Geophagy and Mineral Preference by Gemsbok (*Oryx gazella*) in the Southern Kalahari

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Abstract

Geophagy is commonly observed in various animals. There are many possible reasons for geophagy in antelope and speculation usually revolves around mineral supplement for dietary requirements. Although previous observations of geophagy amongst gemsbok have been documented, this behaviour has never been studied extensively. To investigate geophagy behaviour amongst gemsbok, a route was followed along the Nossob and Auob riverbeds in the Kgalagadi Transfrontier Park in both the dry and wet seasons. Time of day, sex, age and reproductive stage of soil-eating gemsbok were noted. In order to determine if geophagy is stimulated by the presence of specific minerals, soil samples were collected at sites where these antelopes were observed eating soil. As control, samples were also collected at sites where no geophagy occurred. These samples were analysed with ICP-OES. Although a spectrum of chemical elements was detected during analysis, only a few were present in considerable amounts which include Na, K, Ca and Mg. The presence of high concentrations of Na at soil feeding sites can be indicative of the desired chemical element, but it is also possible that a combination of chemical elements or less frequent chemical element are accountable for geophagy in gemsbok. Furthermore, geophagy occurred in both sexes and all ages of gemsbok and therefore it is suggestive that mineral supplementation might not be the only motivation behind geophagy. Another possible reason for geophagy might include the counteraction of acidosis in relation to diet selection.

Keywords: *Soil consumption, Schmidtia kalihariensis, salt lick, pH*

1. Introduction

Geophagy (eating of soil) is a common occurrence in various animals. According to Kreulen & Jager (1984) it has been studied in reptiles, birds and mammals, in areas ranging from deserts and rainforests to mountains. Despite this, the real reason behind geophagy remains somewhat controversial.

Various studies suggest that mineral supplementation, chemical element imbalance or pharmacognosy (Mahaney, 1999; Mahaney et al., 1990) 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 greater parts of their activity budget feeding on soil than males. It is therefore suggested that geophagy may be driven by a nutritional requirement (especially Na or Fe), due to the fact that reproductive elephant cows probably had greater nutritional requirements than males because of pregnancy and lactation. Sodium is especially important during pregnancy and severe restriction over a long period of time can result in reduced fertility, - reproduction and - milk production (McDowell 1985a).

Knight (1991) also concluded that sodium was probably the desired mineral by gemsbok (*Oryx gazella*) from geophagy sites in the southern Kalahari as sodium and its anions, sulphate and chloride, were present in significantly higher concentrations in geophagy soil than in the surrounding control sites. Kreulen & Jager (1984), Tracy & McNaughton (1995), Abrahams (1999), Atwood & Weeks (2003), and Brightsmith & Muńoz-Najar (2004) further suggest that Na is the desired mineral in geophagic soils. Both Penzhorn (1982) and Langman (1978) suggested that Ca and P deficiency might be the motivation behind geophagy in Cape mountain zebras and giraffe respectively, while Krishnamani & Mahaney (2000) and Mahaney and Khrishnamani, (2003) amongst others, suggested that soil provides extra iron for primates at high altitudes.

Other suggested reasons for geophagy include the counteraction of endoparasites (Krishnamani & Mahaney 2000), the counteraction of acidosis (Kreulen & Jager 1984; Abrahams 1999 and Krishnamani & Mahaney 2000), detoxification and buffering of unpalatable plant compounds (Krishnamani & Mahaney 2000; Voight *et al.* 2008 and Chandrajith *et al.* 2009) and soil as an antidiarroeal agent (Mahaney et al., 1990; Abrahams 1999 and Krishnamani & Mahaney 2000). Krishnamani & Mahaney (2000) also suggested that geophagy might satisfy olfactory senses, serve as a substitute for food in extreme hunger and even that geophagy might have no reason at all. According to Kreulen & 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 of these animals.

Although previous observations of geophagy amongst gemsbok have been documented, this behaviour has never been studied extensively. The aim of this study is to investigate possible driving forces that stimulate gemsbok to consume soil.

2. Materials and Methods

2.1 Study area

The study was conducted in the Kgalagadi Transfrontier Park, which is situated in the southern Kalahari, from September 2008 to September 2009. According to Low & Rebelo (1996) the Kgalagadi Transfrontier Park forms part of the Savanna biome, and more particular the Shrubby Kalahari Dune Bushveld vegetation type, also known as Kalahari thornveld. The landscape comprises of undulating dunes, but pans are found scattered throughout this vegetation type. Low & Rebelo (1996) adds that the average rainfall for the area is about 200mm, which falls mainly from November to April. Typical trees in the area include Camel Thorn (*Acacia erioloba*) and Shepherd's Tree (*Boscia albitrunca*). The grass layer is well developed and gives the impression of grassland. Typical grasses include *Stipagrostis obtusa* (Small bushman grass), *Stipagrostis ciliata* (Tall bushman grass) and *Schmidtia kalihariensis* (Kalahari sour grass).

There are two rivers in the Kgalagadi Transfrontier Park namely the Auob and the Nossob. Both rivers rise outside the park, entering from the west, and join up near the southern boundary where they flow out of the park as one river. Van Rooyen (1984) adds that these two rivers are very seldom in flood due to the fact that drainage is mainly through infiltration into the sandy soil and underground zones. He also states that soils of the Oakleaf, Dundee and Valsrivier forms, are mainly confined to the riverbeds and that a marked feature of all these soils are their alkaline nature and that high concentrations of soluble salts are present in some places. It was also found that clay and silt fractions are the dominant mineralogical components of these soils in the riverbeds. According to Mills & Haagner (1989) riverbeds in the Kgalagadi Transfrontier Park have important salt licks and seasonal waterholes, which are created when rain wash minerals and fine soil particles from the side of the riverbed and carries it to the lowest point.

2.2 Geophagy behaviour and soil sampling

To investigate geophagy behaviour amongst gemsbok, a route was followed along the Nossob and Auob riverbeds in the Kgalagadi Transfrontier Park. The exact same route was followed in both the dry and wet seasons, namely from Twee Rivieren to Nossob, from Nossob to Mata-Mata and from Mata-Mata back to Twee Rivieren. Time of day, sex, age and reproductive stage of soil-eating gemsbok were noted and recorded. Gemsbok were divided into categories of male, reproductive female (pregnant or lactating cows), non-reproductive female, juvenile and unknown. Where possible, the duration of geophagy was also noted. Furthermore, vegetation in the vicinity of the geophagy sites and feeding behaviour of gemsbok were noted.

In order to determine if geophagy is stimulated by the presence of specific minerals or chemical elements, soil samples were collected (± 500 g) at four selected geophagy sites where these antelopes were observed eating soil. The samples were collected at the exact location where the gemsbok consumed soil namely in holes they made with their front legs or where their lip marks were still visible in the soil (especially clay). These sites included Kransbrak, Rooikop, Marie se Gat and Kwang, which are all situated along the Nossob riverbed (Fig 1). As control, samples were also collected at sites where no geophagy occurred, namely on the red dunes in the vicinity of Nossob. Additionally, faecal samples of gemsbok in the vicinity of geophagy sites were collected.

2.3 Soil analysis

Soil samples collected at four geophagy sites and one control site were prepared for analysis by sub sampling 10g of soil and dissolving it in 100ml of deionised water. The solutions were mixed continuously for an hour after which it was left to stabilise overnight. Subsequently, the solutions were decanted, filtrated and analysed with Inductively coupled plasma - optical emission spectroscopy (ICP-OES). Furthermore, the pH values of the soil samples were determined and the faecal samples dissected to find possible traces of soil.

3. Results and discussion

The preliminary analysis showed that the geophagy soil contained a whole spectrum of chemical elements, however, only chemical elements present in considerable amounts namely calcium, magnesium, sodium and potassium (from here on referred to as Ca, Mg, Na and K) are listed in Table 1.

Table 1: Concentrations (mg/L=ppm by volume) of the main minerals present in soil samples taken at four geophagy sites, as well as a control site, along the Nossob riverbed in the Kgalagadi Transfrontier Park.

	Chemical elements			
Location	**Ca**	**Mg**	**Na**	**K**
Kransbrak	33	1.0	2090	45.2
Rooikop	28	23	139	20.4
Marie se Gat	47	23	934	72.8
Kwang	31	15	654	30.9
Control	28.5	9.45	17.75	14.5

Knight (1991) found the exact same chemical elements to be significant in soil samples taken next to two waterholes situated in the Nossob riverbed. According to Kreulen & Jager (1984) high levels of Na in Kalahari soil often occur together with significant amounts of Ca and Mg. McDowell (1985a) adds that Ca, Mg, Na and K play an extremely important role in the bodily functions of ruminants due to the fact that an ionic balance exists between these four minerals.

3.1 Mineral supplementation

According to Kreulen & Jager (1984) and Thornton (2002) it has commonly been supposed that soil ingestion by antelope is related to mineral deficiencies in the animals' diet. Van der Walt *et al*. (1984) mention that the brackish areas in riverbeds in the Kgalagadi Transfrontier Park provide minerals to animals throughout the whole year. Kreulen & Jager (1984) found that ungulates in the Kalahari spend as much as half an hour daily consuming soil at geophagy sites and concluded that quite a substantial amount of soil must be taken in. They further speculated that it is reasonable to assume that a chemical element that is found in higher concentrations inside than outside the consumed soil, might be the desired element. Figure 2 clearly illustrates that Na is not only present in much higher concentrations than any other element in the geophagy soil, but also in substantial higher concentrations when compared with the control sample.

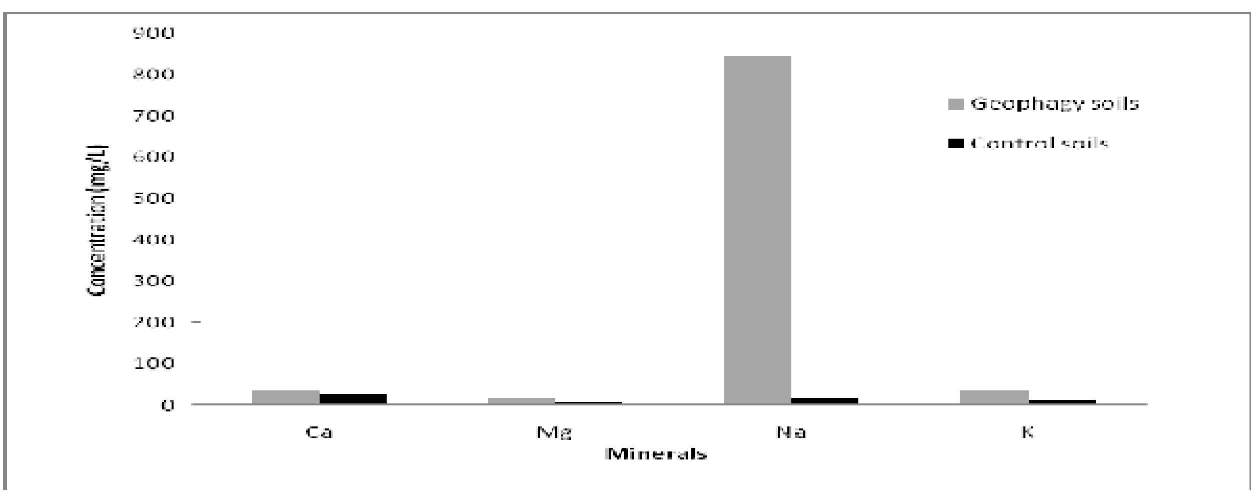

Figure 2: Comparison between the average values of minerals found in soil consumed by gemsbok (*Oryx gazella*), and the control soils, in the Kgalagadi Transfrontier Park.

The fact that Na is present in considerable higher concentrations in the geophagy soil than in the control soil, might be indicative of the desired chemical element. Kreulen & Jager (1984) noted, however, that there is a possibility that geophagy sites are chosen by compromise, rather than on the basis of the highest concentration of a single element, and this might obscure the element that the gemsbok predominantly desire. Observations made at Kransbrak indicated that it is almost exclusively reproductive cows and calves that utilise the natural lick. It is thus suggested that mineral supplementation might be the motivation behind lick use at this specific site. This can further be accentuated by the fact that adult males and non-reproductive females were also present at Kransbrak, but did not ingest any soil or made use of the licks. Due to the presence of extremely high concentrations of Na at Kransbrak, and not other chemical elements (*see* Table 1), when compared to the control, it can possibly be concluded that Na might be the desired element by gemsbok at this particular site.

According to Smith (2008) animals have a more well-defined appetite for salt (or the Na in it) than any other compound in nature, except water. McDowell (1985) mentioned the need for NaCl by ruminants has been demonstrated for thousands of years by a natural craving for salt. Smith (2008) adds that ruminants instinctively know they need salt, and if their diet is salt-deficient, they will seek alternative sources. This could possibly explain soil consumption by gemsbok. McDowell (1985a) further adds that Na requirement are highest and deficiency is most likely to occur during lactation (due to the secretion of Na in milk), in rapidly growing animals, under hot, semi-arid conditions where large losses of water and Na occur in the sweat and where available forage is low in Na. McDowell (1985a) also reported that the initial sign of Na deficiency is a craving for salt, displayed by the eager licking of soil and sweat from other animals, and by the drinking of water. In support of this, Parris (1984) suggested that the use of highly mineralised artificial waterholes by gemsbok in the Kgalagadi Transfrontier Park may be as much for the minerals as for the water itself.

Sodium also plays an essential role in nutrient transport on a cellular level (Smith 2008). Sodium is required for the transmission of nerve impulses, which are responsible for contraction of skeletal, heart and digestive tract muscles. According to both Smith (2008) and McDowell (1985a) Na deficiency causes a loss in appetite, reduced growth, reduced fertility and reduced milk production. With these symptoms in mind, it is expected that reproductive cows and calves might have a greater demand for Na compared to non-reproductive cows and adult bulls and thus it might explain why the former spent a greater part of their activity budget utilising the lick at Kransbrak.

Potassium is chemically very much like Na and is associated with Na in many biological systems (McDowell 1985a). Sodium is the main electrolyte in the plasma and extracellular fluids, while K is present primarily inside the cells. Given this, the fact that gemsbok might need a combination of both Na and K cannot be excluded. The geophagy site with the highest concentration of K was Marie se Gat (see Table 1), which appeared to be a highly sought after geophagy site, utilised by gemsbok of both sexes and all ages, during both the dry and wet seasons. According to McDowell (1985a) K must be supplied daily in the diet due to the fact that it is not readily stored in ruminants and therefore there are no appreciable reserves other than that in the muscle and nerve cells. He adds that the majority of K excretion is via urine and sweat and lastly that there is more K secreted in milk than any other element. Given this, it is reasonable to speculate that reproductive gemsbok at Kransbrak might utilise the lick for a combination of both Na and K.

Several observations of osteophagy (eating of bones) by gemsbok have been documented along the Auob and Nossob riverbeds in both the dry and wet seasons. According to McDowell (1985b) the chewing of bones by ruminants might be an indicator of Ca and P deficiency and although Ca deficiency is usually displayed in the form of osteophagy, it is possible that it can be displayed in the form of geophagy. This was the case in a study done by Penzhorn (1982) on Cape mountain zebras. Therefore, the fact that gemsbok chew on bones serve as direct evidence that they might have a Ca deficiency; thus, it is possible that they display geophagy behaviour in order to supplement low Ca levels.

3.2 Counteraction of acidosis

Due to the fact that gemsbok of both sexes and all ages display geophagy behaviour (Fig. 3), it is suggested that mineral supplementation might not be the only reason for geophagy.

As mentioned before, another possible reason why gemsboks consume soil might be for the counteraction of acidosis. Kreulen & 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. According to Wheeler (1980) large quantities of volatile fatty acids are produced in the reticulorumen as a result of feeding on high grain diets. Krishnamani & Mahaney (2000) explained that large quantities of volatile fatty acids could cause the stomach pH to decrease and cause acidosis, whilst Wheeler (1980) mentioned that several physiological abnormalities have been associated with acidic conditions in the reticulorumen.

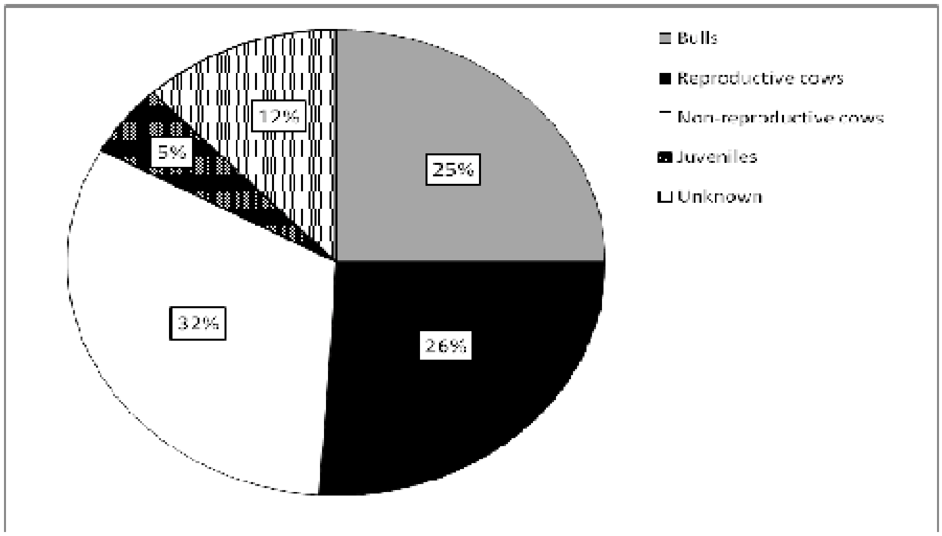

Figure 3: Geophagy behaviour displayed by a total of 57 gemsbok (*Oryx gazella*) observed between September 2008 and September 2009 in the Kgalagadi Transfrontier Park.

According to Leistner (1959) *Schmidtia kalihariensis* (Kalahari sour grass) is one of the most common grasses found along the banks of the Nossob riverbed in the Kgalagadi Transfrontier Park. However, *Schmidtia kalihariensis* is a very unpalatable grass with a low grazing value, which is very hard to digest due to the high fibre content (Van Oudtshoorn 1996). In addition, *Schmidtia kalihariensis* contains glandules that produce an acidic secretion in the flowering stage and therefore the grass has a sour sticky smell, and can irritate the skin if it comes into too much contact with it. According to Eloff (1962), Van Hoven *et al*. (1984) and Van Oudtshoorn (2006) it is for this reason that *Schmidtia kalihariensis* is only utilised when still green and young, or completely dried. However, in the current study, there is no indication that gemsbok discriminated against growth stage. Various observations have been made of gemsbok consuming *Schmidtia kalihariensis* at different times of the year, regardless of the growth stage. Therefore, it is suggested that gemsbok consume soil in the Kgalagadi Transfrontier Park to buffer the acids associated with *Schmidtia kalihariensis*.

According to Van Rooyen (1984) a marked feature of the soils in the Auob and Nossob riverbeds is their alkaline nature. Both Knight (1991) and Klaus *et al*. (1998) also found geophagical soil to have an alkaline characteristic. The pH values of geophagy soil in this study showed that all geophagy sites had very strong alkaline soil and also that it all had a considerable higher pH than the control sample (Fig. 4).

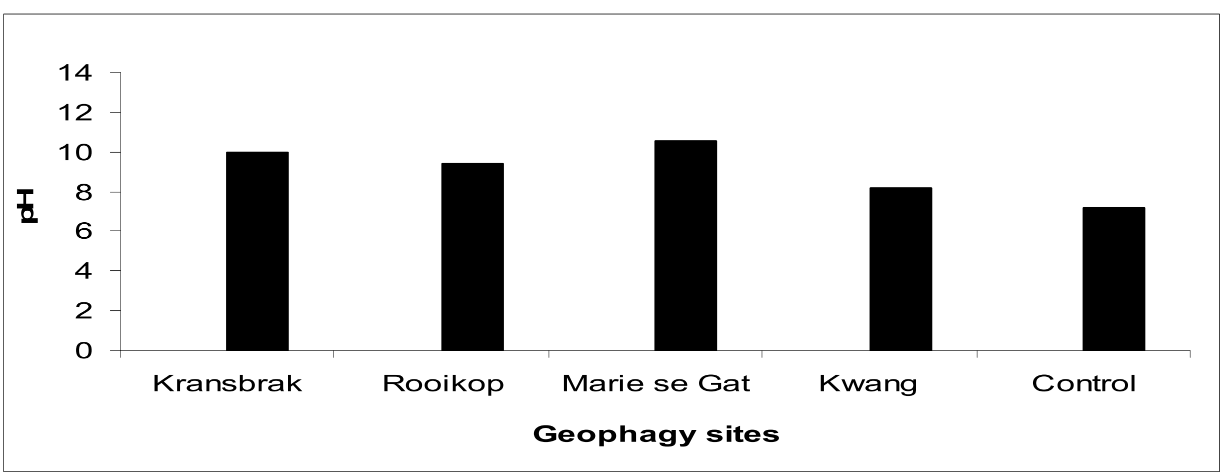

Figure 4: The pH values of soil collected at four geophagy sites, and the control site, along the Nossob riverbed in the Kgalagadi Transfrontier Park.

Wheeler (1980) found that sodium bicarbonate, potassium bicarbonate and calcium bicarbonate can all act as buffers in ruminants. Qualitative soil analysis showed that carbonate ions were present in soil of all geophagy sites and thus it becomes likely that gemsbok might consume soil for its buffering effect. Another factor that might influence acidosis is the clay content of the soil. Although the clay content of the geophagy soil in this study is unknown, Van Rooyen (1984) found that clay and silt fractions are the dominant mineralogical components of soil in the riverbeds of the Kgalagadi Transfrontier Park. Various authors, including Klaus *et al.* (1998); Krishnamani & Mahaney (2000) and Chandrajith *et al*. (2009), have suggested that the clay content of soil might be a motivation for geophagy, since it helps adjust the gastric pH and thus act as an efficient antacid. In addition, clay can also detoxify unpalatable compounds in the animals' diet.

3.3 Management implications of geophagy by gemsbok

The availability of geophagy sites seem to play an important role in attracting gemsbok to these locations and, thus, affecting their movement and habitat-use patterns. Stapelberg *et al.* (2008) commented that the frequent use of natural licks can have a degrading effect on the vegetation around waterholes, but not serious enough for conservation efforts. Although it is clear that vegetation in the vicinity of geophagy sites are overgrazed, management practices in this regard are not recommended. The Kgalagadi Transfrontier Park stretches over nearly 3.8 million hectares and there is plenty of opportunity for migration, should the gemsbok require better forage. In addition, gemsboks in the park appear to be in a very good condition.

Gemsbok (or other antelope) utilising natural mineral licks at waterholes in the Kgalagadi Transfrontier Park might potentially create a cause for management consideration due to the fact that they constantly break the calcrete rocks used for building the waterholes. It is therefore suggested that waterholes are built with an alternative material that do not provide antelope with nutritional value. This, in turn, will reduce the current efforts applied towards waterhole maintenance.

Gemsbok translocated to areas where they did not previously occur, or gemsbok unable to migrate due to confinement into smaller spaces, such as camps, should be provided with mineral or salt blocks in periods of nutritional stress. Behavioural and physiological signs of dietary mineral deficiencies can be used to establish possible nutritional stress. Subsequently, the same procedure can be followed as in this study, whereby soil samples and control samples are collected, compared and the possible desired mineral or soil features determined.

4. Conclusion

From this study it is concluded that gemsbok in the Kgalagadi Transfrontier Park consume soil for two reasons, namely mineral supplementation and the counteraction of acidosis. The high concentrations of Na and to a lesser extent K in the geophagy soil, when compared with the control sample, suggest that these two minerals might be the desired ones. However, the occurrence of osteophagy clearly indicates that gemsbok might have a Ca deficiency. The alkaline nature of the geophagy soil and the presence of carbonate ions suggest that gemsbok might consume soil to buffer acids, especially when the utilisation of sour grass such as *Schmidtia kalihariensis* is taken into consideration. Lastly, it is also possible that the clay content of the soil might be a motivation for geophagy, since clay can help adjust the gastric pH and act as an antacid and also detoxify unpalatable compounds in the gemsbok's diet. In any study involving geophagy behaviour, a complete geochemical and mineralogical soil analysis should be done, preferably in combination with nutritional and physiological studies to establish possible nutritional deficiencies or biological instabilities in the studied animal. In order to make a more accurate prediction of the mineral requirements of gemsbok, soil analysis should be done in relation with the available minerals in the vegetation they consume and also the minerals lost via faeces. Furthermore, the consumed soil should be quantified to determine the exact concentration of minerals ingested. In addition, it is also important to do a behavioural study, as the behaviour of the animal is very often one of the first indicators of possible nutritional deficiencies.

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References

Abrahams, PW. (1999). The chemistry and mineralogy of three savanna lick soils. Journal of Chemical Ecology 25: 2215-2228.

Atwood TC and Weeks Jr. HP. (2003). Sex-specific patterns of mineral lick preference in white-tailed deer. Northeastern Naturalist 10: 409-414.

Brightsmith, DJ. and Muńoz-Najar, R.A. (2004). Avian geophagy and soil characteristics in Southeastern Peru. Biotropica 36: 534-543.

Eloff, FC. (1962). Observations on the migration and habits of the antelopes of the Kalahari Gemsbok National Park. Part IV. Koedoe 5: 128-136.

Chandrajith, R., Kudavidanage, E., Tobschall, H.J. & Dissanayake, C.B. (2009). Geochemical and mineralogical characteristics of elephant geophagic soils in Undawalawe National Park, Sri Lanka. Environmental Geochemical Health 31: 391-400.

Holdø, R.M., Dudley, J.P. & Mcdowell, L.R. (2002). Geophagy in the African elephant in relation to availability of dietary sodium. Journal of Mammology 83: 652-664.

Klaus, G., Klaus-Hügi, C. & Schmid, B. (1998). Geophagy by large mammals at natural licks in the rain forest of the Dzanga National Park, Central African Republic. Journal of Tropical Ecology 14: 829-839.

Knight, M.H. (1991). Ecology of the gemsbok Oryx gazella gazella (Linnaeus) and blue wildebeest Connochaetes taurinus (Burchell) in the southern Kalahari. Ph.D. thesis. University of Pretoria, Pretoria, South Africa.

Kreulen, D.A. & Jager, T. (1984). The significance of soil ingestion in the utilization of arid rangelands by large herbivores with special reference to natural licks on the Kalahari pans. In: Gilchrist, F.M.C. & Machie, R.I. (Eds.); Herbivore Nutrition in the Subtropics and Tropics. The Science Press, Johannesburg, pp 204-221.

Krishnamani, R. & Mahaney, W.C. (2000). Geophagy among primates: adaptive significance and ecological consequences. Animal Behaviour 59: 899-915.

Langman, V.A. (1978). Giraffe pica behaviour and pathology as indicators of nutritional stress. Journal of Wildlife Management 42: 141-147.

Leistner, O.A. (1959). Notes on the vegetation of the Kalahari Gemsbok National Park with special reference to its influence on the distribution of antelopes. Koedoe 2: 128-151.

Low, A.B. & Rebelo, A.G. (1996). Vegetation of South Africa,Lesotho and Swaziland. Dept. of Environmental Affairs and Tourism, Pretoria.

Mahaney, W.C. (1999). Paleoclimate and paleonutrition—paleozoopharmacognosy, a timely connection. Festschrift for Wolfgang Andres. In Frankfurter Geowissenschaftliche Arbeiten. Series 25, 123-134.

Mahaney, W.C., Hancock, R.G.V., and Watts, D.P. (1990). Geophagia by mountain gorillas (Gorilla gorilla beringei) in the Virunga Mountains, Rwanda. Primates, 31: 113-120.

Mahaney, W.C. and Khrishnamani, R., 2003. Understanding geophagy in animals: standard procedures for sampling soils. Journal of Chemical Ecology, 29: 1477-1499.

Mcdowell, L.R. 1985a. Common salt (Sodium and Chlorine), Magnesium, and Potassium. In: McDowell, L.R. (ed.); Nutrition of grazing ruminants in warm climates, pp. 213-235. Academic Press, Inc., Orlando.

Mcdowell, L.R. 1985b. Detection of mineral status in grazing ruminants. In: McDowell, L.R. (ed.); Nutrition of grazing ruminants in warm climates, pp. 339-357. Academic Press, Inc., Orlando.

Mills, G. & Haagner, C. (1989). Guide to the Kalahari Gemsbok National Park. Southern Book Publishers, Cape Town.

Parris, R. (1984). Pans, rivers and artificial waterholes in the protected areas of the south-western Kalahari. Koedoe (Suppl.) 27: 63-82.

Penzhorn, B.L. (1982). Soil-eating by Cape mountain zebras Equus zebra zebra in the Mountain Zebra National Park. Koedoe 25: 83-88.

Smith, T. (2008). Salt: An essential element. Angus Journal 02.

Stapelberg,H., Van Rooyen, M.W., Du P. Bothma, J., Van Der Linde, M.J. & Groeneveld, H.T. (2008). Springbok behaviour as affected by environmental conditions in the Kalahari. Koedoe 50: 145-153.

Thornton, I. (2002). Geochemistry and the mineral nutrition of agricultural livestock and wildlife. Applied Geochemistry 17: 1017-1028.

Tracy, B.F. & Mcnaughton, S.J. (1995). Elemental analysis of mineral lick soils from the Serengeti National Park, the Konza Prairie and Yellowstone National Park. Ecography 18: 91-94.

Van Der Walt, P.T., Retief, P.F., Le Riche, E.A.N., Mills, G.L. & De Graaf, G. (1984). Features of habitat selection by larger herbivorous mammals and the ostrich in the southern Kalahari. Koedoe (Suppl.) 27: 119-128.

Van Hoven, W., Boomker, E.A. & De Beer, G.C.O. (1984). Preliminary results of in vitro digestion of some plants utilized by Kalahari ungulates. Koedoe (Suppl.) 27: 143-151.
Van Oudtshoorn, F. (2006). Guide to the grasses of southern Africa. Briza publications, Pretoria.
Van Rooyen, T.H. (1984). The soils of the Kalahari Gemsbok National Park. Koedoe (Suppl.) 27: 45-61.
Voight, C.C., Caps, K.A., Dechmann, K.N., Michener, R.H. & Kunz, T.H. (2008). Nutrition or Detoxification: Why bats visit mineral licks of the Amozonian Rainforest. PLos One 3: 1-4.
Wheeler, W.E. (1980). Gastrointestinal tract pH environment and the influence of buffering materials on the performance of ruminants. Journal of Animal Science 51: 224-235.
Map of the Kgalagadi Transfrontier Park Ed (2008). http://www.sanparks.org/parks/kgalagadi/tourism/map.php (Accessed 19 October 2009).