ABSTRACT

SULLIVAN, KATHLEEN. The Impact of Nutrition on the Development of Urolithiasis in Captive Giraffes and Meat Goats. (Under the direction of Eric van Heugten and Matthew Poore).

Obstructive urolithiasis is a documented problem in domestic ruminants, such as the meat goat, and also in captive giraffe. A survey of the health history, feeding practices, and dietary contents in captive giraffes in North America was conducted to examine the possible connection between diet and the development of urolithiasis. Samples of urine, serum and feed were collected and analyzed for basic panels and mineral content. There appeared to be a positive correlation between diet and physiologic phosphorus levels in giraffe. This may not have been related to the ingredients of the diet but rather to the ratio of concentrate to hay eaten and the nutrient composition of the concentrate. We hypothesized that high phosphorus content in the diet and a high level of concentrate feeding would increase indicators of urolith formations including crystal formation and high urine mineral content. We followed up with a metabolic trial in meat goats, testing 2 different complete pelleted feeds and 2 complete pelleted feed to hay ratios in a 2 by 2 factorial randomized complete block design. The intent of this study was to look at the impact of type of diet (ADF-16 or Wild Herbivore complete pelleted feed) and complete pelleted feed to hay ratios (20 or 80 % hay) on the development of urolithiasis in meat goats, in the context of captive giraffe feeding practices. The four treatments had a range of fiber content and differed in mineral content, particularly Ca to P ratio and levels of P. We also measured the number of crystals in the fresh urine, as these may be considered precursors to urolith formation. The ADF-16 diet where hay was 20% of the diet had the lowest levels of fiber, lowest Ca

to P ratio, and highest level of phosphorus compared to the other 3 diet treatments. From our results, it can be concluded that feeding the ADF-16 diet where hay is 20% of the diet, produced a trend of high urinary P, high serum P and a tendency for a high crystal count in the urine over the four week experimental period. These can be considered strong risk factors for the development of phosphatic uroliths. As one third of the zoos which responded to the survey fed a majority of their diets as ADF-16, this conclusion warrants further investigation.

THE IMPACT OF NUTRITION ON THE DEVELOPMENT OF UROLITHIASIS IN CAPTIVE GIRAFFES AND MEAT GOATS

by
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DEDICATION

For my parents

BIOGRAPHY

Kathleen Elizabeth Sullivan was born on November 10, 1982 in Yonkers, N.Y. She grew up in suburban Tappan, N.Y. with her parents Lawrence and Joann Sullivan and her siblings Jennifer and Brian. She received her high school diploma from Tappan Zee High School in Blauvelt, N.Y. in May of 2000. She then completed a Bachelor of Science degree in Animal Science at Cornell University concentrating in nutrition during the years 2000 – 2004. She also spent a semester of her undergraduate degree at the University of Melbourne, in Victoria, Australia. Following undergraduate studies, the author enrolled at North Carolina State University in 2004 to obtain a graduate degree in Nutrition with a co-major in Animal Science.

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Chapter 1
Literature Review
Urolithiasis in Giraffe and Goats

Introduction

Dietary mineral imbalance, dehydration, possible genetic predisposition and dietary form are all contributing factors in the causation of obstructive urolithiasis (Belknap and Pugh, 2002; Matthews, 1999; Osbourne and Finco, 1999). Many partial solutions have been found, but obstructive urolithiasis still occurs in captive ruminant populations in the world, killing or debilitating otherwise healthy animals.

Phosphatic urolithiasis in goats, giraffes, and other ruminant species is a problem often based in improper nutrition (Osbourne and Finco, 1999, Belknap and Pugh, 2002, Matthews, 1999). High concentrate diets with high phosphorus, high magnesium and low calcium, lead to metabolic shifts in mineral balance, pH and excretion. Low water intake can cause urine to become more concentrated in an effort to retain water, hence leading to urine supersaturated with mineral ions. Supersaturated alkaline urine is the ideal medium for the precipitation of uroliths (Belknap and Pugh, 2002; Bartges et al., 1999). The intention herein is to elucidate the background of the major species in question, the giraffe and the meat goat; to examine the history of research on urolithiasis, with a focus on phosphatic urolithiasis in ruminants; and to describe the issue of obstructive urolithiasis in giraffes and goats.

Giraffes

Giraffe (*Giraffa camelopardalis*) are one of the two extant members of the family Giraffidae. The other member is the okapi (*Okapia johnstoni*). Both are highly specialized concentrate selector (CS) browsing ruminants. Giraffe are the tallest living terrestrial animal. Male giraffes are on average 5.3 meters in height and weigh a

maximum of 1,930 kilograms (Nowak, 1999). Female giraffes are on average shorter (4.3 meters) and weigh less (minimum 550 kg) (Nowak, 1999). The average adult weight is 800 kg. They can eat up to 34 kg (75 pounds) of feed a day and can live up to 36 years in captivity (Nowak, 1999). Lifespan in the wild may reach up to 26 years. Giraffe are adapted for intake of twigs and stripping leaves, with their tall body shape, narrow muzzle, prehensile hairy lips and their long tongue (46 centimeters). Free- ranging giraffe are found on the dry savannah and open woodlands of Africa, south of the Sahara (Nowak, 1999). Their habitat is spread throughout numerous areas, due to the infringement of humans and to their preference for certain trees and bushes for browse (Dagg and Foster, 1982). In the wild, giraffes have been reported to prefer to forage on the young shoots of various species in the genus Acacia, which have digestible protein contents greater than 12 % (Pellew, 1984). Giraffe, unlike most domestic grazing species, choose their diet from a wide variety of forages that differ in nutrient content. The daily dry matter intake of wild giraffe has been estimated to be 1.6% of body weight in males and 2.1% of body weight in females (Pellew, 1984). Giraffe will drink water when available, but are able survive on the water from their browse or feed for a period of weeks (Nowak, 1999).

Under the classification system of Hofmann (1989), ruminants can be divided into overlapping morphophysiological types consisting of concentrate selectors (CS), grass and roughage eaters (GR) and intermediate, opportunistic mixed feeders (IM). Giraffes fit their classification as concentrate selectors as they actively avoid solely insoluble fibrous feed and select plants for nutrient rich plant cell contents (Hofmann and Matern, 1988). They have morphological adaptations such as proportionally larger salivary

glands compared to grazing species (GR). Parotid glands in CS species on average are 0.36% of body weight, 0.26% in intermediate feeders, and only 0.18 % in GR (Hofmann, 1989). More saliva may be used for buffering against tannins, but more importantly it may help carry soluble carbohydrates down the ventricular groove into the abomasum, escaping rumen microbes (Hofmann, 1989). Giraffe and other CS have a faster rate of passage than any GR, and larger surface areas of papillae for short chain fatty acid (SCFA) absorption. Due to the large size of the giraffe and the need to support metabolism, giraffes also have a very large ceco-colonic distal fermentation chamber in their hindgut which they likely rely on to produce additional short chain fatty acids and energy (Hofmann, 1989).

Marked differences in rumen morphology have been found between captive giraffe and free ranging giraffe (Hofmann and Matern, 1988). They estimated that wild giraffe have nine times the absorptive capacity for SCFA's compared to the captive giraffe examined, due to greater surface area and papillae size. SCFA can provide up to 90% of available energy for ruminants and are absorbed through the rumen mucosa (papillae) (van Soest, 1982). The smaller absorptive surface of the captive animal implies that the diet of the captive animal may not have stimulated papillae growth, possibly due to a lack of fiber.

The International Species Information System (ISIS) reports that over 1275 giraffes are held in captivity around the world (ISIS, 2002). Captive giraffe have been documented to have many health problems in captivity, including nutritionally related problems such as peracute mortality, chronic wasting, urolithiasis, pancreatic disease, dental disease, and laminitis (Ball, 2005). There have been 7 reported incidences of

obstructive urolithiasis responsible for the death of captive giraffe in North America in the last 10 years (Chapter 2). Adequacy of the diets fed to giraffe in captivity has been called into question. Diet recommendations have been modified often to compensate for issues with energy deficits, mineral imbalances, and overfeeding soluble carbohydrates without enough soluble fiber, leading to possible acidosis. Research into the mineral metabolism has been scarce.

Directly studying giraffe metabolism can be difficult, due to public perception and their value as a prized zoo animal. However, analyzing their diet to address issues of nutritional health, and evaluating epidemiological evidence of compromised health provide opportunities for coalescing a solid plan for feeding and maintaining healthy captive giraffe.

Goats

Goats are small ruminants that can be used and raised for various different purposes, such as pets and show animals, or as a means of converting forage into usable animal products (meat, milk, fiber) (Rankins et al., 2002). Goats have small mouths compared to other domestic ruminants such as cattle and sheep, and prehensile lips. They are active foragers and can utilize browse. When given a choice, goats will choose grass over legumes and browse over grass (Rankins et al., 2002). Meat goats prefer a diet of 80 to 85 % browse and 15 to 20 % grasses when given a choice. Goats are considered intermediate feeders. The browsing adaptations of the goat puts them morphophysiologically closer to the browsing CS. Intermediate feeders (IM) and CS ruminants produce a much higher proportion of thin, proteinaceous serous saliva for

carrying away soluble plant cell contents than GR, as well as having larger salivary glands than GR (Hofmann, 1989). Goats with esophageal fistulas browsing on blackbrush were observed to have bound 50% of the tannins before swallowing, likely because of the excess saliva (Provenza and Malechek, 1984). In comparing goats to what seem to be the closest related ruminant in size, the sheep which is a GR, marked differences in digestive capabilities and preferences have been reported. Free ranging fistulated east African goats in Kenya were reported to be highly selective with a greater harvesting efficiency, lower intake of higher quality forage, larger absorptive surface (larger ruminal papillae), faster feed passage rates, and faster short chain fatty acid (SCFA) uptake than free ranging fistulated Somali blackhead sheep (Schwartz et al., 1987). Intermediate feeder (IM) ruminants choose a mixed diet but avoid fiber when possible, because like CS, they digest the soluble portion of plant cell contents easier than the fibrous cell walls (Hofmann, 1989). Goats, unlike sheep, are very particular about their diets, and will browse most of the species of forage in their environment to gain the greatest nutritional content (Rankins et al., 1999). Goats choose the available feed highest in nutritional content, whether that is grasses when the protein content is high, or browse flowers, fruits and leaves when they are highly digestible (Luginbuhl et al., 1996).

In captivity, the goat may not have the option to maximize its nutrition by browsing many species of forage, and so must receive a high quality diet. In order to meet their energy needs for growth or good condition, under situations of limited high quality digestible forage or browse, a concentrate supplement may be fed, such as whole cottonseed, ground corn or soybean meal (Luginbuhl et al., 1996). When little quality

browse is available it has been recommended for growing meat bucks to have high quality concentrate (16% crude protein) added to their diet along with quality forage (Luginbuhl and Poore, 1998). There have been issues with low NDF digestibility, low intake and high fat content lowering availability of soluble carbohydrates when feeding whole cottonseed (Luginbuhl et al., 2000) or a cottonseed made with applied hot gelatinous cornstarch, named Easiflo cottonseed (Solaiman et al., 2002). The whole cottonseed was fed to growing male Boer goats on a hay based diet, and had detrimental effects on animal performance (Luginbuhl et al., 2000). The Easiflo cottonseed was fed to mature Nubian wethers on a 45% hay diet, replacing a corn and soybean meal mix where digestibility of fiber and soluble carbohydrates decreased significantly as Easiflo replaced the corn and soybean meal mix (Solaiman et al., 2002). Lallo (1996) reported healthy growth of Guyanese meat goats when fed a completely pelleted by-product based diet. Young growing goats should have a diet with 68% TDN, and 14% crude protein, which is higher than would normally be provided by hay alone (Poore and Green, 1995). When stiffleg goats were tested to see the economic impact of concentrate supplementation (16% protein corn and soybean meal mix at 0.25 pounds per animal per day), they grew faster than goats on hay alone, but the supplement with concentrate was not shown to have any economic advantage (Poore and Green, 1995). Lambs netted approximately $4.20 more per 30 pounds of gain on a whole-grain diet compared to a pelleted diet containing alfalfa meal in one study (Umberger, 1997). In a study by Cameron et al. (2001), comparing Boer cross performance with Spanish goat performance, all animals were fed an all concentrate diet with low levels of fiber containing mainly corn, oats, soybean meal, alfalfa meal, and grain by-products. When

on the diet 52 of 55 animals grew well indicating that goats will do well on an all concentrate diet. Overall, goats have been shown to do well on diets which are concentrate based.

Meat goats are of growing interest in the United States due to the rising Latin and Indian immigrant populations who have a preference for goat meat. The South African Boer goat (*Capra hircus*) represents the only goat breed in the world that is routinely involved in performance and progeny tests for meat production (Luginbuhl, 2000). In North Carolina alone it is estimated that over 150,000 goats were sold for meat in 1998, representing over 6 million dollars of revenue (Luginbuhl, 2000). This number is expected to have increased with the increasing population. The meat goat industry is also expanding as seen by the growing numbers of goats entered in the NC and Mountain State fairs from 51 goats in 1996, to 330 in 1999, representing a 68 % increase (Luginbuhl, 2000). This demonstrates the increase in meat goat popularity and numbers in NC.

In the growing meat goat industry, the goal is to optimize growth cost effectively while maintaining health. In order to raise meat goats for profit, a producer must optimize the use of high quality forage and use concentrate feeds strategically (Luginbuhl and Poore, 1998). However, if the primary use of the meat goat is as a pet, or as a show animal, concentrates may be used as a large proportion of the diet (Luginbuhl and Poore, 1998). Concentrates can be used to feed growing goats with high growth rates prior to weaning, as well as lactating and late gestation does, and goats fed low quality forage. However, any feeding of concentrate must be done considering that goats are ruminants that need a minimum of 1.5 % of their BW as forage to ensure a healthy rumen

(Schoenian, 2006). They also should not be given large quantities of grain at once, as this may cause acidosis by decreasing pH in the rumen. Other important considerations are adequate protein, and adequate calcium in the diet. Cereal grains tend to be low in calcium but high in phosphorus, leading to low Ca to P ratios, a main issue in the development of urolithiasis.

Urolithiasis

Urolithiasis is a condition of the urinary tract in which insoluble mineral and salt concretions develop and aggregate around a nidus of proteinaceous material within the bladder or urethra (Belknap and Pugh, 2002). These stones may consist of various mineral combinations and have many shapes and sizes. Nidus formation occurs when mucoproteins in the urine coalesce and precipitate with crystals in supersaturated urine (Belknap and Pugh, 2002). However, if the stones become too numerous or too large, they may cause obstruction of the urethra at the vermiform appendage, the ischial arch, or the neck of the bladder, particularly in castrated male ruminants (Pinsent and Cottom, 1987). This condition, termed obstructive urolithiasis, can rapidly progress to bladder or urethral rupture, uremic crisis, and death (Baxendell, 1984). Male animals are more likely to be affected as females generally have a shorter, wider urethra (Matthews, 1999). Uroliths can occur in all species but are a common problem in domestic ruminants. It has been noted as more of a problem in castrated males (Matthews, 1999; Belknap and Pugh, 2002). Phosphatic calculi in particular affect domestic ruminants fed a high concentrate diet, and have been reported to cause death in captive giraffe (Matthews, 1999; Belknap and Pugh, 2002; Hoar et al., 1970; Wolfe et al., 2000).

Uroliths may be composed of one or several minerals. Examples of the minerals observed in animal species would be magnesium ammonium phosphate (MAP), calcium oxalate, silica, calcium phosphate, or calcium carbonate (Bartges et al., 1999). While some minerals aggregate together, forming complex stones, many types of minerals will not crystallize in the same environment within the animal. It has been indicated that diets designed to minimize MAP urolith formation in cats through urine acidification, increased the occurrence of calcium oxalate stones by inducing hypercalciuria (Lekcharoensuk et al., 2001). Magnesium ammonium phosphate stones will become insoluble in an alkaline environment (Bartges et al., 1999). Silica uroliths have been demonstrated to form more commonly under high dietary calcium: phosphorus ratios and acidic urinary pH in sheep. Sheep have been shown to benefit from less silica urolith formation from P supplementation (Stewart et al., 1991). Magnesium ammonium phosphate uroliths will form under conditions of high P and Mg intake, and low Ca to P ratios (Belknap and Pugh, 2002). High P intake was shown to increase urinary P excretion and promote supersaturation of urine with magnesium, ammonium and phosphate (Finco et al. 1989; McIntosh, 1978).

Urolithiasis is a multi-factorial condition due to the combined influences of multiple dietary factors, urinary pH, and water intake. As previously noted, a diet designed to minimize one kind of stone formation may inadvertently cause another kind. However, individual species have been observed to demonstrate one or two particular types of stones with high frequencies. This may be due to the way the species is fed in captivity, such as feedlot lambs on high concentrate diets for fast growth, or cattle grazing in certain geographic areas with high silica content of the grasses. In some cases

there may be possible genetic predisposition involved such as the Saanen breed of sheep generally excreting high levels of phosphorus in their urine (Matthews, 1999).

The etiology of urolith formation has been studied extensively in ruminant species, and while many questions remain, some points are clear. Calcium, phosphorus and magnesium levels in the diet, serum and urine are integral in the formation of MAP (struvite), calcium phosphate and calcium carbonate uroliths in cattle, sheep and goats. Studies have induced calculi by feeding high phosphorus diets in sheep and goats (Sato and Omari, 1977, Crookshank et al., 1967; Robbins et al., 1965; Bushman et al., 1965; Packett et al., 1964; Bushman et al., 1967, Emerick et al., 1959, Godwin and Williams, 1982, Emerick and Embry, 1963). The results were characterized by consistent findings that sheep or goats on calculogenic diets had high serum and urinary phosphorus concentrations. High urinary phosphorus was found to be directly correlated with incidence of urinary calculi. It was also found that by increasing dietary phosphorus, urinary and serum phosphorus increased. Bushman et al. (1965) reported a significant increase in serum magnesium and phosphorus and a decrease in serum calcium, with increased dietary phosphorus. They also reported an increase in urinary phosphorus and a decrease in urinary magnesium and calcium with increased dietary phosphorus. Robbins et al. (1965) and Crookshanks and Robbins (1962) reported high urinary excretion of phosphorus, and low urinary calcium excretion in lambs which readily developed phosphatic calculi. Robbins et al. (1965) demonstrated that lambs which developed urolithiasis had higher serum levels and lower urinary excretions of magnesium ($p < 0.05$) then unaffected animals. Increased dietary magnesium has also

been shown to increase the incidence of calculi in feedlot lambs even at a normal Ca to P ratio, but especially in the presence of high urinary phosphorus (Poole, 1989).

The dietary mineral imbalances involved with phosphatic calculus formation are often attributed to high grain and low roughage diets. Most of the studies which induced calculi did so by feeding all concentrate, or primarily concentrate diets to test animals. Normal healthy ruminant species have very low urinary phosphorus excretion, due to phosphorus recycling mechanisms (Matthews, 1999). Normally, any excess phosphorus absorbed will be re-secreted into the digestive tract as saliva and lost in the feces. High grain, low roughage diets decrease the formation of saliva, resulting in excess phosphorus excretion into the urine (Belknap and Pugh, 2002). Cereal grains may have inverse Ca to P ratios such as 1:4 or 1:6 (Belknap and Pugh, 2002). Feeding a low level of calcium, especially with an inverse ratio of Ca to P, would lead to high phosphorus absorption in the gut and subsequently high phosphorus in the urine (Matthews, 1999). When feeding an all concentrate diet to lambs and adding 2% sodium bicarbonate, Hoar et al. (1969), reported an increase in stone formation. However, when feeding an 85% concentrate diet with 15% alfalfa hay to lambs, and adding 2% sodium bicarbonate, Hoar et al. (1970) did not report any effect on stone formation. This agrees with Crookshank (1966) who observed no increase in phosphatic calculi in lambs after adding 1.4% sodium bicarbonate to a diet with 40% cottonseed hulls. These examples demonstrate that an all concentrate diet with an alkalizing agent would promote calculi, but the addition of roughage can serve to buffer the calculogenic effects of the sodium bicarbonate. Godwin and Williams (1982) demonstrated that increased feeding of grain in the diet resulted in

increased urinary calcium, phosphorus and magnesium, which in turn led to an alkaline urinary pH.

Dietary composition will affect electrolyte balance and subsequently urinary pH. Ion aggregation and crystal formation are dependent on the pH of the solution and the concentration of ions in the urine (Stratton-Phelps and House, 2004). The pH is integral to crystal formation as certain minerals are only soluble in certain ranges of pH. Once a mineral becomes insoluble and crystallizes, it is more likely to aggregate with other insoluble complexes and grow in size. While a single crystal is considered a microlith, and is not indicative of stone formation, an aggregation of crystals in the urine of an otherwise healthy individual may indicate the onset of macrolith (urolith) formation (Osbourne and Finco, 1999). Another factor in crystallization is how saturated the solution is with mineral ions. Even in a neutral urine pH, a mineral may leave solution and crystallize due to an oversaturation of that mineral in solution, hence increased water intake (and subsequent increased urine volume), will lower the possibility of oversaturation (Matthews, 1999; Pugh 2002). Obviously, control of dietary mineral intake is also necessary to prevent excesses or deficiencies in mineral balance (Matthews, 1999).

Obstructive urolithiasis is often difficult to detect until it is a life threatening problem. The main clinical signs including lethargy, grinding of teeth, anorexia, reluctance to walk, and straining to urinate are present only when the condition is advanced (Baxendell, 1984). Surgical alleviation via perineal urethrostomy, tube cystomy, or urethral process amputation has been successful in domestic animals, such as sheep and goats, but is costly and animals still may have recurrent problems (Haven et

al., 1993; Van Metre and Fubini, 2006). There are risks to long term fertility and copulatory function with surgery and no guarantee that the same blockage will not occur again (Van Metre and Fubini, 2006). Management of struvite stones in ruminants involves a diet with an appropriate macromineral balance, a supplement to acidify the urine, and also encouraging water consumption in order to increase urine volume (Stratton-Phelps and House, 2004).

In order to minimize the potential for reoccurrence of obstructive urolithiasis, the first concern should be scrutinizing the diet for calculogenic potential. As previously described, high grain and low roughage feeding has consequences in terms of phosphorus imbalances. A Ca to P ratio of 2:1, with low magnesium and phosphorus levels should minimize dietary imbalances. It has been recommended for sheep and goats to eliminate alfalfa and grain feeding, in favor of a grass hay diet with potential grazing and ammonium chloride supplementation (Ewoldt et al., 2006). These changes are primarily intended to decrease calcium and phosphorus in the urine (Van Metre and Fubini, 2006). It is also proposed that changing to a grass hay diet with less than 1% ammonium chloride will lead to a more anionic electrolyte balance.

Ammonium chloride has been reported to be more effective than other ammonium salts and calcium chloride in terms of anticalculogenic activity without affecting feed efficiency and growth at levels of 1% inclusion (Crookshank, 1970, Bushman et al., 1967). It has been demonstrated to reduce the incidence of MAP calculi in high magnesium and phosphorus diets in goats (Senthilkumar et al., 2001). Ammonium chloride inclusion has reduced incidence of silica calculi by acidifying the urine of sheep (Stewart et al., 1991). Ammonium chloride may increase Ca excretion, as

well as Ca absorption and resorption from bone in sheep (Braithwaite, 1972). Hence, it may serve to aid in regaining a higher circulating Ca to P ratio by absorbing more Ca and freeing more from bone. However, ammonium chloride has been known to decrease intake levels if inclusion rates exceed the 1 – 2% of dietary dry matter intake (Van Metre et al., 1996). To increase urine volume, extra salt may be added as 3 – 5 % of the diet DM, part of which may be provided as an available plain salt block lick (Van Metre et al., 1996). Increased sodium chloride intake would contribute to increased water intake, especially during the winter months where the lower temperature of the water has been shown to have negative impacts on water consumption (Cooper et al., 1992). Due to ammonium chloride's negative impact on diet intake at higher levels and sodium chloride's inefficiency as an acidification agent, it has been proposed that an anionic diet or supplement may be the solution (Stratton- Phelps and House, 2004). It was shown that the anionic supplement did increase urine volume and urine acidification. Keeping the animal in a state of mild metabolic acidosis could be a problem in long term use due to loss of calcium in the urine and possible effects on bone density (Stratton- Phelps and House, 2004).

The proper all encompassing solution for dealing with the problem of urolithiasis in domestic species has yet to be completely determined. More research is needed regarding the metabolic effects of dietary changes, and the feasibility of implementation of non invasive treatments, as well as post-operative long term recovery. While obstructive urolithiasis is a multi-factorial issue which has been investigated and elucidated from many angles, the influence and role of each factor must be established to predict and prevent animal death.

Urolithiasis in giraffe

According to the International Species Information System (2002), captive adult giraffe mean serum calcium levels are 8.0 ± 0.8 mg/dl (sample size = 142; number of animals sampled = 42), and serum phosphorus levels average 10.5 ± 2.9 mg/dl (sample size = 135; number of animals sampled = 37). The normal ranges of serum calcium and phosphorus for goats are 8.9 - 10.6 mg/dl and 3.2 - 9.8 mg/dl, respectively (Lazzaro, 2005), and for cattle are 9.7-12.4 mg/dl and 5.6-6.5 mg/dl, respectively (Johnson, 1981). Captive giraffe have been documented to have inverse serum ratios of calcium to phosphorus as low as 0.53:1 (Schlegel et al. 2004). These values indicate that high phosphorus levels and imbalanced Ca to P ratios occur in captive giraffe. These imbalances in minerals could be causative factors in the formation of phosphorus-based uroliths that have been demonstrated in captive giraffe.

The predominant chemical composition of captive giraffe uroliths have been reported to be magnesium ammonium phosphate (commonly called struvite) or calcium magnesium phosphate in a carbonate form, often with a combination of the two (Wolfe et al. 2000). In the 75 free ranging giraffe studied by necropsy by Langman (1978), 29% had kidney stones present, described as magnesium based. Langman attributed the stones to a Ca to P imbalance, perhaps indicating that the majority of the uroliths were magnesium ammonium phosphate. This mineral precipitates with high phosphorus present in the urine, as would occur in a Ca to P imbalance. Struvite and calcium phosphate stones will crystallize dependent on pH and concentration of these compounds in the solution. Alkaline urine has been shown to be linked to the precipitation of struvite stones in both in vitro studies and in vivo studies in dogs (Osbourne and Finco, 1995).

Management of struvite stones in ruminants involves a diet with an appropriate macromineral balance, supplements to acidify the urine, and also encouraging water consumption in order to increase urine volume (Stratton-Phelps and House, 2004).

Giraffe may be prone to uroliths in captivity due to the issue of concentrated urine. According to Maluf (2002), the giraffe kidney may be predisposed to the development of urolithiasis due to its ability to concentrate urine during conditions of drought. Since giraffes naturally obtain most of their water from *Acacia* spp. leaves in the wild, they may not drink adequate water in captivity when consuming the conventional diet of concentrates and hay. In domestic species, urine volume can be increased by adding extra salt as 3 – 5 % of the diet DM, part of which may be provided as an available plain salt block lick (Van Metre et al. 1996). While this may be an option, a more natural approach would be an increase in fresh forage or browse intake, with concomitant increase in dietary water content, serving to combat this issue as well as to increase dietary fiber.

Dietary fiber appears to affect length and width of ruminal papillae, rumenoreticular volume and fermentative rate (Hofmann and Matern, 1988). There is an effect of dietary fiber and forms of carbohydrates on absorption and excretion of minerals in ruminants (Van Soest, 1982). Excess concentrate intake may lead to blunting of rumen papillae, causing a reduction in the absorption of nutrients and minerals, as well as decreased salivation, leading to rumen acidosis and altered mineral excretion. In the wild giraffes feed on predominantly browse as described previously (Pellew, 1984). Feeding browse in a zoo setting can be challenging due to the seasonal challenge of obtaining fresh browse, as well as expense, especially during winter months. Research is being

performed to find ways of providing browse to giraffes in captivity during the winter by creating browse silage (Hatt and Clauss, 2001; Clauss et al., 2003b; Nijboer et al., 2002; Livingston et al., 2006).

Since feeding an all browse diet is difficult in captivity, zoos often feed hay and pelleted concentrates. The AZA Nutrition Advisory Group (Lintzenich and Ward, 1997) recommended 30-40 % concentrate and 60-70 % hay in diets for giraffe and okapi. In the okapi, eight surveyed European zoos were documented as feeding 48% of okapi diets as alfalfa hay, 42% as energy and protein concentrates (mainly grain) and 10% as high sugar fruits and vegetables (Kanselaar et al., 1999). More recently, a group of independent scientific experts in domestic ruminant nutrition and specialists in captive giraffe management met to discuss and establish new feeding guidelines for captive giraffe (Schmidt and Barbiers, 2005). They created recommendations regarding the composition of giraffe diets, that included decreasing starch and simple sugar content, protein content, phosphorus content, and increasing fiber. Their suggestion was to change the composition of the concentrate fed to captive giraffe, acknowledging that zoos generally feed 50% - 75% of the diet as concentrate (Schmidt and Barbiers, 2005). Hummel et al. (2006) makes a similar recommendation for feeding okapi, to lower sugars and starches in the concentrate, rather than decrease the level of concentrate fed. In his review of browser diets in captivity, Clauss et al. (2003a) reported that hay to concentrate ratios were 1:1, or 50% concentrate and 50% browse in captive animals. Individual dietary intakes of captive giraffe studied by Kearney (2005) were 1% of captive giraffe body weight as concentrate supplement and 0.24% as hay, and for the second animal, 0.98% as

concentrate and 0.23% as hay. Both animals were fed a diet with a high concentrate to hay ratio.

It would be nearly impossible to control the feeding of every captive giraffe in the world. Nor would they necessarily be able to eat the same diet or consume as much water as we would target. Giraffes are individual in their palates, and a perfectly formulated diet for one animal may be distasteful for another. Until research has absolutely established causation and solution for the issue of urolithiasis, a perfect diet is still not in existence.

Urolithiasis in goats (domestic ruminants)

Goats and giraffes are both considered browsing ruminants (Stevens and Hume, 1995). While giraffes in the wild are considered concentrate selectors, feeding mainly on browse, (especially the leaves and twigs of the African acacia species) giraffes in captivity in North American zoos have been reported to be fed mainly pelleted concentrate with variable amounts of alfalfa hay and minimal amounts of browse (see Chapter 2). Goats are considered browsers though far less selective than giraffes. Domesticated goats may be fed a variety of diets with successful growth depending on their purpose. Goats have been shown to tolerate at least 50% of their diet as grain sorghum, the rest consisting of alfalfa hay, without any negative impact on their fiber digestion (Cerrillo et al., 1999). In the growing industry of meat goats as well as popular show goats, high concentrate diets may be recommended due to faster rates of gain, getting more animal for the money invested (Poore and Green, 1995).

Goats of various breeds and purposes have been documented with urolithic stone problems in captivity (Gutierrez et al., 2000, Bellenger et al, 1981, Unanian et al. 1985, Smith and Sherman, 1994). These stones often occur when a mainly concentrate diet is presented to the goats, with a high phosphorus content. For example, Brazilian goats fed a concentrate ration of three parts corn and one part cottonseed developed stones with a Ca to P ratio of 1.08 to 1 (Unanian et al. 1985) and the Australian angora male goats fed a feedlot fattening ration with a Ca to P ratio of 0.067 to 1 (Bellenger et al. 1982). The high phosphorus content can lead to an imbalance of Ca: P ratio, which is recommended to be between 2 to 1 and 4 to 1 for meat goats (Luginbuhl and Poore, 2000). A high concentrate to hay ratio will also affect phosphorus homeostasis in terms of salivary (mainly parotid) phosphorus secretion, net intestinal absorption and the partitioning of phosphorus excretion between the urine and feces (Scott and Buchan, 1987; Tomas, 1974; Putnam et al., 1966; Sato, 1976).

Several studies reported a high incidence of urinary calculi in sheep fed a phosphorus supplemented diet (Bushman et al., 1965; Emerick et al., 1963; Hoar et al., 1969) as well as one study reporting the same response in goats (Sato and Omari, 1977). For example, eighty seven lambs fed 0.47% of the diet as phosphorus and 0.31% as calcium (a Ca: P ratio of 0.67 to 1), developed phosphatic calculi at a 50 to 52 % incidence (Hoar et al., 1969). Six goats developed phosphatic calculi when on a diet consisting of 0.98% of the diet as phosphorus, and a Ca to P ratio of 0.08 to 1, and one died from obstructive urolithiasis (Sato and Omari, 1977). While these studies demonstrate the positive correlation of high phosphorus in the diet and phosphatic stone formation, there remains debate on the relative importance of other causative factors such

as the interrelationships of minerals coming from the diet, the influence of dietary form, and the influence of water intake.

Goals for Project

Our first objective for this project was to determine the health and diet of captive giraffes in North America in order to elucidate the possible relationship between dietary intake and the development of urolithiasis. This was attempted by a comprehensive survey (Appendix 1) with questions regarding giraffe housing, feeding practices, dietary contents, the ratio of dietary components offered, water sources, and medical histories. Giraffe holding institutions were recruited to submit samples of feeds, water, serum, urine and feces. The survey was distributed to 98 institutions through the giraffe American Zoo and Aquarium Association's Species Survival Plan (SSP).

In May of 2005, a group of independent scientific experts in domestic ruminant nutrition and specialists in captive giraffe management met to discuss and establish new feeding guidelines for captive giraffe (Schmidt and Barbiers, 2005). They created recommendations regarding the composition of giraffe diets, suggesting decreasing starch and simple sugar content, protein content, phosphorus content, and increasing fiber. With the committee's recommendations, Mazuri PMI International formulated a new concentrate diet for wild herbivores addressing these concerns. The goal for the second portion of our studies was to test this revised diet in comparison to the most prevalent commercial diet fed in North America to captive giraffe according to recent survey data (Chapter 3). We also aimed to compare two opposing concentrate to hay ratios, which would serve to investigate differing levels of fiber in a diet for wild herbivores. Goats

were used as a model species, as they are browsing ruminant herbivores. Goats also have been reported to develop the same kind of urolith, under similar nutritional conditions. Overall, we aimed to investigate the effects of the new diet formulation compared to the older, as well as differing concentrate to hay ratios, on the formation of urolithic compounds, urinary pH, mineral balance and other indicators of health, such as nitrogen and phosphorus balance. Based on previous studies, we would expect to see more urolithic compound formation, higher urine pH and higher levels of phosphorus for all parameters in a diet with high concentrate and high phosphorus with lower fiber content.

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Chapter 2

An evaluation of nutrient concentrations in the diet, serum and urine of giraffe from a survey of North American Zoological Institutions and their possible relationship to urolithiasis

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Introduction

Urolithiasis is a condition of the urinary tract in which mineral and salt concretions develop and aggregate within the bladder and urethra. These stones may consist of various mineral combinations and have many shapes and sizes. However, if the stones become too numerous or too large, they may cause obstruction of the urethra at the vermiform appendage, the ischial arch, or the neck of the bladder, particularly in castrated male ruminants (Pinsent and Cottom, 1987). This condition, termed obstructive urolithiasis, can rapidly progress to bladder or urethral rupture, uremic crisis, and death (Baxendell, 1984). Uroliths can occur in all species but are a common problem in domestic ruminants fed a high concentrate diet, and have been reported to cause death in captive giraffe (Wolfe et al., 2000). It is often difficult to detect obstructive urolithiasis, as the main clinical signs of lethargy, grinding of teeth, anorexia, reluctance to walk, and straining to urinate are present only when the condition is advanced (Baxendell, 1984). Surgical alleviation via perineal urethrostomy has been successful in domestic animals, but is problematic in giraffe due to anatomical constraints (Haven et al., 1993).

The International Species Information System (ISIS) reports over 1275 giraffes currently held in captivity around the world (ISIS, 1999). According to ISIS, captive adult giraffe mean serum calcium levels are 8.1 mg/dl (n = 121), and serum phosphorus levels average 10.6 mg/dl (n = 115). The normal ranges of serum calcium and phosphorus for goats are 8.9 - 10.6 mg/dl and 3.2 - 9.8 mg/dl, respectively (Lazzaro, 2005), and for cattle are 9.7-12.4 mg/dl and 5.6-6.5 mg/dl, respectively (Johnson, 1981). Captive giraffe have been documented to have inverse serum ratios of calcium to phosphorus as low as 0.53:1 (Schlegel et al., 2004). These values may indicate that high

phosphorus levels and imbalanced Ca: P ratios occur in captive giraffe. These imbalances in minerals could be causative factors in the formation of phosphorus-based uroliths demonstrated in captive giraffe.

The predominant chemical composition of captive giraffe uroliths have been reported to be magnesium ammonium phosphate (commonly called struvite) or calcium magnesium phosphate in a carbonate form, often with a combination of the two (Wolfe et al. 2000). Ion aggregation and crystal formation are dependent on the pH of the solution as well as the concentration of ions in the urine (Stratton-Phelps and House, 2004). Alkaline urine has been shown to be linked to the precipitation of struvite stones in both in vitro studies and in vivo studies in dogs (Osbourne and Finco, 1995). Management of struvite stones in ruminants involves a diet with an appropriate macromineral balance, a supplement to acidify the urine, and also encouraging water consumption in order to increase urine volume (Stratton-Phelps and House, 2004).

Giraffe also may be more prone to uroliths in captivity due to the issue of urine concentration. According to Maluf (2002), the giraffe kidney may be predisposed to the development of urolithiasis due to its ability to concentrate urine during conditions of drought. Since giraffes naturally obtain most of their water from *Acacia* spp. leaves in the wild, they may not drink adequate water in captivity when consuming the conventional diet of concentrates and hay. In domestic species, urine volume can be increased by adding extra salt as 3 – 5 % of the diet DM, normally as an available plain salt block lick (Van Metre et al. 1996). While this may be an option, a more natural approach would be an increase in fresh forage (browse) intake, with concomitant increase

in dietary water content, serving to combat this issue as well as serving to increase dietary fiber.

Dietary fiber appears to affect length and width of ruminal papillae, rumenoreticular volume and fermentative rate (Hofmann and Matern, 1988). There is an effect of dietary fiber and forms of carbohydrates on absorption and excretion of minerals in ruminants (Van Soest, 1982). Excess concentrate intake may lead to blunting of rumen papillae, causing a reduction in the absorption of nutrients and minerals, as well as decreased salivation, leading to rumen acidosis and altered mineral excretion. The Nutrition Advisory Group (Lintzenich and Ward, 1997) recommended 30-40 % concentrate and 60-70 % hay in diets for giraffes. More recently, a group of independent scientific experts in domestic ruminant nutrition and specialists in captive giraffe management met to discuss and establish new feeding guidelines for captive giraffe (Schmidt and Barbiers, 2005). They created recommendations regarding the composition of giraffe diets, in terms of decreasing starch and simple sugar content, protein content, phosphorus content, and increasing fiber. Their suggestion was to change the composition of the concentrate fed to captive giraffe, acknowledging that zoos do feed 50% - 75% of the diet as concentrate (Schmidt and Barbiers, 2005). In his review of browser diets in captivity, Clauss et al. (2003a) also reported that hay to concentrate ratios were 1:1, or 50% concentrate and 50% browse were fed to captive giraffe. Individual dietary intakes of captive giraffe studied by Kearney, were 1% of captive giraffe body weight as concentrate supplement and 0.24% as hay (Kearney, 2005).

We proposed to investigate the current status of giraffes in captivity in North America in terms of health history, feeding practices, dietary contents, housing, water

sources, and ratio of dietary components. We aimed to obtain samples of hay, concentrates, browse, urine, serum, water and feces in order to compare across zoos, the possible factors relating to the development of urolithiasis in captive giraffe.

Methods and Materials

In order to investigate the possible dietary causes of urolithiasis in giraffe, a comprehensive survey was initiated in September 2004 of giraffe within North American zoological institutions and completed in March of 2006. Questions were asked regarding giraffe housing, feeding practices, dietary contents, the ratio of dietary components offered, water sources, and medical histories (Appendix A). Giraffe holding institutions were recruited to submit samples of feeds, water, serum, urine and feces, and asked to participate in a planned feeding trial. The survey was distributed to 98 institutions through the giraffe American Zoo and Aquarium Association's Species Survival Plan.

All contributing institutions were given a working protocol to use for sample collection. Blood was to be collected from the tail vein of giraffe for serum in glass tubes in a quantity of at least 6 ml or more if possible. Urine was collected within 24 h of the blood sampling in one of two ways: 1) Trained animals urinated into a cup on a long pole, recommended for a clean sample; 2) To collect morning urination from a drain cup, which would be placed previous to giraffe entering stall. Fecal samples were collected at the time of urine collection or fresh after blood sampling (maximum time limit within 24 hours of blood draw) and at least 100 g of sample was requested. Feed samples were taken at maximum within 24 hours of blood sampling- of currently fed concentrate, hay, and browse offered to the animal(s) which had donated serum, urine, or serum and urine, in a quantity of at least 100 g of each (for browse, at least one branch with living leaves). Other information requested was that for the 3 days prior to blood sampling, intake should be recorded as exactly as possible, considering amount (weight) of concentrate and alfalfa hay given, and orts remaining. Water samples were also taken at maximum,

within 24 hours of blood sampling At least 100 ml was requested from the same water valve (or hose) used to water the captive giraffes. After all samples were taken they were to be frozen in -20 ºC freezer until shipping or analysis. The shipping requested was priority overnight with dry ice to ensure all samples remained frozen. Once received and processed, all samples of serum, urine, concentrate, hay and browse were sent to commercial laboratories for analyses.

A total of eight zoos sent 16 feed samples, which were analyzed for nutrient content including ADF, NDF, crude protein and minerals (Dairy One Forage Laboratory, Ithaca, NY). The hay, concentrate and browse samples were analyzed for crude protein, soluble protein, degradable protein (undegradable intake protein, UIP), acid detergent or neutral detergent insoluble crude protein (ADI-CP, NDI-CP), non protein nitrogen (NPN), acid detergent fiber (ADF), neutral detergent fiber (NDF), crude fiber, and lignin according to AOAC procedures. Elements including Ca, P, Mg, K, Na, Fe, Zn, Cu, Mn, Mo, Co were analyzed using a Thermo Jarrell Ash IRIS Advantage Inductively Coupled Plasma (ICP) Radial Spectrometer. Ten serum samples were submitted and analyzed for large animal serum chemistries including minerals in duplicate, using an automated wet chemistry analyzer, the Hitachi 917, which measured sodium (Na), potassium (K), chloride (Cl), calcium (Ca), magnesium (Mg), phosphorus (P), creatinine, anion gap, glucose, globulin, total protein, sorbitol dehydrogenase (SDH), alkaline phosphatase (ALK PHOS), total bilirubin, direct bilirubin, indirect bilirubin, total iron binding capacity (TIBC), bicarbonate, blood urea nitrogen (BUN), albumin, albumin / glucose ratio (A/G), aspartate aminotransferase (AST), gamma-glutamyltransferase (GGT), iron (Fe) and percent saturation (Cornell Veterinary Diagnostic Laboratory, Ithaca, NY).

Eleven urine samples were submitted for a urinary electrolyte and mineral panel in duplicate measuring Ca, P, Mg, Na, K, Cl, creatinine, and pH (Cornell Veterinary Diagnostic Laboratory, Ithaca, NY). The Hitachi 917 was also used for all urine sample analysis.

All data were analyzed by analysis of variance using Proc GLM of SAS. Zoos were compared using the least significant difference test when the model was significant ($P \leq 0.05$).

Results and Discussion

Forty-one out of the 98 institutions contacted responded to the 2004 survey, with a total of 218 giraffe included (71 males and 147 females). The subspecies reported were reticulated or Rothschild's (n = 140), Masai (n = 64) and subspecies hybrids (n = 14). A majority of both males and females represented were between the ages of 4 and 20 years and considered sexually mature. Three of the institutions (7%) held their giraffe in multiple species exhibits and 36 (88%) reportedly fed their giraffe in groups. Of the 36 zoos which group fed, 14 (34%) fed their male(s) separately from the herd and 7 (17%) allowed singular night feeding for certain animals.

All responding zoos fed concentrate. Thirty-two percent of institutions fed one type of concentrate (Mazuri ADF 16 "low fiber" pellets, PMI Nutrition International, St. Louis, MO), but 24 different types of concentrate were reported overall. Alfalfa hay was the primary forage in 100% of zoos. While 65% of the zoos reportedly fed browse, 43 different species of browse were listed, with little to no quantification of intake amounts. Three fourths of the zoos fed trace mineral salt blocks, while 25% gave a plain salt block, and 10% gave a vitamin E supplement. Seventy percent of zoos used city water and 25% used well water, with the remaining 5% using both sources. Many forms of "treats" were noted, though not quantified.

The approximated intake of concentrate and hay for surveyed animals was calculated when possible. The average intake was calculated for all reported animals (Table 1), with a separation for females, males, and for reported groups of mixed sex whose intake could not be separated. Concentrate to hay ratios were also calculated. We

received samples from eight institutions, each submitting samples of serum and / or urine from up to 3 individuals, as well as concentrate and hay samples.

Six zoos surveyed reported a history of urolithiasis in their collections, seven reported wasting syndromes, and ten reported peracute mortality, which is a sudden death syndrome that is not fully understood but thought to be linked to energy deficiencies. The giraffes found with urolithiasis reportedly had stones consisting of calcium phosphate (carbonate form), magnesium ammonium phosphate and calcium oxalate. A variety of other problems were noted from 10 institutions, some of which may be related to urolithiasis, such as blood on the prepuce and renal disease. Sixteen institutions reported no health problems.

Giraffes in the wild are concentrate selectors, having a faster passage rate through the rumen and larger surface area of papillae for absorption of short chain fatty acids (SCFA's) than grazing or intermediate ruminants. Marked differences in rumen morphology have been found between captive giraffe and free ranging giraffe (Hofmann and Matern, 1988). They estimated that wild giraffe have nine times the absorptive capacity for SCFA's compared to the captive giraffe examined, due to greater surface area and papillae size. SCFA's can provide up to 90% of available energy for ruminants and are absorbed through the rumen mucosa (papillae) (van Soest, 1982). The smaller absorptive surface of the captive animal implies that the diet of the captive animal may not have stimulated papillae growth, possibly due to a lack of fiber. Concentrate selectors are designed to absorb soluble carbohydrates well, possibly through excess saliva helping to carry soluble carbohydrates down the ventricular groove into the abomasum, escaping rumen microbes (Hofmann, 1989). In the wild, giraffe would need

this adaptation to maximize their energy intake, considering they may be consuming leaves and browse with little soluble carbohydrate. Concentrate selectors would have trouble surviving on insoluble fiber alone as a grazer could, due to the fast passage time previously noted. Leaves and browse do, however, provide the stimulation for the rumen papillae growth. A plan for feeding captive giraffe a rumen stimulating diet with enough energy, may involve feeding concentrates that are high in soluble fiber, like pectins and gums, rather than just increasing insoluble fiber that provides rumen stimulation without providing much energy (Schmidt and Barbiers, 2005; Kearney, 2005).

The feeding practices of giraffes in the wild would be extremely difficult to duplicate in captivity in North America. The results of the present survey demonstrate that prevalent feeding practices in 2005 to most often include a form of pelleted concentrate. The concentrate often represented the majority of the diet being fed, making the internal balance of nutrients in the concentrate important. This conclusion was also reached by other giraffe researchers (Schmidt and Barbiers, 2005; Clauss, 2003a; Clauss, 2003b; Kearney, 2005). Surveyed zoos reported feeding concentrate to hay ratios as high as 3.47 to 1, with varied concentrates and alfalfa hay (Table 1). This practice stands unlikely to change, as pelleted concentrate is easy to store and feed, and is also an efficient way of getting energy and nutrients to the animal. Composition of the concentrate is a variable that can be changed, especially to try and better mimic a wild diet. Decreasing simple sugars and starch, decreasing phosphorus content, decreasing protein content and increasing soluble fiber were the recommendations of the committee (Schmidt and Barbiers, 2005). Our data agrees in that sugars and phosphorus are elevated in current giraffe diets when high levels of concentrate are fed.

The complete dietary nutrient intake of surveyed giraffe (Table 2) indicates that giraffe are receiving high levels of ADF and NDF beyond the recommendation of Lintzenich and Ward, (1997). While this seems to indicate that giraffe are receiving more than enough fiber for rumen "scratch factor" and papillae stimulation, it actually shows their fiber intake to be closer to a grazer rather than a concentrate selector. As noted previously, the fast rumen passage of a giraffe does not allow the rumen microbes enough time to break down the highly indigestible cellulose and lignin and produce adequate SCFA. Therefore high levels of insoluble fiber would not aid in obtaining energy from the diet. This potential lack of energy may be involved in other giraffe health problems such as chronic wasting and peracute mortality (Ball, 2005).

Our analysis of diets included intake (as measured by disappearance) of hay and concentrate, but did not account for browse, treats or vitamin supplements to the diet. This was due to not all institutions quantifying the amounts of browse, treats and vitamin supplements given, nor providing samples of each. All values appeared to meet nutrient recommendations for giraffe, although intake varied considerably among individuals as well as zoos (Table 5). The nutrient values that were elevated compared to recommendations were ADF, NDF, calcium, and magnesium (Lintzenich and Ward, 1997). Zoo C demonstrated a more than 5-fold increase in concentrate to hay intake over Zoo D, based on the fact that Zoo D's animal consumed an unusually large amount of hay and does so regularly. We noticed that these two institutions (C and D) also showed the greatest difference in serum phosphorus concentrations. The concentrate to hay intake ratio and serum phosphorus level were shown to be positively correlated (Pearson correlation coefficient = 0.75; P = 0.01) (Figure 1). Serum phosphorus was negatively

correlated with hay intake (Pearson correlation coefficient = -0.68; P = 0.03). This reveals an interesting trend in that animals consuming more concentrate appear to have higher serum phosphorus levels.

Serum levels are reported in Table 3. Overall, the concentrate to hay ratio showed many significant correlations with serum concentrations (Table 6), such as P, Na, K, Cl, bicarbonate, urea N, creatinine and glucose. Serum K, Cl, and bicarbonate were negatively correlated with concentrate to hay ratio, meaning they would increase with less concentrate and more hay eaten (Pearson correlation coefficient = -0.558, P = 0.09; -0.777, P = 0.008; -0.822, P = 0.004; respectively). The positive correlation of hay intake with serum K (Pearson correlation coefficient = 0.818, P = 0.004) and the negative correlation of concentrate intake with serum Cl, (Pearson correlation coefficient = -0.593, P = 0.07) support this comparison. It is reasonable that bicarbonate would increase with less concentrate, as it is an alkaline buffer carried in saliva (van Soest, 1982). Forage stimulates saliva production in ruminants and concentrates do not do so to the same extent. Without as much buffering bicarbonate produced, the high levels of concentrate may induce acidosis. The increase of serum K and Cl with a lower ratio of concentrate to hay intake, may be related to the higher levels of K and Cl in the alfalfa hay than the concentrate. Serum Na, BUN, creatinine and glucose were significantly positively correlated with concentrate to hay ratio (Pearson correlation coefficients = 0.657, P= 0.04; 0.863, P = 0.001; 0.658, P = 0.04; 0.951; P = 0.0001; respectively). Blood urea N was not different among zoos (P = 0.10). As with K and Cl, the changes in Na and BUN likely reflect a higher Na and protein content respectively in the concentrate, rather than a problem with renal function. Serum glucose would not be expected to increase with

increasing levels of concentrate, because gluconeogenesis is constantly occurring in ruminants, and they do not have large spikes in glucose production, nor to they obtain a large portion of their energy as glucose (Van Soest, 1982). Serum glucose levels were different among zoos (P = 0.03). Glucose was also significantly correlated with concentrate to hay ratio (Pearson correlation coefficient = 0.95). When examining the significant differences between zoos for glucose, it was noted that giraffe from Zoo C showed very high levels of glucose. While it is an average of only 3 animals, all three animals ranked highest for glucose, with levels above the ISIS normal range of 105 ± 62 mg/dl. On further investigation these high values for Zoo C may reflect a stress response, as these animals were not acclimated to the blood collection procedure. Therefore, cortisol levels may have increased, hence increasing levels of circulating glucose. The positive correlation of creatinine to concentrate to hay ratio, as well as to most other dietary parameters, may reflect slight dehydration (Van Soest, 1982). Most intriguing for our research was that serum P was highly significantly correlated to concentrate to hay intake (Figure 1), and serum Ca, while not significant, tended toward a negative correlation with concentrate to hay ratio. While the differences in serum phosphorus values were not statistically significant, it should be noted that giraffe from zoos A, B, D and F had serum phosphorus levels less than ISIS reference ranges of 10.5 ± 2.9 mg/dl (ISIS, 2002). While a reverse Ca to P ratio was not demonstrated, it may be possible to develop one feeding high levels of concentrate without enough forage supplementation. All calcium to phosphorus ratios were above 1:1 and there were no significant differences in Mg levels.

Urine concentrations of individual zoos are shown in Table 4. The correlations between urine concentrations and dietary parameters did not show many significant relationships (Table 7), except the dietary Ca to P ratio's relation to urine mineral concentrations before standardizing for creatinine. When the dietary Ca to P ratio increased, it seems that more P, Na and Cl were excreted in the urine. Urinary phosphorus levels showed significant differences due to zoos B and F having highly aberrant values ($P < 0.0001$). Urinary phosphorus was positively correlated with dietary calcium to phosphorus ratio (Pearson correlation coefficient = 0.61; $P = 0.04$), but when put on a creatinine standardized basis, it became a tendency ($P = 0.10$). It seems unlikely that there would be more excretion of P with a higher Ca to P ratio. The highly aberrant values of urinary P demonstrated at 2 zoos may likely represent a contaminant since in both cases the urine was collected from the floor. A strong cleaner containing phosphate may have been present on the floor giving falsely elevated urinary P. Urinary Na tended to be different among zoos ($P = 0.09$), with Zoo B and E showing the highest levels, but it should be noted that those zoos also had the highest creatinine levels. Urine creatinine and urine Na were correlated (Pearson correlation coefficient = 0.72; $P = 0.01$), so these differences seem to represent differences in urine concentration. The changes in Na and Cl concentration are likely due to differences in the concentration of the urine between zoos and hence showed no correlation when put on a creatinine standardized basis. Urine pH significantly decreased with increasing Ca to P ratio (Pearson correlation coefficient = -0.673; $P = 0.02$). Since the most common MAP and calcium phosphate stones generally form in alkaline urine, a low urine pH is desirable and hence a high dietary Ca to P ratio would also be beneficial.

When comparing urine concentrations to serum concentrations (Table 8), the most interesting relationship was between serum Mg and urinary Ca and Mg, both on a regular and creatinine standardized basis. Urinary Ca and Mg were positively correlated with serum Mg. Interestingly, increasing dietary Mg showed a trend of decreasing serum Ca (Table 6). High dietary Mg seems to lead to lower serum Ca, and more urinary Ca excretion. It may do this by blocking Ca re-absorption in the kidneys hence more Ca is excreted in the urine. Higher amounts of Ca and Mg ions in the urine may aid in the over saturation of urine. This can lead to the precipitation of crystals and subsequently urolith formation. While the concentrate to hay ratio was not shown to be correlated with serum or urine Mg, the relationship between Ca and Mg demonstrates a need for low Mg content of the diet. The level of Mg in the nutrient composition of concentrate used may also be important in the development of uroliths.

The mean calcium to phosphorus ratio in the dietary composition of responding zoos appeared to be approximately 2 to 1 (Table 2). However, when looking at the serum Ca and P concentrations for individual zoos (Table 3), it is interesting to note the only zoo with a lower serum Ca to P ratio (close to 1 to 1, rather than 2 to 1 like all the other zoos), is the same zoo with a highest concentrate to hay ratio of 2.71 to 1 (Table 5). This may be explained by the high P of the concentrate fed at that particular zoo. Alfalfa hay generally has high Ca levels, which may balance a high P level in the concentrate, but only if a low concentrate to hay ratio was fed.

There appeared to be a positive correlation between diet and physiologic phosphorus levels in giraffe (Figure 1). This may not be related to the ingredients of the diet per se but rather to the ratio of concentrate to hay eaten and perhaps the nutrient

composition of the concentrate. Incidentally, giraffe ISIS normal reference ranges for phosphorus, approximately 7.6 – 13.4 mg / dl, are nearly double those expected for domestic ruminants (ISIS, 2002). As concentrates are typically high in phosphorus content, and native browses are generally low in this mineral, we aim to continue this investigation to further elucidate whether dietary concentrate intake in captive giraffe is related to high levels of phosphorus excretion leading to the development of phosphatic calculi in giraffe.

Table 1: Average Daily Feed Intake for all surveyed captive giraffe with available information from 41 responding zoos

All Surveyed Giraffe	N	Mean	Std Dev	Minimum	Maximum
Amt of concentrate (kg) / animal	50	6.15	2.70	2.72	14.00
Amt of alfalfa hay / animal /day	30	7.37	5.48	2.75	24.00
Concentrate to Hay Ratio	29	1.10	0.73	0.23	3.47
Only Female Giraffe					
Amt of concentrate (kg) / animal	19	5.71	2.51	2.72	13.66
Amt of alfalfa hay / animal /day	9	7.30	6.78	2.75	24.00
Concentrate to Hay Ratio	9	1.18	0.75	0.34	2.81
Only Male Giraffe					
Amt of concentrate (kg) / animal	19	7.29	3.11	2.72	14.00
Amt of alfalfa hay / animal /day	11	9.33	6.27	2.75	24.00
Concentrate to Hay Ratio	11	1.07	0.92	0.23	3.47
Giraffe in groups of Mixed Sex Exhibits that could not be separated					
Amt of concentrate (kg) / animal	12	5.03	1.51	2.72	7.18
Amt of alfalfa hay / animal /day	10	5.27	1.65	2.75	7.27
Concentrate to Hay Ratio	9	1.07	0.48	0.42	1.80

Table 2: Dietary Composition Analysis for 12 Captive Giraffe in 6 Zoos

Intake of Hay and Conc.	Mean	Range	Recommendation[a]
Crude Protein %	18.5	17.5 - 19.4	15 - 19
Acid detergent fiber %	29.4	18.1 - 43.9	13 - 18
Neutral detergent fiber %	44.7	25.5 - 67.9	25 - 34
Ca, %	1.09	0.9 - 1.57	0.7 - 0.97
P, %	0.56	0.28 - 0.73	0.36 - 0.54
Mg, %	0.26	0.19 - 0.33	0.18 - 0.22
Na, %	0.21	0.14 - 0.37	0.10 - 0.44
K, %	2.0	1.5 - 2.7	1.6 - 1.8
Cl, %	0.67	0.42 - 1.29	NA[b]
S, %	0.25	0.18 - 0.33	NA

[a]Lintzenich, BA and Ward, AM, 1997, NAG Fact Sheet #6
[b]NA = Not Applicab

Table 3: Serum concentrations for captive giraffe from 5 zoos (A-D and G)

	A (n = 3)	B (n = 2)	C (n = 3)	D (n = 1)	G (n = 2)	SEM	P-Value
Glucose, mg/dl	76[a]	111[a]	255[b]	79[a]	96[a]	33.8	0.03
BUN, mg/dl	21.5[a]	20.7[a]	29.0[b]	23.0[a]	23.3[a]	2.12	0.1
Ca, mg/dl	9.6	9.1	8.6	9.0	10.6	0.54	0.21
P, mg/dl	4.3	4.7	6.2	3.1	4.7	0.75	0.19
Mg, mg/dl	1.5	1.6	1.9	1.8	1.7	0.18	0.61

[ab]- Means within a row without a common superscript differ ($P < 0.05$)

Table 4: Urinary mineral concentrations for captive giraffe from 7 zoos (A-F and H)

	A (n = 3)	B (n = 1)	C (n = 3)	D (n = 1)	E (n = 1)	F (n = 1)	H (n = 1)	SEM	P-value
Na, mEq/L	172[a]	285[b]	102[a]	53[a]	305[b]	70[a]	11[a]	50	0.09
K, mEq/L	575	329	320	625	554	311	59	121	0.17
Cl, mEq/L	285	443	141	395	375	178	21	80	0.12
Creatinine, mg/dl	392	411	373	340	628	291	32	117	0.29
Ca, mg/dl	4.2	1.1	11.4	19.1	12.5	5.9	10.0	5.2	0.41
P, mg/dl	Nd	101.2[a]	4.1[b]	nd	nd	92.7[a]	2.4[b]	1.2	0.0001
Mg, mEq/L	31	13	58	38	92	23	10	16	0.17

[ab]- Means within a row without a common superscript differ ($P < 0.05$)

Table 5: Dietary Intake Parameters for 12 Captive giraffe from 6 Zoos (A-E and G)

	A (n = 3)	B (n = 2)	C (n = 3)	D (n = 1)	E (n = 1)	G (n = 2)	SEM	P-value
DM intake, kg	8.41[a]	8.9[a]	10.2[a]	26.5[b]	12.8[ab]	14.8[ab]	1.71	0.03
Concentrate Intake, kg	4.0[a]	4.4[a]	7.5[b]	8.8[b]	6.2[ab]	4.7[a]	0.93	0.05
Hay Intake, kg	4.5[a]	4.5[a]	2.7[a]	17.7[b]	6.6[a]	10.2[c]	1.30	0.006
Concentrate /Hay Ratio	1.01[a]	0.97[a]	2.71[b]	0.50[a]	0.94[a]	0.55[a]	0.25	0.003

[abc]- Means within a row without a common superscript differ ($P < 0.05$)

Table 6: Pearson Correlation Coefficients for Dietary Parameters (vertical) versus Serum Concentrations (horizontal) for Captive Giraffe from 5 Zoos

	P	Ca	Mg	Na	K	Cl	bicarbonate	UreaN	Creatinine	Total Protein	Glucose
Conc. Intake	0.152	-0.188	**0.681**	0.290	0.208	*-0.593*	*-0.561*	*0.594*	0.271	-0.410	**0.540**
Hay Intake	**-0.678**	0.288	0.125	-0.506	**0.818**	0.299	0.342	-0.381	-0.428	-0.419	-0.525
Conc : Hay Ratio	**0.751**	-0.487	0.441	**0.657**	*-0.559*	**-0.777**	**-0.822**	**0.863**	**0.658**	0.153	**0.951**
DM Intake	0.372	-0.518	0.162	0.373	-0.475	-0.215	-0.527	0.224	**0.887**	*0.609*	0.520
CP	0.419	*-0.542*	0.204	0.411	-0.486	-0.285	-0.585	0.305	**0.902**	*0.584*	*0.587*
P	0.511	-0.484	0.358	*0.549*	-0.483	*-0.428*	**-0.684**	*0.607*	**0.913**	0.422	**0.708**
Ca	0.519	*-0.563*	0.290	0.510	*-0.541*	-0.561	**-0.670**	0.445	**0.848**	0.512	**0.752**
Mg	0.531	*-0.592*	0.319	0.464	-0.520	-0.485	**-0.704**	0.502	**0.891**	0.512	**0.747**
Na	0.337	*-0.544*	0.0002	0.114	-0.456	0.018	-0.447	-0.003	**0.721**	**0.664**	0.386
K	0.133	-0.351	0.119	0.232	-0.308	-0.131	-0.316	0.116	**0.764**	*0.582*	0.312
Cl	0.464	**-0.754**	0.114	0.239	-0.396	-0.094	**-0.641**	0.096	**0.837**	*0.594*	0.534
S	**0.631**	**-0.650**	0.300	*0.540*	*-0.573*	-0.458	**-0.770**	0.492	**0.913**	0.495	**0.792**
Ca : P Ratio	-0.099	0.248	-0.200	-0.128	-0.050	0.419	0.351	-0.505	-0.375	-0.344	-0.349

All values marked in bold are significant at $p < 0.05$; All values marked in italics are at significant at $p < 0.10$.

Table 7: Pearson Correlation Coefficients for Dietary Parameters (vertical) versus Urine Concentrations (horizontal) for Captive Giraffe from 7 Zoos

	P	Ca	Mg	Na	K	Cl	pH	Crea	P / Crea	Ca / Crea	Mg / Crea	Na / Crea	K / Crea	Cl / Crea
Conc. Intake	-0.143	**0.726**	0.481	-0.294	0.018	-0.039	0.203	0.133	-0.179	-0.235	0.038	-0.538	-0.264	-0.128
Hay Intake	0.105	0.361	-0.285	-0.436	-0.042	0.057	0.011	-0.410	0.220	0.389	0.185	-0.350	**0.627**	0.573
Conc : Hay Ratio	-0.272	0.258	0.502	-0.017	-0.091	-0.251	0.220	0.271	-0.353	-0.300	0.056	-0.199	**-0.645**	**-0.659**
DM Intake	-0.133	-0.216	-0.002	0.053	-0.090	-0.156	-0.028	0.014	-0.267	-0.400	-0.260	0.277	-0.285	-0.224
CP	-0.164	-0.160	0.046	0.032	-0.092	-0.175	0.008	0.031	-0.297	-0.394	-0.228	0.224	-0.316	-0.269
P	-0.363	0.044	0.229	-0.133	-0.114	-0.354	0.275	0.029	-0.445	-0.307	-0.026	-0.043	-0.337	-0.516
Ca	-0.197	-0.065	0.154	0.005	-0.135	-0.226	0.054	0.060	-0.324	-0.380	-0.153	0.145	-0.406	-0.370
Mg	-0.220	-0.033	0.181	0.018	-0.090	-0.190	0.078	0.103	-0.348	-0.384	-0.152	0.110	-0.425	-0.378
Na	0.166	-0.390	-0.145	0.325	-0.012	0.139	-0.363	0.149	-0.002	-0.423	-0.434	0.490	-0.391	-0.012
K	-0.265	-0.236	-0.048	-0.001	0.037	-0.149	0.135	-0.030	-0.376	-0.399	-0.278	0.253	-0.051	-0.145
Cl	0.214	-0.155	-0.083	0.146	-0.188	0.065	-0.439	0.047	0.036	-0.355	-0.320	0.318	-0.456	0.022
S	-0.100	-0.029	0.160	0.003	-0.216	-0.228	-0.049	0.063	-0.227	-0.335	-0.116	0.110	-0.518	-0.395
Ca : P Ratio	**0.612**	-0.114	0.083	**0.605**	0.065	**0.584**	**-0.673**	0.362	0.515	-0.220	-0.336	0.475	-0.331	0.446

All values marked in bold are significant at $P < 0.05$; All values marked in italics are significant at $P < 0.10$.

Table 8: Pearson Correlation Coefficients for Serum Concentrations (vertical) versus Urine Concentrations (horizontal) for captive giraffe from 8 zoos

	P	Ca	Mg	Na	K	Cl	pH	Crea	P / Crea	Ca / Crea	Mg / Crea	Na / Crea	K / Crea	Cl / Crea
P	-0.003	-0.068	0.197	0.026	-0.517	-0.442	-0.067	0.059	-0.040	-0.147	0.268	0.005	**-0.756**	**-0.661**
Ca	-0.003	-0.068	0.197	0.217	0.368	0.172	0.199	0.353	0.081	-0.015	0.074	-0.014	0.206	0.014
Mg	-0.228	**0.684**	0.418	-0.251	-0.267	-0.217	0.283	-0.066	-0.186	**0.684**	**0.640**	-0.273	-0.158	-0.153
Na	-0.105	0.151	0.346	-0.154	-0.544	-0.663	0.144	-0.031	-0.079	0.064	0.474	-0.138	-0.591	**-0.776**
K	-0.002	0.382	-0.242	-0.406	0.530	0.354	0.100	-0.176	0.047	0.524	-0.199	-0.479	**0.784**	**0.622**
Cl	**0.600**	-0.485	**-0.648**	0.182	0.238	0.437	**-0.601**	-0.117	0.568	-0.412	**-0.863**	0.315	0.400	**0.613**
Bi carb	0.042	-0.455	-0.131	0.371	0.465	0.414	0.014	0.180	0.066	-0.483	-0.393	0.331	0.428	0.382
Urea N	-0.565	**0.642**	**0.708**	-0.299	-0.102	-0.483	0.590	0.229	-0.528	0.525	**0.866**	-0.562	-0.380	**-0.736**
Crea.	-0.086	0.068	-0.180	-0.271	-0.593	-0.467	-0.061	-0.461	-0.141	0.176	0.165	0.103	-0.239	-0.221
Total Prot.	0.051	-0.682	-0.586	-0.082	-0.248	-0.205	-0.204	-0.434	-0.015	-0.525	-0.405	0.314	0.031	0.015
Glucose	-0.255	0.418	0.392	-0.180	-0.495	-0.479	0.191	-0.006	-0.273	0.366	**0.617**	-0.199	**-0.612**	**-0.602**

All values marked in bold are significant at $P < 0.05$; All values marked in italics are significant at $P < 0.10$.

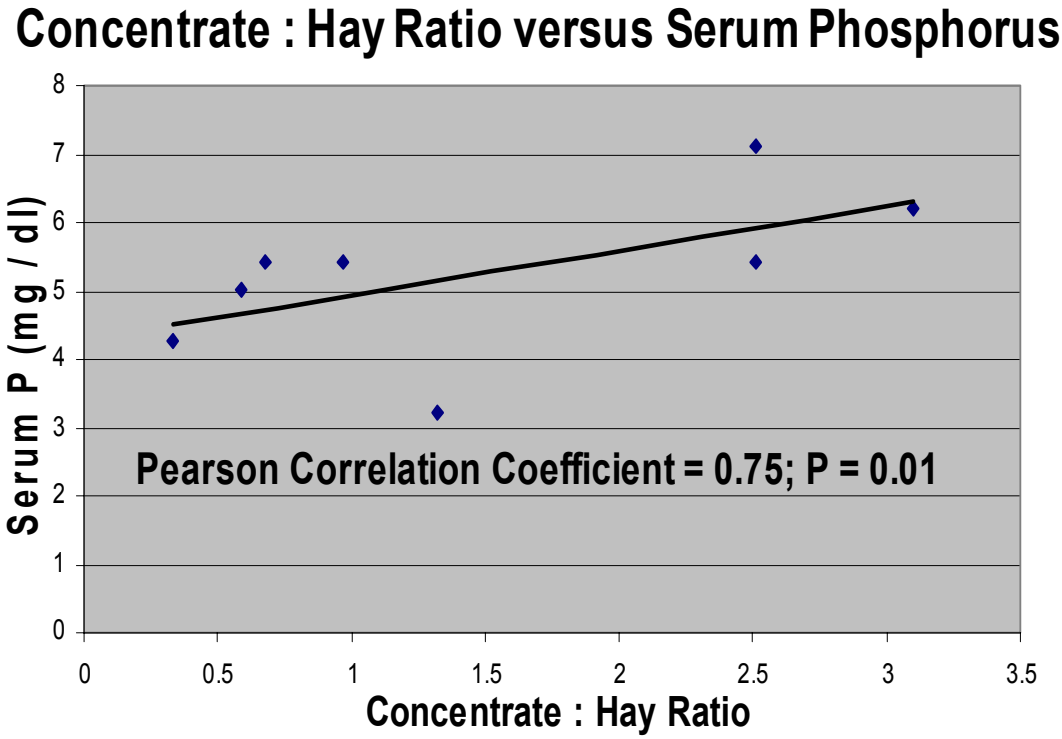

Figure 1: Concentrate to Hay Ratio versus Serum Phosphorus in 8 captive giraffe across 5 zoos

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APPENDIX

Appendix A: Giraffe Nutrition Survey

1. Facility (name, address, phone & e-mail):

2. Primary contact (include e-mail and phone if different than above):

3. How many giraffe does your institution hold? Please list animals with age, gender, origin (if known) and length of time at your institution

4. a). Are your animals fed singly or in a group?

   b). <u>If they are group fed</u>, do other species have access to the food, too? **YES or NO**
   (If so … can you estimate the percentage consumed by other species?)

   c). <u>If they are group fed</u>, are their dominance issue regarding feeding? **YES or NO**
   (If so … could you explain how this may affect daily intake, for example does one animal eat the majority of produce, etc.)

5. Feeds: Please provide the exact brand name, source, form (if appropriate) and amount fed **per animal per day**. (<u>If the animals are fed individually please attach their amounts on a separate page</u>).

   a. Concentrate:

   b. Hay (please include geographic source if possible):

   c. Browse (indicate common or scientific name if known):

   d. Produce:

e. Treats (please include the food used for behavior enrichment as well as the food that is given if / when the public is allowed to feed the animals):

f. Supplements (mineral/salt block or other):

6. How is feed provided?

7. Does your institution conduct feed analysis? **YES or NO**

   Browse analysis? **YES or NO**

   Hay analysis? **YES or NO**

   (If yes, please attach most recent analysis)

8. Do your animals have access to pasture? **YES or NO**

   Live browse? **YES or NO** <u>If yes</u>, do they graze/browse?

9. Water source (circle one): Well City Surface Other (specify)

10. How is water provided? Demand Trough Pond/Stream Other (specify)

11. Are you able to quantify water intake? **YES or NO**

12. Do you conduct water analysis? **YES or NO** (If yes, please attach most recent)

13. Are you able to separate animals for individual study? **YES or NO**

14. Please indicate history in your giraffe collection of any of the following clinical signs or medical conditions:

    a. Urolithiasis

    b. Wasting/poor body condition

    c. Blood around prepuce/vulva

    d. Blood in urine

    e. Renal disease

    f. Straining to urinate/defecate

    g. Oliguria

15. Please indicate history of any of the following **post mortem** findings in your giraffe collection:

    a. Uroliths/renoliths (composition if available)

    b. Wasting

    c. Peracute mortality

    d. Digestive disorders

    e. Dental disease

16. Estimate percentage of time housed indoors? With access to indoor/outdoor holding?

17. Are your giraffe conditioned for blood sampling?

    a. If so, how often do you collect blood samples?

18. Does your institution bank serum samples? **YES or NO**
    If yes, would you be willing to provide samples?

19. Are you able to collect urine from your giraffe? **YES or NO**
    If yes, would you be willing to provide samples?

20. Does your institution conduct urinalysis on giraffe? **YES or NO**

21. Would your institution be willing to participate in a future feeding trial? **YES or NO**

Chapter 3

The impact of two types of complete pelleted feed and two complete pelleted feed to hay ratios on the development of urolithiasis in meat goats

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Introduction

Goats and giraffes are both considered browsing ruminants (Stevens and Hume, 1995). While giraffes in the wild are considered concentrate selectors (feeding mainly on browse, especially the leaves and twigs of the African acacia species), giraffes in captivity in North American zoos have been shown to be fed mainly pelleted concentrate with variable amounts of alfalfa hay and minimal amounts of browse (Chapter 2). Goats are considered browsers though far less selective than giraffes. Domesticated goats may be fed a variety of diets with successful growth depending on their purpose. Goats have been shown to tolerate at least 50% of their diet as grain sorghum, the rest consisting of alfalfa hay, without any negative impact on their fiber digestion (Cerrillo et al., 1999). In the growing industry of meat goats as well as popular show goats, high concentrate diets may be recommended due to faster gain rates, getting more animal for the money invested (Poore and Green, 1995).

Goats of various breeds and purposes have been documented with urolithic stone problems in captivity (Gutierrez et al., 2000, Bellenger et al, 1981, Unanian et al. 1985, Smith and Sherman, 1994). Urolithiasis is a condition of the urinary tract in which mineral concretions develop and aggregate within the bladder and urethra. If the stones become too numerous or too large, they may cause obstruction of the urethra at the vermiform appendage, the ischial arch, or the neck of the bladder, particularly in castrated male ruminants (Pinsent and Cottom, 1987). This condition, termed obstructive urolithiasis, can rapidly progress to bladder or urethral rupture, uremic crisis, and death (Baxendell, 1984). The predominant chemical composition of both goat and giraffe uroliths have been reported to be magnesium ammonium phosphate (commonly called

struvite) or calcium magnesium phosphate in a carbonate form, often with a combination of the two (Unanian et al. 1985, Wolfe et al. 2000, Sato and Omari, 1977, Cooper et al. 1992, Bellenger et al. 1981, Pearce et al. 2003). These stones often occur when a mainly concentrate diet is presented to the goats, with a high phosphorus content. For example, Brazilian goats fed a concentrate ration of three parts corn and one part cottonseed meal with a Ca : P ratio of 1.08 : 1 developed stones (Unanian et al. 1985) and Australian angora male goats fed a feedlot fattening ration with a Ca : P ratio of 0.067: 1 also developed stones (Bellenger et al. 1982). The high phosphorus content can lead to an imbalance of Ca: P ratio, which is recommended to be between 2: 1 – 4: 1 for meat goats (Luginbuhl et al., 2000). Several studies reported a high incidence of urinary calculi in sheep fed a phosphorus supplemented diet (Bushman et al., 1965; Emerick et al., 1972; Hoar et al., 1969) as well as one study reporting the same response in goats (Sato and Omari, 1977). For example, lambs fed a diet with 0.47% phosphorus and 0.31% calcium (a 0.67: 1 Ca: P ratio), developed phosphatic calculi at a 50 to 52 % incidence (Hoar et al., 1969). Six goats developed phosphatic calculi when on a diet containing 0.98% phosphorus, and a Ca: P ratio of 0.08: 1, and one died from obstructive urolithiasis (Sato and Omari, 1977). While these studies demonstrate the positive correlation of high phosphorus in the diet and phosphatic stone formation, there remains debate on other causative factors such as the interrelationships of minerals coming from the diet, the influence of dietary form, and the influence of water intake.

Giraffe have been found to have similar problems with obstructive urolithiasis, as well as reversed Ca: P ratios in captivity. Within the last 10 years, seven giraffe have had phosphatic urolithiasis reported as a cause of death (Wolfe et al. 2000). Reversed Ca: P

ratios have been reported as low as 0.53:1 (Schlegel et al. 2004). The average serum Ca level in captive giraffe is reported as 8.0 ± 0.8 mg /dl based on a sample size of 142 from 42 animals, while the average serum P level in captive giraffe is reported as 10.5 ± 2.9 mg / dl based on a sample size of 135 from 37 animals (ISIS, 2002).

In May of 2005, a group of independent scientific experts in domestic ruminant nutrition and specialists in captive giraffe management met to discuss and establish new feeding guidelines for captive giraffe (Schmidt and Barbiers, 2005). They created recommendations regarding the composition of giraffe diets, in terms of decreasing starch and simple sugar content, protein content, phosphorus content, and increasing fiber. A new complete pelleted feed for wild herbivores was formulated by Mazuri PMI International, based on the recommendations to address these concerns. Our objective was to test this revised diet in comparison to the most prevalently fed commercial diet fed in North America to captive giraffe according to recent survey data (Chapter 2). We also aimed to compare two opposing complete pelleted feed to hay ratios, which would serve to investigate differing levels of fiber content in a diet for wild herbivores. Goats were used as a model species for wild herbivores such as the giraffe, as they are browsing ruminant herbivores. Overall, we aimed to investigate the effects of the new diet formulation compared to the older, as well as differing complete pelleted feed to hay ratios, on the formation of urolithic compounds, urinary pH and other indicators of health, such as nitrogen and phosphorus balance. Based on previous studies, we would expect to see ultimately more urolithic compound formation and higher levels of phosphorus for all parameters in goats fed a diet with a high level of complete pelleted feed and high phosphorus content.

Materials and Methods

Animals and Equipment:

This experiment was a randomized complete block design with 18 Boer cross male uncastrated goats in 4 treatments and 4 replicates blocked by weight (16 animals) with 2 spare animals starting at approximately 23.5 kg ± 4.0 kg. All replicates were run simultaneously at the North Carolina State University Metabolism Education Unit where all bucks were housed. Each buck was kept in a metabolism crate, half in plastic crates that were 1.57 m by 1.24 m by 0.77 m, and half in wooden crates 1.37 m by 1.37 m by 0.64 m. The bucks in both sets of crates had access to water ad libitum. The plastic crates had water in 1 quart buckets weighed and refilled daily. The wooden crates had inverted jugs with stoppers and tubes leading to trays where the bucks could access them. The jugs were weighed and refilled as necessary.

Treatments:

Four treatments that were arranged in a 2 by 2 factorial design were used in this trial. Factors consisted of diet (two types of Mazuri PMI Nutrition International brand complete pelleted concentrate ration, ADF-16, and Wild Herbivore (WH)) and diet to hay ratio (2 ratios, 20% alfalfa hay to 80% complete pelleted feed; and 80% alfalfa hay and 20% complete pelleted feed (Table 1)). During the 2 weeks of standardization, the goats were adjusted gradually to the ratio and complete pelleted feed treatment they were assigned. In order to ensure these ratios, the goats were fed at a rate of 115% of their previous day's intake at the appropriate ratios.

Procedure:

Eighteen bucks were obtained from an auction in Monroe, NC in early March 2006. They were dewormed with cydectin. They were vaccinated for Clostridium Perfringens types C and D / tetanus toxoid at 2 cc / animal. They were group housed in quarantine and group fed and watered. Corid was placed in the water for 10 days to control coccidia infection. The bucks were group fed approximately 2% of the goat's total weight as concentrate. The complete pelleted ration fed during this adjustment period consisted of 50% WH and 50% ADF-16. Gamma grass hay was fed ad libitum and a salt block was available. Goats were also fed 2 % of their total body weights as alfalfa hay beginning on April 1, 2006. On April 24, 2006 the bucks were brought into the barn and put into individual metabolism crates for standardization.

The four goats on each replicate and 2 spare animals were allowed 2 weeks of standardization to their diets, metabolism crates and watering systems. Once per week during both the standardization and trial period, all goats were simultaneously allowed approximately 4 hours of exercise in a 4.27 m by 4.57 m outdoor pen. Metabolism crates were cleaned daily. After the 2 weeks of standardization, a 28 day trial period began. There were 2 experimental periods of 2 weeks, with a 7 day adjustment before the 2 day harness adjustment, then a 5 day fecal and urine collection.

Diets:

At the start of the standardization period individual goats were fed 3.5% of their body weight, half as alfalfa hay and half as complete pelleted feed. The complete

pelleted feed which was fed consisted of 50% WH and 50% ADF-16. As soon as the standardization period began, the amount of hay was either increased or decreased in 10% increments over 8 days. After the desired complete pelleted feed: hay ratio was reached, the type of complete pelleted feed was gradually adjusted by 25% every 3 days, to either 100% WH or 100% ADF-16. Due to high consumption, amount of diet offered was also raised to 4% of each individual's body weight by the end of the standardization period. In order to ensure ad libitum intake while retaining the proper ratios, the amount of complete pelleted feed and alfalfa hay offered were calculated daily, based on 115% of each individuals' actual consumption on the previous day.

During the 28 day metabolism trial, orts were removed and quantified once daily, in the morning. Feed was weighed out once daily in the morning as 115% of previous day's total intake in the proper ratios. One hundred percent of complete pelleted feed was offered at the AM feeding and 35% of the hay was offered at the AM feeding (9:00AM) and the other 65% was offered at the PM feeding (3:30PM).

Measurements:

A 50 g feed sample of each type of complete pelleted feed and of alfalfa, was collected daily throughout the experiment, except on fecal harness adjustment days (the 2 days prior to the start of collections). These samples were pooled each week. Orts were composited for each individual animal to correspond with the feed samples. The total sample yield being 4 alfalfa hay samples (one for each week of the trial), 4 ADF 16 complete pelleted feed samples, 4 Wild Herbivore complete pelleted feed samples, and 64 ort samples (32 total orts separated for complete pelleted feed and hay).

Water:

A 50 ml sample of water was taken from the faucet the animals' drinking water was drawn from on a daily basis and the samples composited for the weeks preceding the fecal harness adjustment days and for the collection periods. No samples were taken during adaptation to the fecal harnesses. As the two types of crates had different watering systems, different procedures were used for each one.

Plastic crates: Water was checked daily in the AM. If water depth was less than 2 in., the water bucket was removed, weighed, and residual weight recorded to allow calculation of disappearance. The weigh back was discarded and fresh water added. The bucket was weighed again and its new weight recorded. If an animal spilled his bucket it was noted. If there was a significant amount of feed in the water at the time of weigh back, it was to be removed and put into a forced air oven at 55° C to dry. After it had dried and air equilibrated, it was weighed, the weight recorded, and the dried weigh back added to the total weekly feed weigh back before sampling and subtracted from water intake. This was not a common problem during this experiment.

Wood crates: Water was checked daily in the AM. If the water was within 2 in. of the neck of the bottle, the water bottle and tray was removed to ensure no water was spilled during the removal process. The contents of the tray were emptied into the bottle with the aid of a funnel and the bottle was then weighed and the weight recorded to allow calculation of disappearance. If there was feed in the tray, the procedure described above for the plastic crates was followed, but this was not a problem during this experiment. The water weigh back was discarded and fresh water placed into the water bottle. The

water bottle was reweighed and its weight recorded with the fresh contents. The bottle and tray then returned to the correct crate. If water was spilled into the feeder by the animal, it was noted.

Sampling:

Fresh Urine: On the first and third day of the collection periods, upon arrival in the AM, a clean, dry, tared bucket was placed under each urine funnel/spout and the acidified urine from the previous day moved aside in a location where it could not be spilled or contaminated. To obtain a fresh sample, we waited for each animal to urinate into the clean bucket. Fresh urine volume had to be at least 50 ml before processing.

As each animal urinated, the fresh urine was removed in its bucket from underneath the urine spout/funnel. A separate clean bucket was placed under the urine spout/funnel. The fresh urine was immediately taken into the lab, weighed, and the weight recorded. The bucket was swirled to mix the urine, pH was determined using a pH meter, and then a representative sample of 50 ml was removed using a tared volumetric flask. The 50 ml sample was then weighed and the specific gravity calculated (weight in g / 50 ml). For crystal examination, 10 ml was removed from the 50 ml and the remaining 40 ml was returned to the new bucket at the crate from which it was removed. The fresh urine was combined with the total urine from the 24 h period it was collected. The bucket with the remaining 40 mL of urine was transferred into the clean bucket using two aliquots of 50 mL of water to ensure all the rinsate went into the new bucket.

Total Urine: One composited sample of at least 250 ml was obtained for each goat for each 5 d collection period. Buckets used for the collection were tared in advance of the collection. Sulfuric acid was used to maintain total urine pH between 3 and 5 to prevent loss of N from ammonia development. The bucket containing the acidified urine collected over the preceding 24 h was removed. It was replaced with a clean, dry bucket. Total urine pH was determined using pH paper sensitive to pH 1-12 and recorded. Total urine pH was maintained in 3-5 range. If pH > 5, enough acid was added to obtain the desired pH of 3 – 5 and the volume of the acid added recorded. If pH < 3, the total acid added to the urine was reduced slightly to obtain the desired pH during the next 24 h collection interval. A gross weight on the total urine with all acid additions was determined. The bucket tare weight was subtracted to calculate net urine weight.

The volume of the total urine was determined using a 1000 ml graduated cylinder. The specific gravity of the total acidified urine was calculated (weight in g / volume in ml). The urine was then sub-sampled at the % determined for each animal on day 1 of the collection. (Sample size % = 50 / total weight x 100 or 5%, whichever was greater). Sub-samples were obtained by weighing them into clean, dry containers (one per animal) which could then be sealed for transporting them to a freezer. When all of the sub-samples were obtained, they were added to the composite urine samples for each individual animal. Composite samples were stored at all times in a freezer at -20°C.

Feces: Total feces were collected from all animals by means of a collection harness and sub-samples obtained to yield about 100 g DM for the 5 day collection period. The assumption that goat feces are 40% DM was used to determine sub-sampling proportion. This assumption led to the conclusion that approximately 50 g of wet feces from each

animal should be saved for each of the 5 days. Sampling proportion was determined on day 1 of the collection and held constant for each animal for the 5 days. (Sub-sample % = 50 / weight of feces in g x 100 or 5%, whichever is greater). Fecal samples were composited daily by animal by placing them into a common container in a forced air oven (55° C).

Fecal collection harnesses were placed on the goats 2 days prior to collection initiation to allow adjustment of the animals to the harnesses. The feces in the harnesses were collected twice daily for the duration of the time the animals wore them. During the adjustment period feces were discarded.

At the initiation of the collection, the harnesses were vacated one after the other beginning at the designated start time. The harnesses were vacated every 24 h at approximately the same time. During the collection, each animal's feces was placed into a tared bucket that had been designated for that individual animal and the bucket placed near that animal's crate in a location where it could not be spilled or contaminated.

To obtain a daily sub-sample, the bucket and its contents were weighed to determine gross weight. The tare weight was subtracted to determine net weight. Sub-sample size was determined from the net weight. After thoroughly mixing the feces, by churning it by hand with clean gloves for each animal, a representative sub-sample was removed and placed in an appropriately labeled weigh pan. When all the sub-samples for a given day were obtained, they were transported to the oven and placed into composite containers designated for each animal. Only after the sub-samples were safely in their composite containers was excess feces discarded.

Blood: Blood samples were taken from each animal on the day the animals arrived at the MEU and on the last day of each collection period using 20 gauge x 1.5 inch needles. Blood was drawn into untreated 10 ml vaccutainer tubes. Blood samples were held on ice for a maximum of 4 hours after which they were centrifuged at 3000 rpm. The serum was collected and stored at -20 C until it was analyzed approximately 2 months later.

Ruminal fluid: Ruminal fluid was obtained on the last day of the experiment by rumenocentesis. The technique involved the use of a 2 in. x 14 gauge needle that was inserted through the body wall into the ventral sac of the rumen with the animal restrained by hand. A 25 ml plastic exocentric syringe was used to extract the fluid from the rumen with gentle suction, specifically 10 ml of air was first drawn in to the syringe, the needle was inserted and when ruminal fluid was seen, the syringe was attached to the needle. Ruminal fluid was then gently drawn into the syringe with the exocentric "top part" up. If the syringe clogged air was pushed back through the needle to clear it, and maintain fluid flow. A minimum of 5 ml of fluid was obtained from each goat. The procedure took approximately one minute, and usually only one insertion of the needle was needed. All samples were kept on ice for a maximum of 2 hours until storage in a -20°C freezer.

Lab Analysis

A total of 97 samples of hay, complete pelleted feed and feces underwent the process to determine air equilibrated percent dry matter. This was done by drying a predetermined sample weight in a 60° C oven for 48 hours then weighing, followed by 72 hours in a vented area to air equilibrate and then reweighing. All samples were then

ground using a Wiley Mill through a 1 mm screen. The samples were then analyzed for dry matter content in the laboratory, by drying a predetermined sample size between 0.9995 – 1.005 g overnight at 105° C, allowing 2 hours in a dessicator and reweighing the samples. The samples were then placed in a muffle furnace for at least 5 hours to determine ash content, and organic matter was calculated by subtracting % ash of the sample from 100%.

According to Goering and Van Soest (1970), with modifications according to Van Soest and Robertson (1980), samples were analyzed for neutral detergent fiber (NDF), acid detergent fiber (ADF), cellulose and lignin. Hemicellulose was calculated as (NDF – ADF). Nitrogen was analyzed according to the procedure described by AOAC (1990) for the semi-automated Kjehldahl method for nitrogen determination.

Serum samples were analyzed for large animal serum chemistries using an automated wet chemistry analyzer, the Hitachi 917, which measured sodium (Na), potassium (K), chloride (Cl), calcium (Ca), magnesium (Mg), phosphorus (P), creatinine, anion gap, glucose, globulin, total protein, sorbitol dehydrogenase (SDH), alkaline phosphatase (ALK PHOS), total bilirubin, direct bilirubin, indirect bilirubin, total iron binding capacity (TIBC), bicarbonate, blood urea nitrogen (BUN), albumin, albumin / globulin ratio (A/G), aspartate aminotransferase (AST), gamma-glutamyltransferase (GGT), iron (Fe) and percent saturation (Cornell Veterinary Diagnostic Laboratory, Ithaca, NY 14850). Urine samples were analyzed for a urinary electrolyte and mineral panel measuring Ca, P, Mg, Na, K, Cl, and creatinine (Cornell Veterinary Diagnostic Laboratory, Ithaca, NY). The Hitachi 917 was also used for all urine sample analysis.

Rumen fluid samples were analyzed for rumen ammonia and volatile fatty acids. Rumen ammonia was measured via nitrogen analysis according to AOAC (1990). Rumen fluid was thawed at air temperature and mixed well by inverting the tubes. Samples were transferred to Sorvall round bottom tubes and spun at 2000 rpm in a Damon IEC Sorvall floor model centrifuge. After centrifugation 1 ml of the clear supernatant was pipetted into a 15 ml test tube and 0.2 ml of 25% w/v meta-phosphoric acid was added. The tubes were covered and mixed by inversion and stood for 30 minutes. The tubes were then centrifuged at 2000 rpm for 10 minutes. With a disposable pipette, the clear supernatant was removed to a small test tube. The small test tubes were then centrifuged again at 2000 rpm for 10 minutes. Next, 0.8 ml of sample was pipetted into a gas chromatography vial and 80 µl of internal standard was added (2-ethyl butyric acid) and mixed well by inversion of the tubes. The samples were kept refrigerated until analysis on the gas chromatograph.

Short chain fatty acids concentrations were determined using a Varian 3800 gas chromatograph with a Varian 8200 autosampler (Chromatography Systems Business, Sugar Land, TX, 77478). The volatile fatty acids were analyzed using a Nukol fused silica capillary column (30m X 0.25mm X 0.25um film thickness, Supelco Park, Bellefonte, PA). Duplicate injections of 0.5 µL were analyzed using a 1:25 split. The injector and the detector were 25°C. The carrier gas was N. Column pressure was 25 psi and the initial start temperature in the column was 100°C, increased to 150°C at the rate of 60°C per minute and held there for 5 minutes. The temperature was then raised to 175°C for an additional minute to help clean the column.

The 97 collected hay, pellet and fecal samples were analyzed for Ca, P, and Mg using a Thermo Jarrell Ash IRIS Advantage Inductively Coupled Plasma (ICP) Radial Spectrometer.

Statistical Analysis

All data were analyzed by analysis of variance using Proc GLM and Proc Mixed of SAS (Cary, NC, 27511). Treatment main effects and their interactions, replicates, and collection time were compared using Proc Mixed for nutrient digestibility, retentions, body weight, and all serum and urine parameters using the PDIFF option of the least significant difference test when the model was significant ($P \leq 0.05$). Treatments and replicates were compared using Proc GLM, for rumen ammonia and volatile fatty acids using the least significant difference test when the model was significant ($P \leq 0.05$).

Results:

All 18 goats successfully underwent this trial in good health. When examining our analysis of the 2 complete pelleted feeds and alfalfa hay used for the diets compared to the estimates given by the Mazuri company estimated nutrient composition (Table 1), our analysis found similar nutrient content with notably higher levels of crude protein for the wild herbivore (WH) and ADF-16 complete pelleted feed. The actual composition of the complete pelleted feed and hay combinations given to the goats (Table 2) shows the treatments to differ most in crude protein, fiber and mineral content. The lowest Ca to P ratio (1.6 to 1) was seen in the treatment with 80% of the diet fed as ADF-16 complete pelleted feed and 20% of the diet as alfalfa hay. The treatments using Wild Herbivore (WH) complete pelleted feed had higher levels of the fiber components NDF, ADF, and cellulose as well as Mg, with the greatest levels of these nutrients in the 20% hay with 80% WH complete pelleted feed.

Body weight of the goats increased over time (Table 3). Dry matter intake was higher when the hay was 20 % of the diet ($P < 0.05$). Dry matter digestibility, Ca digestibility and P digestibility were not affected by dietary treatments, though Ca digestibility increased over time ($P < 0.05$) (Table 4). Animals on a diet with ADF-16 pellets had lower digestibilities of NDF, ADF, and cellulose than those given WH pellets ($P < 0.05$) (Table 4). Digestibility of NDF, ADF, and cellulose were greater ($P < 0.05$) in goats fed 80% hay compared to 20% hay within the ADF-16 treatments, but not the WH treatments. Digestibility of N was higher in goats fed hay as 80 % of the diet compared to those animals fed hay as 20% of the diet, ($P < 0.05$) and was higher on the diet using ADF-16 pellets compared to WH pellets ($P < 0.05$). Ash digestibility decreased over

time, as well as being higher in goats fed the ADF-16 pellet, and higher for goats fed hay as 80 % of the diet ($P < 0.05$) (Table 4). Also, ash digestibility was lowest in goats fed WH complete pelleted feed with hay as 20 % of the diet ($P < 0.05$). Digestibility of Mg was significantly higher in goats fed hay as 20 % of the diet compared to those fed hay as 80% of the diet. While digestibilities had multiple significant interactions, retention was not as intriguing (Table 5). Ca and Mg retention increased from collection period 1 to period 2 ($P < 0.05$). N retention had significant main effects, with retention decreasing over time. Retention of N was also lower in goats fed hay as 80% of the diet compared to those fed hay as 20 % of the diet ($P < 0.05$).

When examining the serum mineral baseline concentrations and the concentrations from the 2 collection periods (Table 6), only P, K, Mg and Fe were affected by dietary treatments. The K concentration was higher in goats fed hay as 20% of the diet compared to those animals fed hay as 80 % ($P < 0.05$). Serum P concentration significantly increased from the baseline value to the first collection period. Serum P decreased in the second collection period, but only when goats were fed hay as 20 % of the diet (Table 6). Iron and Mg both increased from the baseline value to the first collection period values ($P < 0.05$). Iron was higher in goats on the WH treatment fed hay as 20% of the diet, compared to those on the WH treatment fed hay as 80 % of the diet ($P < 0.05$). Iron was also higher in goats fed the ADF-16 complete pelleted feed with hay as 80 % of the diet, compared to the goats fed the WH complete pelleted feed with hay as 80 % of the diet ($P < 0.05$). It should be noted that although there were no significant main effects for Ca to P ratio, the only treatment to decrease from the baseline value was the ADF-16 diet fed with hay as 20 % of the diet (Table 6).

Serum concentrations of bicarbonate, total protein, creatinine, and glucose were not affected by dietary treatments (Table 7). Serum urea N was higher for treatments with hay as 80 % of the diet compared with the treatments with hay as 20 % of the diet ($P < 0.05$), and increased from the baseline to the first collection period value ($P < 0.05$). Globulin was higher in animals fed the ADF-16 complete pelleted feed with hay as 80 % of the diet compared to those fed the ADF-16 diet with hay as 20 % of the diet ($P < 0.05$), but not for those fed the WH complete pelleted feed (Table 7). Sorbitol dehydrogenase (Sdh) was significantly higher when the type of diet fed was WH, and increased from the baseline value to the first collection period ($P < 0.05$). Alkaline phosphatase (Alk Phos), gamma-glutamyltranspeptidase (GGT), creatine kinase (CK) and total iron binding capacity (TIBC) significantly increased from the baseline value to the first collection period (Table 7).

All the urinary mineral concentrations measured were affected by dietary treatments, although urine creatinine was not (Table 8). Urinary Na was higher in animals fed hay as 20 % of the diet compared to those fed hay as 80 % of the diet, ($P < 0.05$) but only during the 2 collection periods for animals on the WH complete pelleted feed ($P < 0.05$), and only for the baseline and first collection period for animals on the ADF-16 complete pelleted feed ($P < 0.05$). Animals fed the WH complete pelleted feed had increased urinary Na from the baseline to the first collection period and the baseline to the second collection period, but only when fed the diet with hay as 20 % of the diet ($P < 0.05$). Urinary K, Ca, P and Mg all increased over time from the baseline value to the first collection ($P < 0.05$). It should be noted that values reported for urinary P only, are reported as actual means rather than least squared means. Urinary Cl was higher in goats

fed the treatment using WH complete pelleted feed with hay as 20 % of the diet ($P < 0.05$), compared with the WH diet fed with hay as 80 % of the diet (Table 8). However, urinary Cl did not affect the treatments using ADF-16 as the complete pelleted feed. Urinary Ca was higher in goats fed the treatment using WH complete pelleted feed with hay as 20 % of the diet ($P < 0.05$) compared to goats fed the treatment using ADF-16 complete pelleted feed with hay as 20 % of the diet. Urinary Mg was highest in goats fed with the treatment using WH complete pelleted feed with hay as 20 % of the diet ($P < 0.05$) compared with all of the other 3 treatments (Table 8).

When urinary mineral concentrations were standardized by dividing all values by the corresponding values of urine creatinine, there were fewer significant interactions (Table 9). For standardized urinary Na, the same 3 way interactions were present. Standardized urinary K showed an increase from the baseline values to the first collection values ($P < 0.05$), with a significantly higher increase for the treatment with hay as 80% of the diet compared to the treatment with hay as 20 % of the diet (Table 9). Standardized urinary Cl showed a different significant effect than non-standardized Cl in that it decreased from the baseline value to the first collection value ($P < 0.05$). Urinary Ca no longer had significant treatment effects once standardized. Standardized urinary Mg was significantly higher when the goats were fed hay as 20 % of the diet. Standardized urinary P increased from the baseline value ($P < 0.05$), (though not significantly) when the diet type was ADF-16 with hay as 20 % of the diet (Table 9).

Analysis of urine crystal scoring supported a trend ($P < 0.10$) of a higher crystal score when hay was 20 % of the diet compared to when hay was 80 % of the diet (Table 10). The number of crystals varied greatly with a large standard error, but increased from

collection 1 to collection 2 ($P < 0.05$). A majority of the crystals counted were visually identified as calcium phosphate. Urine pH was higher when hay was 80 % of the diet compared to when hay was 20 % of the diet ($P < 0.05$). Urine pH was also higher when the diet was WH compared to when it was ADF-16 ($P < 0.05$) (Table 10).

The volatile fatty acid composition of the rumen fluid obtained by rumenocentesis was considered normal, with significant differences for acetic acid, valerate and rumen ammonia (Table 11). All three variables were different among the types of diet the animal was receiving. Valerate was significantly higher in goats on the treatment with ADF-16 complete pelleted feed compared with the WH complete pelleted feed. Acetic acid was lower in goats fed the treatments with ADF-16 compared to those fed WH complete pelleted feed ($P < 0.05$). Rumen ammonia was significantly higher for animals on the ADF-16 dietary treatments compared to those on the WH dietary treatments (Table 11).

Also monitored was the goat's intake of water per day (Table 12). The only significant difference was that when hay was 20% of the diet on either ADF-16 or WH during collection period 2, the goats drank more water than when hay was 80% of the diet. No other comparisons showed any significance.

The balance of intake, N, P, Ca, and Mg was calculated for each collection period for all goats (Table 13). Hay intake was higher when hay was 80% of the diet, and highest when hay was 80% of the ADF- 16 diet in the first collection period ($P < 0.05$). Complete pelleted feed intake was higher when hay was 20% of the diet ($P < 0.05$), and highest when the WH diet was fed with hay as 20 % of the diet ($P < 0.05$). Fecal output was higher when hay was 20% of the diet ($P < 0.05$). Fecal output was highest when the

WH diet was fed with hay as 20 % of the diet ($P < 0.05$). N balance was found to be higher in the first period compared to the second ($P < 0.05$). N balance was also higher when hay was 20% of the diet ($P < 0.05$). Intake of N was not significantly different between treatments and time. Fecal N was higher when hay was 20% of the diet ($P < 0.05$). Urine N was higher in the second collection period, higher when the complete pelleted feeds was ADF-16, and higher when hay was 80% of the diet ($P < 0.05$). P balance was found to be higher when hay was 20 % of the diet and when the complete pelleted feed was ADF-16 ($P < 0.05$). P intake was highest when hay was 20% of the diet and ADF-16 was the complete pelleted feed ($P < 0.05$). Fecal P is higher when hay is 20% of the diet ($P < 0.05$), and when ADF-16 was the complete pelleted feed ($P < 0.05$). Urine P was higher during the second collection period. Ca balance was higher in the second collection period ($P < 0.05$). Intake of Ca was higher in the second collection period ($P < 0.05$), and highest when hay was 80% of the diet and WH was the complete pelleted feed ($P < 0.05$). Fecal Ca was higher when hay was 80% of the diet in the second collection period ($P < 0.05$). Urine Ca is highest when hay is 20% of the diet and WH was the complete pelleted feed ($P < 0.05$). Mg balance was highest when hay was 20% of the diet and the WH diet was fed ($P < 0.05$). Intake of Mg was highest when hay was 20% of the diet and the WH diet was fed ($P < 0.05$). The same relationship existed with fecal and urine Mg ($P < 0.05$). Intake of Mg was higher when hay was 20% of the diet ($P < 0.05$) and when WH was fed ($P <0.05$). Fecal Mg was higher when WH was the complete pelleted feed ($P < 0.05$). Urine Mg was higher at the second collection ($P < 0.05$) and was higher when hay was 20% of the diet ($P < 0.05$).

Table 1: Analyzed composition of diet components on a dry matter basis used to feed 18 male uncastrated Boer -cross meat goats versus Mazuri estimates of nutrient analysis on an as fed basis

	Analyzed Composition			Mazuri Approximate Nutrient Composition	
	ADF - 16	Wild Herbivore	Alfalfa Hay	ADF- 16	Wild Herb
DM %	90.8	91.5	90.3	NR[1]	NR
Moisture %	9.2	8.5	9.7	NR	NR
OM %	91.7	92.0	89.9	92.6	92.7
Ash %	8.3	8.1	10.1	7.4	7.3
NDF %	30.0	54.4	43.9	29.0	50.0
ADF %	15.1	35.9	29.3	15.5	34.1
Cellulose %	11.6	32.8	22.8	NR	NR
CP %	19.4	14.2	20.2	17.1	12.6
Ca %	0.8	1.0	1.5	0.8	0.8
P %	0.7	0.4	0.2	0.7	0.4
Mg %	0.4	0.4	0.4	0.3	0.3
Ca to P Ratio	1.2	2.6	6.4	1.2	2.1

[1] NR = Not reported

Table 2: Nutritional content of 4 dietary treatments on a DM basis for 18 male uncastrated Boer- cross meat goats

	ADF-16		Wild Herbivore	
Hay as % of diet	Hay = 20 %	Hay = 80 %	Hay = 20 %	Hay = 80 %
DM %	90.73	90.39	91.29	90.53
Moisture %	9.27	9.61	8.71	9.47
OM %	91.37	90.27	91.54	90.31
Ash %	8.63	9.73	8.46	9.69
NDF %	32.77	41.10	52.26	45.98
ADF %	17.90	26.43	34.58	30.60
Cellulose %	13.82	20.52	30.78	24.75
CP %	19.52	20.05	15.42	19.02
Ca %	0.96	1.33	1.07	1.36
P %	0.60	0.32	0.35	0.26
Mg %	0.35	0.37	0.42	0.39
Ca to P Ratio	1.60	4.16	3.06	5.23

Table 3: Dry matter intake and body weight by 18 male uncastrated Boer cross goats on one of 4 diets during 2 one week collection periods

	ADF-16		Wild Herbivore[1]		Mean Hay to Concentrate Ratio[2]		Mean Diet[3]		
	Hay = 20	Hay = 80	Hay = 20	Hay = 80	0.25	4.00	ADF- 16	WH	P-value
DM Intake (kg / 5 d)									
Collection 1	5.95	5.41	6.92	4.72	6.44	5.06	5.68	5.82	
Collection 2	6.03	5.01	6.86	5.19	6.44	5.10	5.52	6.02	
Mean	5.99	5.21	6.89	4.95	6.44	5.08	5.60	5.92	H[a]
BW (kg)									
Collection 1	26.6	28.2	28.9	26.8	27.8[b]	27.5[b]	27.4	27.9	
Collection 2	30.9	30.9	33.1	29.8	32.0[a]	30.4[a]	30.9	31.5	
Mean	28.8	29.6	31.0	28.3	29.9	28.9	29.2	29.7	P[a] P*H[a]

[a] – $P < 0.05$
[1] – SEM for individual interactions of DM intake = 0.30; of BW = 1.19;
[2] – SEM for mean hay to concentrate ratio interactions of DM intake = 0.22; of BW = 0.90
[3] – SEM for mean type of diet interactions of DM intake = 0.21; of BW = 0.84
H = significant interaction for Hay to Concentrate ratio; H*D = significant interaction between Hay to concentrate ratio and type of diet interaction; P = significant interaction for collection period; P*H = significant interaction between collection period and hay to concentrate ratio interaction; D = significant interaction for type of diet; P*H*D = significant 3 way interaction between collection period, hay to concentrate ratio, and type of diet; NS = not significant

Table 4: Digestibility of dietary components of 18 male uncastrated Boer -cross goats on one of 4 diets during 2 one week collection periods

	ADF-16		Wild Herbivore[1]		Mean Hay to Concentrate Ratio[2]		Mean Diet[3]		
	Hay = 20	Hay = 80	Hay = 20	Hay = 80	0.25	4.00	ADF- 16	WH	P-value
DM Digestibility %									
Collection 1	69.1	67.2	67.4	67.4	68.3	67.3	68.1	67.4	
Collection 2	69.3	67.8	65.8	67.9	67.7	67.8	68.7	66.9	
Mean	66.7	64.9	64.9	65.2	68.0	67.6	68.4	67.1	NS
N Digestibility %									
Collection 1	74.4	76.4	68.5	74.9	71.4	75.7	75.4	71.7	
Collection 2	75.2	77.0	68.6	76.0	71.9	76.5	76.1	72.3	
Mean	74.8 [b]	76.7[b]	68.5[a]	75.5 [b]	71.6	76.1	75.7	72.0	H[a] D[a] H*D[a]
NDF Digestibility %									
Collection 1	44.6	53.4	62.5	58.9	53.6	56.1	49.0	60.7	
Collection 2	46.8	55.7	60.5	61.5	53.6	58.6	52.1	61.0	
Mean	45.7[c]	54.5[b]	61.5[a]	60.2[a]	53.6	57.4	50.1	60.9	H[a] D[a] H*D[a]
ADF Digestibility %									
Collection 1	38.3	48.2	60.3	55.2	49.3	51.7	43.2	57.8	
Collection 2	39.9	49.1	56.6	56.2	48.2	52.7	44.5	56.4	
Mean	39.0[c]	48.7[b]	58.5[a]	55.7[a]	48.8	52.2	43.9	57.1	D[a] H*D[a]
Cellulose Digestibility %									
Collection 1	48.8	59.0	66.7	62.3	57.8	61.9	53.9	65.8	
Collection 2	49.2	59.6	62.3	64.9	55.8	62.3	54.4	63.6	

Table 4 continued

									H^a D^a
Mean	49.0^c	59.3^b	64.5^a	64.9^a	56.7	62.1	54.2	64.7	$H*D^a$
Ash Digestibility %									
Collection 1	60.1	62.9	54.6	62.0	57.4	62.4	61.5	58.3	
Collection 2	59.8	55.9	51.0	56.2	55.4	56.0	57.8	53.6	
									P^a H^a D^a
Mean	59.9^b	59.4^b	52.8^a	59.1^b	56.4	59.2	59.6	56.0	$H*D^a$
P Digestibility %									
Collection 1	36.1	39.9	33.3	42.1	34.7	41.0	38.0	37.7	
Collection 2	40.7	35.4	40.3	46.0	40.5	40.7	38.0	43.2	
Mean	38.4	37.6	36.8	44.1	37.6	40.9	38.0	40.4	NS
Ca Digestibility %									
Collection 1	21.1	17.3	18.3	18.0	19.7	17.7	19.2	18.2	
Collection 2	31.2	22.2	27.5	23.6	29.3	22.9	26.7	25.6	
Mean	26.2	19.7	22.9	20.8	24.2	20.3	22.9	21.9	P^a
Mg Digestibility %									
Collection 1	41.8	37.8	42.4	39.5	44.4	39.8	39.8	41.0	
Collection 2	45.0	35.2	44.6	39.0	44.8	38.3	40.1	41.8	
Mean	43.4	36.5	43.5	39.3	44.6	39.0	39.9	41.4	H^a

[a] – $P < 0.05$

[1] – SEM for individual interactions of DM digestibility = 1.08; N digestibility = 1.05; NDF digestibility = 1.72; ADF digestibility = 1.83; Cellulose digestibility = 1.83; Ash digestibility = 1.59; P digestibility = 5.26; Ca digestibility = 3.73; Mg digestibility = 3.08;

[2] – SEM for mean hay to concentrate ratio interactions of DM digestibility = 0.74; N digestibility = 0.75; NDF digestibility = 1.24; ADF digestibility = 1.32; Cellulose digestibility = 1.32; Ash digestibility = 1.14; P digestibility = 3.77; Ca digestibility = 2.68; Mg digestibility = 2.21;

[3] – SEM for mean type of diet interactions of DM digestibility = 0.76; N digestibility = 0.76; NDF digestibility = 1.22; ADF digestibility = 1.29; Cellulose digestibility = 1.30; Ash digestibility = 1.13; P digestibility = 3.72; Ca digestibility = 2.65; Mg digestibility = 2.18;

H = significant interaction for Hay to Concentrate ratio; H*D = significant interaction between Hay to concentrate ratio and type of diet interaction; P = significant interaction for collection period; P*H = significant interaction between collection period and hay to concentrate ratio interaction; D = significant interaction for type of diet; P*H*D = significant 3 way interaction between collection period, hay to concentrate ratio, and type of diet; NS = not significant

Table 5: Retention of minerals of 18 male uncastrated Boer- cross goats on one of 4 diets during 2 one week collection periods

	ADF-16		Wild Herbivore[1]		Mean Hay to Concentrate Ratio[2]		Mean Diet[3]		
	Hay = 20	Hay = 80	Hay = 20	Hay = 80	0.25	4.00	ADF- 16	WH	P-value
N Retention %									
Collection 1	36.4	27.3	39.0	31.1	35.9	27.5	30.2	33.1	
Collection 2	30.8	23.3	33.5	28.2	26.8	22.1	23.3	25.6	
Mean	33.6	25.3	36.2	29.7	31.4	24.8	26.8	29.4	H[a] P[a]
P Retention %									
Collection 1	35.4	40.0	33.2	42.1	34.3	41.0	37.7	37.6	
Collection 2	39.9	35.5	40.3	47.5	40.1	40.8	37.7	43.2	
Mean	37.6	37.7	36.8	44.1	37.2	40.9	37.7	40.4	NS
Ca Retention %									
Collection 1	20.2	16.3	17.2	17.2	18.7	16.8	18.3	17.2	
Collection 2	31.2	22.1	27.5	23.6	29.3	22.9	26.7	25.6	
Mean	25.7	19.2	22.4	20.4	24.0	19.8	22.5	21.4	P[a]
Mg Retention %									
Collection 1	20.4	19.9	22.7	23.1	21.6	21.5	20.2	22.9	
Collection 2	45.0	35.1	44.6	39.0	44.8	37.1	40.0	41.8	
Mean	32.7	27.5	33.7	31.1	33.1	29.3	30.1	32.4	P[a]

[a] – $P < 0.05$

[1] – SEM for individual interactions of N retention = 2.77; P retention = 5.15; Ca retention = 3.78; Mg retention = 3.57;

[2] – SEM for mean hay to concentrate ratio interactions of N retention = 1.99; P retention = 3.69; Ca retention = 2.72; Mg retention = 2.56;

[3] – SEM for mean type of diet interactions of N retention = 1.96; P retention = 3.65; Ca retention = 2.68; Mg retention = 2.53;

H = significant interaction for Hay to Concentrate ratio; H*D = significant interaction between Hay to concentrate ratio and type of diet interaction; P = significant interaction for collection period; P*H = significant interaction between collection period and hay to concentrate ratio interaction; D = significant interaction for type of diet; P*H*D = significant 3 way interaction between collection period, hay to concentrate ratio, and type of diet; NS = not significant

Table 6: Serum mineral concentrations of 18 male uncastrated Boer- cross goats on one of 4 diets during 2 one week collection periods

	ADF-16		Wild Herbivore[1]		Mean Hay to Concentrate Ratio[2]		Mean Diet[3]		
	Hay = 20	Hay = 80	Hay = 20	Hay = 80	0.25	4.00	ADF- 16	WH	P-value
Na (mg/dl)									
Baseline	110.00	148.54	104.40	124.29	107.20	136.42	129.27	114.35	
Collection 1	140.60	162.79	153.60	132.29	147.10	147.54	151.70	142.95	
Collection 2	103.60	122.79	134.20	130.29	118.90	126.54	113.20	132.25	
Mean	118.07	144.60	130.73	128.96	124.40	136.83	131.39	129.85	NS
K (mg/dl)									
Baseline	4.06	6.41	4.04	4.59	4.05	5.50	5.24	4.31	
Collection 1	5.22	6.26	5.08	4.76	5.15	5.51	5.74	4.92	
Collection 2	3.60	4.59	4.68	5.51	4.14	5.05	4.09	5.10	
Mean	4.29	5.75	4.60	4.95	4.45	5.35	5.02	4.78	H[a]
Cl (mg/dl)									
Baseline	80.60	108.37	74.40	89.37	77.50	98.87	94.48	81.88	
Collection 1	98.60	118.87	108.40	94.62	103.50	106.74	108.73	101.51	
Collection 2	74.40	90.12	95.60	96.37	85.00	93.24	82.26	95.98	
Mean	84.53	105.79	92.80	93.45	88.67	99.62	95.16	93.12	NS
Ca (mg/dl)									
Baseline	7.44	10.58	7.08	8.30	7.26	9.44	9.01	7.69	
Collection 1	10.10	11.95	11.36	9.25	10.73	10.60	11.03	10.31	
Collection 2	7.02	9.18	10.04	9.40	8.53	9.29	8.10	9.72	
Mean	8.19	10.57	9.49	8.98	8.84	9.78	9.38	9.24	NS

Table 6 continued

P (mg/dl)									
Baseline	3.46	6.66	3.85	4.70	3.65[c]	5.68[ab]	5.06	4.28	
Collection 1	6.63	6.61	5.53	4.78	6.08[a]	5.7[ab]	6.62	5.16	
Collection 2	4.22	4.41	5.21	5.16	4.71[bc]	4.78[abc]	4.31	5.19	
Mean	4.77	5.89	4.86	4.88	4.81	5.39	5.33	4.88	P*H[a] P[a]
Mg (mg/dl)									
Baseline	1.48	1.92	1.38	1.80	1.43	1.86	1.70	1.59	
Collection 1	2.08	2.42	2.34	1.90	2.21	2.16	2.25	2.12	
Collection 2	1.38	1.67	1.88	1.72	1.63	1.65	1.53	1.80	
Mean	1.65	2.00	1.87	1.81	1.76	1.89	1.83	1.84	P[a]
Iron (µg/dl)									
Baseline	80.80	168.40	103.60	95.65	92.20	132.03	124.60	99.63	
Collection 1	179.80	176.40	199.00	117.65	189.40	147.03	178.10	158.33	
Collection 2	110.60	123.15	140.80	137.90	125.70	130.53	116.88	139.35	
Mean	123.73[ab]	155.98[a]	147.8[a]	117.07[b]	135.77	136.53	139.86	132.43	H*D[a] P[a]
Ca to P Ratio									
Baseline	2.04	1.69	1.84	1.76	1.94	1.73	1.87	1.80	
Collection 1	1.55	1.88	2.01	2.02	1.78	1.95	1.72	2.02	
Collection 2	1.67	2.11	1.88	1.80	1.78	1.96	1.89	1.84	
Mean	1.75	1.89	1.91	1.86	1.83	1.88	1.82	1.89	NS

[a] – $P < 0.05$

[1] – SEM for individual interactions of serum Na = 17.53; K = 0.63; Cl = 12.90; Ca = 1.43; P = 0.69; Mg = 0.30; Iron = 23.60; Ca to P = 0.19;

[2] – SEM for mean hay to concentrate ratio interactions of serum Na = 12.47; K = 0.45; Cl = 9.17; Ca = 1.02; P = 4.90; Mg = 0.22; Iron = 16.84; Ca to P = 0.14;

[3] – SEM for mean type of diet interactions of serum Na = 12.42; K = 0.45; Cl = 9.13; Ca = 1.01; P = 4.90; Mg = 0.21; Iron = 16.72; Ca to P = 0.14;

H = significant interaction for Hay to Concentrate ratio; H*D = significant interaction between Hay to concentrate ratio and type of diet interaction; P = significant interaction for collection period; P*H = significant interaction between collection period and hay to concentrate ratio interaction; D = significant interaction for type of diet; P*H*D = significant 3 way interaction between collection period, hay to concentrate ratio, and type of diet; NS = not significant

Table 7: Serum parameter concentrations of 18 male uncastrated Boer- cross goats on one of 4 diets during 2 one week collection periods

	ADF-16		Wild Herbivore[1]		Mean Hay to Concentrate Ratio[2]		Mean Diet[3]		
	Hay = 20	Hay = 80	Hay = 20	Hay = 80	0.25	4.00	ADF- 16	WH	P-value
Bicarbonate (mEq/L)									
Baseline	14.6	17.0	14.4	16.3	14.5	16.6	15.8	15.3	
Collection 1	18.8	21.0	22.8	17.8	20.8	19.4	19.9	20.3	
Collection 2	15.0	18.8	22.0	18.8	18.5	18.8	16.9	20.4	
Mean	16.1	18.9	19.7	17.6	17.9	18.3	17.5	18.7	NS
Anion Gap (mEq/L)									
Baseline	19.0	29.6	19.6	23.3	19.3	26.4	24.3	21.5	
Collection 1	28.6	29.1	27.4	24.6	28.0	26.8	28.8	26.0	
Collection 2	17.8	18.6	21.4	21.1	19.6	19.8	18.2	21.2	
Mean	21.8	25.7	22.8	23.0	22.3	24.4	23.8	22.9	P[a]
Urea N (mg/dl)									
Baseline	18.6	25.1	16.6	18.1	17.6	21.6	21.9	17.4	
Collection 1	24.4	36.1	21.0	29.6	22.7	32.9	30.3	25.3	
Collection 2	18.8	27.6	19.0	27.6	18.9	27.6	23.2	23.3	
Mean	20.6	29.6	18.9	25.1	19.7	27.4	25.1	22.0	H[a] P[a]
Creatinine (mg/dl)									
Baseline	0.5	0.4	0.4	0.7	0.4	0.6	0.5	0.5	
Collection 1	0.5	0.7	0.6	0.6	0.5	0.7	0.6	0.6	
Collection 2	0.4	0.4	0.5	0.6	0.4	0.5	0.4	0.5	
Mean	0.5	0.5	0.5	0.6	0.5	0.6	0.5	0.6	NS

Table 7 continued

Total Protein (g/dl)									
Baseline	5.2	7.4	5.3	6.0	5.3	6.7	6.3	5.7	
Collection 1	6.6	8.3	7.7	6.6	7.2	7.5	7.5	7.2	
Collection 2	4.8	6.3	6.5	6.1	5.6	6.2	5.5	6.3	
Mean	5.5	7.4	6.5	6.3	6.0	6.8	6.4	6.4	NS
Glucose (mg/dl)									
Baseline	50.8	70.5	49.0	54.7	49.9	62.6	60.7	51.9	
Collection 1	60.6	59.2	61.0	45.2	60.8	52.2	59.9	53.1	
Collection 2	54.6	60.5	77.4	60.5	66.0	60.5	57.6	69.0	
Mean	55.3	63.4	62.5	53.5	58.9	58.5	59.4	58.0	NS
Globulin (µg/dl)									
Baseline	2.9	4.1	3.2	3.1	3.0	3.6	3.5	3.1	
Collection 1	3.5	4.8	4.4	3.5	3.9	4.1	4.1	3.9	
Collection 2	2.5	3.4	3.5	3.1	3.0	3.3	3.0	3.3	
Mean	3.0^{b}	4.1^{a}	3.7^{ab}	3.2^{ab}	3.3	3.7	3.5	3.5	$H*D^{a}$
Sdh (U/L)									
Baseline	10.0	9.2	11.2	13.7	10.6	11.5	9.6	12.5	
Collection 1	15.0	17.5	24.6	18.7	19.8	18.1	16.2	21.7	
Collection 2	12.8	11.0	19.4	16.2	16.1	13.6	11.9	17.8	
Mean	12.6	12.6	18.4	16.2	15.5	14.4	12.6	17.3	D^{a} P^{a}
Alk Phos (U/L)									
Baseline	133.6	321.4	129.0	149.7	131.3	235.5	227.5	139.3	
Collection 1	315.8	442.9	295.2	258.2	305.5	350.5	379.4	276.7	
Collection 2	260.8	260.4	275.0	230.7	267.9	245.5	260.6	252.8	
Mean	236.7	341.6	233.1	212.8	234.9	277.2	289.2	222.9	P^{a}

Table 7 continued

GGT (U/L)									
Baseline	39.0	36.2	33.8	45.4	36.4	40.8	37.6	39.6	
Collection 1	46.4	60.7	50.2	49.7	48.3	55.2	53.5	49.9	
Collection 2	35.0	38.9	41.0	44.2	38.0	41.6	37.0	42.6	
Mean	40.1	45.3	41.7	46.4	40.9	45.9	42.7	44.1	P[a]
CK (U/L)									
Baseline	121.6	203.7	138.0	158.2	129.8	181.0	162.7	148.1	
Collection 1	169.8	253.2	200.2	206.7	185.0	230.0	211.5	203.5	
Collection 2	167.8	154.0	179.2	173.5	173.5	163.7	160.9	176.4	
Mean	153.1	203.7	172.5	179.5	162.8	191.6	178.4	176.0	P[a]
TIBC (µg/dl)									
Baseline	221.0	290.5	202.6	227.8	211.8	259.2	255.8	215.2	
Collection 1	320.6	351.0	333.4	277.0	327.0	314.0	335.8	305.2	
Collection 2	245.8	264.8	300.8	255.5	273.3	260.2	255.3	278.2	
Mean	262.5	302.1	278.9	253.5	270.7	277.8	282.3	266.2	P[a]

[a] – $P < 0.05$

[1] – SEM for individual interactions of serum Bicarbonate = 2.93; Anion Gap = 2.97; Urea N = 3.12; Creatinine = 0.14; Total Protein = 1.00; Glucose = 8.28; Globulin = 0.58; Sdh = 3.40; Alk Phos = 62.98; GGT = 7.59; CK = 28.19; TIBC = 42.44;

[2] – SEM for mean hay to concentrate ratio interactions of serum Bicarbonate = 2.09; Anion Gap = 2.12; Urea N = 2.22; Creatinine = 0.10; Total Protein = 0.71; Glucose = 5.90; Globulin = 0.41; Sdh = 2.42; Alk Phos = 45.11; GGT = 5.42; CK = 20.11; TIBC = 30.20;

[3] – SEM for mean type of diet interactions of serum Bicarbonate = 2.08; Anion Gap = 2.10; Urea N = 2.21; Creatinine = 0.10; Total Protein = 0.70; Glucose = 5.87; Globulin = 0.41; Sdh = 2.40; Alk Phos = 44.64; GGT = 5.38; CK = 19.97; TIBC = 30.06;

H = significant interaction for Hay to Concentrate ratio; H*D = significant interaction between Hay to concentrate ratio and type of diet interaction; P = significant interaction for collection period; P*H = significant interaction between collection period and hay to concentrate ratio interaction; D = significant interaction for type of diet; P*H*D = significant 3 way interaction between collection period, hay to concentrate ratio, and type of diet; NS = not significant

Table 8: Urinary mineral excretion concentrations of 18 male uncastrated Boer- cross goats on one of 4 diets during 2 one week collection periods

	ADF-16		Wild Herbivore[1]		Mean Hay to Concentrate Ratio[2]		Mean Diet[3]		
	Hay = 20	Hay = 80	Hay = 20	Hay = 80	0.25	4.00	ADF- 16	WH	P-value
Urinary Na (mg/dl)									
Baseline	1848[abc]	1064[c]	1259[c]	1248[c]	1554[b]	1156[b]	1456[b]	1254[b]	
Collection 1	2562[ab]	1016[c]	4615[a]	1060[c]	3589[a]	1039[b]	1790[b]	2838[a]	H^a P^a D^a $P*D^a$
Collection 2	1872[bc]	1059[c]	4260[a]	969[c]	3066[a]	1014[b]	1466[b]	2614[a]	$P*H^a$ $H*D^a$
Mean	2095	1046	3378	1092	2736	1070	1571	2236	$P*H*D^a$
Urinary K (mg/dl)									
Baseline	6965	8624	10646	6063	8806	7344	7795	8354	
Collection 1	12705	16182	13247	13030	12976	14606	14444	13138	
Collection 2	10323	13460	11665	12854	10994	13157	11891	12260	
Mean	9998	12755	11853	10649	10925	11702	11377	11251	P^a
Urinary Cl (mg/dl)									
Baseline	5261	6167	7523	5113	6392	5641	5714	6182	
Collection 1	6665	7333	7554	5317	7109	6325	6999	6436	
Collection 2	4767	5843	6554	5029	5661	5435	5305	5792	
Mean	5564[ab]	6447[ab]	7210[a]	5153[b]	6387	5800	6006	6182	$H*D^a$
Urinary Creatinine (mg/dl)									
Baseline	42.9	42.0	54.4	37.7	48.6	39.8	42.4	46.0	
Collection 1	47.6	51.3	56.2	46.8	51.9	49.1	49.4	51.5	
Collection 2	38.6	48.3	52.4	44.5	45.5	46.4	43.5	48.4	
Mean	43.0	47.2	54.3	43.0	48.7	45.1	45.1	48.7	NS

Table 8 continued

Urinary Ca (mg/dl)									
Baseline	6.8	6.6	6.7	3.7	6.7	5.1	6.7	5.2	
Collection 1	9.5	13.1	16.0	9.8	12.7	11.5	11.3	12.9	
Collection 2	6.4	11.0	12.9	10.2	9.7	10.6	8.7	11.6	
Mean	7.6[b]	10.2[ab]	11.9[a]	7.9[ab]	9.7	9.1	8.9	9.9	H*D[a] P[a]
Urinary Mg (mg/dl)									
Baseline	557.0	415.9	600.0	353.6	578.5	384.7	486.4	476.8	
Collection 1	835.9	707.5	1196.1	594.8	1016.0	651.1	771.7	895.4	
Collection 2	644.0	662.2	1132.6	589.9	888.3	626.0	653.1	861.3	
Mean	678.9[b]	595.2[b]	976.2[a]	512.8[b]	827.6	554.0	637.1	744.5	H[a] P[a] H*D[a]
Urinary P (mg/dl)[4]									
Baseline	0.36[c]	0.00[c]	0.16[c]	0.00[c]	0.26	0.00	0.36	0.16	
Collection 1	9.82[b]	0.38[c]	0.38[c]	0.14[c]	5.12	0.26	5.10	0.26	
Collection 2	15.08[a]	0.54[c]	0.28[c]	0.79[c]	7.68	0.67	7.68	0.76	
Mean	8.42	0.31	0.27	0.31	4.35	0.31	4.36	0.66	P[a] P*H*D[b]

[a] – $P < 0.05$
[b] – $P < 0.07$
[1] – SEM for individual interactions of urinary Na = 339.73; K = 1374.78; Cl = 906.38; Creatinine = 9.61; Ca = 1.96; Mg = 104.14; P = 1.99;
[2] – SEM for mean hay to concentrate ratio interactions of urinary Na =243.02; K = 983.76; Cl = 647.43; Creatinine = 6.86; Ca = 1.41; Mg = 74.42; P = 1.43;
[3] – SEM for mean type of diet interactions of urinary Na = 240.76; K = 974.31; Cl = 642.28; Creatinine = 6.81; Ca = 1.39; Mg = 73.80; P = 1.41;
[4] – Urinary P values are expressed as actual means rather than least squared means
H = significant interaction for Hay to Concentrate ratio; H*D = significant interaction between Hay to concentrate ratio and type of diet interaction; P = significant interaction for collection period; P*H = significant interaction between collection period and hay to concentrate ratio interaction; D = significant interaction for type of diet; P*H*D = significant 3 way interaction between collection period, hay to concentrate ratio, and type of diet; NS = not significant

Table 9: Urinary mineral excretion concentrations standardized by urine creatinine in 18 male uncastrated Boer- cross goats on one of 4 diets during 2 one week collection periods

	ADF-16		Wild Herbivore[1]		Mean Hay to Concentrate Ratio[2]		Mean Diet[3]		
	Hay = 20	Hay = 80	Hay = 20	Hay = 80	0.25	4.00	ADF- 16	WH	P-value
Urinary Na / Creatinine (mg/dl)									
Baseline	45.78[abc]	28.22[c]	23.38[c]	42.81[c]	34.58[b]	35.51[b]	37.00	33.10	
Collection 1	56.72[ab]	20.17[c]	82.19[a]	24.20[c]	69.45[a]	22.18[b]	38.45	53.19	
Collection 2	49.16[bc]	22.72[c]	81.72[a]	22.81[c]	65.44[a]	22.77[b]	35.94	52.27	H^a $P*H^a$
Mean	50.55	23.70	62.43	29.94	56.49	26.82	37.13	46.18	$P*H*D^a$
Urinary K / Creatinine (mg/dl)									
Baseline	191.6	207.5	222.4	162.2	207.0[c]	184.9[c]	199.5	192.3	
Collection 1	276.3	324.0	237.9	312.8	257.1[b]	318.4[a]	300.1	275.3	
Collection 2	265.9	286.5	226.0	298.8	245.9[bc]	292.6[a]	276.2	262.4	
Mean	244.6	272.6	228.7	257.9	236.7	265.3	258.6	243.3	$P*H^a$ P^a
Urinary Cl / Creatinine (mg/dl)									
Baseline	142.9	152.3	151.9	153.2	147.4	152.8	147.6	152.6	
Collection 1	144.1	145.1	135.1	117.1	139.6	131.1	144.6	126.1	
Collection 2	124.3	121.1	125.9	113.2	125.1	117.2	122.7	119.5	
Mean	137.1	139.5	137.6	127.8	137.4	133.7	138.3	132.7	P^a
Urinary Ca / Creatinine (mg/dl)									
Baseline	0.24	0.17	0.14	0.11	0.19	0.14	0.21	0.13	
Collection 1	0.19	0.26	0.29	0.23	0.24	0.25	0.23	0.26	
Collection 2	0.16	0.23	0.24	0.23	0.20	0.23	0.20	0.24	
Mean	0.20	0.22	0.22	0.19	0.21	0.21	0.21	0.21	NS

Table 9 continued

Urinary Mg / Creatinine (mg/dl)									
Baseline	18.18	10.12	12.82	9.57	15.50	9.85	14.15	11.20	
Collection 1	17.41	14.02	21.37	13.66	19.39	13.84	15.72	17.52	
Collection 2	16.59	14.01	21.38	13.02	18.99	13.52	15.30	17.20	
Mean	17.39	12.72	18.52	12.08	17.96	12.40	15.06	15.30	H[a]
Urinary P / Creatinine (mg/dl)[4]									
Baseline	0.01[c]	0.02[c]	0.00[c]	0.02[c]	0.01	0.02	0.01	0.01	
Collection 1	0.30[b]	0.01[c]	0.01[c]	0.03[c]	0.15	0.02	0.15	0.02	
Collection 2	0.46[a]	0.01[c]	0.03[c]	0.05[c]	0.25	0.03	0.23	0.04	
Mean	0.26	0.01	0.01	0.03	0.13	0.02	0.13	0.02	P[a] P*H*D[b]

[a] – $P < 0.05$

[1] – SEM for individual interactions of creatinine standardized urinary Na = 8.61; K = 22.60; Cl = 12.50; Ca = 0.07; Mg = 2.88; P = 0.07;

[2] – SEM for mean hay to concentrate ratio interactions of creatinine standardized urinary Na =6.15; K = 16.15; Cl = 8.96; Ca = 0.04; Mg = 2.05; P = 0.05;

[3] – SEM for mean type of diet interactions of creatinine standardized urinary Na = 6.10; K = 16.01; Cl = 8.86; Ca = 0.04; Mg = 2.04; P = 0.05;

[4] – Urinary P values are expressed as actual means rather than least squared means

H = significant interaction for Hay to Concentrate ratio; H*D = significant interaction between Hay to concentrate ratio and type of diet interaction; P = significant interaction for collection period; P*H = significant interaction between collection period and hay to concentrate ratio interaction; D = significant interaction for type of diet; P*H*D = significant 3 way interaction between collection period, hay to concentrate ratio, and type of diet; NS = not significant

Table 10: Average urinary crystal numbers, based on actual one slide count and on a 1 – 5 scale (1 being no crystals present and 5 being slide saturated with crystals) as an average of measurements taken in quadruplicate over 2 collection periods and urine pH for 18 male uncastrated Boer- cross goats on one of 4 diets during 2 one week collection periods

	ADF-16		Wild Herbivore[1]		Mean Hay to Concentrate Ratio[2]		Mean Diet[3]		
	Hay = 20	Hay = 80	Hay = 20	Hay = 80	0.25	4.00	ADF- 16	WH	P-value
Crystal Score (1-5)									
Collection 1	2.80	1.51	2.20	1.76	2.50	1.63	2.16	1.98	
Collection 2	3.10	1.98	2.40	2.33	2.75	2.15	2.54	2.37	
Mean	2.75	1.75	2.80	2.04	2.63	1.89	2.35	2.18	H[b]
Number of Crystals Counted									
Collection 1	132.5	13.4	103.5	43.8	118.0	28.6	72.9	73.6	
Collection 2	278.6	84.3	196.2	229.3	237.4	156.8	181.4	212.7	
Mean	205.6	48.8	149.8	136.5	177.7	92.7	127.2	143.2	P[a]
Average Urine pH									
Collection 1	8.51	8.67	8.83	8.96	8.67	8.82	8.59	8.90	
Collection 2	8.37	8.51	8.63	8.88	8.50	8.70	8.44	8.76	
Mean	8.44	8.59	8.73	8.92	8.59	8.76	8.52	8.83	H[a] D[a]

[a] – $P < 0.05$
[b] – $P < 0.10$
[1] – SEM for individual interactions of urine crystal score = 0.54; number of crystals = 84.42; average urine pH =0.12;
[2] – SEM for mean hay to concentrate ratio interactions of urine crystal score = 0.39; number of crystals = 60.56; average urine pH = 0.04;
[3] – SEM for mean type of diet interactions of urine crystal score = 0.38; number of crystals = 59.84; average urine pH = 0.08;
H = significant interaction for Hay to Concentrate ratio; H*D = significant interaction between Hay to concentrate ratio and type of diet interaction; P = significant interaction for collection period; P*H = significant interaction between collection period and hay to concentrate ratio interaction; D = significant interaction for type of diet; P*H*D = significant 3 way interaction between collection period, hay to concentrate ratio, and type of diet; NS = not significant

Table 11: Volatile fatty acid (VFA) composition and rumen ammonia level of rumen fluid collected from 18 male uncastrated Boer-cross goats on one of 4 diets during 2 one week collection periods

	ADF-16		Wild Herb			P- values		
	Hay = 20	Hay = 80	Hay = 20	Hay = 80	SEM	Hay	Diet	Diet*hay
Total VFA (mM)	106.35	110.58	102.58	98.75	12.84	0.99	0.57	0.76
AP Ratio	3.06	3.44	3.22	3.28	0.29	0.45	0.95	0.57
Molar %								
Acetic	62.28	67.45	66.71	67.95	1.17	0.01	0.04	0.11
Proprionate	21.61	19.72	20.88	20.81	1.38	0.49	0.96	0.52
Isobutryate	1.45	0.92	1.14	1.18	0.50	0.63	0.91	0.57
Butyrate	10.89	9.55	8.63	7.39	1.08	0.25	0.06	0.96
Isovalerate	2.17	1.09	1.51	1.48	0.73	0.46	0.79	0.49
Valerate	1.60	1.27	1.14	1.20	0.11	0.20	0.01	0.08
NH_3 (ml/dl)	30.01	24.5	11.79	14.04	3.44	0.64	< 0.001	0.28

Table 12: Water Intake of 18 male uncastrated Boer- cross goats on one of 4 diets during 2 one week collection periods

	ADF-16		Wild Herb			P- values		
	Hay = 20	Hay = 80	Hay = 20	Hay = 80	SEM	Hay	Diet	Diet*hay
Collection 1 Daily Water Intake (kg)	2.75	2.57	3.25	2.56	0.33	0.22	0.41	0.44
Collection 2 Daily Water Intake (kg)	3.94	3.30	3.60	3.07	0.23	0.03	0.22	0.81
Average Daily Water Intake (kg)	3.21	2.76	3.39	2.88	0.25	0.09	0.55	0.91

Table 13: Balance of Intake, N, P, Ca, and Mg for 18 male uncastrated Boer-cross goats on one of 4 diets during the 2 one week collection periods

	Collection 1				**Collection 2**					
	ADF 16		**Wild Herbivore**		**ADF 16**		**Wild Herbivore**			
	Hay = 20%	**Hay = 80%**	**Hay = 20%**	**Hay = 80%**	**Hay = 20%**	**Hay = 80%**	**Hay = 20%**	**Hay = 80%**	**SEM**	**P-value**
DM Intake (kg/d)	1.19	1.08	1.38	0.94	1.21	1.00	1.37	1.04	0.07	H
DM Hay Intake (kg/d)	0.22	0.81	0.24	0.71	0.22	0.75	0.20	0.78	0.22	H P*H*D
DM Pellet Intake (kg/d)	0.97	0.27	1.15	0.23	0.98	0.25	1.17	0.26	0.21	H D H*D
DM Fecal Output (kg/d)	0.40	0.37	0.44	0.33	0.40	0.35	0.52	0.36	0.03	H H*D
DM Digestibility (%)	69.14	67.22	67.37	67.44	69.63	67.76	65.78	67.92	0.22	NS
Intake of N (g/d)	36.86	34.96	33.57	28.62	37.93	34.33	34.37	33.52	2.21	.
Fecal N (g/d)	10.16	8.71	10.41	7.64	10.30	8.58	11.89	8.62	0.78	H
Urine N (g/d)	15.06	18.17	10.79	13.77	18.36	20.13	13.29	17.59	1.27	P H D
N balance (g/d)	11.64	8.08	12.37	7.21	9.27	5.62	9.19	7.31	1.11	P H
N Digestibility %	74.4	76.4	68.5	74.9	75.2	77.0	68.6	76.0	1.47	H D
N Retention %	36.4	27.3	39.0	31.1	30.8	23.3	33.5	28.2	2.77	H P
Intake of P (g/d)	8.00	4.20	5.18	2.86	7.79	3.83	5.65	3.21	0.30	H D H*D
Fecal P (g/d)	5.10	2.46	3.15	1.62	4.59	2.49	3.37	1.66	0.31	H D
Urine P (g/d)	0.067	0.002	0.000	0.010	0.139	0.010	0.002	0.003	0.03	P
P balance (g/d)	2.83	1.74	2.03	1.23	3.06	1.33	2.28	1.55	0.28	H D

P Digestibility %	36.1	39.9	33.3	42.1	40.7	35.4	40.3	46.0	5.70	NS
P Retention %	35.4	40.0	33.2	42.1	39.9	35.5	40.3	47.5	5.53	NS
Intake of Ca (g/d)	11.91	15.17	15.46	13.37	12.99	16.28	16.77	17.12	1.02	P H*D
Fecal Ca (g/d)	9.38	12.21	11.49	10.78	8.93	12.46	12.13	12.77	1.00	P*H H*D
Urine Ca (g/d)	0.104	0.150	0.164	0.121	0.104	0.145	0.159	0.141	0.02	H*D
Ca balance (g/d)	2.43	2.81	3.81	2.47	3.96	3.68	4.48	4.21	0.65	P
Ca Digestibility %	21.1	17.3	18.3	18.0	31.2	22.2	27.5	23.6	4.05	NS
Ca Retention %	20.2	16.3	17.2	17.2	31.2	22.1	27.5	23.6	4.13	NS
Intake of Mg (g/d)	4.55	4.55	6.32	4.09	4.67	4.31	6.47	4.67	0.31	H D H*D
Fecal Mg (g/d)	2.65	2.70	3.32	2.40	2.56	2.69	3.58	2.75	0.24	D H*D
Urine Mg (g/d)	0.95	0.81	1.23	0.68	1.05	0.88	1.40	0.79	0.09	P H H*D
Mg balance (g/d)	0.95	1.04	1.77	1.01	1.06	0.74	1.49	1.13	0.21	H D
Mg Digestibility %	41.8	37.8	42.4	39.5	45.0	35.2	44.6	39.0	3.40	H
Mg Retention %	20.4	19.9	22.7	23.1	45.0	35.1	44.6	39.0	3.77	NS

H = significant interaction for Hay to Concentrate ratio; H*D = significant interaction between Hay to concentrate ratio and type of diet interaction; P = significant interaction for collection period; P*H = significant interaction between collection period and hay to concentrate ratio interaction; D = significant interaction for type of diet; P*H*D = significant 3 way interaction between collection period, hay to concentrate ratio, and type of diet; NS = not significant

Discussion:

The contrast of two different complete pelleted feed types containing very different ingredients (Appendix A) fed at 2 opposing ratios with alfalfa hay, were expected to produce some stark differences in dietary content (Table 2). Our intentions in choosing these ratios were to reproduce the possible diets and hay to complete pelleted feed ratios that would be given to captive giraffe in zoos. While NDF, ADF and cellulose content of the Wild Herbivore (WH) diet was higher than that of the ADF-16 diet (Table 1), when WH was fed with hay as 20 % of the diet, the fiber components' content rose. A range of NDF content from 32.8 to 52.3 was produced, creating different levels of fiber in the treatments, but also having different types of fiber, as the 2 diets of WH and ADF-16 had different components providing their fiber (Appendix A). An example of this difference would be that in ADF-16, the first three ingredients are dehydrated alfalfa meal, wheat middlings (a good source of fiber), and ground corn, while in WH, the first three ingredients are ground soybean hulls, dehulled soybean meal and ground aspen wood (Appendix A). The Ca to P ratio ranged from the lowest 1.6 to 1, to the others all being about 3 to 5 to 1 (Table 2). These high ratios are likely due to the relatively high levels of Ca in combination with low P in the alfalfa hay (Table 1).

Dry matter intake was higher when 20% of the diet was fed as hay (Table 3). Most goats preferred the complete pelleted ration and consumed most of their pellets before eating their alfalfa hay (personal observation). The goats were consuming about 4 to 6 % of their BW as dry matter and all animals gained weight over the course of the trial (Table 3).

Type of diet and the amount of hay versus complete pelleted feed had some interesting effects on digestibility. Nitrogen was more digestible in goats fed the ADF-16 diet and when hay was 80 % of the diet, so the majority of the diet was alfalfa hay. ADF-16 and the alfalfa hay had much higher crude protein content than the WH (Table 1). The differences in the ingredients of the 2 complete pelleted feeds and the alfalfa hay also may influence the digestibility of N considering how that protein is presented to the rumen microbes. Neutral detergent fiber, ADF, and Cellulose were significantly more digestible when the animal was given the WH diet, especially at the high level of complete pelleted diet feeding (lower percentage of hay). The treatments using WH complete pelleted feed had the highest levels of these fiber components (Table 1), suggesting that by increasing the fiber in the complete pelleted feed, the rumen may be more stimulated. The rumen wall would be stimulated to increase the size of papillae. This may lead to increased papillary surface area for absorption. Passage rate would be slowed by the increase in fiber content due to slower breakdown, allowing more time for absorption and hence increasing digestibility (Van Soest, 1982). In terms of mineral digestibility, Mg seemed to be better absorbed when the majority of the diet was the complete pelleted feed. Minerals such as Mg may be bound in complex molecules such as phytate, or with insoluble fiber, both of which can be broken down by the microbes of the rumen (van Soest, 1982). It is possible that due to the relatively fast passage rate of the intermediate feeder type goat (Hofmann, 1989), if Mg is bound in such complexes in the alfalfa hay, there may not be adequate time for full breakdown and subsequent absorption of Mg, compared to a more processed complete pelleted feed. Phosphorus and Ca digestibility did not seem to differ across treatments or over time.

Retention of N, Ca, P and Mg, showed that none of the animals were in negative balance (Table 5 and Table 13). N retention was higher when hay was 20 % of the diet, the opposite of N digestibility, which was higher with hay as 80 % of the diet. It should also be noted, that retention was numerically higher for WH, again the opposite of N digestibility. The lower levels of crude protein in the WH and in the overall diet when hay was 20% of the diet, where most of the diet was complete pelleted feed, one might expect the animal would retain more of its N for growth. However, the requirement for 150 g / d of growth in 30 kg meat goats is estimated to be 93 g / d of total protein or about 13 % CP of total DM intake (NRC, 1981). Since crude protein levels in the present study were above the requirements, the excess N would be excreted in the urine and retention would decrease for the diets with high levels of crude protein. This agrees with data showing that the treatment with hay as 20 % of the diet for the WH diet had the lowest level of crude protein, and the highest level of N retention and N balance.

The baseline values were taken when the animals were fed hay as 50 % of the diet and complete pelleted feed as 50 % of the diet. The complete pelleted diet consisted of half of each type of diet. The first collection began a week after the animals were fully adjusted to their particular treatments. Serum P markedly increased from the baseline to the first collection period, especially when there was a majority of complete pelleted feed in the diet. This agrees with previous work indicating high levels of complete pelleted concentrate fed with low levels of hay disrupt phosphorus homeostasis (Scott and Buchan, 1987; Tomas, 1974; Putnam et al., 1966; Sato et al., 1976). It seems the animals adjusted to this high level of complete pelleted feed, regaining P homeostasis by the second collection period, as serum P decreased significantly from the first collection

period for the goats fed hay as 20 % of the diet. Urine P increased accordingly by the second collection (Table 13).

Alfalfa hay had the highest level of crude protein compared to either concentrate, hence feeding it as a majority of the diet led to more than adequate protein for metabolic functions. This led to the decrease in retention noted earlier. It also explains why serum urea N was higher when hay was 80 % of the diet. Globulin was highest for the ADF-16 diet fed with hay as 80 % of the diet, but this may be explained since an increase in globulins may be a sign of increased immunoglobulins or antibodies, to fight a possible virus or infection (Goldsby et al., 2003). Sorbitol dehydrogenase (Sdh) was higher in treatments using the WH concentrate, which was interesting as the WH concentrate was formulated to have lower levels of simple sugars and starches (Schmidt and Barbiers, 2005). Sdh, one of 2 enzymes controlling the polyol pathway oxidizing sorbitol to fructose using NAD+, is important in control of diabetes. While the significant increase of Sdh was not biologically excessive, it should be noted that high expression of Sdh may have a role in glucose toxicity (Amano et al., 2002).

Urinary mineral excretion varied among the dietary treatments. As shown in Appendix A, ADF-16 pellets have an estimated nutrient composition of 0.44% Na, while WH pellets were reported as 0.93% Na content, and alfalfa hay was reported to be low in Na (0.22%) (NRC, 1981). High dietary levels of Na would lead to excess Na excreted in the urine, explaining the high Na excretion in goats fed the treatments with high levels of WH concentrate. The composition of the two types of pellets may also be responsible for chloride urinary excretion being highest for when hay was 20 % of the diet and lowest when hay was 80 %, but only in goats fed the diets with WH complete pelleted feed. The

lack of difference in urine creatinine indicated that dehydration was not a factor in the health of the goats.

Urinary Ca and Mg, like their serum counterparts, not surprisingly increased from the baseline value to the first collection value, to reflect the transition to their treatment diets. WH had a higher level of Mg than ADF-16 or the alfalfa hay (Table 1) which explains why urinary Mg was highest for the high level of WH complete pelleted feed and Mg balance was highest for that treatment P balance was higher on treatments using ADF-16 and when hay was 20 % of the diet. . Urinary Ca was found to be lowest in animals on the high complete pelleted feed diet with the ADF-16 complete pelleted feed, as this was the only treatment with a Ca to P ratio of less than 2 to 1 (Table 2). Ca balance increased from the first collection to the second, perhaps to cope with issues with Ca to P ratio. Animals given lower ratios and lower overall levels of Ca, with relatively higher levels of P, would be less likely to excrete Ca and more likely to excrete P in the urine, which was seen, though not significant. Urinary P concentrations were only significantly different between collections, but for the ADF-16 treatment with 20% of the diet as hay, urinary P seemed to markedly increase. The increase may be explained by the change in P homeostasis involved with high levels of complete pelleted feed, and a low Ca to P ratio. P balance was higher on treatments using ADF-16 and when hay was 20 % of the diet. The treatment with ADF-16 with hay as 20 % of the diet had the highest level of phosphorus feeding at about 0.6 % of the diet versus the other 3 treatments having about 0.3% P. The dietary requirement for 30 kg goats growing 150 g per day for P is 2.8 g / d, or about 0.25 % of DM intake (NRC, 1981). This would indicate that the levels of P which the goats are receiving on any treatment are above their

requirements. Most of P is excreted in the feces (Suttle and Underwood, 1999). A high level of P will lead to overflow of P excretion from the feces into the urine, which may explain why the treatment with the highest dietary P level also has a higher excretion of urinary P.

Despite the similar creatinine levels, there may have been some differences in hydration in the animals. Urinary Cl actually decreased when it was standardized for creatinine between the baseline value and the first collection value, when without the standardization, it increased. It is possible that less chloride would be excreted as salt if there was a slight dehydration involved. Urinary Ca excretion becomes no longer different, and Mg and P maintain the same trends once standardized.

The crystal counting and scoring was expected to demonstrate an increase in precursors to urolith formation (crystals) on treatments that were more calculogenic. The trend found for the lower amount of hay in the diet agreed with our initial hypothesis that high concentrate to hay ratios increases the amount of urolith precursors. The actual count of the crystals (number of crystals) increased overall for all treatments from the first collection to the second collection. The standard error for the crystal number values was quite large, explaining why, although the high complete pelleted feed treatments (hay = 20% of the diet) have a higher value, they were not statistically significant. The type of diet did not appear to affect the crystal formation. Also worth noting was that urine pH was higher for the animals fed a high level of hay and for the animals fed the WH complete pelleted feed. However, all goats on all of the treatments had a urinary pH between 8 and 9, which is considered to be alkaline. An alkaline urinary pH is conducive

to the development of magnesium ammonium phosphate and calcium phosphate uroliths (Bartges et al., 1999).

Rumen volatile fatty acid composition appeared to be mostly similar across treatments, which differs from expectations. The rumen might have produced more propionate and more acetate on the high complete pelleted feed diet due to faster breakdown (van Soest, 1982). The high complete pelleted feed diets actually produced less acetic acid than the high hay diets, with the lowest levels for those animals on ADF-16 concentrate. This could be related to fermentability of the varied types of fiber in the two complete pelleted feeds. Rumen ammonia was higher in goats fed the ADF-16 complete pelleted feed compared to the WH complete pelleted feed, perhaps due to the higher crude protein content and the high starch content leading to fast breakdown of the complete pelleted feed (van Soest, 1982).

The intent of this study was to look at the impact of type of diet and concentrate to hay ratios on the development of urolithiasis in the context of captive giraffe feeding practices. The four treatments had a range of fiber content and differences in mineral content as well, namely differing Ca to P ratio and levels of P. From our results, it can be concluded that feeding the ADF-16 diet with hay as 20 % of the diet, produced a trend of high urinary P, high serum P, and a tendency for a high crystal count over a short period of time. These can be considered strong risk factors for the development of phosphatic uroliths. It should be noted that only precursors to the uroliths were measured, and crystals are not always indicative of urolith formation. Ideas for future studies would include a longer time period on the diets exceeding the 56 day minimum noted by Sato and Omari (1977) for actual formation of uroliths. Obstructive urolithiasis remains an

often deadly problem for goats and giraffes. The solution involves understanding and demonstrating the proper balance of minerals and nutrients in their diets, while mitigating environmental factors, to minimize the risk of this disease.

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APPENDIX

Appendix A

Mazuri® ADF-#16 Herbivore 5648

Description

Mazuri® ADF-#16 Herbivore is specially formulated for use in the feeding of ungulates fed hay or grass pasture during production phases or seasons where energy requirements are high.

Features and Benefits

- **Nutritionally balanced** - Promotes growth and reproduction by nutritionally balancing available grass or hay.
- **Contains high-energy ratio** - Provides the energy needed to meet the increased energy requirements of certain reproduction phases and during the cooler seasons.
- **Contains vitamin E and selenium** - Convenient means of supplementing these important nutrients.
- **Pellet form** - Easy to feed; minimizes waste.

Product Form

- Pellet size: 1/4" diameter x 3/4" length. 50 lb. net weight paper sack.

Guaranteed Analysis

Crude protein not less than	17.0%
Crude fat not less than	3.0%
Crude fiber not more than	15.0%
Acid Detergent Fiber not more than	16.0%
Ash not more than	8.0%

Ingredients

Dehydrated alfalfa meal, wheat middlings, ground corn, dehulled soybean meal, cane molasses, soybean oil, salt, dicalcium phosphate, calcium carbonate, calcium propionate (a preservative), dl-alpha tocopheryl acetate (source of vitamin E), choline chloride, biotin, cholecalciferol (source of vitamin D_3), ethoxyquin (a preservative), calcium pantothenate, vitamin A acetate, thiamin mononitrate, riboflavin, nicotinic acid, cyanocobalamin (source of vitamin B_{12}), manganous oxide, zinc oxide, ferrous carbonate, copper sulfate, zinc sulfate, calcium iodate, cobalt carbonate, sodium selenite.

Feeding Directions

May be fed ad libitum, or intake may be limited, along with free-choice hay or grass pasture. Provide animals with access to plenty of fresh, clean water. Amounts consumed will be determined by experience, age and reproductive phase of animal, and seasonal variations. A guide: consumption of Mazuri® ADF-#16 Herbivore will usually be about 1% of body weight.

CAUTION: This product contains a level of copper that may be toxic to certain herbivores such as sheep.

5648 Mazuri® ADF-#16 Herbivore

Approximate Nutrient Composition

NUTRIENTS

Protein, %	**17.1**
Arginine, %	0.97
Cystine, %	0.23
Glycine, %	0.81
Histidine, %	0.40
Isoleucine, %	0.90
Leucine, %	1.28
Lysine, %	0.80
Methionine, %	0.26
Phenylalanine, %	0.78
Tyrosine, %	0.49
Threonine, %	0.63
Tryptophan, %	0.21
Valine, %	0.83
Fat, %	**3.2**
Linoleic Acid, %	1.2
Fiber (Crude), %	**12.5**
Neutral Detergent Fiber, %	29.0
Acid Detergent Fiber, %	15.5
Total digestible Nutrients, %	65.0
Digestible Energy, kcal/g	2.87
Metabolizable Energy (Ruminant), kcal/g	2.40
Net Energy, Maintenance, kcal/g	1.47
Net Energy, Gain, kcal/g	0.85

Quality Controlled by PMI Nutrition International, a subsidiary of America's oldest and largest animal nutrition company.

MINERALS

Ash, %	**7.4**
Calcium, %	0.81
Phosphorus, %	0.68
Phosphorus (non-phytate), %	0.40
Potassium, %	1.36
Magnesium, %	0.30
Sodium, %	0.44
Chlorine, %	0.91
Sulfur, %	0.24
Iron, ppm	310
Zinc, ppm	150
Manganese, ppm	150
Copper, ppm	20
Iodine, ppm	1.3
Selenium, ppm	0.36
Cobalt, ppm	0.58

VITAMINS

Vitamin K (as menadione), ppm	3.6
Thiamin Hydrochloride, ppm	11
Riboflavin, ppm	10
Niacin, ppm	90
Pantothenic Acid, ppm	32
Choline Chloride, ppm	1,620
Folic Acid, ppm	1.7
Pyridoxine, ppm	4.6
Biotin, ppm	0.49
Vitamin B_{12}, mcg/kg	23
Vitamin A, IU/kg	6,500
Vitamin D_3 (added), IU/kg	1,200
Vitamin E, IU/kg	330
Carotene, ppm	38

Mazuri® Wild Herbivore Diet Hi-Fiber 5ZF1

Description
Mazuri® Wild Herbivore Diet Hi-Fiber is a nutritionally balanced starch and phosphorus controlled diet designed for captively held browsers.

Features and Benefits
- **Nutritionally Balanced.**
- **High in fermentation fibers** – Provides energy and promotes healthy rumen.
- **Starch controlled (<4.0%).**
- **Reduced and controlled phosphorus formulation.**
- **Highly Palatable** – Accepted by numerous browsers including Giraffe.
- **Contains Flaxseed** – Source of Omega-3 Fatty Acids.
- **Naturally preserved with mixed tocopherols.**

Product Form
- Pellet: 1/4" diameter x 1/2" to 3/4" length. 50 lb. net weight paper sack.

Guaranteed Analysis
Crude protein not less than 12.0%
Crude fat not less than 3.0%
Crude fiber not more than 30.0%

Ingredients
Ground Soybean Hulls, Dehulled Soybean Meal, Ground Aspen, Dried Beet Pulp, Cane Molasses, Ground Oat Hulls, Soybean Oil, Salt, Lignin Sulfonate, Flaxseed, Dicalcium Phodphate, Monocalcium Phosphate, Brewers Dried Yeast, Calcium Propionate, Sodium Sesquicarbonate, Artificial Flavor, Magnesium Oxide, Riboflavin, Sucrose, D-Alpha Tocopheryl Acetate (natural source vitamin E), Tocopherols (A Preservative), Biotin, Cholecalciferol (vitamin D_3), Calcium Carbonate, Calcium Pantothenate, Vitamin A Acetate, Thiamin Mononitrate, Nicotinic Acid, Cyanocobalamin (vitamin B_{12}), Choline Chloride, Manganous Oxide, Zinc Oxide, Ferrous Carbonate, Copper Sulfate, Zinc Sulfate, Calcium Iodate, Cobalt Carbonate, Sodium Selenite.

Feeding Directions
Feed ad libitum. Plenty of fresh, clean water should be available at all times. Offer grass hay and/or browse at a level to provide 25% to 50% of daily feed intake.

5ZF1 Mazuri® Wild Herbivore Diet Hi-Fiber

Approximate Nutrient Composition

NUTRIENTS

Protein, %	**12.6**
Arginine, %	0.65
Cystine, %	0.13
Glycine, %	0.33
Histidine, %	0.37
Isoleucine, %	0.60
Leucine, %	0.83
Lysine, %	0.84
Methionine, %	0.12
Phenylalanine, %	0.73
Tyrosine, %	0.63
Threonine, %	0.47
Tryptophan, %	0.20
Valine, %	0.84
Fat, %	**3.0**
Fiber (Crude), %	**27.7**
Neutral Detergent Fiber, %	50.0
Acid Detergent Fiber, %	34.1
Metabolizable Energy, kcal/g	**1.96**
Starch, %	<4.0

Quality Controlled by PMI Nutrition International, a subsidiary of America's oldest and largest animal nutrition company.

MINERALS

Ash, %	**7.3**
Calcium, %	0.75
Phosphorus, %	0.35
Phosphorus (non-phytate), %	0.25
Potassium, %	1.16
Magnesium, %	0.33
Sodium, %	0.93
Chlorine, %	0.70
Sulfur, %	0.20
Iron, ppm	360
Zinc, ppm	120
Manganese, ppm	120
Copper, ppm	21
Iodine, ppm	1.7
Cobalt, ppm	1.5
Chromium, ppm	2.0
Selenium, ppm	0.76

VITAMINS

Vitamin K (as menadione), ppm	0.0
Thiamin Hydrochloride, ppm	7.0
Riboflavin, ppm	130
Niacin, ppm	55
Pantothenic Acid, ppm	26
Choline Chloride, ppm	630
Folic Acid, ppm	0.30
Pyridoxine, ppm	1.4
Biotin, ppm	0.40
Vitamin B_{12}, mcg/kg	23
Vitamin A, IU/gm	5.0
Vitamin D_3 (added), IU/gm	1.3
Vitamin E, IU/kg	380
Ascorbic Acid, ppm	0