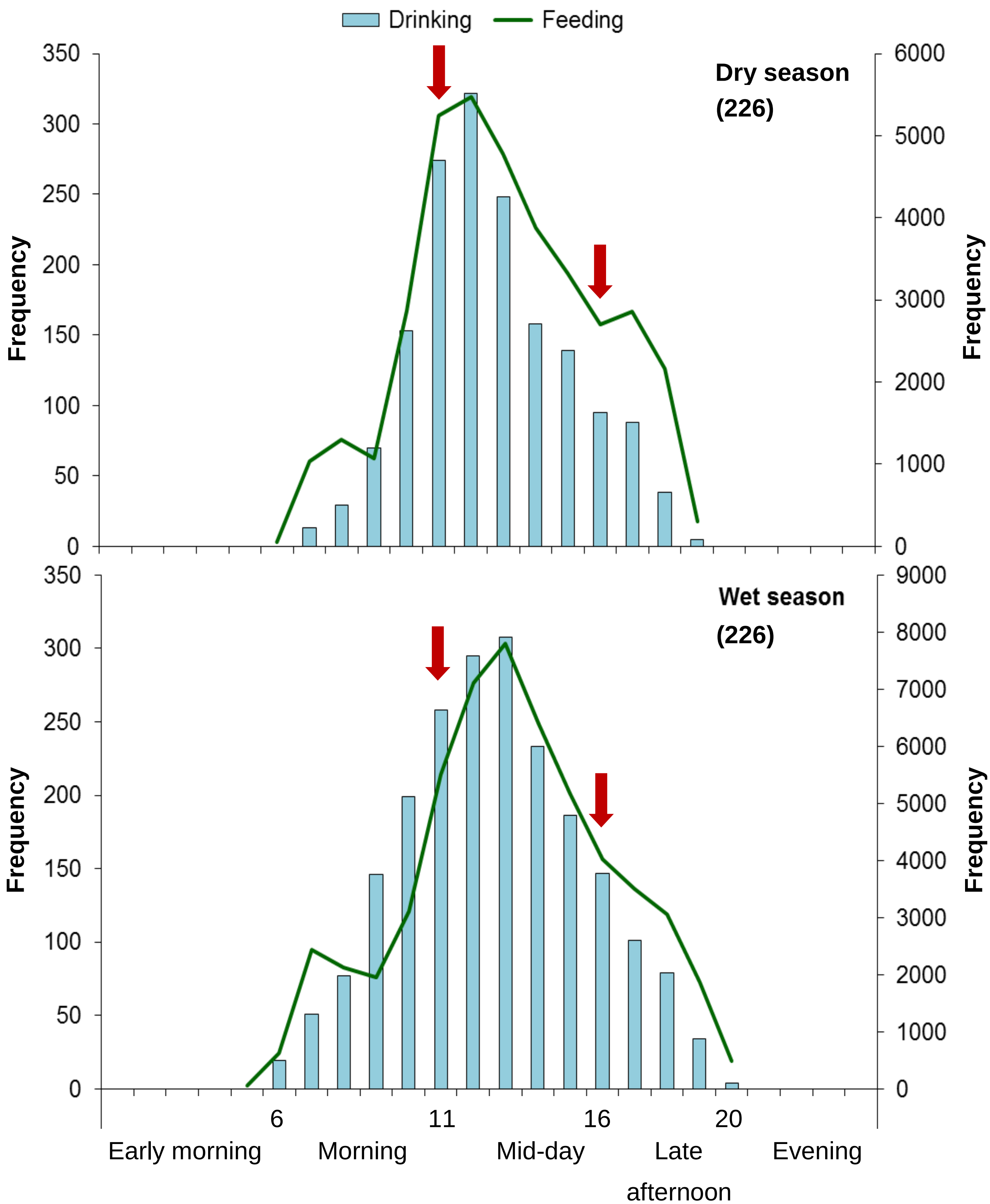

Figure 5.2 Daily frequency of water drinking and feeding by all the cows during the dry and wet seasons at Amperplaas in the central Free State. Red arrows indicate the time which feeding troughs were filled. Numbers between brackets indicate the maximum number of individuals observed.

5.1.2 Seasonality of geophagy

Kreulen and Jager (1984) states that geophagy is a seasonal behaviour and peaks during spring or early summer (at the beginning of the rainy season) and again during the transition to the dry, winter season. Caecero *et al*. (2009), however, found that only moderate consumption occurs during the winter/autumn period and that no mineral consumption occurs during the mating season in spring. Arthur and Gates (1988) reported peak soil consumption rates during December (winter), March to May (spring) and again in September and October (autumn) amongst pronghorns and black-tailed jackrabbits during a study conducted in the United States of America (Idaho). McGreevy *et al*. (2001) noted that geophagy activity among horses was mainly observed once these animals retuned to a pasture after spending the winter in a stable. According to Mahaney *et al.* (1995) geophagy occurs during the dry season as a change in feeding habits brings about diarrhoea in mountain gorillas.

During the study period at Amperplaas, the most geophagy incidences (42%) occurred during winter, with 24% and 21% occurrence in autumn and spring respectively and only 13% during summer. Upon comparison of the total number of seasonal occurrences between the groups, non-lactating individuals displayed a far lower incidence count than the milk producing individuals (Figure 5.3 and 5.4). The heifers were only observed consuming soil during autumn and winter with the highest occurrence during winter. Cows of the dry group showed no soil consumption in summer and almost equally low incidences during the other three seasons (Figure 5.3). This low soil consumption of the dry group may be explained by the decline in dietary intake by individuals at this stage as dry individuals display a decrease in appetite of 30 to 50% at parturition as the growing foetus increase in size (Anonymous Undated a).

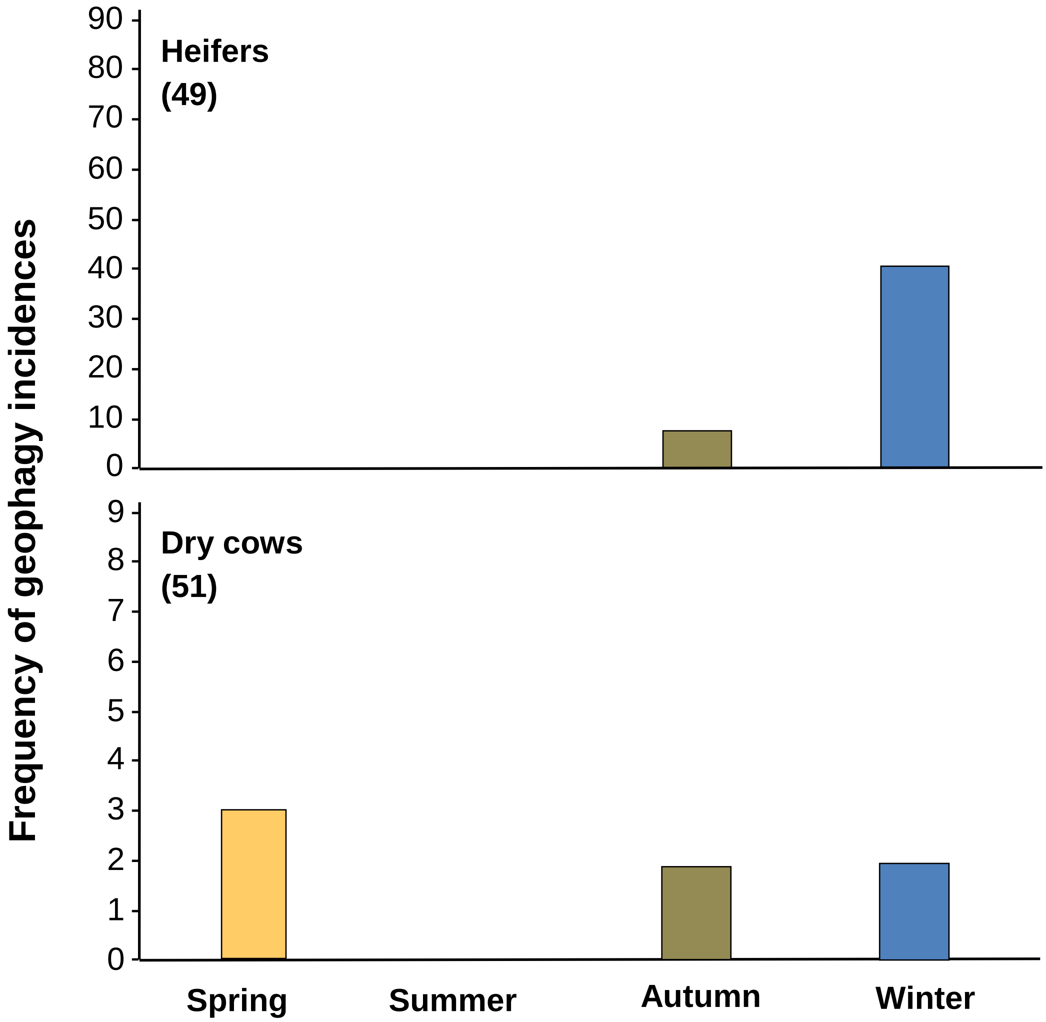

Figure 5.3 Incidences of geophagy amongst non-milk producing cows (heifers and dried up cows) over different seasons in the Free State. Numbers between brackets indicate the maximum number of individuals observed.

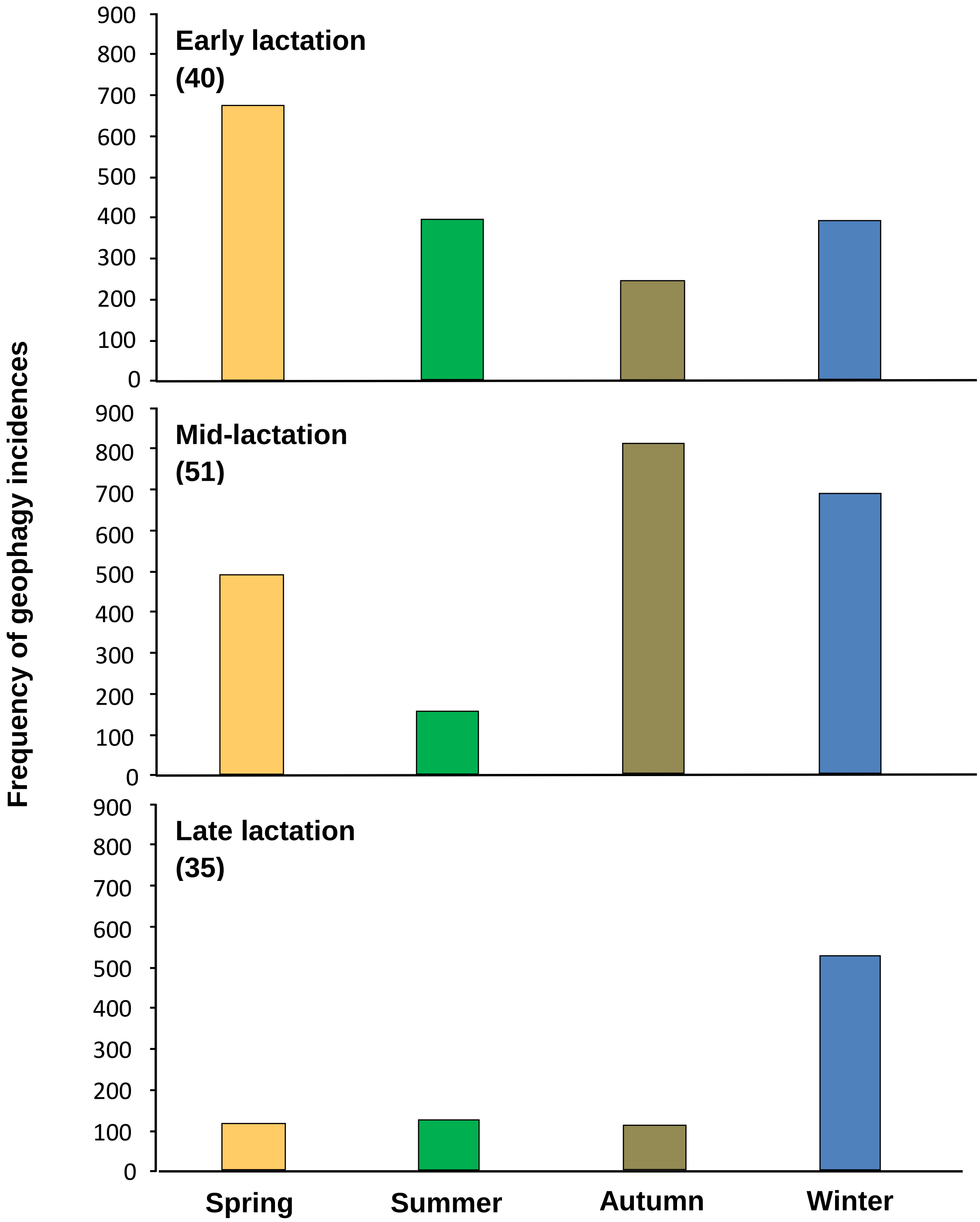

Figure 5.4 Incidences of geophagy amongst different lactation stages of dairy cows over different seasons in the Free State. Numbers between brackets indicate the maximum number of individuals observed.

Geophagy among early lactation cows was highest during spring (Figure 5.4) and lowest during autumn with almost equal amounts of events occurring during summer and winter. The mid-lactation group displayed the highest occurrence counts during autumn and the number of occurrences gradually decreased towards summer. The late lactation group exhibited an elevated number of occurrence counts during winter and almost equal incidences during the other seasons (Figure 5.4).

According to Figure 5.5, the early lactation group displayed the highest number of daily geophagy incidences during spring. A gradual decrease in daily events was noticed during this season as milk production dropped, except for the heifers which showed no ingestion during spring. This was also observed among the milk producing cows during summer. The early lactation group showed the greatest number of geophagy events per day after which a decline was seen to an almost equal amount of incidences by the mid- and late lactation groups. Daily occurrences by the early lactation cows was lowest during autumn where after a peak was observed among the mid-lactation group. A gradual decrease was thereafter observed to only two geophagy events per day by the dry individuals. Daily geophagy events were highest during the winter months for all the lactating groups.

Apart from the higher number of daily occurrences of soil eating observed in the early lactation group of cows, the total time spend at this behaviour was also the highest of all lactating as well as non-lactating groups (Figure 5.5). Furthermore, the time that cows invested in geophagy decreased as milk production between progressive lactation stages dropped. This tendency where less time is spend in consuming soil between following lactation groups is also evident for summer as well as the winter months. The only season when the mid-lactation cows spent more time at this activity compared to the rest is during autumn. During this season, the duration of geophagy was more than double the time invested by any other group. Apart from cows in the mid-lactation phase, all other cows engaged for almost similar time in the eating of soil during autumn.

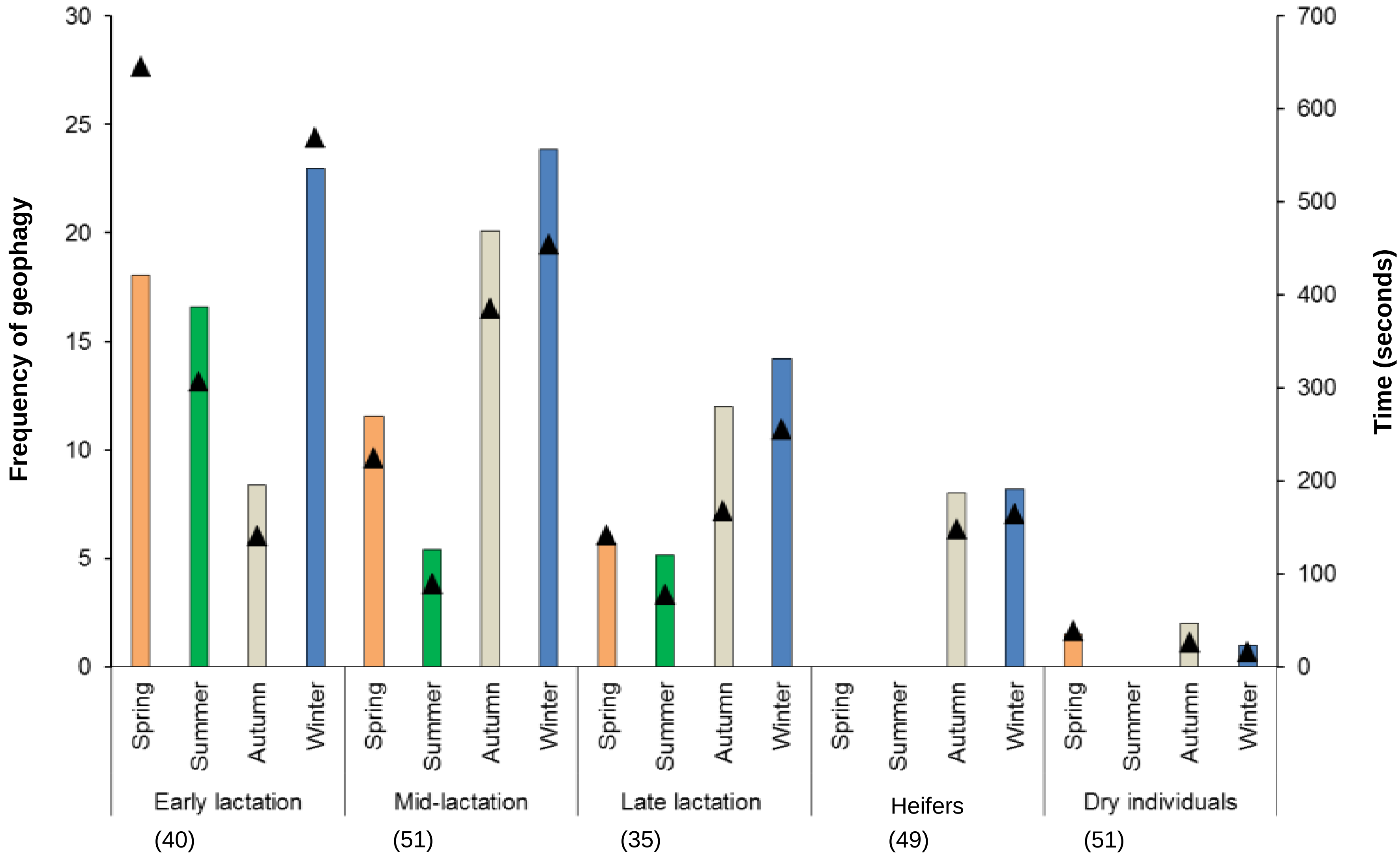

Figure 5.5 Average daily frequency and time spent (triangles), per group, engaging in geophagy amongst different lactation stages of dairy cows during different seasons at Amperplaas in the central Free Sate. Numbers between brackets indicate the maximum number of individuals observed.

5.1.3 Daily geophagy

According to Fig 5.6 – 5.8 all the lactation groups showed a slightly higher occurrence of geophagy activity during the first hour of the early morning period after which declining towards the morning. The lack of data for the 4th and 5th hour for the mid- and late lactation group can probably be explained by the absence of cows in the camps due to milking occurring during these hours. All the lactation groups displayed a gradual increase in hourly soil consumption incidences from morning towards mid-day. Geophagy was most prominent during mid-day after which there was a decline in occurrences towards the afternoon. A second less distinctive peak was observed during the later hours of the afternoon where after a decline in geophagy events occurred towards the evening hours. Using the Pearson Correlation Coefficient the hourly fluctuation of geophagic events was positively correlated with the hourly occurrences of water consumption by the early, mid- and late lactation groups (R^2 = 0.76, R^2 = 0.87 and R^2 = 0.85 respectively). The elevated levels in geophagy events also coincide with an increase in feeding activity by the early, mid- and late lactation groups (R^2 = 0.65, R^2 = 0.83 and R^2 = 0.56 respectively).

As geophagy behaviour coincide with times of feeding and water consumption (Figure 5.6 – 5.8), one can assume that this behaviour is perceived equally as important as feeding and drinking, since time that could be spent feeding is invested in soil consumption. As shown in Figure 5.1, these individuals spend the largest portion of the day on inactive behaviour (standing and lying). If the activity of soil consumption was not important, the part of the day that was spent on inactive behaviour could be spent on geophagy.

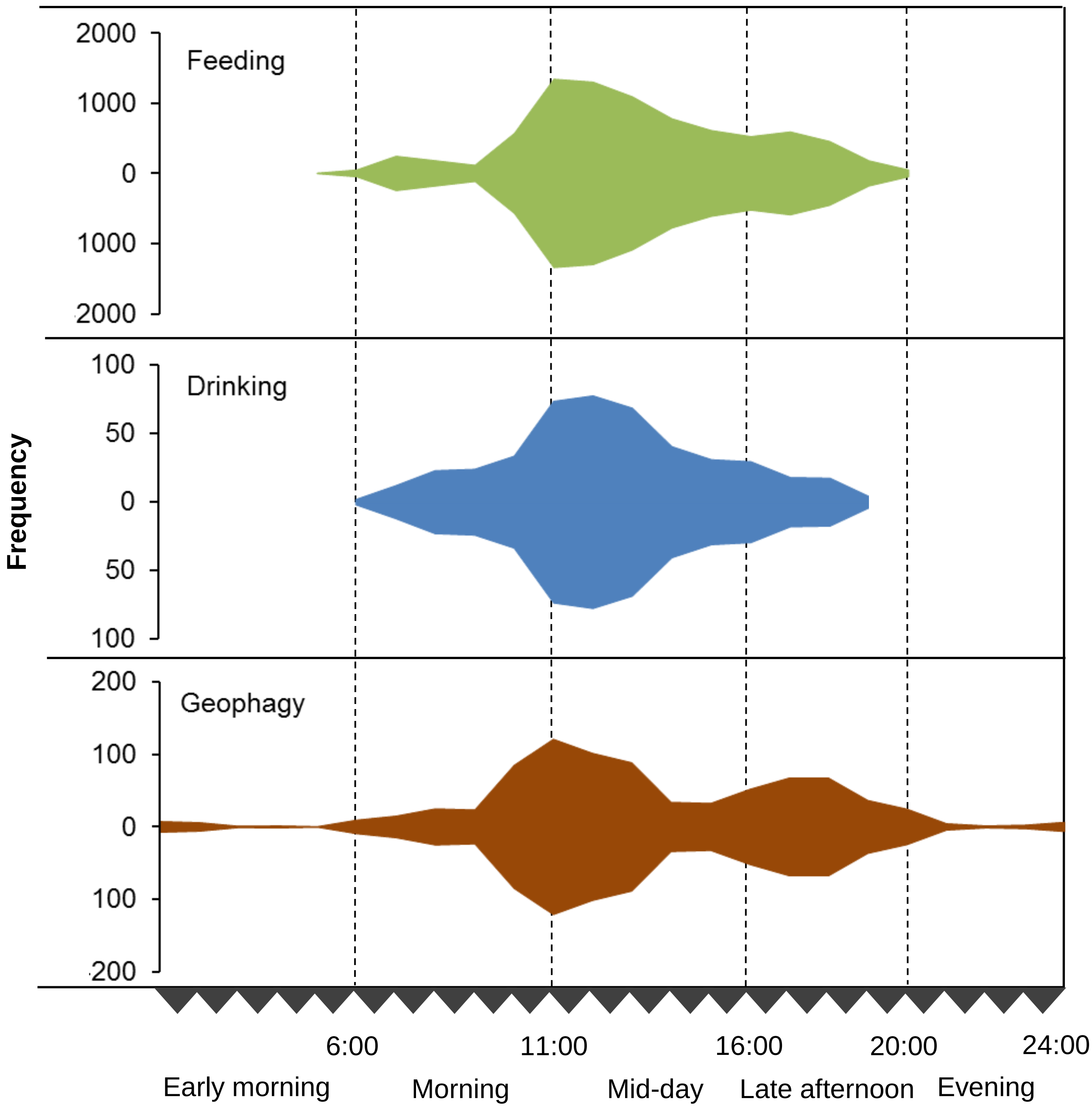

Figure 5.6 Frequency of feeding, water drinking and geophagy of dairy cows during the early lactation phase, n = 40.

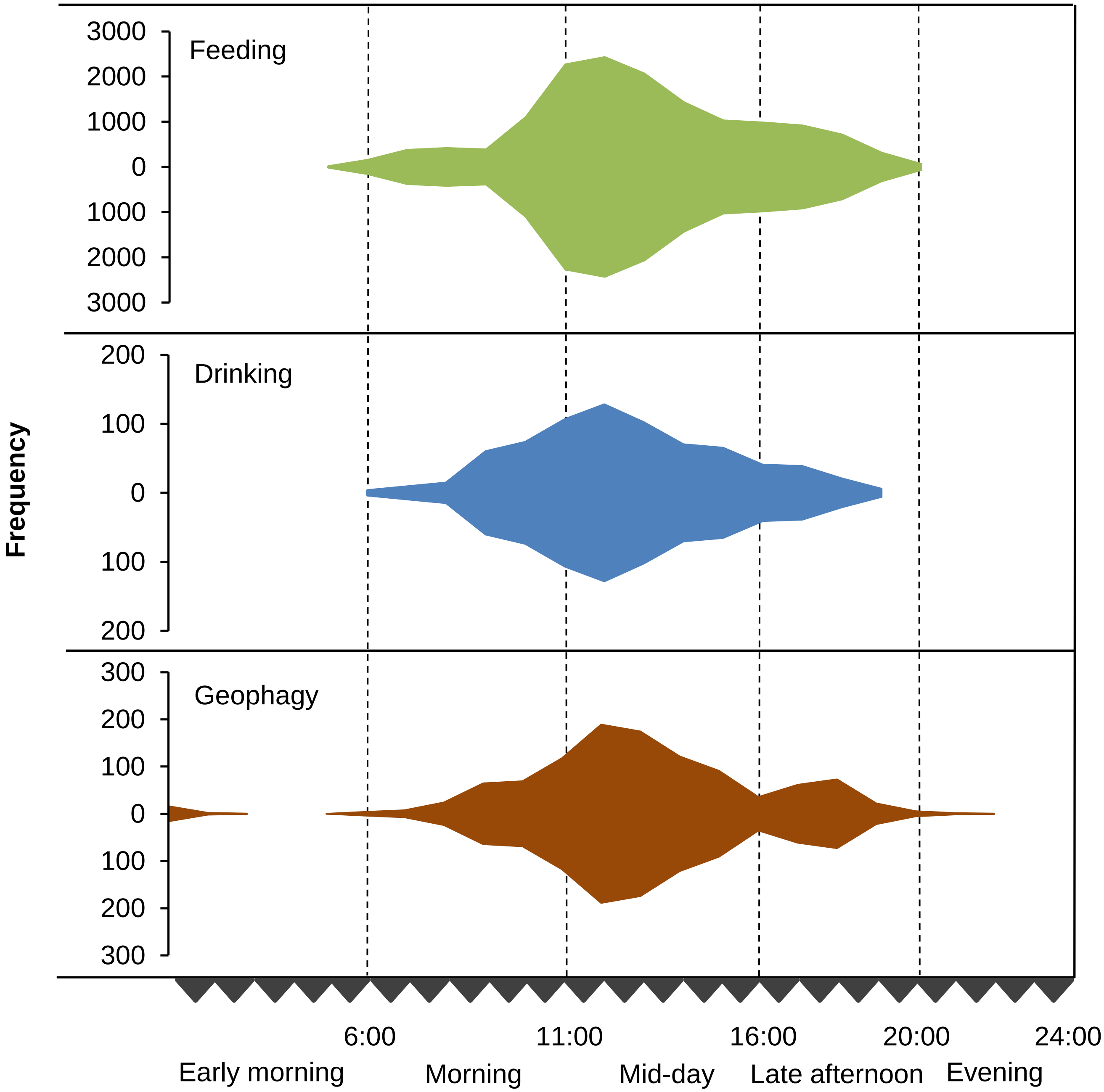

Figure 5.7 Frequency of feeding, water drinking and geophagy of dairy cows during the mid-lactation phase, n = 51.

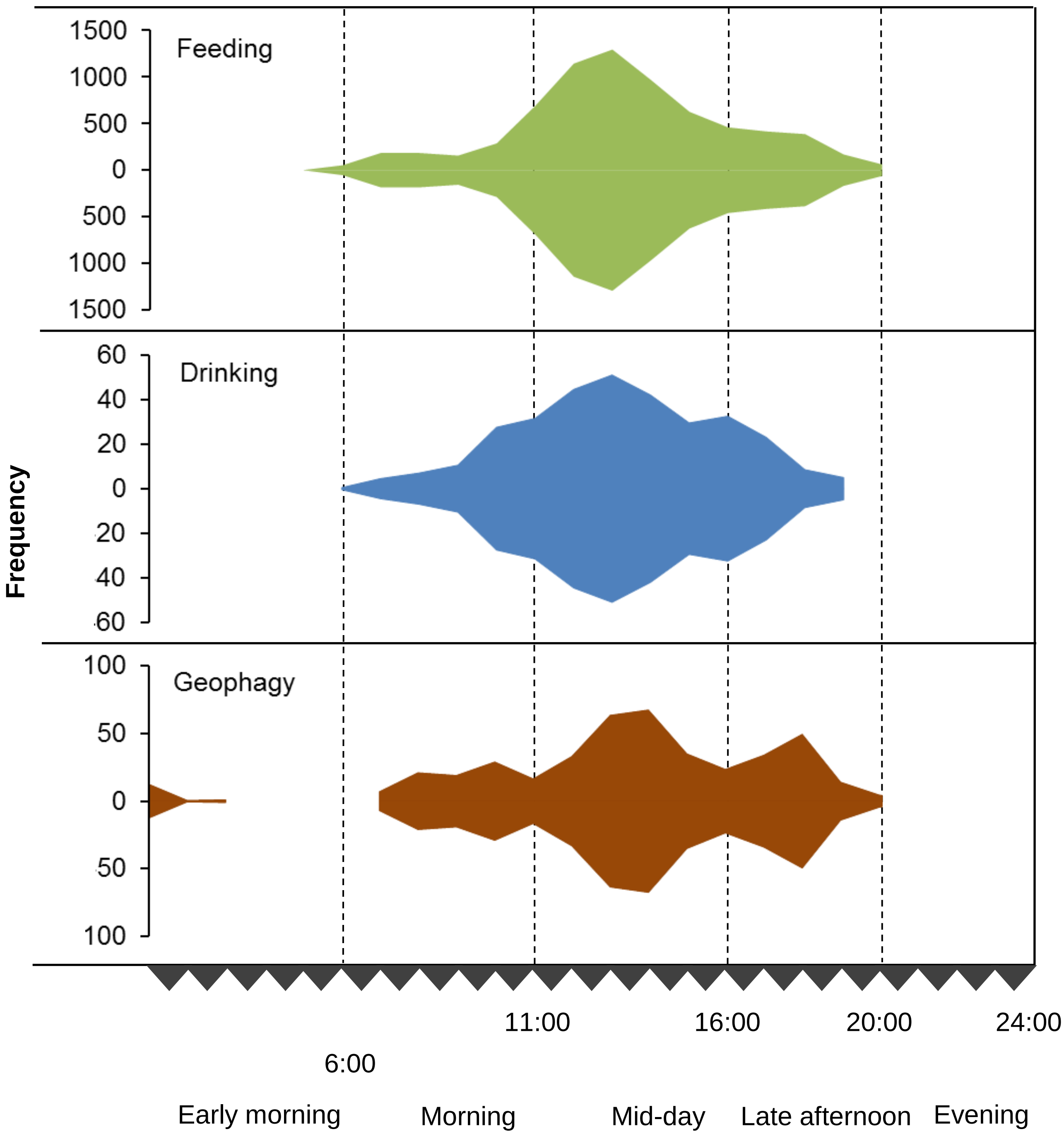

Figure 5.8 Frequency of feeding, water drinking and geophagy of dairy cows during the late lactation phase, n = 35.

5.1.4 Lick preference

Upon comparing daily geophagy occurrences at licks, camps 1 to 4 had licks which showed average uses ranging from one to four per day (Figure 5.9), with only two licks that showed an average frequency of 14 uses per day. The licks in camps 5 to 9 had frequencies ranging from one to six uses per day, with only one lick that showed an average of 14 uses per day (Figure 5.10). Camps 2 (early lactation phase) and 5 (second period of mid-lactation phase) had the highest geophagy lick frequency (Figure 5.9 and 5.10). A single geophagy site can increase in size and depth from only a small indent to a well dug out hole (Figure 5.11) in a period of only six months.

In comparing geophagy occurrences at different areas, lick sites were categorised according to four main areas: lick sites at wooden poles, metal poles, beneath fence wires and random. The random category included lick sites within or outside camps, away from fences (all sites not included in the first three categories). Geophagia occurrences were dominated (69%) by lick sites beneath the fence wires followed by occurrences at wooden poles (22%) which were higher than those at metal poles (4%). Soil ingestion occurrences at the random sites also accumulated to 4%.

The preference for licks beneath the fence wire may be attributed to higher concentrations of magnesium, calcium in combination with lower silica, titania, alumina as well as barium and zirconium (*vide* Table 4.2 and 4.3). In comparison to the newest lick, CaO and P_2O_5 was almost depleted at the other lick sites except for the abandoned site (*vide* Table 4.1). Less than 0.5% variation was observed in Fe_2O_3 concentrations between the abandoned and newest sites, it would seem that the ferric oxide concentration stays relatively constant throughout geophagic events.

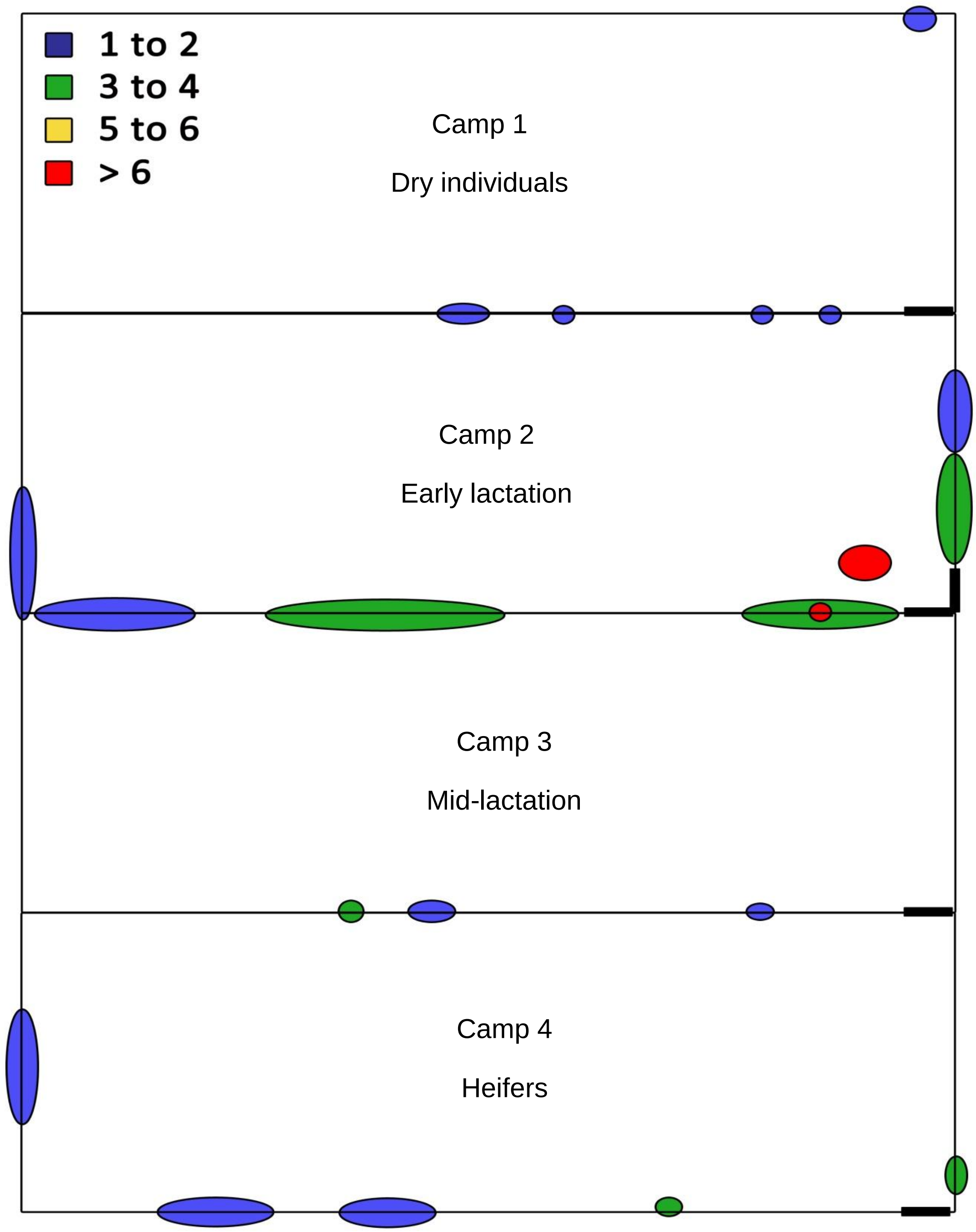

Figure 5.9 Distribution of mineral licks in camps 1 to 4 at Amperplaas in the central Free Sate. Daily geophagy frequency is indicated by different colours.

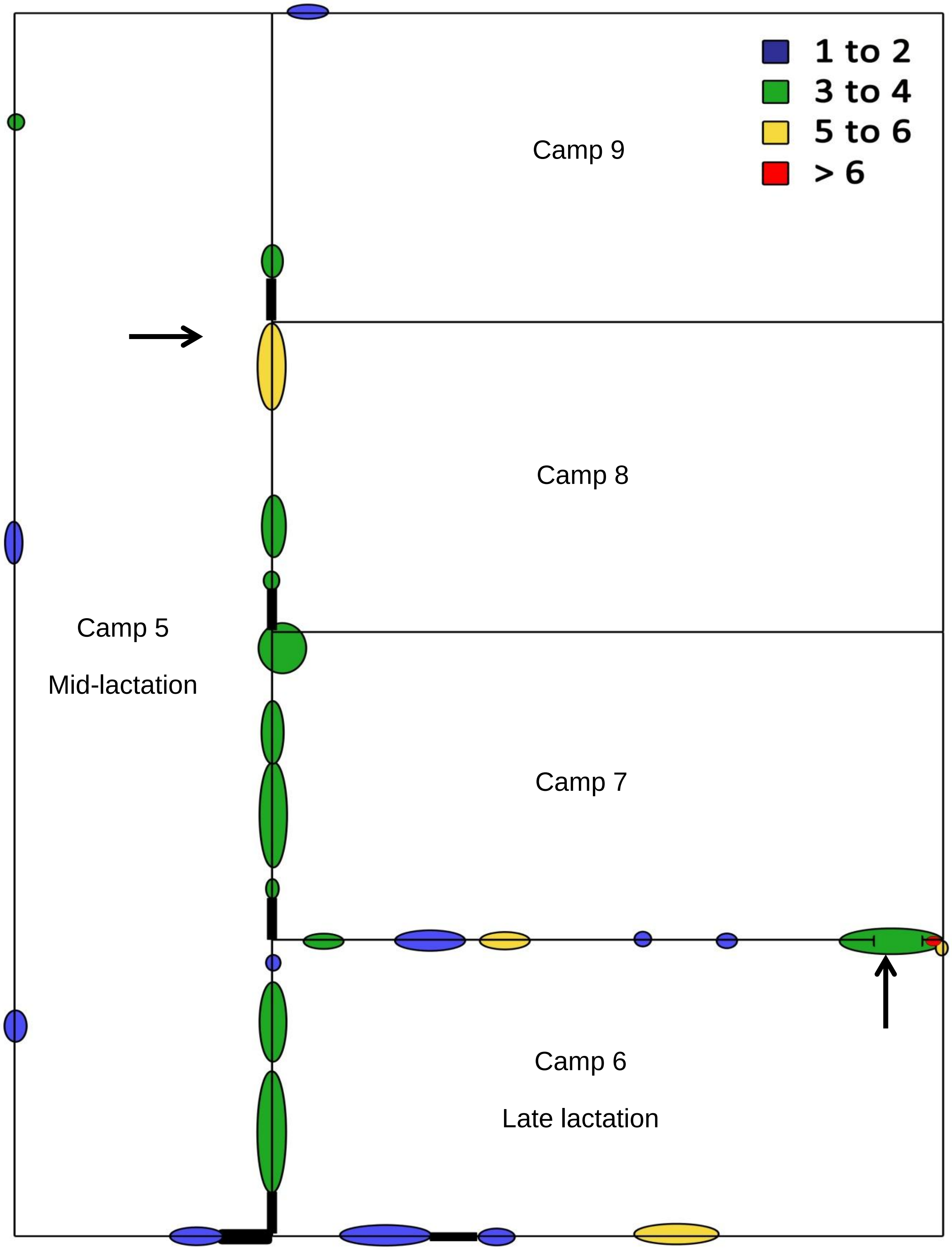

Figure 5.10 Distribution of mineral licks in camps 5 to 9 at Amperplaas in the central Free Sate. Daily geophagy frequency is indicated by different colours and arrows indicate largest licks.

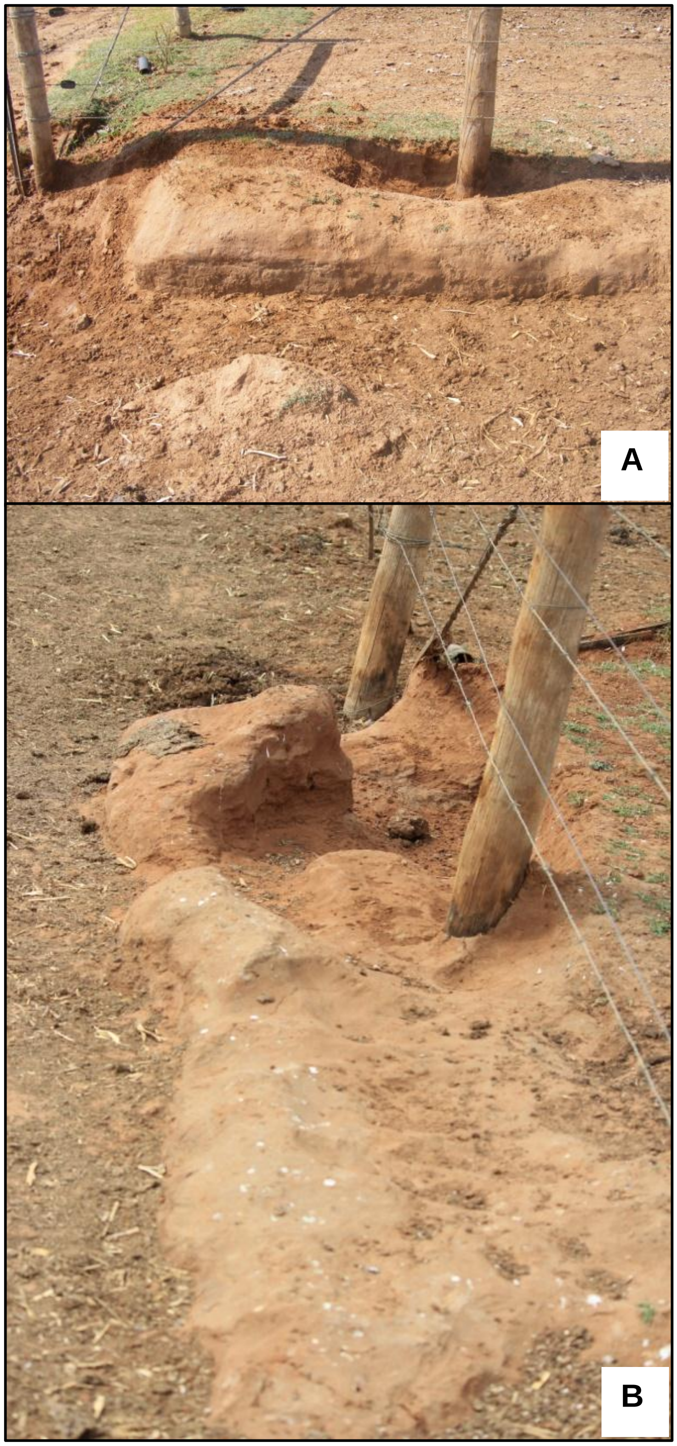

Figure 5.11 Mineral lick with the highest frequency of utilisation (**A**) in camp 5. The same mineral lick six months later (**B**).

According to the National Research Council of America (NRC) (Anonymous 2001) normal growth and reproduction in animals require several inorganic, major and trace, elements. According to McDonald *et al*. (2011) and the NRC (Anonymous 2001) major elements, including calcium, phosphorus, potassium, sodium, chlorine, sulphur and magnesium, are required in relative high quantities and are important for bone structure, tissue components as well as components of body fluids. Trace elements such as cobalt, copper, iodine, iron, manganese, molybdenum, selenium, zinc, chromium and fluorine are required in lesser quantities and are essential for the production of hormones or metalloenzymes or enzyme cofactors. As the cattle at Amperplaas were completely dependent on supplied feed, the diet and therefore nutrients available to these animals were determined by feed as well as feed supplementation. The diet of these cattle consisted mostly of lucerne together with formulated, scientific bovine semi complete and scientific bovine complete diary feed. It has been reported that both sodium and phosphorus are the most limiting minerals for ungulate species (Ceacero *et al*. 2009).

Calcium, being the most abundant mineral in the animal body is essential in a number of bodily functions and components. In addition to forming part of the skeletal structure, aiding in enzyme system efficacy and blood clotting, calcium forms an integral part of milk (Anonymous 2001, McDonald *et al*. 2011). According to Anonymous (2001) in addition to calcium loss to digestive secretions, sweat and urine, a particularly large percentage of calcium loss occurs during milk production. Calcium loss through these routes can be replaced from dietary calcium, reabsorption of calcium stored in the bone or through reducing urinary calcium loss. The amount of absorbed calcium needed for the maintenance of non-lactating cattle is 15.40 mg/kg body weight (Visek *et al.* 1953, Hansard *et al.* 1957) and for lactating cows 31 mg/kg body weight (Martz *et al*. 1990) per day.

Phosphorus is the second most abundant mineral present in the body with the most known functions. It plays an integral part in the skeletal system as well as all cells and it forms part of energy metabolism (Anonymous 2001, Chase 1998, McDonald *et al*. 2011). McDonald *et al.* (2011) advises the provision of calcium and phosphorus in the proper ratio as an incorrect ratio may be detrimental to the animal. McDonald *et al.* (2011) suggest a calcium : phosphorus ratio of 1 : 1 to 2 : 1 although a ratio up to 7 : 1 is still acceptable (Miller 1983).

As the recommended dietary allowance of micro and macro elements for dairy cows in South Africa is not available, recommendations as published by the National Research Council of America was used as a guideline for daily nutritional intake. According to Table 5.1, the calcium and phosphorus content of the daily formulated feed seem sufficient for the cows' daily calcium and phosphorus requirements. As the provided feed contains sufficient levels of calcium and phosphorus to provide for the daily nutritional needs, these major elements in the soil is less likely to be the stimuli for geophagy. However, the newly established lick site do have elevated concentrations of these elements compared to the abandoned sites (*vide* Table 4.2).

According to the manufacturing labels, no other elements were quantified in the formulated feed. As these animals require other major as well as trace elements, which is not provided through the formulated feed, these elements have to be supplemented from another source. Some of the required elements were present in the soil licks in varying concentrations, while iodine and selenium were not tested for in the soil. According to Anonymous (undated a) and Anonymous (2001), the daily potassium requirements are approximately 10 000 mg/kg body weight per day. The freshly established site beneath the fence was the only lick site that contained sufficient potassium. Except for the exposed soil, magnesium concentrations of all the lick sites seem sufficient to satisfy the magnesium requirement while the sodium content of all lick sites were sufficient to supply in the daily requirements of cows prescribed by the NRC (Anonymous 2001).

Iron was found in very high concentrations in all the mineral licks. The average iron content of the established mineral licks ranged from 18 884 to 20 982 mg/kg (Table 5.1). According to the National Research Council (Anonymous 2001) the suggested dietary iron allowance is 14 mg/kg body weight (Table 5.1), for a Jersey cow with an average body weight of 415 kg (Gertenbach undated) the daily allowance would be 5 810 mg.

Table 5.1 Comparison of macro- and micro elements in prescribed recommended dietary allowance, feed and soil from geophagy sites as well as ingested soil at Amperplaas. (NRC, National Research Council of America)

	Recommended dietary allowance NRC (USA) (mg/kg body weight)	Feed (mg/kg)	Geophagy soil (mg/kg)	Ingested elements (mg) per 78.30 ± 8.39 g soil
Ca	5 700	7 000 - 15 000	2 200	170 ± 18
P	3 300	3 000 - 5 000	700	54 ± 5.87
K	10 200	-	7 300	570 ± 61
Mg	1 800	-	3 700	290 ± 31
Na	2 000	-	1 100	86 ± 9.22
Co	0.11	-	6.63	0.52 ± 0.06
Cu	10	-	34	2.63 ± 0.28
Mn	12	-	< 23	< 1.80 ± 0.19
Zn	45	-	34	2.62 ± 0.28
I	0.44	-	-	-
Fe	14	-	20 020	1 570 ± 170
Se	0.30	-	-	-

It was calculated that individuals consumed an average of 78.30 ± 8.39 g of soil per day during the study period. This calculates to iron ingestion of 1 570 ± 170 mg per day (Table 5.1). According to Oruc *et al.* (2009), oral or injected dosages of iron exceeding 150 mg/kg body weight may lead to iron poisoning. Although few cases of iron poisoning in cattle have been reported, the symptoms include depression, discoloration of buccal mucosa and lips, abdominal pain and discoloration of blood (Oruc *et al.* 2009). Anonymous (2001) advise that dietary iron should not exceed 1 000 mg/kg body weight, as this can lead to acute iron poisoning. Although the concentration of iron in ingested soil was considerably high, the risk of iron poisoning was very low and no symptoms were observed or recorded at any stage among the cows at Amperplaas.

With cobalt content of 6.63 mg/kg in the soil at Amperplaas, the risk of cobalt poisoning was also low among these cows as Anonymous (1980) cautions against cobalt ingestion over 10 mg/kg body weight (4 150 mg per 415 kg cow). However, signs and symptoms of cobalt poisoning are similar to that of cobalt deficiency which include reduced feed intake, loss of body weight, hyperchromemia and eventually anaemia (Anonymous 2001), none of which that were noted at Amperplaas. Similar risks are associated concerning copper of which 34 mg/kg were present in the geophagic soil. Anonymous (2001) advise against copper ingestion exceeding 40 mg/kg body weight (16 600 mg per 415 kg cow), as large amounts of copper can accumulate in the liver before any symptoms are shown. Signs and symptoms of copper toxicosis include hemolysis, jaundice, methemoglobinemia, widespread necrosis and often death (Anonymous 2001).

It is unclear why the abandoned lick beneath the fence was deserted as it still contains higher concentrations of magnesium, calcium, phosphorus as well as bromide and strontium compared to the other utilised licks, which seemed to be the stimuli for the start of a new lick. The relative high proportion of quartz (*vide* Table 4.1) might be the reason as high quantities of silica collect in excavated minerals licks, which may increase tooth wear if continuously ingested. Kaiser *et al.* (2009) cautioned that prolonged eating of substrate with high silica contents might increase tooth wear.

5.1.5 Ingested and excreted soil

During the study period soil and grit was extracted from six stomachs. The first stomach was from an individual (cow No. 1250) that died in the second month of field work and during this time she was not observed consuming soil (Table 5.2). Two stomachs were from cows, No. 41 and No. 242, which were observed ingesting soil while three stomachs were from individuals which did not have an ear tag or any other way to identify these individuals (Table 5.2). The soil and grit extracted from the stomachs ranged from soil

Table 5.2 Soil extracted from cow stomachs collected from Amperplaas and duration of soil consumption.

Cow number	Soil/grit < 150 µm (g)	Soil/grit > 150 µm (g)	Total (g)	Soil as proportion of dry stomach content (%)
1250	74	284	358	1.02
Unknown	34	105	139	0.40
Unknown	53	185	238	0.68
242	24	644	668	1.91
Unknown	-	181	181	0.52
41	213	34	247	0.71

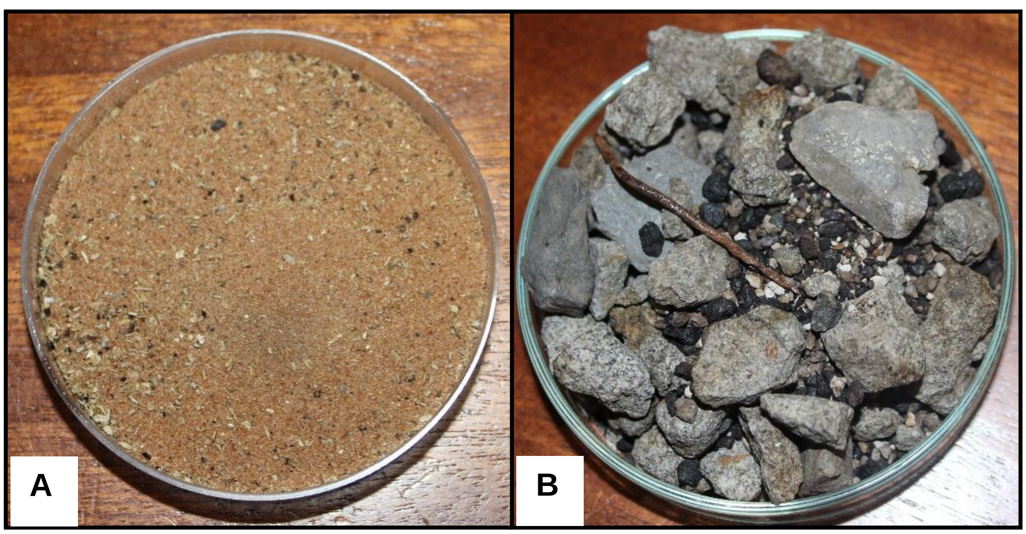

Figure 5.12 Soil extracted from the omasum and abomasum of cow No. 41. Particles < 150 µm (**A**) and particles > 150 µm (**B**).

particles smaller than 150 µm to rocks up to 30 mm in size (Figure 5.12). Several wires, screws, nails and other metal pieces were also retrieved from the stomachs.

Cows No. 41 and No. 242 were recorded to eat soil, during the study period, for an average of 46.50 and 17.40 seconds per day respectively. This amounts to roughly 147 and 55 g respectively using the formula described in Methodology. Kreulen and Jager (1984) state that the daily soil ingestion capacity of a 150 kg animal is 0.50 kg (dry-mass). The maximum amount of soil retrieved from a stomach was 668.03 g which accumulated over a period of at least four months of observation. This implies an average ingestion of 5 g per day for four months, far lower than the suggested capacity of 1.38 kg of Kreulen and Jager (1984). Taking into account the average weight of a jersey cow (415 kg) (Gertenbach undated) the soil consumed accumulates to roughly 0.04% and 0.01% of body weight per day, respectively, for the abovementioned individuals. This value is far lower than the capacity of 0.33% suggested by Kreulen and Jager (1984).

During the study period, cows No. 41 and No. 242 was recorded consuming soil for a total of 905 seconds (approximately 2 860 g) and 186 seconds (approximately 588 g) respectively at several areas (Figure 5.13). After death, the total mass of soil and grit, extracted from the stomachs accumulated to 247.02 g (cow No. 41) and 668.03 g (cow No. 242) (Table 5.2).

The possibility of fatal sand impaction depends on the amount of soil consumed by the animal and the rate at which consumed soil is excreted on a daily basis. Several fatal sand impaction cases have previously been reported. Mushi *et al.* (1998) and Abutarbush and Petrie (2006) reported on ostriches and a one-month-old alpaca, respectively, which died of fatal sand impaction. Furthermore, in 2007 Melendez *et al.* (2007) accounted for a case of sand impaction in dairy cows. These previous reports suggest that excessive geophagy result in one or more of the following symptoms: depression, behavioural stress, lack of faecal passage, mild colic (pains) with mucosal damage, an inactive rumen and diarrhoea (Mushi *et al*. 1998, Abutarbush and Petrie 2006, Melendez *et al*. 2007).

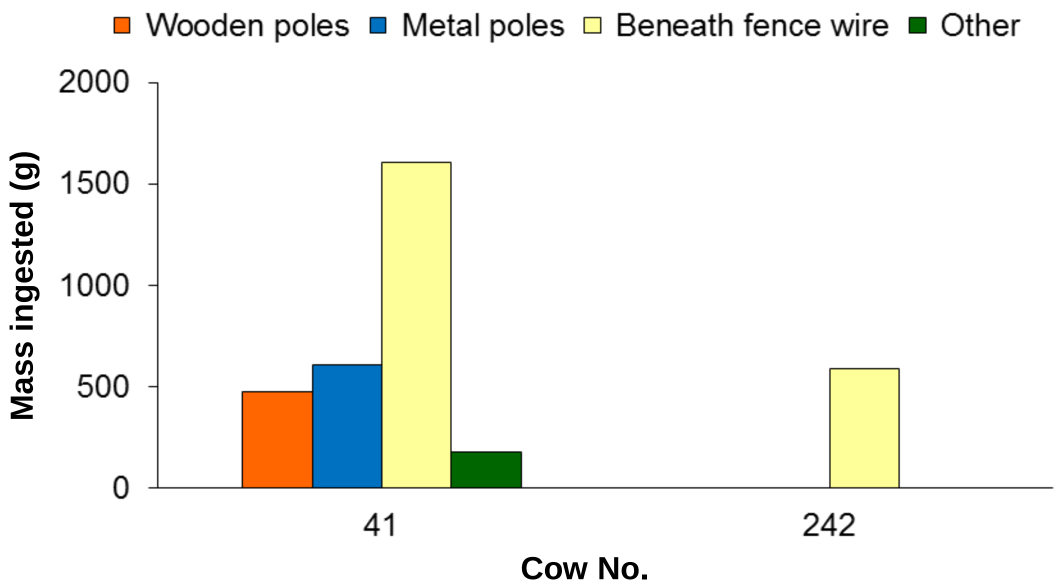

Figure 5.13 Calculated soil ingestion of cows No. 41 and No. 242 according to time spent at the four main geophagy sites during the study period.

In a study conducted by Mayland *et al.* (1975) it was found that soil constituted up to 30% of faecal mass depending on feed intake. Ingestion of plant parts above ground, with adhering soil, may result in faecal matter containing up to 2% soil of the total faecal mass. It was suggested that the amount of soil of more than 2% of faecal mass, was due to soil adhering to stem bases and roots or from direct soil ingestion. Therefore soil in voided faecal matter of up to 2% of faecal mass can be attributed to accidental soil intake.

Based on faecal mass an average of 3.49% soil per faecal sample was extracted from voided faecal matter collected from individual cows at Amperplaas (Table 5.3). The highest percentage soil extracted from a single sample was 10.09 % (cow No. 26) which displayed soil consumption for an average duration of 43.70 seconds per day. Four of the samples collected from voided faecal matter, were less than the value suggested for accidental soil intake.

Table 5.3 Soil extracted from faecal samples collected at Amperplaas

Cow number	Dry mass of voided faecal matter (g)	Soil extracted from faecal matter (g)	Amount of soil (%) in faecal matter	Average daily time spent on geophagy (s)	Calculated average daily soil consumed (g)
09024	405.6	9.35	2.31	10.18	32.17
25	316	9.81	3.10	17.67	55.83
26	87.5	8.83	10.09	43.70	138.08
30	229.3	11.01	4.80	28.70	90.69
45	289.1	2.65	0.92	15.77	49.82
66	472.4	7.18	1.52	30.40	96.06
95	259.3	6.01	2.32	13.81	43.64
225	245.3	10.01	4.08	23.72	74.96
230	176.8	2.97	1.68	19.31	61.06
282	225	13.13	5.84	12.88	40.69
510	187	7.18	3.84	20.37	64.36
534	293.4	3.99	1.36	14.00	44.24
Average	265.56	7.68	3.49		

Morse *et al.* (1994) states that a 454 kg Holstein dairy cow excretes an average of 44.6 kg raw waste per day which contained 6.08 kg solid material. According to Anonymous (2011), the average manure excreted by a 450 kg cow is 27 kg/day, of which 24 kg is water and 3 kg is solid material. The average soil extracted from the faecal matter at Amperplaas was 24.10 g/kg. Therefore the average dry mass of voided faecal matter per cow per day according to Morse *et al.* (1994) and Anonymous (2011) is 4.11 kg and the calculated excreted soil is 98.93 g per day. Based on calculated soil ingested (Table 5.3) cows excrete almost the same amount of soil than ingested. Therefore the risk of sand impaction among the cows at Amperplaas is limited.

The extracted soil from cow No. 242 contained high concentrations of Al_2O_3, CaO, Fe_2O_3, MgO as well as Na_2O (Table 5.4). The soil extracted from the stomachs also contained calcite, which was not found in any of the other soil samples. The soil collected

Table 5.4 Elemental concentrations (%), in oxidation state, in soil extracted from stomachs.

	Unknown cow 1	Unknown cow 2	Cow No. 41	Cow No. 242
SiO_2	91.7	88.3	88.2	60.6
TiO_2	1.0	2.5	1.2	0.6
Al_2O_3	1.7	1.7	1.7	5.8
Fe_2O_3	2.5	4.2	2.5	6.0
MgO	0.2	0.1	0.7	4.7
MnO	0	0.1	0	0.1
CaO	1.1	1.7	2.1	10.2
K_2O	0.4	0.4	0.3	0.3
P_2O_5	0	0	0.1	0.1
Na_2O	0.1	0.1	0.2	0.8
Loss on ignition	1.3	0.9	3.0	10.8
Total	**100**	**100**	**100**	**100**

from No. 242 was the only samples that contained smectite and siderite (Figure 5.14). Comparing the trace elements present in the soil, cow No. 242 displayed elevated concentrations of cobalt, copper, nickel, strontium and especially chromium and zinc (Table 5.5).

Upon comparison of the elemental content of lick soil, soil extracted from the stomach and soil from the faecal matter, iron was the element with the highest concentration in all samples (Figure 5.15). The average major and trace element content was lower in all the faecal matter soil than in the soil extracted from the stomach except for potassium and copper. This suggests that the elements are absorbed in varying concentrations as it passes through the digestive tract. The higher potassium and copper content of faecal matter indicates a greater excretion than absorption rate, which might lead to a deficiency over a prolonged period. The potassium and copper content of the geophagic soil was much higher than that found in the faecal matter, implying that a sufficient amount of the

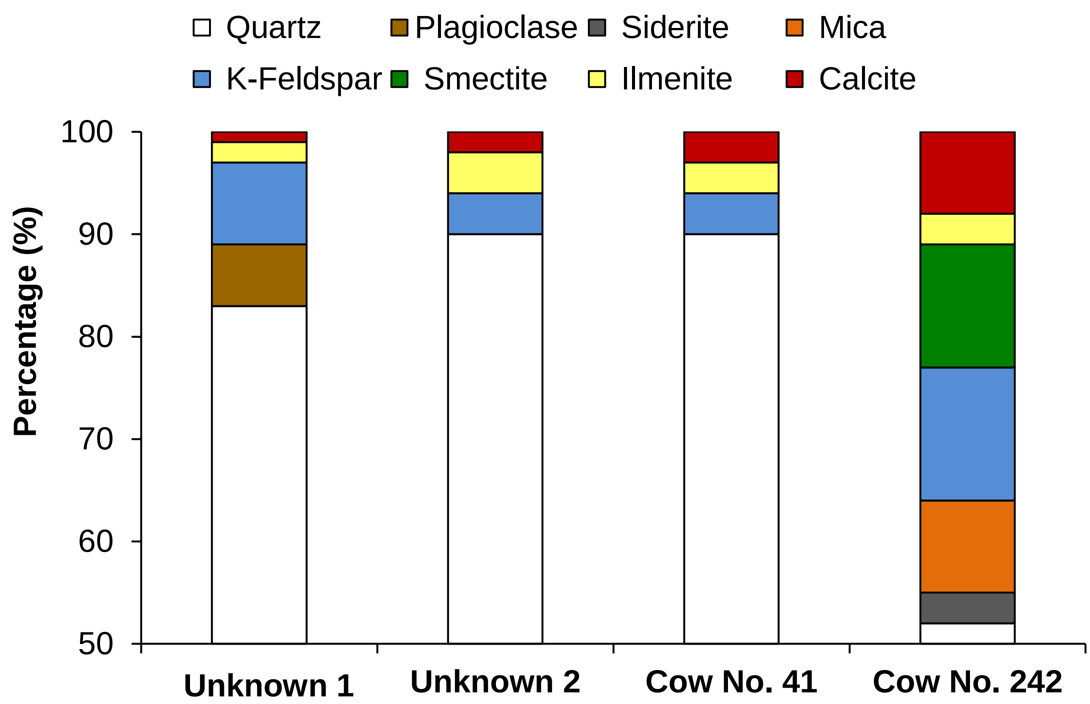

Figure 5.14 Concentrations of clay components in soil retrieved from stomachs.

element was absorbed and the excess excreted. In comparing the composition of supplied feed, ingested soil and stomach soil, only calcium and phosphorus were quantified in the supplied feed, therefore the high concentrations of other elements is expected to originate from the mineral licks.

Table 5.5 Content (mg/kg) of trace elements in soil extracted from stomachs.

	Unknown cow 1	Unknown cow 2	Cow No. 41	Cow No. 242
As	<4	<4	<4	<4
Ba	1288	1109	1288	760
Br	<1	<1	<1	1
Co	5	7	5	23
Cr	82	90	82	376
Cu	47	26	47	67
Mo	<1	<1	<1	<1
Nb	8	7	8	2
Ni	13	15	13	100
Pb	10	4	10	12
Rb	16	18	16	15
Sb	59	57	59	59
Sc	4	<2	4	14
Sr	27	19	27	63
Th	3	3	3	<2
V	151	128	151	94
Y	6	6	6	10
Zn	104	38	104	421
Zr	641	618	641	241

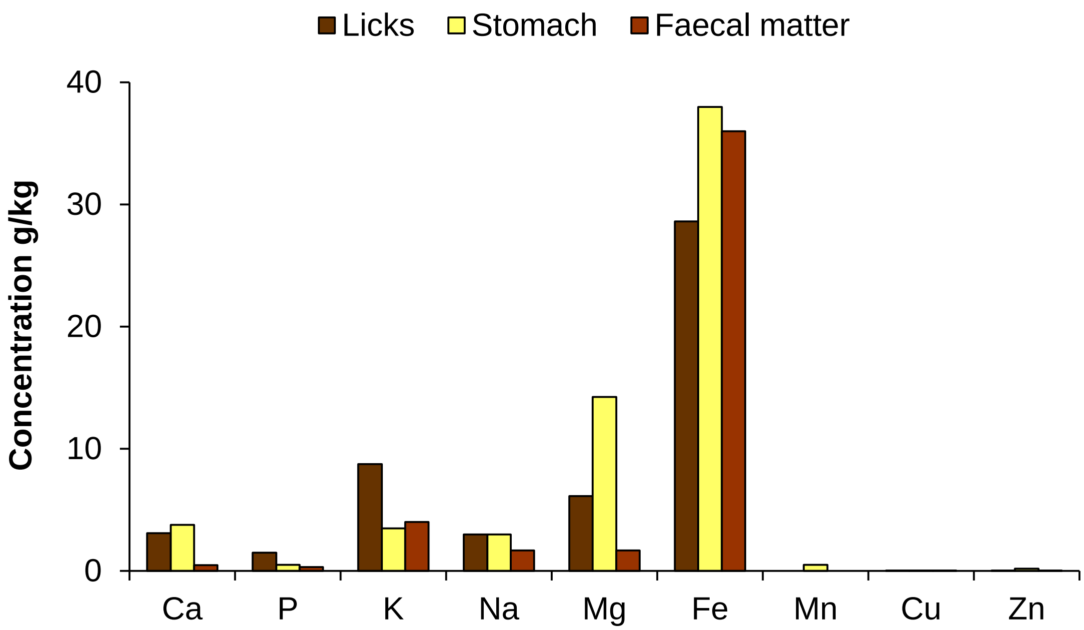

Figure 5.15 Average trace element content of soil collected from mineral licks, stomachs and faecal matter.

5.1.6 Milk yield and composition

In order to compare milk yield and milk composition, milk samples as well as milk production records were collected from selected individuals which were recorded to consume soil. Cows No. 4, 9, 26 and 10021, from the mid-lactation group, cows No. 2, 3, 18, 98, 230 and 1390 from the late lactation group and cow No. 5, representative of the dry group, were selected. An ANOVA test was used to determine the statistical difference, if any, between the concentrations of minerals present in the milk from the different individuals within the mid- and late lactation groups respectively. No significant difference ($p \geq 0.05$) (Tables 5.6 and 5.7) was found and the values of the individuals from each lactation phase were therefore grouped together and the averages calculated. The average milk yield for the mid-lactation and late lactation group was calculated at 15.35 and 5.90 kg/day respectively. As expected, the decrease in milk yield from mid- to late lactation follows the decline in milk production of cows in these phases of the lactation cycle.

The calcium content of all three groups was far below those suggested by Schönfeldt *et al.* (2012) for countries of Australia, Denmark, United Kingdom, United States of America and South Africa, or that calculated by Gaucheron (2005) for France (Table 5.8). Results from the samples collected at Amperplaas suggests a range closer to 510 and 970 mg/kg, although two samples from cow No. 18 (late lactation) had calcium content above 1 800 mg/kg and one sample from cow No. 9 (mid-lactation) had calcium content of more than 1 500 mg/kg. Iyengar (1982) and Jenness (1985) noted that calcium as well as phosphorus levels are lowest during peak milk production where after it increases as lactation progresses. All cows at Amperplaas dairy farm were past the early lactation phase and calcium concentrations of milk should have stabilised at this phase. A possible explanation for the low calcium levels might be that milk calcium concentration varies between regions as bioavailability of minerals in soil and therefor in plants, differs. A low calcium diet might contribute to low milk calcium concentrations as the amount of calcium absorbed by an animal is dependent on the calcium available from the foodstuff and the inorganic calcium sources in the diet as well as the physiologic state of the animal (Anonymous 2001).

Table 5.6 Milk yield, milk composition and mineral mixture consumption of selected individuals of the mid-lactation group.

Group		**Mid-lactation group**				**P-value**
Cow Number		**4**	**9**	**26**	**10021**	
$\bar{x}$ Milk yield (kg/day)		13.94	17.00	15.20	15.18	
$\bar{x}$ Milk composition (contents in mg/kg)	Ca	682	729	621	707	0.51
	P	1 088	920	1 119	985	0.56
	K	1 464	1 220	1 334	1 398	0.37
	Na	571	561	451	527	0.56
	Mg	155	153	136	137	0.60
	Fe	2.42	2.47	4.33	2.92	0.61
	Cu	0.28	0.29	0.39	0.26	0.61
	Mn	0.89	2.44	13.75	0.76	0.61
	Zn	6.75	4.89	5.63	5.41	0.61
$\bar{x}$ Soil mixtures consumed (g)	Ca	~	~	6.32	~	
	P	6.32	21.07	22.98	20.54	
	NaCl	20.54	25.85	19.59	45.82	
	Control	6.32	12.64	25.28	~	

Table 5.7 Milk yield, milk composition and mineral mixture consumption of selected individuals of the late lactation group.

Group		Late lactation group						P-value
Cow number		**2**	**3**	**18**	**98**	**230**	**1390**	
$\bar{x}$ Milk yield (kg/day)		4.00	7.00	7.40	2.68	8.16	7.00	
$\bar{x}$ Milk composition (contents in mg/kg)	Ca	624	730	1 539	794	806	676	0.33
	P	1 101	929	1 198	908	1 015	269	0.86
	K	1 665	934	988	679	888	1326	0.42
	Na	483	482	519	1 268	784	395	0.06
	Mg	157	157	170	169	146	128	0.06
	Fe	2.28	0.36	1.42	2.91	1.25	1.64	0.06
	Cu	0.26	0.06	0.32	0.25	0.31	0.24	0.06
	Mn		0.12	0.65	0.41	0.67	10.50	0.06
	Zn	5.48	5.48	6.17	6.45	5.88	1.22	0.06
$\bar{x}$ Soil mixtures consumed (g)	Ca	9.48	~	~	~	9.48	~	
	P	24.19	32.92	22.65	~	17.91	35.81	
	NaCl	23.38	~	25.58	20.54	24.49	~	
	Control	~	~	20.22	~	15.80	~	

Table 5.8 Recommended content of major and minor elements of milk as well as tested content at Amperplaas.

Element (mg/kg)	Australia	Denmark	UK	USA	SA	France	Amperplaas Mid-lactation	Amperplaas Late lactation	Amperplaas Dry group
Ca	1170	1160	1150	1130	1200	1043 - 1283	685	862	668
P	920	930	920	910	903	930 - 993	1028	863	1038
K	1550	1440	1400	1430	1570	1212 - 1681	1339	963	992
Na	-	454	550	400	483	391 - 644	528	533	361
Mg	110	111	110	100	117	97 - 146	145	154	127
Fe	-	0.40	0.50	0.30	-	-	3.04	1.64	4.72
Cu	0.03	0.10	-	0.10	-	-	0.31	0.24	0.41
Mn	0.01	0.10	-	0.03	-	-	4.46	2.47	1.00
Zn	4.00	4.20	4.00	4.00	-	-	5.67	5.11	5.86

Becker *et al.* (1933) state that when a deficiency in dietary calcium is experienced, the calcium concentration in the milk does not decrease. Iyengar (1982) also reported that only milk production is affected by low dietary calcium intake and not milk composition. Anonymous (Undated a) states that an individual in the mid-lactation phase requires an average of 22 kg dry matter per day with a calcium content of 0.8 to 1.0% while cows in the late lactation phase require 11.5 kg dry matter per day with a calcium content of 0.7 to 0.9%. Furthermore, according to Hansard *et al.* (1954) the efficiency of calcium absorption will decrease as the age of the individual increase. The formulated feed at Amperplaas had calcium content ranging from 7 000 to 15 000 mg/kg (0.7 to 1.5%). The calcium content of the formulated feed seems to be sufficient for the daily requirements of these cows.

The milk from the cows in the different lactation phases contained average phosphorus content close to the suggested values (Table 5.8). Anonymous (Undated a) states that an individual in the mid-lactation phase requires an average of 22 kg dry matter per day with a phosphorus content of 0.4 to 0.8% while cows in the late lactation phase require 11.5 kg dry matter per day with a calcium content of 0.4 to 0.7%. The phosphorus content of the supplied feed ranged between 3 000 and 5 000 mg/kg (0.3 to 0.5%) which is sufficient for these animals' daily requirements.

The concentrations of elements in the milk is dependent on the bio-availability of elements in the soil and plants as the elements in the soil gets absorbed the plants and are then ingested by animals (Osthoff 2017 pers comm[1]). Although the cows at Amperplaas are reliant on formulated feed with fixed nutrients for elemental supplementation, absorption of elements through the ingestion of soil also occurs. When comparing the suggested elemental content of milk with the actual concentrations found in the milk from Amperplaas, all the micro elements are present in elevated levels, especially iron and manganese (Table 5.8). The high content of micro elements in the milk can be attributed to the presence of these elements in high concentrations in the ingested soil, except for the manganese, since no evidence was found for presence of manganese, LLD = 0.002%, in the formulated feed or the lick soil.

[1] Present address: University of the Free State, 205 Nelson Mandela Drive, Bloemfontein, 9300, South Africa.

It was expected that the calcium as well as phosphorus concentrations would be lower in the mid-lactation group as this levels gradually increase with progression of the lactation phases (Iyengar 1982 and Jenness 1985). This was not the tendency among the different lactation groups at Amperplaas. The potassium content however was highest among the mid-lactation group and decreased as the lactation phases progressed.

5.1.7 Free-choice mineral selection

In order to supplement the body with daily nutritional needs, animals must, theoretically be able to discriminate between different mineralsIt is thus assumed that animals must seek to ingest maximum levels of the minerals deficient in their diet, to supplement it accordingly. Several studies have shown that animals are able to detect the contents of some minerals (specifically Na and P) and modify their behaviour or regulate consumption according to their needs (Ceacero *et al*. 2009). Supplementation is thought to be especially high during calving and lactation, or when suffering excessive mineral loss due to diarrhoea (Stephenson *et al*. 2010, Ping *et al*. 2010). In addition to this, calves are highly dependent on minerals obtained during the early stages of their life, as lactation influences growth (body and skeletal) and reproduction (Ceacero *et al*. 2009).

5.1.7.1 Mineral selection amongst different lactation groups and individuals

During the free-choice mineral selection experiment, the individuals of each lactation group were presented with four containers, three of which was filled with soil combined with either a high calcium mineral (Table 5.9), a calcium-phosphorus mineral and sodium chloride. The fourth container served as a control containing only soil collected from Amperplaas. The containers were initially presented to each lactation group for a period of five days and for another five days during the repeat of the free-choice mineral selection experiment.

Individuals from all the lactation groups selected to feed on soil, enriched with phosphorus and sodium chloride more than soil containing only calcium or soil originally

Table 5.9 Composition of FEEDLIME, KIMTRAFOS 12 Grande and sodium chloride used during cafeteria experiment.

FEEDLIME	
Calcium	360 g/kg min
Fluorine	1 g/kg max
Aluminium	10 g/kg max
KIMTRAFOS 12 Grande	
Phosphorus	120 g/kg
Calcium	220 g/kg
Iron	1.5 g/kg
Copper	0.3 g/kg
Manganese	1.2 g/kg
Zinc	1.2 g/kg
Iodine	0.03 g/kg
Cobalt	0.006 g/kg
Selenium	0.006 g/kg
Sodium chloride	
Sodium	393 g/kg
Chlorine	607 g/kg

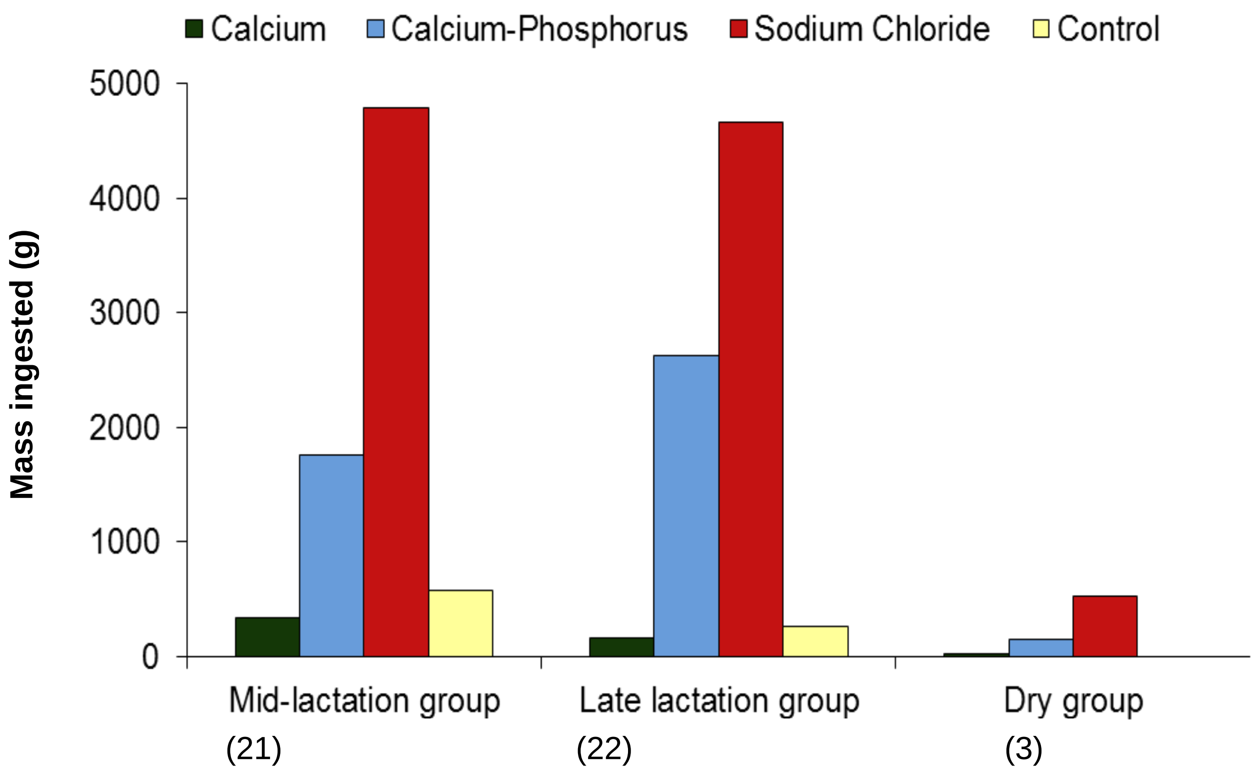

Figure 5.16 Average consumption, per group, of soil, mixed with calcium, calcium-phosphorus, sodium chloride and a control sample of soil with no added salts by three lactation groups over a period of ten days.

from geophagy sites at Amperplaas (Figure 5.16). A possible explanation for the preference of the calcium-phosphorus mixture to the high concentration calcium mixture might be that calcium is required in proportion to phosphorus and these animals selected the minerals based on a more balanced composition. Both mid- and late lactation phases consumed more of the control soil than the calcium enriched soil. As determined in the geochemistry of the soil (Chapter 4), the calcium content of the geophagic soil, which was used as control during the experiment, was 0.22% while the calcium content of the calcium enriched soil was more than 36%. Since both the lactation phases preferred the control soil, calcium therefore is probably not the stimulus for soil consumption.

Denton (1967) noted that all mammals are able to taste sodium chloride. According to Berger (2006) cattle have a stronger appetite for sodium chloride than for any other compound except for that of water and in addition, cattle also have an excellent smell for sodium (Bell 1983). This may explain why cows displayed such a high intake of sodium chloride mixture during the cafeteria experiment. The mid-lactation and late lactation groups ingested soil with an average mass of 4 785 and 4 659 g respectively during the ten days the cafeteria experiment was executed (Figure 5.16), this calculates to an average of 256 g per cow of the mid-lactation group and 254 g per cow of the late lactation group during the cafeteria experiment. The dry group displayed an estimated average ingestion of 174 g of soil per cow during the ten days of the cafeteria experiment.

The calcium-phosphorus mixture was consumed to a lesser extent. More than half of the offered calcium-phosphorus mixture (2 628.07 g) was consumed by the late lactating group of 22 individuals which is calculated to an average of 119.46 g per individual. The mid-lactation group consumed less (1 759.07 g) with an average of 83.76 g per individual. Individuals where milk production stopped, ate only 149.94 g of the calcium-phosphorus soil, with an average of only 49.98 g per cow.

Cows from the mid-lactation group displayed the greatest preference for the sodium chloride mixture (Figure 5.17). Only two individuals did not consume any of the salt mixture. The most sodium chloride enriched soil consumed by one individual was 767.88 g while cow No. 7 ingested only 3.16 g. The calcium-phosphorus mixture was consumed to a lesser extent, with four individuals not ingesting any. The greatest amount of calcium-phosphorus consumed was 303.36 g. Of the mineral mixtures, calcium containing soil was least preferred, since only nine individuals ate of this mixture, the maximum amount ingested being 170.64 g. The ingestion of control soil by individuals of the mid-lactation group ranged from 4.74 to 127.98 g.

Individuals from the late lactation group also showed a greater preference for the sodium chloride mixture than the other mineral mixtures (Figure 5.18). The most soil ingested by one individual was 929.04 g while some of the other cows ingested only 3.16 g. The calcium-phosphorus mixture was not as preferred as the sodium chloride although several individual did consume large amounts of the calcium-phosphorus mixture, the greatest ingested amount being 790 g. Of the three mineral mixtures, the calcium was

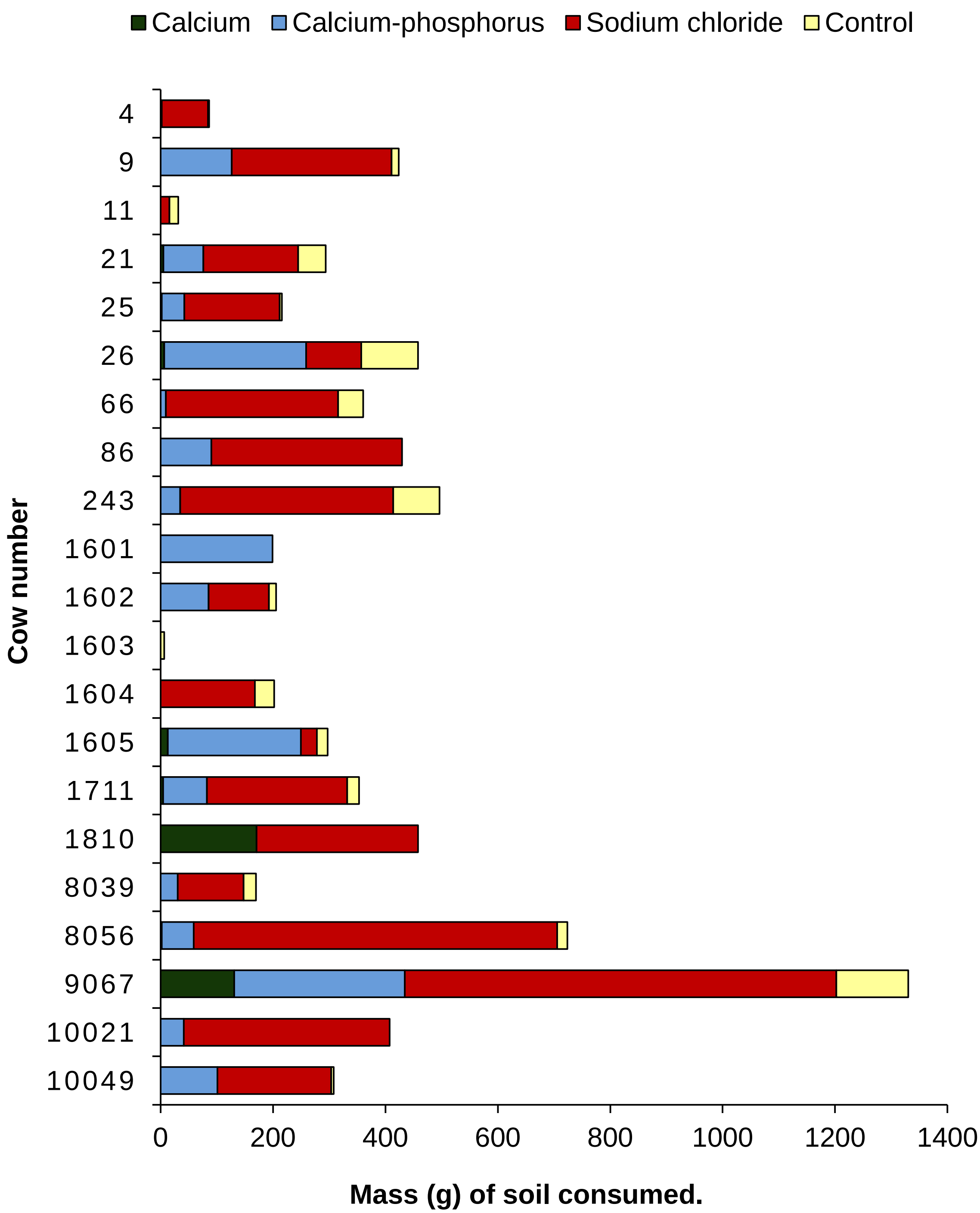

Figure 5.17 Average consumption, per individual, of soil, mixed with calcium, calcium-phosphorus, sodium chloride and a control sample of soil with no added elements by mid-lactation cows over a period of ten days.

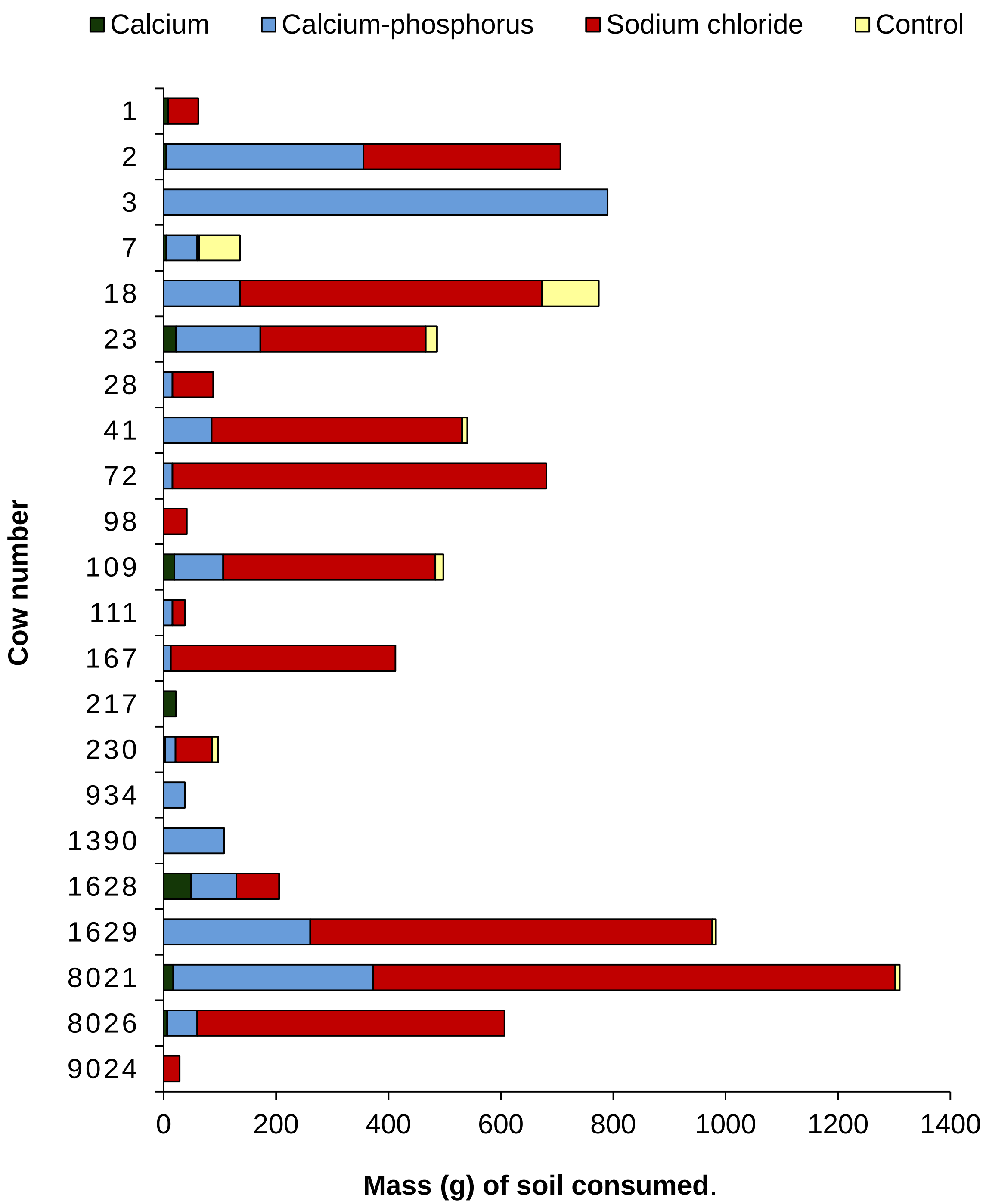

Figure 5.18 Average consumption, per individual, of soil, mixed with calcium, calcium-phosphorus, sodium chloride and a control sample of soil with no added elements by late lactation cows over a period of ten days.

again the least selected. Less than half the cows in this group ate of the calcium mixture, with ingestion masses ranging between 3.16 and 48.98 g. Only eight individuals ate of the control soil.

The sodium chloride mixture was also the most consumed mixture by the dry individuals, followed by the calcium-phosphorus mixture (Figure 5.19). Only one of the three individuals of the dry individual group exhibited calcium mixture consumption during the cafeteria experiment. None of the control soil was ingested by this group.

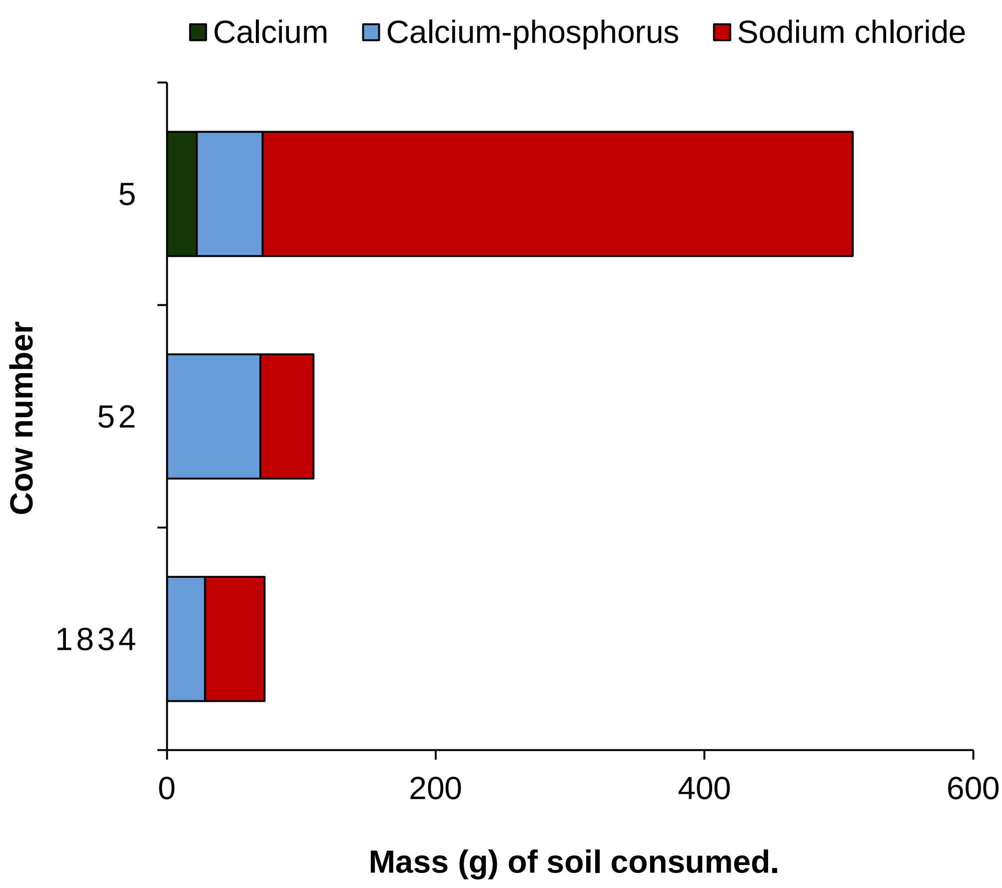

Figure 5.19 Average consumption, per individual, of soil, mixed with calcium, calcium-phosphorus and sodium chloride by the dry individuals over a period of ten days.

5.1.8 The behaviour of geophagia

In 2013, several new individuals were bought from another farmer. Within a day of arrival at Amperplaas, three of the new cows were observed engaging in geophagy at some of the established lick sites in their encampment. This raises the question of whether geophagy was a familiar behaviour to these individuals and they just needed a visual stimulus from the resident cows for the best geophagy site? Or did these individuals detect a source of minerals through olfactory sensing?

According to Ceacero *et al.* (2009), the optimal foraging theory predicts that animals should be able to adjust their diet in order to maximise their energy intake. Several studies suggest that ruminants display nutritional wisdom in selecting diets with higher nutritional value (Arnold and Dudzinski 1978, Provensza and Balph 1990, Rosenthal and Janzen 1979, Raupp and Tallamy 1991, Rosenthal and Berenbaum 1992). Like in many species, the ability of young individuals to learn nutritional wisdom plays an important role in animal nutrition (Provenza 1994). Young individuals most often learn the importance as well as toxicity of certain plant products from the mother and other individuals. Thornton and Raihani (2008) suggest that animals are more likely to consume a particular food if it sees another individual consuming that food item.

The heifers at Amperplaas were kept in the camp next to the first lactation group which was known to ingest soil at several established geophagy sites in the encampment. It was observed that when the older individuals ingested soil beneath the wire separating the two groups, the heifers showed a keen interest in their activity (Figure 5.24). Shortly after this observation the heifers started consuming soil at the same established mineral licks beneath the fence and after a while several other licks were observed in the heifers' encampment. From this it is assumed that social learning played a prominent role in the geophagy behaviour of the heifers at Amperplaas.

Figure 5.20 Heifers (left of fence) observe adult cows ingesting soil at a regular geophagy site at Amperplaas dairy farm.

5.2 Conclusion

Cows at Amperplaas invest approximately one third of the day on ingestive behaviour, leaving the greatest part of the day for inactive behaviour such as lying and standing. Geophagy at this dairy farm coincides with times of feed and water consumption. Therefore, it can be interpreted that geophagy is considered equally as important as feeding and water drinking to these cows.

All the lactating individuals were recorded investing in geophagy on an almost daily basis while the non-lactating individuals practiced soil consumption on only a few occasions. This suggests that lactation brings about a change in the elemental concentrations in the body which has to be rectified through some channel. It was also noticed that as the lactation phases progress, geophagy incidences as well as time invested in this behaviour decrease suggesting that mineral requirements is maximal in the first phase after parturition due to the mineral output to the development of the calf and colostrum. As the soil at Amperplaas contains several minerals required for maintenance and milk production, it is concluded that soil is consumed in order to supplement mineral requirements.

Recorded geophagy occurrences were most during winter and thereafter spring. As the nutritional value of plants and therefore natural feed is lowest during winter and the transition to spring and the cows at Amperplaas are partly reliant on natural feed, soil ingestion might aid in the supplementation of nutrient deficiencies caused by lower quality natural feed.

In addition to the preference to initiate licks under the fence wires rather than around the iron and wooden droppers or in the cleared open areas in the encampments, certain locations in the camps were also favoured. It would appear that mineral licks with certain contents were periodically instigated and abandoned as these sought after contents were depleted. As these animals require certain elements for bodily maintenance and only some are met by the formulated and natural feed, the other needed elements has to be supplemented from another source. When comparing the dietary requirements of animals with the elements available in the soil at the mineral licks, not taking into account calcium and phosphorus as these are supplied by formulated feed, magnesium (expect at the mineral licks in the cleared area), cobalt, copper and iron was present in sufficient amounts to supplement in their daily needs. Potassium and zinc was the only elements present in sufficient amounts at the newest mineral lick but at none of the other licks to achieve the recommended requirements prescribed by the NRC. Therefore it is assumed that potassium and zinc are the main motivators for the initiation of a new mineral lick.

Concerning the risks of geophagy, literature cautions against poisoning by certain elements and sand impaction. The risk of iron-, cobalt- and copper poisoning is very low at Amperplaas and no deaths were reported to be caused by either. When comparing the estimated amount of soil ingested per second with the excreted amount of soil, it appears that the daily excretion rate of soil is almost equal to the ingestion rate, therefore not posing any threat for sand impaction.

The concentrations of elements in milk are dependent on the absorption of elements available in the feed or other ingested material. Except for calcium, the content of milk from Amperplaas is reflective of the availability of elements in the consumed soil. Except for calcium and potassium, the elemental content in the milk seem to adhere to the suggested values of elemental content of milk. It is unknown why the calcium levels are low as enough calcium is supplied through the feed according to the prescribed dietary requirements. The low potassium levels in the milk might be indicative of a slight potassium deficiency and soil is possibly ingested to supplement this deficiency.

When offered soil combined with different minerals, most cows at Amperplaas showed a preference for the sodium chloride mixture, followed by the calcium enriched phosphorus mixture. From this selection it is clear that these animals are able to distinguish between different minerals. In addition, because these cows prefered the calcium-phosphorus mixture more than the high concentration calcium mixture, it is possible that these animals are able to discriminate and select the correct proportions of elements needed for bodily maintenance.

To conclude, the results of this study confirm the ability of some animals to detect deficiencies in their diet and to attempt to correct these deficiencies from available resources. Results also support the theories that this nutritional wisdom is partly from cultural transmission and partly from instinct.

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SUMMARY & OPSOMMING

SUMMARY

Modern confinements imposed on animals limit their access to natural resources required for optimal nutrition. This lack of resources may lead to nutrient deficiencies and one of the hypotheses for the deliberate consumption of soil is to supplement mineral deficiencies. Counteraction of acidosis, detoxification, buffering of unpalatable plant compounds as well as the use of soil as anti-diarrhoeal agent are other suggested motivations for geophagy. By means of direct observation as well as camera traps, the behaviour of geophagy amongst dairy cows in a confined feedlot system was documented. In addition, soil analysis was done to determine the geochemistry of ingested as well as excreted soil. Geophagy amongst cows at Amperplaas constituted less than 2% of daily activity. The non-lactating individuals invested less time in this behaviour than lactating individuals and the frequency as well as time spent on this behaviour decreased as the lactation phases progressed. Recorded geophagy occurrences were most during winter and thereafter spring and peak soil ingestion occurred during mid-day. At Amperplaas, all but one of the mineral licks were situated on the undisturbed elevated areas underneath the fence wire or around the wooden and iron poles. The average size of a typical mineral lick was about 40 cm by 15 cm with a depth of 10 cm. The soil collected from the mineral licks was alkaline and classified as sandy clay loam. Quartz, Plagioclase and K-Feldspar were identified in all samples while Ilmenite was quantifiable in all but one of the control sites. Silica concentrations were supportive of quartz dominance in the soil collected from mineral licks as well as soil from the stomachs and faecal matter. The most recent mineral lick contained the lowest silica, arsenic, copper, lead, scandium, and zirconium content. But this site had elevated calcium, iron, potassium, magnesium, sodium and phosphorus as well as bromine, nickel, strontium and zinc levels. When offered soil combined with different minerals, the preference of most cows was sodium chloride mixture and thereafter calcium-phosphorus. When comparing the estimated amount of soil ingested per second with the excreted amount of soil, it appears that the daily excretion rate of soil is almost equal to the ingestion rate, therefore not posing any threat for sand impaction. Milk collected at Amperplaas had low levels of calcium as well as potassium and therefore, soil is possibly ingested to supplement this deficiency. Results of this study confirm the ability of some animals to detect deficiencies in the body and to attempt to correct these deficiencies from available resources. Results also support the theories that this nutritional wisdom is partly from cultural transmission as well as innate behaviour.

Keywords: dairy cows, feedlot system, geophagy, mineral deficiency, macro and micro elements, mineral supplement, free-choice mineral selection.

OPSOMMING

Diere in aanhouding word van toegang tot natuurlike hulpbronne wat noodsaaklik is vir optimale voeding ontneem. Hierdie gebrek aan hulpbronne kan lei tot verskeie voedingstekorte en een van die hipoteses vir die doelbewuste inname van grond is om mineraaltekorte aan te vul. Die teenwerk van asidose (suurvergifting), ontgifting, die buffer van onsmaaklik plant verbindings, asook die gebruik van grond as anti-diarreale middel is ander voorgestelde motiverings vir geofagie. Deur middel van direkte waarnemings en kamera lokvalle is geofagie by melkkoeie in 'n voerkraal stelsel gedokumenteer. Addisionele grondontledings is uitgevoer om die geochemie van gevrete asook uitgeskeide grond te bepaal. Koeie by Amperplaas spandeer minder as 2% van daaglikse aktiwiteite aan grondvreet. Nie-lakterende individue spandeer minder tyd aan hierdie gedrag as lakterende individue en die frekwensie asook tyd spandeer aan hierdie gedrag verminder soos die laktasie fases vorder. Aangetekende voorvalle van geofagie was die meeste tydens die winter en daarna die lente en grondvreet het ‘n hoogtepunt bereik gedurende die middel van die dag. Al die mineraal lekke by Amperplaas, met die uitsondering van een, was op die ongestoorde, verhewe areas onder die kampdrade of rondom die hout- en ysterpale geleë. 'n Tipiese mineraal lek het afmetings van ongeveer 40 by 15 cm met ‘n diepte van 10 cm gehad. Grond wat by die mineraal lekke versamel was is geklassifiseer as alkaliese sanderige leem klei. Kwarts, plagioklaas en K-Veldspaat is in alle monsters geïdentifiseer terwyl ilmeniet slegs by een kontrole gebied nie gevind is nie. Hoë silika konsentrasies was ondersteunend van die kwarts oorheersing in die versamelde grond van die mineraal lekke asook van grond wat uit die pense en mis verwyder is. Die mees onlangse gevestigde mineraal lek het die laagste silika, arseen, koper, lood, skandium en sirkonium inhoud gehad. Hierdie lek het ook verhoogde vlakke van kalsium, yster, kalium, magnesium, natrium en fosfor asook broom, nikkel, strontium en sink gehad. Grond, gemeng met verskeie minerale, is vir die koeie aangebied en die voorkeur van meeste koeie was die natrium kloried mengsel met kalsium-fosfor mengsel as tweede keuse. Wanneer die geskatte hoeveelheid grond wat ingeneem is met die uitgeskeide hoeveelhede vergelyk word, blyk dit dat die daaglikse uitskeidingstempo van grond byna

gelyk is aan die tempo van inname. Daar dus nie ‘n risiko vir sandverstopping by die koeie van Amperplaas nie. Melk wat versamel is by Amperplaas het lae vlakke van kalsium sowel as kalium getoon en grond word heel waarskynlik ingeneem om verligting vir hierdie tekort teweeg te bring. Resultate van hierdie studie bevestig dat diere oor die vermoë beskik om tekorte in die liggaam agter te kom en dus te poog om hierdie tekorte vanuit beskikbare hulpbronne reg te stel. Resultate ondersteun vervolgens die teorieë dat hierdie voedingswysheid deels aan kulturele oordrag en deels aan aangebore gedrag toegeskryf kan word.

Sleutelwoorde: melkkoeie, voerkraal stelsel, geofagie, mineraal tekort, makro- en mikro elemente, minerale aanvulling, vry-keuse minerale seleksie.

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