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The feeding of rhinoceros in captivity

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Rhinoceros are large herbivores that are adapted for gaining energy from the fermentation of fibrous plant material. In this paper we address issues of oversupplementation of energy (leading to obesity) and minerals (particularly iron in Black rhinoceros *Diceros bicornis),* outline a diet design that relies on forage as the staple component with a reduction in use of pelleted compound feeds and give suggestions for supplement provision. Acquisition of adequate roughage is probably the most important step in the feeding management of large herbivores and should be regarded and organized accordingly. Ration calculation must be an integral part of diet design to avoid the imbalances that are currently observed, especially in relation to mineral provision. The use of grain or grain products in pelleted compound feeds is largely discouraged.

Key-words: Asian rhinoceros, Black rhinoceros, browse, hay, nutrition, obesity, pelleted compound feed, protein, White rhinoceros

Rhinoceros nutrition has been reviewed by Dierenfeld (1995, 1996, 1999) and in this article we aim to expand on those reviews, without duplicating the information. Four rhinoceros species are maintained in captivity: the White rhinoceros *Ceratotherium simum,* Asian rhinoceros *Rhinoceros unicornis,* Black rhinoceros *Diceros bicornis* and Sumatran rhinoceros *Dicerorhinus sumatrensis.* At time of writing, few facilities maintain Sumatran rhinoceros outside their native country and, therefore, the feeding of *D. sumatrensis* is not addressed specifically in this review, although the species can be expected to have similar nutritional requirements to the Black rhinoceros.

Rhinoceros species can be classified as strict browsers (Black rhinoceros), and strict (White rhinoceros) or less strict (Asian rhinoceros) grazers (Laurie *et al.,* 1982; Clauss, Castell *et al.,* in press a). The Asian rhinoceros is often termed a 'mixed feeder', owing to observations of browse and fruit ingestion in the wild (e.g. Owen-Smith, 1988). From an ecological point of view, this is correct; however, from a husbandry point of view classification as a mixed feeder may erroneously encourage the provision of an increased proportion of concentrates or fruits. In the wild, the diet of Asian rhinoceros consists of 70–89% grasses. Dinerstein & Wemmer (1988) report a maximum intake of 5·1 kg of *Trewia nudiflora* fruit per day during the monsoon season, with a dry matter (DM) content of *c.* 16%. This results in a DM intake from fruit pulp of <820 g and, assuming a total daily DM intake of 1·5% of body mass in a 2 tonne Asian rhinoceros, *T. nudiflora* fruits would thus account for $<3\%$ of the total daily DM intake. This finding and the fact that wild fruits do not resemble commercial fruits usually provided for animals in zoos (Oftedal & Allen, 1996), emphasize that offering fruits to Asian rhinoceros in captivity cannot be justified by chance observations of their natural diet. The natural diet of any rhinoceros species is characterized by a high-fibre and low-to-moderate protein content (Table 1). The protein content of forage for Black rhinoceros (strict browsers) is generally higher than that of the grazing species. It should be noted that this increase in protein is not accompanied by a reduction in fibre content. It is generally recognized that crude protein measurements in browse do not reflect available protein, as some part

SPECIES	CP	CF	SOURCE
White rhinoceros *Ceratotherium simum*	5	36	Kiefer *et al.* (2003)
Asian rhinoceros *Rhinoceros unicornis*	5	40	Duke & Atchley (1986); data for staple diet item, grass *Saccharum spontaneum*
Black rhinoceros *Diceros bicornis*	6–18	30–45	Castell (2005); collated data

Table 1. Crude protein (CP) and crude fibre (CF) content of natural forages of free-ranging rhinoceros species. Values in % dry matter.

of the nitrogen in browse may stem from, or may be bound to, plant secondary compounds (Oftedal, 1991). Therefore, high measurements of crude protein in the natural diet of browsing species need not necessarily translate into higher protein requirements as compared to grazers.

The anatomy of the digestive system in rhinoceros species roughly resembles that of horses: rhinoceros are monogastric animals with a hindgut-fermentation chamber (Stevens & Hume, 1995). Microbial fermentation of plant fibre in the hindgut provides the main energy source for rhinoceros.

The digestive strategy of grazing rhinoceros is characterized by a slow ingesta passage and, hence, a high digestive efficiency that is comparable to that of domestic horses (Kiefer 2002, Clauss, Polster *et al.,* 2005a). In contrast, Black rhinoceros seem to have a comparatively faster ingesta passage and a lower digestive efficiency (Clauss, Froeschle *et al.,* 2005; Clauss, Castell *et al.,* in press a). Dry-matter intake in an adult rhinoceros ranges 1–2·5% of body mass in zoo studies (Dierenfeld, 1999; Dierenfeld *et al.,* 2000).

It appears reasonable to use the dietary requirement data from horses, in particular for minerals and some vitamins, as feeding recommendations for rhinoceros. However, using the standards recommended for horses to evaluate the nutrient status of rhinoceros from blood samples may not be appropriate for all target nutrients (Clauss *et al.,* 2002; Dierenfeld *et al.,* 2005).

DIET FORMULATION: QUANTITY AND COMPOSITION

Energy provision should be the first area of concern when evaluating captive-feeding regimes for rhinoceros. Atkinson *et al.* (2004) collated evidence that Asian rhinoceros in captivity may be substantially heavier than their free-ranging counterparts. Dierenfeld *et al.* (2000) warned that Sumatran rhinoceros could become obese if offered food *ad libitum,* and reported that the removal of the pelleted compound feed from the diet and a limit on the amount of hay offered could resolve the problem. Apart from inappropriate flooring (Von Houwald & Flach, 1998), obesity is considered a major contributor to foot problems in Asian rhinoceros (Atkinson *et al.,* 2004) and it is also suspected that the condition contributes to foot problems in Black rhinoceros (Boever, 1976). Uterine tumours (leiomyomas) are frequently reported in Asian rhinoceros (collated in Clauss, Polster *et al.,* 2005b), and similar problems in humans and elephants give rise to the suspicion that obesity may be a contributing factor (see also Hatt & Clauss, this volume). General considerations on energy requirements and utilization efficiency (explained in Clauss, Polster *et al.,*

2005b) lead to the conclusion that the maintenance requirements of hindgut fermenters should be *c.* 0·6 MJ digestible energy per $kg^{0.75}$ metabolic body mass. Digestible-energy intakes in excess of this figure have been measured in Asian, White and Black rhinoceros in captivity on conventional zoo diets of hay, pelleted compound feeds and produce, and even in Asian rhinoceros on *ad libitum* hay-only diets (Kiefer, 2002; Castell, 2005; Clauss, Polster *et al.,* 2005b). The roughage portion of the diet should possibly be restricted (see also Hatt & Clauss, this volume). A scoring system for body condition, using the prominence of bony structures, such as the spine, hip bones or shoulder blades, has been developed for Black rhinoceros (Reuter & Adcock, 1998). Such systems should also be developed for the other rhinoceros species and they should be used regularly, in addition to frequent weighing, to assess the nutritional status of the animals (Plates 1a,b, 2a,b and 3a,b). For large animals, such as rhinoceros, built-in scales should be readily available, at least in newly constructed facilities. In the authors' experience, it seems that the two grazing and more 'lethargic' rhinoceros species are more prone to obesity in captivity than the 'nervous' Black rhinoceros (see Plates); however, a systematic investigation of this suggestion is pending.

DIET COMPOSITION: HAY

Hay should account for the major proportion of any diet for rhinoceros in captivity. The importance of the hygienic quality of the hay has been emphasized by cases resembling a 'farmer's lung' condition reported in Asian rhinoceros at the zoo in Basle (Rüedi, 1984). The tendency for Black rhinoceros to develop fungal pneumonia is likely to be secondary to a disturbance of immune functions (Miller, 2003); however, using hay of impeccable hygienic status should help to reduce the risk. Constant monitoring of hay quality, and the disposal of unhygienic batches, must be an integral part of rhinoceros husbandry. Processing hay through a mechanical shaker prior to feeding can significantly reduce dust inhalation by both the animals and keepers.

For the grazing species, grass hay is the appropriate roughage. Even Black rhinoceros can be offered grass hay alone, without the problem of low food intake that is often observed in other browsing herbivores, such as tapirs *Tapirus* spp or giraffes *Giraffa* spp (cf. Foose, 1982; M. Clauss, pers. obs). However, if the protein content of the grass hay is not being monitored by laboratory analyses, the addition of a legume hay to the grass-hay portion of the diet (e.g. 20% of the grass hay offered) is recommended in order to ensure adequate protein levels, even in grazing species. For the browsing rhinoceros, a 1:1 mixture of grass hay and lucerne hay *Medicago sativa* (also called alfalfa hay) has been recommended (Dierenfeld, 1995) in order to mimic the nutrient composition of the natural diet. In contrast, the exclusive use of lucerne hay for Black rhinoceros is discouraged (Dierenfeld, 1999), although published evidence is missing so far. When available, freshly cut grass can also be offered but, as for horses, the grass should not be cut too short as it may cause constipation of the hindgut. Hays of particularly high-fibre content are believed to be responsible for the rarely observed cases of obstipation (severe and obstinate constipation) (Dierenfeld, 1999), most probably a result of animals used to more palatable roughage going off their feed for a period of time. Therefore, the hay (mix) offered should not only be of the highest hygienic quality but also of a nutritional quality that guarantees a constant intake by rhinoceros.

A problem not investigated so far is the incidence of excessive tooth wear in browsing species as a result of the use of grass hay (Clauss & Dierenfeld, in press). Grass contains abrasive components

1a

1b

2a

2b

3a

3b

Plate 1a. Free-ranging White rhinoceros *Ceratotherium simum* **and 1b. a White rhinoceros in captivity; Plate 2a. free-ranging Asian rhinoceros** *Rhinoceros unicornis* **and 2b. an Asian rhinoceros in captivity; Plate 3a. free-ranging Black rhinoceros** *Diceros bicornis* **and 3b. a Black rhinoceros in captivity. Note the differences in body condition, in particular with respect to the spinal process above the pelvis. The White rhinoceros (Plate 1a,b) and the Asian rhinoceros (Plate 2a,b) (both grazing species) are particularly prone to obesity in captivity. This appears to be a lesser problem in Black rhinoceros (Plate 3a,b).** *Plate 1a. Mark Atkinson. Plate 1b. The Wilds, Cumberland, OH, USA. Plates 2a and 2b. Nick Lindsay, ZSL, UK. Plates 3a and 3b. White Oak Conservation Center, Yulee, FL, USA.*

(silica), which do not occur in lucerne. Grazing species are adapted to this by their hypsodont (high-crowned) dentition, but in browsing species with lower tooth crowns, the chronic ingestion and chewing of grass material could, in theory, lead to early severe tooth wear. Excessive tooth wear has been observed in one old and one middle-aged Black rhinoceros kept on a grass-hay-based diet (M. Clauss *et al.,* pers. obs). Systematic evaluations are lacking so far. However, these reflections might support the concept that diets for Black rhinoceros contain not only grass hay but also lucerne hay and especially browse as the staple items.

In our experience, achieving a regular supply of fresh grass, and especially lucerne hay of acceptable quality, is sometimes a problem for European zoos and should probably be regarded as the major limiting factor for the optimization of the husbandry of large herbivores. The provision of high-quality hay is essential and personnel responsible for purchasing these products should be experienced in evaluating hay quality, and should be able to discuss the production and harvesting methods with farmers. The logical solution to the dilemma of limited availability of forage is to either contract farmers or cultivate land owned by the zoo. Potentially several zoos could collaborate to contract a farmer if it is more economical to purchase a high tonnage. Such cooperation should be a long-term commitment with a mutual learning process that would eventually result in the production of forage of the highest quality, as specified by zoos and within the limitations of the land being cultivated. Silage could be produced for winter and browse could be farmed (e.g. Hoellerl *et al.,* 2005). The hygiene problems associated with storage could partially be reduced by using fresh forage (grass, lucerne) during the growing season.

Supplementation It is recommended that the portion of pelleted compound feeds (or other forms of concentrates) in the diet should not exceed one-third of the overall calorific value (Dierenfeld, 1999) but it should be emphasized that this is a *maximum* recommendation; it should be possible to deliver sufficient amounts of energy and protein while providing a substantially lower proportion of pelleted compound feeds or concentrates in the diet. In spite of uniform recommendations for the proportion of pelleted compound feeds to be offered in the diets of all rhinoceros species (Lintzenich & Ward, 1997; Dierenfeld, 1999), in practice there seems to be a tendency to provide Black rhinoceros (strict browsers) with a diet that has a higher proportion of concentrate than the grazing species (Clauss, Castell *et al.,* in press a). There is no scientific basis for this practice and high levels of mineralized pelleted compound feeds may contribute to health problems in Black rhinoceros. In general, a high proportion of pelleted compound feeds and a correspondingly lower proportion of hays and/or browse, are probably contributory factors to the dental calculus often observed in this species (Walter *et al.,* 1992; Miller, 2003; Hatt *et al.,* 2004), which may lead to parodontosis (chronic inflammation of the gums) and oral abscesses.

Pelleted compound feed may be used to balance mineral, vitamin and, in some cases, protein requirements; it should only be used to satisfy energy needs when adequate roughage is not available. There is no scientific rationale for the inclusion of grain products in pelleted compound feeds for strict herbivores. Because the addition of grain ingredients to pelleted compound feeds will also influence their fatty-acid composition unfavourably, the development of a herbivore pelleted compound feed (to be used sparingly) based on lucerne meal, with a high concentration of vitamins and minerals, is recommended for rhinoceros as well as other strictly herbivorous species. The levels of the amino acid tyrosine in the ingredients of a compound feed should be evaluated and, based on this, a supplementation of the formula could be considered because higher levels of tyrosine have been reported in the red-blood cells of rhinoceros and equids than in other mammals, and Black rhinoceros in captivity have significantly lower tyrosine levels than their free-ranging conspecifics. There is speculation that tyrosine might act as an important antioxidant in the red-blood cells of these species (Weber *et al.,* 2004). An investigation into potentially beneficial effects of tyrosine supplementation in the diet of rhinoceros is warranted.

SELECTED MICRONUTRIENTS AND NON-ROUGHAGE FOOD ITEMS

Mineral deficiencies have rarely been reported in rhinoceros in captivity and for most micronutrients the dietary concentrations as recommended for horses should also be adequate for rhinoceros (Dierenfeld, 1999). Some zoo diets offered to Asian rhinoceros have been found to be deficient (when compared to the recommendations for horses) in several nutrients, such as phosphorus, copper or zinc (Clauss, Polster *et al.,* 2005b). In contrast, owing to the higher proportion of pelleted compound feeds in diets offered to Black rhinoceros, zoo diets analysed by Castell (2005) offered to this species invariably supplied an excess of all the minerals investigated (iron in particular), with the notable exception of copper, which was low in several cases. Here, some observations on selected minerals are presented.

Available data on the mineral composition of natural diet items of Black and White rhinoceros, compared to values in grass, lucerne and browse used in temperate-zone zoos, are collated in Table 2. From the table, a general necessity to supplement certain minerals to roughage-based diets becomes evident. Generally, the mineral and vitamin content of a diet needs to be monitored by ration calculation, in order to avoid deficiencies or excesses.

Sodium (Na) Compared to horses, Black rhinoceros have been found to have higher endogenous faecal sodium losses (Clauss, Castell *et al.,* in press b). For this species, as for other rhinoceros species and herbivores in general, salt licks should be available *ad libitum.*

Calcium (Ca) and phosphorus (P) Browse material has a drastically higher calcium to phosphorus ratio than grass, a fact that is reflected in the difference in calcium levels in forage in the natural diets of Black and White rhinoceros (Table 2). Given the high calcium content in browse, the feeding of lucerne hay should not be discouraged on account of its higher calcium content (compared to grass hay). A diet based on any hay (grass or lucerne) or browse, supplemented with a pelleted compound feed on the basis of lucerne meal, does not require any additional calcium source. For example, Kiefer (2002) reports a case of a feeding regime for White rhinoceros in captivity where the calcium levels were already higher than those found in the diet of free-ranging conspecifics, but the animals in captivity still received a calcium supplement. The mineral mix integrated in the pelleted compound feed based on lucerne meal should also not contain an additional calcium source. This is particularly relevant insofar as calcium is usually supplied by adding lime, which is often rich in iron. The omission of an additional calcium source might, therefore, be a significant contribution to the reduction of iron in the pelleted compound feed and the overall diet (see below). Roughage-based diets are particularly prone to phosphorous deficiency. Hypophosphataemia (low levels of phosphorus in the blood) has been observed in Black rhinoceros with haemolytic crises, so a deficiency of this mineral in the diet should be avoided. Anecdotal success in cases of haemolytic crises or necrolytic dermatitis (skin disease) in Black rhinoceros in which, amongst other treatments, phosphorous supplementation was administered, recommend this practice in such cases. Whether particular phosphorous supplementation should be regarded as a medical treatment in diseased animals only or recommended in regular diets remains to be investigated.

Copper (Cu) Dierenfeld *et al.,* (2000), Clauss, Polster *et al.,* (2005b) and Castell (2005) all reported some diets for rhinoceros to be deficient in copper. Further to these findings, Dierenfeld *et al.* (2005) observed low copper levels in the liver tissue of browsing rhinoceros and recom-

MINERAL	FORAGE		TEMPERATE			MAINTENANCE RECOMMENDATION FOR HORSES[4]
	BLACK RHINOCEROS[1]	WHITE RHINOCEROS[2]	BROWSE[3]	LUCERNE[3]	GRASS[3]	
g/kg DM						
Ca	17·6 (7·0–42·7; $n=25$)	2·4 (1·8–3·7; $n=6$)	15·6 (9·3–23·8; $n=12$)	21	4·8 (2·1–9·7; $n=14$)	2·4
P	1·2 (0·4–2·0; $n=25$)	1·0 (1·0–1·1; $n=6$)	2·7 (1·6–4·7; $n=12$)	3·0	2·7 (2·0–3·1; $n=14$)	1·7
Mg	2·7 (1·2–6·5; $n=18$)	0·8 (0·6–1·1; $n=6$)	3·4 (2·0–6·9; $n=12$)	2·8	1·5 (0·6–2·7; $n=13$)	0·9
Na	0·14 (0·01–0·94; $n=18$)	0·3 (0·2–0·4; $n=6$)	0·09 (0·01–0·31; $n=10$)	1·10	0·05 (0·02–0·08; $n=5$)	1·0
K	8·7 (2·8–17·7; $n=18$)	8·5 (7·0–10·8; $n=6$)	14·9 (7·3–31·8; $n=11$)	22	21·6 (16·0–27·0; $n=14$)	3·0–6·0
mg/kg DM						
Fe	82 (12–215; $n=28$)	177 (91–220; $n=6$)	120 (64–191; $n=12$)	180	129 (46–391; $n=10$)	40–70
Mn	60 (1–269; $n=28$)		92 (14–248; $n=12$)	40	74 (37–147; $n=9$)	40
Cu	5 (1–12; $n=28$)	4 (3–6; $n=6$)	11 (7–20; $n=12$)	11	6 (4–9; $n=6$)	10
Zn	14 (3–67; $n=28$)	23 (16–35; $n=6$)	53 (13–121; $n=12$)	24	19 (15–23; $n=5$)	40

Table 2. Mineral content (mean, with range and number of samples in parentheses) of the diet of free-ranging Black rhinoceros and White rhinoceros as compared to temperate browse, grass, lucerne, and recommendations for maintenance requirements in domestic horses: [1]. Joubert & Eloff (1971), Ghebremeskel *et al.* (1991), Dierenfeld *et al.* (1995); [2]. Kiefer (2002); [3]. DLG (1960); [4]. National Research Council (1989), Meyer & Coenen (2002); DM. dry matter.

mended further research into copper metabolism in these species. To date, a clinical case of copper deficiency in a rhinoceros has, however, not been reported to our knowledge.

Zinc (Zn) Zinc deficiency may lead to the development of skin and foot lesions, so the supply of zinc should be according to recommendations.

Iron (Fe) Oversupplementation with iron is of particular concern in browsing rhinoceros, which have contracted several uncommon diseases (Miller, 2003) that have been hypothetically linked to the excessive iron stores observed in specimens in captivity, in contrast to free-ranging conspecifics (reviewed by Paglia & Dennis, 1999; Paglia *et al.,* 2001; Dierenfeld *et al.,* 2005). Dierenfeld *et al.* (2005) interpreted data on circulation and tissue-mineral levels were analysed, and the conclusion is that dietary oversupplementation is unlikely to be the sole cause of this phenomenon but a particularly effective absorption mechanism (or a lack of a functional negative feedback) is a likely contributory factor. Nevertheless, dietary oversupplementation should strictly be avoided. The recommendation for horses of 100 mg iron/kg DM will probably be met by the hay mixes described (Castell, 2005). Any manufactured pelleted compound feed, including the one based on lucerne meal, is likely to increase this concentration (Clauss, Hummel *et al.,* 2005). Green meal from grass is particularly prone to high iron levels. Care should be taken that the mineral premix ingredient of a pelleted compound feed does not increase the iron content any further.

It has been speculated that, with regard to excessive iron absorption, browsing rhinoceros should benefit from the addition of tannins to their diet (e.g. Paglia & Dennis, 1999). Tannins are natural chelators of metal ions, which reduce the availability of dietary iron, and occur in the forage of free-ranging browsing rhinoceros but rarely in the grass or lucerne hays offered as staple diet items in zoos (Wright, 1998). To date, there is no quantitative proof of the effect of tannin supplementation on rhinoceros in captivity but assessing the results of studies on other species (reviewed by Clauss, 2003), it is probable that an increased dietary tannin content will reduce iron absorption in rhinoceros. However, in studies with humans it has been shown that the tannin source must be consumed in synchrony with the iron source, in order for the tannin to have an effect (e.g. Disler *et al.,* 1975). Tannins can only be added to manufactured feed components (e.g. in the form of tea leaves or as red-grape pomace) and as these feeds will always represent the minor proportion of the diet of rhinoceros in captivity, this goal is unlikely to be met. Nevertheless, the inclusion of a tannin source that does not in itself increase iron content should be considered when composing a pelleted compound feed for browsing rhinoceros. However, this should not be an excuse for not attempting to reduce the iron levels in the diet in rhinoceros. In most zoos, it appears unlikely that excessive iron absorption in Black rhinoceros can be avoided completely, therefore veterinary monitoring of iron status, including intervention in the form of regular phlebotomy (controlled bleeding, as carried out in humans with iron-storage disease) if necessary, should be an integral part of the husbandry routine for Black rhinoceros (Paglia, 2004).

Vitamin E Circulating vitamin E levels of both free-ranging and captive rhinoceros are generally very low (Dierenfeld *et al.,* 1988; Clauss *et al.,* 2002). Since 1991 vitamin E supplementation of rhinoceros has increased and, on average, higher circulating vitamin E levels have been detected (Clauss *et al.,* 2002). However, no significant effect of this increase on the occurrence of uncommon diseases

in Black rhinoceros has been reported. It appears unlikely that supplementation with specially designed, water-soluble vitamin E forms is necessary, and dietary levels of 150–200 IU/kg DM should be adequate (Dierenfeld, 1999).

Fatty acids Serum fatty acids measured in Black rhinoceros in captivity (compared with values from wild counterparts) were at elevated levels for n-6 (linoleic acid) and lowered levels for n-3 (linolenic acid) (Clauss, Dierenfeld *et al.,* 2005), a pattern consistent with the relative concentrations of these nutrients in zoo diets versus wild dietary plant material; the source of n-6 in zoo diets are the grains widely used to formulate compound feeds routinely offered to balance roughage, because these are naturally high in n-6 (Grant *et al.,* 2002). Clauss, Dierenfeld *et al.* (2005) found a significant correlation between the proportion of grain products in the diet of Black rhinoceros in captivity and the proportion of n-6 fatty acids in their serum and red blood cells. These n-6 fatty acids are pro-inflammatory, whereas the n-3 fatty acids are anti-inflammatory. Thus it is not only the quantities that are significant but also the balance between the two. It has been hypothesized that the occurrence of fatty-acid imbalances in zoo diets that use grain-based compound feeds contribute towards a number of uncommon skin-disease phenomena observed in Black rhinoceros (Grant *et al.,* 2002). The n-3 fatty acids can be supplemented by feeding fresh forage, such as freshly cut grass and browse, by increasing the proportion of grass or lucerne hay in the overall diet, by using pelleted feed compounds based on lucerne meal rather than grain or soy products, or by including linseed products or linseed oil in the pelleted compound feed (Grum *et al.,* 2005).

Several commercially available pelleted compound feeds exist for rhinoceros and their use should be judged according to the considerations reported here. The development of a commercially available pelleted compound feed with no grain ingredients is awaited. If a commercial pelleted compound feed is used, it is recommended that it has a high-fibre content [crude fibre 20% or ADF (acid-detergent fibre) 25% of DM]. In parallel to observations in horses (reviewed in Clauss & Kiefer, 2003), Göltenboth (1995) speculated that an increased supplementation with energy-dense feeds, such as grain-based products, could lead to laminitis (founders, inflammation of the hoof-horn producing stratum of the hoof) and contribute to foot problems in rhinoceros species.

There is no nutritional or financial rationale for offering fruits or vegetables to rhinoceros (Oftedal & Allen, 1996). If a fruit component of the natural diet is to be mimicked for pedagogic or emotional reasons, then commercially available green leafy vegetables best resemble 'wild fruits' in their nutritional composition. Onions, brassicas and rape should be avoided, as they have all been linked with haemolytic anaemia in other species (Dierenfeld, 1999).

In order to avoid ingestion of sand, which can cause colic in these species (Miller, 2003), rhinoceros should not be fed on sandy ground.

BROWSE

Black rhinoceros should be provided with fresh browse, such as branches of shrubs or trees, with foliage in the vegetation period or without foliage during wintertime, on a regular basis. In our experience, willow *Salix* spp, beech *Fagus* spp, hazel *Corylus* spp, ash *Fraxinus*, birch *Betula* spp, oak *Quercus* spp, poplar *Populus* spp, apple *Malus* spp, cherry and prune *Prunus* spp, pear *Pyrus* spp and wild rose *Rosa* spp, have been fed to Black rhinoceros, mostly in combination, without problems. It should be stated that Dierenfeld (1999) explicitly warns against the use of maple *Acer* spp and oak, as these have been

reported to lead to haemolysis in other animal species. Dierenfeld (1999) also gives a list of other browse species that can be fed to Black rhinoceros. Before a new browse item is fed, enquiries should be made about any potentially toxic effects of that browse species. In general, a variety of browse species should be offered simultaneously. For winter feeding, browse can be preserved by silaging (Hatt & Clauss, 2001; Nijboer *et al.,* 2003) and bare branches can be offered, which will also provide a source of behavioural enrichment. With the increasing addition of browse to the diet of Black rhinoceros in captivity, their digestive efficiency decreases to values reported for boma-held or free-ranging animals (Clauss, Castell *et al.,* in press a). As Asian rhinoceros are not as high on the priority list of animals that should receive browse in a zoological institution, and if browse supply is limited, they could be offered uneaten branches from other exhibits in the zoo if there is no concern about disease transmission.

ENRICHMENT

To our knowledge, the only behavioural-enrichment study in rhinoceros associated with feeding is on the influence of food dispersal on the behaviour of 1.5 (♂.♀) White rhinoceros in a group exhibit (Schmidt & Sachser, 1996). When hay was offered in only one pile for all the animals there were more agonistic encounters than when hay was provided in several heaps, one for each animal. Stress-hormone levels, as measured in the saliva, were elevated during clumped feeding and agonistic behaviour continued to be observed long after the hay was consumed. Salivary stress-hormone levels of a single bull in an adjacent enclosure also increased during the clumped-feeding period. These results underline the importance of providing an appropriate number of feeding places for animals that are maintained in social groups.

For large herbivores, such as rhinoceros, the best behavioural-enrichment measure is probably to offer a diet that is bulky with a low-energy density, namely a hay-based diet containing few concentrates and with the possible addition of browse.

CONCLUSIONS

Energy and protein should be provided to all rhinoceros species in captivity in the form of roughage: best fresh or silage, or dry (hays). For White and Asian rhinoceros, grass material is most appropriate, with a potential small addition of lucerne to increase protein levels. For Black rhinoceros, the 1:1 mixture of grass and lucerne has been recommended, plus as much browse material as possible.

Commercial fruits, vegetables, cereals and grain products should not be fed, except for medication or training purposes, although even in these cases, green leafy vegetables are to be preferred.

Minerals and vitamins should be balanced by the provision of small amounts of pelleted compound feeds based on lucerne meal. Deficiencies and excesses should be avoided. In the Black rhinoceros in particular, care should be taken to avoid an excess of iron, often introduced to the diet via pelleted compound feeds and mineral supplements.

Rhinoceros are prone to obesity and food should be given restrictively, based on either the results of regular weighing or regular assessment of the body-condition score. Changes to the amount of roughage offered should be accompanied by corresponding changes to the amount of pelleted compound feeds offered.

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