Chisumbanje Vertisols Potential as a Feed Additive in Beef Feedlot Rations: A Systematic Review

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Abstract

Besides their excellent cation exchange capability, clays have unique physical and chemical properties that make them ideal as animal feed additives. The global use of various clays and commercial derivatives as feed additives has sparked interest in using Vertisols in cattle feedlot rations. The review's ultimate goal was to assess the potential efficacy of bentonite/smectite clays as feed additives in beef feedlot rations. This review included a mini-survey on Zimbabwean feed companies use of clay based feed additives. Thematic analysis was used to pick relevant research from a broad pool of literature. Notably, none of the research examined the Chisumbanje Vertisol, but rather its near relative, bentonite. The basis for the review was that bentonite studies could potentially forecast Chisumbanje Vertisol's potential as a feed additive. Zimbabwean livestock feed manufacturers are not using clay based feed additives. However, inclusion of clay in diets of cows result in a higher rumen pH, a scenario ideal for the rumen microflora. Smectite clay supplementation reduced rumen ammonium-N concentrations before and three hours after feeding. Addition of 12 grams dolomite and bentonite per head/day to sheep feeds improved ($p<0.05$) total volatile fatty acids (TVFAs) in the rumen. Smectite clays can be used to improve rumen pH, reduce bloat, bind aflatoxins, and increase volatile fatty acid percentage. The researchers suggest characterising Chisumbanje Vertisols as binders and rumen buffers.

Keywords: bentonite, rumen pH, total volatile fatty acids, aflatoxins

Introduction

Animal nutritionists use clay and other soil-based additives in stock feed to improve feed efficiency because of animal's geophagic[1] behaviour (Sulzberger, 2016). Mahaney and Ramanathan, (2003), asserts that a geophagic soil is rich in clay and fine silt with little sand. Wilson, (2003) summarizes the reasons for animal geophagy as follows: detoxification of noxious or unpalatable compounds present in the diet, alleviation of gastro-intestinal upsets such as scouring, supplementation of mineral nutrients, and alleviation of excess acidity in the digestive tract. Clays, in general, have unique physical and chemical properties, such as plasticity, large specific surface area, and cation exchange capacity (Bergaya & Lagaly, 2006), making them an excellent animal feed ingredient. Smectite clays, both synthetic and naturally occurring, can be employed as binding agents during feed pelleting to improve the pellets' durability and hardness (Fuller et al., 2004). The use of 20% clay (on a dry matter basis) in beef rations has been shown to be a viable alternative to molasses or cane juice as a binding agent in the production of animal feed blocks (Preston, 1995). Clay inclusions in feedstuffs as mycotoxin-binding adsorbents have been reported to reduce bloat in ruminants (Carruthers, 1985), buffer ruminal pH (McDonald, et al., 2010), reduce negative effects of mycotoxins such as aflatoxins in feedstuffs (Vázquez, et al., 2013), improve protein and other nutrient digestibility, and improve feed palatability (Ibrahim, 2012; Subramaniam & Kim, 2015).

Vertisols are black clay soils with high shrink–swell qualities due to their high clay content (up to 30%), which is usually dominated by smectite mineralogy (Kumari & Mohan, 2021). According to Hussein (1994), Vertisols span roughly 1.8 million hectares in Zimbabwe, accounting for 4.6 percent of the country's total land area. This highlights the clay's relative abundance and, as a result, its affordability and accessibility as a feed supplement, which has the net effect of lowering feed costs. Using the 'World Reference Base for Soil Resources' classification system, Mukungurutse et al. (2018) classed some soils in the Bubi area of Lupane District as Calcic Vertisol based on their high clay content and shrink-swell properties. The Chisumbanje black soils have similar properties, according to Hussein & Adey (1995), a high clay content, a substantial cation-exchange capacity (CEC) of 736 mmol kg^{-1}, and a high liquid limit. Smectite (montmorillonite) makes up around 70% of the

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[1] Geophagy refers to animal behaviour of craving for clay rich non-feed substances (Stamp, 2008)

Chisumbanje Vertisol, with some random smectite/illite interstratification ranking the Chisumbanje black clays among the most chemically active soils (Moreno-Maroto & Alonso-Azcárate, 2018; Hussein & Adey, 1995). The soil's physico-chemical qualities suggest that it could be used in a variety of animal feed applications such as beef pen fattening. A typical finishing diet can include 83–87 percent cereal concentrates like processed maize, wheat, barley, or sorghum (Sibanda & Hatendi, 1998). These rations, which are high in easily fermentable carbohydrates, produce acidic conditions and enhance lactic acid production, both of which are harmful to the rumen's cellulolytic bacteria (Wu, 2018). This decreases feed intake and puts the animal at risk of bloat and acidosis (McDonald et al., 2010), both of which are common problems in pen fattening systems. A substantial CEC of 736 mmol kg^{-1} can be very effective in buffering ruminal pH against acidic conditions, common with feedlot rations that can alter rumen microbiota and cause digestive upsets (Sulzberger, et al., 2016). Furthermore, pen fattening predisposes animals to aflatoxin poisoning as feeds of high oil content will be used to cater for the high energy requirements associated with feedlotting (Kannewischer, 2006). A greater CEC, observed in Chisumbanje black clays, can help protect against the absorption of mycotoxins, enterotoxins, and heavy metals from the duodenum (Wu, 2018), as well as changes in rumen microbial communities to acid favouring population and a reduction in gastro-intestinal infections (Subramaniam & Kim, 2015). Furthermore, because of Chisumbanje Vertisol's strong swelling capacity, finely crushed clay material has a high ability to bind a variety of feed components and other important medicinal feed supplements, such as antibiotics, vitamins, and minerals, forming pellets that are easy to package and handle (Murray, 2007). As a result, the characteristics of Chisumbanje vertisols temper interest in further research into their possible applications in beef ration formulation and manufacturing.

Antibiotic usage as a feed additive, for example, increases the risk of antimicrobial resistance in diverse bacterial populations, and as a result, antibiotic use for this purpose has been restricted or outlawed in other parts of the world including England, Netherlands and Taiwan (Maron et al., 2013; McDonald et al., 2010). However, due to the complicated nature of the rumen fermentation system and other factors such as lignin encrustation of cellulose, the use of fibrolytic exogenous enzymes in beef feeding has resulted in inconsistent results (Balci et al., 2007; McDonald et al., 2010; Mendoza et al., 2014). Given the shortcomings of the above additives, using Chisumbanje Vertisol as an ingredient in the cattle feedlot feeds would be justified. This review will aid to put into perspective the discovery of Chisumbanje Vertisols' potential as a cost-effective, easily available, and ecologically friendly supplement in cattle feedlot feeds.

Materials and Methods

To establish the current uptake of clay as a ruminant feed additive in Zimbabwe, a phone survey was undertaken at the outset of this review. A random sample of six feed manufacturing companies was chosen for the telephone interviews on whether they were using any clay additives or not in their processing, with each company's chief nutritionist being interviewed.

A systematic review approach was adopted. From a large pool of literature, relevant papers were picked for factual correctness. Researchers used databases and indexes such as AGRICOLA (EBSCO), Scopus (Elsevier), CAB Abstracts, CAB eBooks, and PubMed to find material for further collation. Following that, a descriptive qualitative synthesis of data was undertaken utilizing the thematic analysis approach. The data was then categorized and blended according to themes: beneficial physico-chemical properties, potential influences of smectites in ruminant production and Chisumbanje physico-chemical properties.

Conceptual framework

Inclusion of clay based feed additives has many beneficial effects (Figure 1).

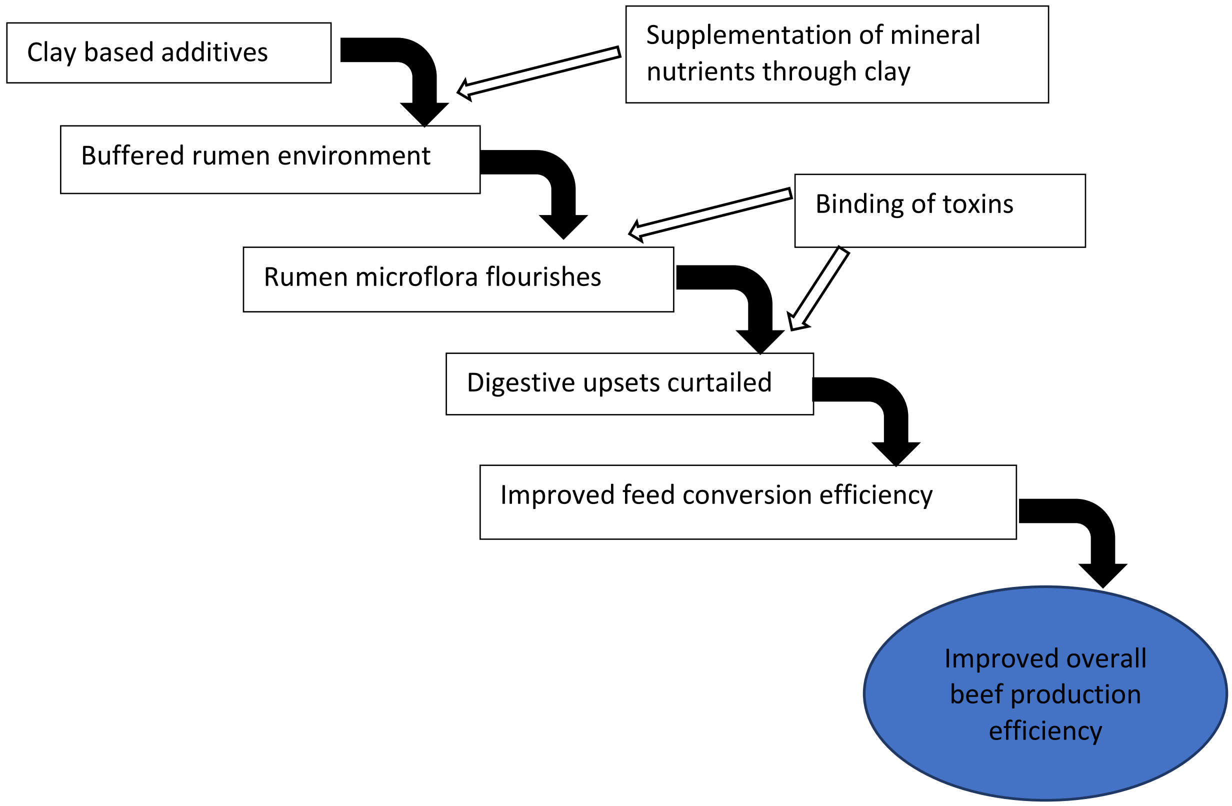

Figure 1. Clay supplementation conceptual framework

Review of Related Literature

Notably, none of the research in the analysis data set have directly addressed the Chisumbanje Vertisols, instead focusing on bentonite, a closely related rock mineral. The underlying hypothesis was that data from bentonite research may forecast Chisumbanje Vertisols' probable application as a feed supplement in beef feedlot rations. This hypothesis was based on the fact that the previously studied smectites (Bangira, 2010, p. 37) and the Chisumbanje Vertisols (Hussein and Adey, 1995) have similar mineralogical properties.

Current Uptake of Clay as a Feed Additive in Zimbabwe

None of the interviewed feed companies were using clay soil as a feed additive. However, other non-clay feed additives were being used, despite admitting to the potential benefits of clay based additives (Table 1).

Table 1 Buffer additives being used in Zimbabwean ruminant feed industry

Variable	Number of Interviewee who responded Yes		
	Clay	Other	None
Buffer additive being used	0	5	1
Inclusion rate being used (%)	-	2	-
Buffer additive deemed most advantageous	4	1	1

Source: Pre-review interviews with feed companies.

Stock feed firms in Zimbabwe employed buffer feed additives other than clay, such as sodium bicarbonate, sodium carbonate, calcium carbonate, and magnesium oxide. Because the ruminants are fed high-energy diets during the pen fattening phase, these are primarily meant to prevent incidences of acidosis or bloat. In Zimbabwe, it appears that the use of clay-based additives in the manufacturing of ruminant feed is yet to be implemented.

Beneficial Physico-chemical Properties of Smectites

These clay minerals are known for their strong plasticity and cohesiveness, as well as their significant drying shrinkage (Nzeukou Nzeugang et al., 2021; Kumari & Mohan, 2021, p. 10). Very weak oxygen-to-oxygen and cation-to-oxygen links hold smectite layers together. The interlayer gap attracts exchangeable cations and their accompanying water molecules, causing the crystal lattice to expand (Kumari & Mohan, 2021). The weak interlayer bonding and free passage of water and cations into and out of this region account for the high shrinkage and swelling capacity (White, 2006). The smectite swelling capacity can be quite useful when used as a bulking agent to increase the bulk density of stock feed (Fuller et al., 2004).

The movement of water and cations into the interlayer spaces of the smectite crystals exposes a very large internal surface that by far exceeds the external surface area of these minerals (Kumari & Mohan, 2021). The specific (total) surface area of montmorillonite is enormous, ranging from 700-800 m^2/g compared to just 15 m^2/g of kaolinite (Kumari & Mohan, 2021).
In addition, isomorphous substitution of Mg^{2+} for some Al^{3+} in the di-octahedral sheet and Al^{3+} for Si^{4+} in the tetrahedral sheet results in smectite crystals with a significant net negative charge. A 'swarm' of cations (including H^+, N^+, Ca^{2+}, and Mg^{2+}) attracted to both the interior and external surfaces satisfy this charge. Smectites are known for having a high cation

exchange capacity (CEC). The CEC of montmorillonite varies between 80 and 120 cmol/kg of clay (Kumari & Mohan, 2021). This high CEC would be extremely beneficial in buffering ruminal pH and reducing the risk of acidosis in ruminant animals. The clay colloid and ruminal fluid can interchange a high number of cations on both the internal and external surfaces of the clay lattice, enhancing the concentration of basic cations in the ruminal fluid while removing excess H^+ from the system. Furthermore, smectitic clays have a high proclivity for intercalating foreign substances, making them ideal toxin adsorbents in animals' gastro-intestinal tracts.

Potential Influences of Smectites in Ruminant Production

The Smectite clays have various uses in the animal feed industry and plays some important roles as feed additives.

Aflatoxin Sequestration from GIT

Aflatoxins are a group of naturally occurring mycotoxins that are produced by *Aspergillus flavus* and *Aspergillus parasiticus*, species of fungi that typically affect corn and peanuts, which are ingredients, used in both food and feed products (Benkerroum, 2020). Aflatoxin M_1 (AFM_1) is the form released into milk or excreted in urine after dietary aflatoxins (AF) are absorbed from the gut and processed in the liver (Kuilman et al., 2000; Rodrigues et al. 2019). Sulzberger (2016) also discovered that faecal and rumen fluid samples from cows receiving clay had lower AFB_1 concentrations than cows not receiving clay ($p = 0.01$ and $p = 0.004$, respectively). Various adsorbent substances have been investigated as potential feed supplements to limit AF absorption in the gastrointestinal system (Rodrigues et al., 2019). To minimize the effects of mycotoxins such as aflatoxins in feedstuffs, clay, activated charcoal, and aluminosilicates can be employed as mycotoxin-binding adsorbents (Vázquez, et al., 2013). Because of their ion exchange properties, montmorillonites, the main component of bentonite, have been widely exploited as mycotoxin-sequestering agents (Shi et al., 2007; Thieu et al., 2008). Clay minerals can bind to other harmful compounds such as plant metabolites, heavy metals, and endotoxins, lowering their biological availability, absorption, and toxicity, in addition to adsorbing and removing mycotoxins from the gastro-intestinal tract of animals (Wu, 2018).

Ruminal pH buffer and incidences of Bloat

Buffers when used correctly result in higher feed intake, better milk yield, and a more favorable milk composition (Hutjens, 2008). Ruminal pH buffers help to prevent milk fat depression by altering volatile fatty acid (VFA) patterns, resulting in higher milk fat content (Hutjens, 2008). In ruminant diets, sodium bicarbonate is employed as a buffer to keep rumen pH at values that promote cellulolytic microbe activity. McDonald et al. (2010) observed that in the United States, it had become routine to add up to 200 g $NaHCO_3$/day to the rations of cows in early lactation, as well as MgO. It has been proposed that employing clays and bentonites that contain insoluble and thus non-degradable anions, which would allow the buffering action to be transported further down the digestive system, may be advantageous because bicarbonate buffers are depleted once CO_2 is released (McDonald et al., 2010). In addition to the pH buffering effect, smectite clays also swell in the rumen (5 to 20 times their original size), absorb and exchange minerals and ammonia, and maybe add weight to the diet (Hutjens, 2008). Sulzberger et al. (2016) found that oral supplementation of clay as a rumen buffer significantly altered blood pH ($p \leq 0.001$), rumen pH ($p \leq 0.001$), faecal pH, base excess, and blood HCO_3^- after a grain challenge in Holstein cows.

Carruthers (1985) investigated the effects of bentonite on dairy cows grazing and stall-feeding ryegrass-white clover pasture and lucerne under grazing and stall-feeding settings. Carruthers (1985) found that as the amount of bentonite in the feed rose, the bloat score decreased. Bloat was observed in 95, 78, and 51 cases, respectively, for the 0, 3, and 6 percent bentonite treatments. In some places, bentonite, a fine powdered clay, is sprinkled over wet pastures to prevent bloating by causing cattle to eat more slowly and emit more saliva which is critical for overall animal health and bloat control (Wu, 2018). The average daily bloat score for cows given the untreated diet (pastures without bentonite dust) was higher than for those fed the treated diet (pasture dusted with 300g of bentonite per cow) for the 17 days when bloat occurred, according to the study. As a result, it can be inferred that including bentonite in the pasture-based feed reduced the incidence of bloat in dairy cows to some extent. The high CEC of bentonite, and thus its high pH buffering capability in the rumen and down the gastro-intestinal tract, is responsible for this impact (McDonald et al., 2010).

Sulzberger et al. (2016) reported that rumen pH was different ($p=0.003$) for cows not exposed to grain challenge and clay (negative control) compared to those exposed to grain challenge but not clay in a study to determine the effects of dietary clay supplementation after a grain challenge on dairy cows (positive control). When compared to positive control, cows given negative control showed a smaller area under the curve below rumen pH of 5.6. These findings were expected because they confirmed that over-engorgement of grain by ruminant animals promotes the rapid fermentation of non-structural carbohydrates (primarily starch) by amylolytic bacteria, which produces volatile fatty acids (VFAs) that dissociate to cause a drop in ruminal pH (Hernández et al., 2014; McDonald, et al., 2010). Due to the possible excellent buffering effect of clay in the rumen, cows fed clay were able to swiftly correct their rumen pH after a grain challenge.

Ibrahim (2012) found that when tafla or bentofarm were added to the diet, the mean values of ruminal pH, 3 hours after feeding, decreased considerably ($p<0.05$), from pH 6.91 to 6.62, compared to the control condition. The increased magnesium and aluminium silicate content of the clay in the study may have contributed to its buffering ability. The findings support Hu & Murphy's (2005) meta-analysis, which found that when buffered diets were utilized instead of unbuffered rations, rumen pH increased. Clays have been found to be alkalinizers with a high capacity for H^+ exchange at various pH levels (Yong et al., 1990). In the pH range of 4.5 to 6, which is close to the pH range of the rumen, the authors found that illite clay (a form of clay with high amounts of magnesium and aluminum silicate) had the best buffer capacity. On the other hand, Jiang et al. (2014) found no significant variations in ruminal pH between four smectite clay doses (0, 0.1, 1, 10 g/L), implying that clay concentration has no influence on rumen pH buffering. This could be because Jiang et al. (2014) employed a commercial product called ConditionAde^{TM}200HPC (Oil-Dri Co. Ltd., Chicago, IL, USA), which had 450–650 g/kg of smectite. If the product had the lower limit of the active ingredient, Jiang and colleagues' dosage levels may have been too low to make a substantial change.

Rumen Ammonia-N lowering effect of smectites

Supplementing tafla or bentofarm reduced rumen ammonium-N (NH_3-N) concentrations three hours after feeding significantly ($p<0.05$) as compared to a control treatment (Saleh et al., 1999; Forouzani et al., 2004; Ibrahim, 2012). Because of some putative clay-protein complexing in the rumen, clay inclusions reduced protein breakdown, resulting in a lower NH_3-N concentration in the rumen. Patterson et al. (1985) observed that increasing zeolite (a clay mineral) levels in the rumen of steers decreased ammonia concentration in the rumen linearly with increasing zeolite levels at 0, 100, 200, and 300g per day. Similarly, Bartos et al.

(1982) discovered lower NH_3-N concentrations in bentonite groups, suggesting that this could be attributable to bentonite's propensity to adsorb ammonia from rumen fluid when concentrations are high and release it when concentrations are low. This is due to the smectite clay minerals' great capacity for adsorption of charged particles. High-performing animals may benefit from this since it increases rumen by-pass protein. However, more scientific research is needed to determine the mechanism of clay interaction in modifying rumen ammonia concentration.

Given the wide range of clay inclusion rates, (0 to 300 g per day), utilized in studies to investigate the effects of clay on rumen ammonia concentration, more research is needed to discover the proper clay inclusion dosages for optimal rumen NH_3-N concentration.

Ruminal Volatile Fatty Acids

Salem et al., (2000), posits that addition of 12 g dolomite and bentonite per head/day to the feeds of developing sheep improve total volatile fatty acids (TVFAs) in the rumen ($p<0.05$). On the contrary, Ibrahim (2012) found that the results of TVFAs at 3 hours after feeding showed no significant differences across treatments and were essentially identical, implying that neither tafla nor bentofarm has a substantial influence on TVFAs in the rumen. The results of microbial protein (MP) synthesis at zero (0) hours before feeding and three (3) hours after feeding revealed significant ($p<0.05$) differences (from 0.99 to 1.41 g/100 ml) between treatments. Jiang et al. (2014) discovered that adding smectite clay (SC) to the dairy ration decreased the TVFA content numerically, however adding bamboo charcoal (BC) raised the total VFA concentration ($p = 0.012$). VFA generation can account for nearly two-thirds of the energy intake in a host ruminant animal, according to Jiang et al., (2014), and hence VFAs produced by rumen fermentation can be regarded as an essential indicator of fermentation efficiency. TVFAs and rumen fermentation efficiency have a positive linear relationship (Wu, 2018). As a result, the findings of Salem et al., (2000) imply that adding bentonite improved the fermentation efficiency of developing sheep, whereas Jiang et al., (2014) clearly contradicts these findings. One possible explanation for the significant disparity is that the two investigations were conducted on different species, and it is reasonable to assume that inter-species variability is at work. As a result, in-vivo research on the impact of distinct clay mineral inclusions on TVFAs in ruminant feeds are needed for each species.

When zeolite was added to the ration for three weeks at 0, 10, and 20 g/kg dry matter in the rumino-intestinal tract of cows, Grabherr et al., (2009) discovered that the molar proportion of acetate in the rumen increased, while propionate and valerate significantly decreased, and the concentration of total fatty acids was unaffected. This resulted in a greater acetate to propionate ratio. In a meta-analysis, Hu and Murphy (2005) found that buffers employed in diets decreased molar quantities of propionate, which raised the acetate to propionate ratio. Low ruminal pH suppresses the growth of ruminal cellulolytic bacteria and acetate-producing bacteria while promoting the growth of propionate-producing bacteria, lowering roughage digestibility and acetate concentration while increasing propionate production (Wu, 2018). High pH, on the other hand, encourages the growth of ruminal cellulolytic bacteria and acetate-producing bacteria while limiting the growth of propionate-producing bacteria, resulting in increased roughage digestibility and acetate concentration while lowering propionate synthesis. Clay maintains a relatively high pH in the rumen, which is favorable for the development of acetate-producing bacteria. Because clay buffers create a shift in microbial population in the rumen in favor of acetate production, it's possible that using Chisumbanje Vertisol in beef feedlot feeds would cause rumen fermentation to shift in favor of acetate as well, resulting in increased rumen fermentation efficiency.

Feed Pelletisation and Bulking

Smectite clays, both manufactured and naturally occurring, can be employed as binding agents during feed pelleting to improve the pellets' durability and hardness (Fuller et al., 2004). Clays, according to Subramaniam and Kim (2015), slow down the movement of feed through the digestive tract, enabling additional time for digestion. Clay feed additives also produce morphological changes in the intestinal mucosa, such as an increase in villus height. Furthermore, a study conducted to evaluate the effects of tafla and bentofarm (natural clays found in Egypt) on lamb performance found that using tafla and bentofarm as a replacement for 3% of dry matter intake, which was based on concentrate and green forage together, for growing lambs resulted in better production performance and economic efficiency with no negative effects on animals (Ibrahim, 2012). Sulzberger et al. (2016), on the other hand, found no change in dry matter intake (DMI) between cows fed clay (0.5, 1, or 2%) and cows fed a positive control with no clay.

Effect of Smectite on Ruminant Feed Digestibility

Soliman et al., (2003), working with Friesian cows, observed that feeding an ammoniated concentrate feed combination supplemented with bentonite improved the digestibility of all nutrients and ration feeding values ($p<0.01$). On the contrary, Ibrahim (2012), reported that clay inclusions in sheep rations resulted in a decrease in the digestibility coefficient of CP and, as a result, a decrease in the overall DM digestibility coefficient. This was likely due to clay's ability to form clay-protein complexes that were difficult to degrade in the rumen.

Physico-chemical Properties of Chisumbanje Vertisol

The Chisumbanje Vertisol's physico-chemical characteristics imply that it could be used in a variety of animal feed applications. According to Hussein and Adey (1995), the Chisumbanje Vertisol contains around 70% smectite (montmorillonite) and some random smectite/illite interstratification. Because of their high clay concentration, the soil has a high cation-exchange capacity (CEC) of 736 mmol kg-1 (Hussein & Adey, 1998). Table 2 shows the textural, chemical, and physical features of the top 150 mm of Chisumbanje soil.

Table 2. Textural, chemical and physical properties of the Chisumbanje soil (0–150 mm)

Property	**Units**	**Quantity**
Coarse sand (2000–500 µm)	g kg^{-1}	30
Medium sand (500–200 µm)	g kg^{-1}	10
Fine sand (200–20 µm)	g kg^{-1}	160
Silt (20–2 µm)	g kg^{-1}	110
Clay (<2 µm)	g kg^{-1}	690
Exchangeable Ca	$mmol_c$ kg^{-1}	500
Exchangeable Mg	$mmol_c$ kg^{-1}	340
Exchangeable Na	$mmol_c$ kg^{-1}	2
Exchangeable K	$mmol_c$ kg^{-1}	21
Cation exchange capacity (CEC)	$mmol_c$ kg^{-1}	736
Exchangeable Sodium Percentage (ESP)		0.27
pH (1:5 $CaCl_2$)		7.5

Carbonate	g kg^{-1}	4.6
Organic carbon	g kg^{-1}	9
Liquid limit	g kg^{-1}	1010
Plastic limit	g kg^{-1}	450
Coefficient of Linear Expansion (COLE)	%	26.5

Adapted from Hussein & Adey (1998).

The high CEC contributes to the soil's ability to adsorb or bind to toxic materials in the gastro-intestinal tract of animals, such as aflatoxins, plant metabolites, heavy metals, and endotoxins, reducing their biological availability, absorption, and possible toxicity (Wu, 2018). Furthermore, the significant CEC and concomitant high percentage base saturation ranging from 95-112 percent in the depth range of 0-33cm can be extremely beneficial in buffering ruminal pH (Sulzberger et al., 2016).

The high CEC of the soil, combined with the smectitic nature of the clay, results in large plasticity and liquid limits, as well as a large coefficient of linear expansion (Hussein & Adey, 1998). The soil's high swelling capacity is an important factor in the clay's possible usage as a bulking agent or feed diluent in feeds to boost indigestible components while also enhancing the feed's bulk density (Fuller et al., 2004). Furthermore, because of the high plasticity of Chisumbanje Vertisols, finely pulverized clay material has a high capacity to bind a variety of feed ingredients and other necessary medicinal feed supplements, such as antibiotics, vitamins, and minerals, into pellets that are easy to package and handle (Murray, 2007).

Clay and clay minerals in general, and smectites in particular, have found widespread acceptance in the cattle production business around the world (Stroud, 2006). On the other hand, in Zimbabwe and the rest of Africa's Sub-Saharan region, there has been little or no adoption of clay in animal feed formulation. As a result, there has been little or no scientific research in the region to investigate the efficacy of locally occurring clays as ruminant ration supplements. In response to the previous arguments, scientific investigations are needed to evaluate the efficacy and, as a result, the suitability of Zimbabwe's Chisumbanje Vertisol as a feed additive.

Conclusion

The capacity of smectite clays to buffer ruminal pH variations has been confirmed. Under predisposing situations, bentonite and other natural smectitic clays have proven to be efficient in reducing the rates of bloat. Clay inclusions in diets may inhibit protein breakdown in the rumen due to hypothesized clay-protein complexing, resulting in a reduced NH_3-N concentration. There is agreement in literature that smectite clay inclusions boost rumen TVFAs. Clay supplements maintain a relatively high pH in the rumen resulting in a decreased acetate to propionate ratio and also low CH_4 losses. Clays can efficiently bind to dietary anti-nutritional factors (AF) and then sequester mycotoxins from the gastrointestinal tract (GIT). As a result, the biological availability of AF is diminished, resulting in higher levels of AF metabolite traces in the milk, urine, and faecal matter of clay-fed-aflatoxin-challenged animals. Clay was not used as a feed ingredient by any of the feed firms that took part in the phone interview; instead, buffer additives including sodium bicarbonate, sodium carbonate, calcium carbonate, and magnesium oxide were used.

Recommendations

Based on the findings and conclusion of this study, future research should focus on further characterisation of clay based binders, specifically the Chisumbanje Vertisols and its Zimbabwean variations, with particular attention to the determination of adsorbent specificity of various smectite species to certain mycotoxins. There is also need for a combined *in-vitro* and *in-vivo* study to ascertain the actual effects of Chisumbanje Vertisols on rumen environment, incidences of bloat, voluntary feed intake and feed digestibility when used as an additive in beef feedlot rations.

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