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Energy and Mineral Nutrition and Water Intake in the Captive Indian Rhinoceros (*Rhinoceros unicornis*)

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In the captive Indian rhinoceros (*Rhinoceros unicornis*), two disease complexes with a high incidence—chronic foot problems and uterine leiomyomas—may be linked to excess body weight (BW). In this study, intake and digestion trials were conducted (by means of 7-day weigh-backs, and 5-day total fecal collections, respectively) with 11 Indian rhinoceroses at four zoological institutions in Europe and the United States to quantify energy and mineral nutrition on conventional or roughage-only diets. Diets comprising a variety of forages (grass hay only, a combination of grass hay and grass silage, straw, or a mixture of grass and legume hay) were offered as the roughage source, along with various concentrates, produce, and supplements. Water intake was quantified, and urine samples were obtained opportunistically. The animals consumed 0.5–1.1% of their BW in dry matter (DM) daily, with calculated digestible energy (DE, in megajoules MJ) values ranging from 0.27 to 0.99 MJ DE/kg BW$^{0.75}$/day compared to an estimated requirement of 0.49–0.66 MJ DE/kg BW$^{0.75}$/day. Seven of 11 rhinos (64%) fed restricted levels of concentrate plus forage consumed DE in excess of this estimate. Even on roughage-only diets, some individuals consumed energy well above the presumed metabolic requirements. Hence, restriction of both

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concentrates and roughage may be important for weight management in this species. Water intake ranged from 30 to 49 mL/kg BW daily (3.4–5.2 L/kg ingested DM), similar to values that have been reported for domestic equids. Excretion amounts and patterns also resembled those found in horses. Endogenous fecal losses measured for Ca, P, Cu, Fe, and Zn indicate that the maintenance requirements of these minerals should be met in Indian rhinoceroses by diets that meet recommendations for domestic horses. It is particularly important to evaluate dietary adequacy in mineral nutrition in this species in concert with the need for restricted energy intake, especially with regard to the hypothetical involvement of a low Zn supply in chronic foot problems. Zoo Biol 24:1–14, 2005. © 2005 Wiley-Liss, Inc.

Key words: perissodactyla; rhinoceros; diet; health; obesity; energy; minerals; zinc

INTRODUCTION

In recent years, there has been an increased awareness within the zoo community of the general problem of animal obesity. This applies to zoo animals in general [Ward et al., 1999], and particularly to primates [Terranova and Coffam, 1997; Lintzenich and Ward, 2001; Schwitzer and Kaumanns, 2001] and very large herbivores, such as elephants [Taylor and Poole, 1998; Ange et al., 2001; Hatt and Liesegang, 2001]. It is difficult to assess the nutritional status of very large animals if the animals cannot be weighed on a regular basis. Although body-condition scores for large animals have recently been made available [e.g., Reuter and Adcock, 1998], an obese condition may go unnoticed due to the large size of these animals, and the fact that they normally "look heavy."

In captive Indian rhinoceroses (*Rhinoceros unicornis*), two pathological conditions occur frequently that may be associated with or exacerbated by obesity. Benign uterus tumors (leiomyomas) occur frequently in both Indian rhinoceroses and elephants [Cotchin, 1964; Jones, 1979; Montali et al., 1982; Wallach and Boever, 1983; Goeltenboth, 1985, 1986, 1995a, b; Kock and Garnier, 1993; Ruedi, 1995]. Such tumors may reduce fertility because they can be mechanical obstacles to natural insemination, and because affected females cease to come into estrus. Hormonal changes have been implicated in the etiopathology of leiomyoma in rhinoceroses and humans, and a correlation between the occurrence of leiomyomas and obesity has also been suspected or demonstrated in humans [Shikora et al., 1991; Kaminski and Rzempoluch, 1993; Sato et al., 1998; Okorowonko, 1999].

Although chronic foot lesions are not fatal, they have long been a veterinary problem in captive Indian rhinoceroses [Jones, 1979; Strauss and Seidel, 1982, 1985; Wallach and Boever, 1983; Ruedi, 1995; Goeltenboth, 1986, 1991, 1995a, b; Kock and Garnier, 1993; Strauss and Wisser, 1995; Von Houwald and Flach, 1998; Seliskar et al., 2000; Atkinson et al., 2002]. This issue has been investigated in detail by Von Houwald [2001], who reported that the incidence of this problem in adult animals approaches 100% in bulls and >50% in females. Although providing an appropriate substrate and access to a water basin are considered to be of major importance in preventing foot lesions, it has also been repeatedly stated that obesity triggered by unnecessary concentrate feeding will exacerbate the problem. Goeltenboth [1995b] speculated that, as in domestic horses, excessive concentrate feeding may induce laminitic lesions and thus contribute to the phenomenon.

Additionally, potential mineral imbalances, especially in zinc supply, are suspected to be a contributing factor. Blood analyses suggest that mineral metabolism in rhinoceroses is similar to that in horses (Dierenfeld et al., unpublished results), although there are marked differences in vitamin metabolism [Clauss et al., 2002]. However, this conclusion has not yet been confirmed by nutritional studies.

With the health problems of captive Indian rhinoceroses in mind, we sought to measure energy intake on conventional zoo diets and roughage-only diets, and establish correlations between mineral intake and excretion that would increase our understanding of mineral metabolism in this species.

MATERIALS AND METHODS

Eleven Indian rhinoceroses from four zoological institutions (A–D) were used for this study. We either weighed the animals or estimated their body weight (BW) using multiple photographs of the weighed animals for comparison (Table 1). All estimations were made by the same person (C.P.). The animals had regular access to outside enclosures, which were cleared of any potential food items prior to the study. For the trial period, the animals were housed separately to allow individual food intake and fecal excretion data to be recorded. Only the two females at zoo C were allowed to access their outside enclosure together, and the correct allocation of feces voided during this period was ensured by constant observation.

At zoos A, B, and D, two rations were fed to the animals: 1) ration RC (the diet regularly fed at the respective zoo, i.e., a mixture of roughage and concentrates), and 2) ration R (roughage feed only, after an adaptation period of 7 days). At zoo C, only the regularly-fed diet was used. The roughage source was grass hay at zoo A, a combination of grass hay and grass silage at zoo B, straw at zoo C, and a mixture of grass and alfalfa hay at zoo D. For details regarding the rations, see Tables 2 and 3. We measured food intake by weighing the food offered and the food left over at the next feeding time for 7 days. Feces were collected and weighed in toto for the last 5 days. We estimated water intake at facilities A–C by measuring the volume of water consumed directly from mobile drinking troughs or from permanent water troughs at the next feeding time. At each of these facilities, we estimated evaporation losses

TABLE 1. Indian rhinoceroses used in this study

No.	Studbook no.	Name	Sex	Age (years)	BW (kg)	Facility
1	152	Niko	M	13	(2300)[a]	A
2	193	Rapti	F	12	(1950)[a]	A
3	135	Noel	M	15	(2200)[a]	B
4	195	Purana	F	10	(1900)[a]	B
5	220	Jaffna	M	8	(2100)[a]	C
6	110	Ellora	F	20	(2000)[a]	C
7	210	Quetta	F	8	(1900)[a]	C
8	53	Vinu	M	31	1821	D
9	139	Kali	F	15	1989	D
10	223	Penny	F	8	1864	D
11	66	Pinky	F	29	1833	D

[a]Bodyweights are either actual weights or estimates.

TABLE 2. Dry matter (DM), gross energy (GE), crude protein (CP), neutral detergent fiber (NDF) and mineral content of feedstuffs (per kg DM) used in this study

Feeds	Facility	m	DM %	GE kJ/g	CP % DM	NDF % DM	Ca g/kg	P g/kg	Cu mg/kg	Fe mg/kg	Zn mg/kg
Hay	A	RC	90.9	18.3	7.8	66.0	3.8	2.0	5.9	287.3	19.4
	A	R	91.0	18.8	8.5	71.3	3.5	2.2	6.7	182.9	21.7
	B	RC	91.1	18.7	6.0	71.4	3.3	2.5	5.7	75.6	38.9
	B	R	91.3	18.5	6.1	68.0	3.5	2.1	4.9	37.6	41.3
	D	RC	92.1	19.8	6.7	62.0	8.0	1.9	6.1	28.0	30.4
	D	R	91.6	19.4	7.3	65.7	5.7	1.2	5.3	24.7	29.4
Silage	B	RC	63.2	18.2	8.3	71.4	3.5	3.3	5.8	48.5	25.1
	B	R	65.3	18.2	8.4	74.6	3.0	3.1	5.8	51.2	24.6
Straw	C	RC	92.0	18.5	5.1	82.6	3.1	0.8	4.3	40.8	7.6
Horse cobs	C	RC	89.2	18.4	9.6	56.8	10.3	5.4	9.5	238.9	44.4
Pellets	A	RC	86.2	18.3	15.2	43.2	13.2	6.7	17.6	386.9	302.9
	B 1	RC	89.0	18.4	16.1	56.4	6.9	3.8	18.2	476.1	71.6
	B 2	RC	85.1	18.0	22.0	37.7	13.8	6.9	125.5	582.0	294.5
	B 3	RC	87.1	17.9	14.9	41.1	11.6	8.6	20.2	476.6	166.4
	D	RC	86.7	19.2	23.0	28.9	15.9	10.2	12.9	171.0	217.1
	C	RC	88.9	18.8	18.5	25.1	11.8	7.2	12.7	326.9	135.3
Bread	A/C	RC	88.4	18.9	16.6	6.5	1.0	2.3	3.7	28.4	15.2
Mineral supplement	A	RC	95.3	2.0	0.8	5.2	204.9	6.1	676.7	1621.9	2908.5
	B	RC	88.8	9.5	8.2	13.0	100.3	1.9	1007.6	1530.4	3004.7
Apple	A/B/C	RC	14.6	19.1	2.1	14.8	0.4	1.0	2.2	9.0	5.9
Pear	A/B/C	RC	16.4	17.2	2.8	15.5	0.2	1.1	8.7	6.7	15.3
Banana	A/B/C	RC	17.3	17.3	5.0	15.0	0.5	1.9	5.7	11.4	8.4
Red beet	A/B/C	RC	11.6	17.4	9.0	15.4	1.8	0.7	9.6	22.3	32.2
Celery	A/B/C	RC	12.6	16.5	9.9	16.7	3.2	1.3	9.6	66.5	28.4
Oranges, peeled	A/B/C	RC	11.9	18.2	7.8	8.1	2.7	0.4	3.8	13.8	12.1
Salad	A/B/C	RC	5.4	14.7	27.5	36.3	13.8	0.6	10.0	1898.7	24.6
Carrots	A/B/C	RC	11.9	17.7	6.7	14.7	2.3	0.5	5.6	24.7	31.2

TABLE 3. Daily dry matter intake of individual feed items and the total diet and absolute and relative digestible energy (DE) intake

Animal	Diet	Silage kg	Hay kg	Straw kg	Horse cobs & pellets kg	Produce & Bread kg	Mineral supplement kg	Total kg	DE MJ	rel. DE $MJ/kg^{0.75}$
1	RC		16.1		3.9	3.2	0.2	23.4	220	0.66
1	R		17.2					17.2	127	0.38
2	RC		10.4		3.1	2.6	0.2	16.3	165	0.56
2	R		8.8					8.8	78	0.27
3	RC	15.0	5.0		7.5	1.2	0.2	28.8	276	0.86
3	R	18.2	4.0			0.1		22.3	216	0.67
4	RC	10.7	2.9		5.7	0.9	0.1	20.3	206	0.72
4	R	13.6	1.7			0.1		15.4	162	0.56
5	RC			10.7	9.5	2.4		22.6	208	0.67
6	RC			10.0	7.9	2.4		20.4	188	0.63
7	RC			8.1	5.3	2.3		15.7	151	0.52
8	RC		17.6		3.2			20.8	205	0.74
8	R		17.7					17.7	148	0.53
9	RC		19.5		2.7			22.2	210	0.70
9	R		18.3					18.3	159	0.53
10	RC		21.4		2.7			24.1	280	0.99
10	R		20.3					20.3	193	0.68
11	RC		10.9		2.7			13.7	143	0.51
11	R		13.3					13.3	75	0.27

throughout a 24-hr period by placing a calibrated bucket close to the indoor exhibit; however, evaporation losses were negligible compared to the accuracy of measurement. Measurements from days during which water spillage was obvious either from direct observation or from wet floors were discarded. Fresh urine was sampled whenever urination on an uncontaminated surface was observed directly, and it was possible to gain access to the urine.

The outer layer of the dung balls was removed to avoid contamination of the sample. The rest of the material was thoroughly mixed, and a subsample representing 10% of the whole sample was taken and frozen at −20°C.

After the samples were thawed, the feces from the whole collection period were pooled for each animal (according to the proportion of the respective daily defecation in the total feces output of an animal) and thoroughly mixed. Samples of feedstuffs and feces were dried at 103°C to constant weight for analysis of dry matter (DM). Crude protein and neutral detergent fiber analyses of feedstuffs were performed as described by Baer et al. [1985]. Gross energy (GE) was determined by bomb calorimetry with the use of an adiabatic IKA-Calorimeter C 4000 (IKA, Staufen, Germany) adiabatic. After wet ashing was performed, we determined calcium (Ca) by flame photometry (Eppendorf Elex 6361; Eppendorf, Hamburg, Germany); phosphorus (P) by spectrophotometry (using ammonium molybdic acid and ammonium vanadic acid, 1:1); and copper (Cu), iron (Fe), and zinc (Zn) by atomic absorption spectroscopy (939 AAS, Unicam; Thermo Electron, Dreieich-Buchschlag, Germany).

Urine samples were pooled per individual and trial period. After intensive stirring to obtain a homogenous sample, Ca content was determined as described above (because rhinoceros urine has a high proportion of particulate Ca, it tends to divide into a sediment and a fluid phase immediately), and creatinine (Cr) was measured with the use of a test kit (Metra Biosystems, Mountain View, CA) and photometry.

Digestible energy (DE) intake (in MJ) was calculated as the difference between GE intake and GE excretion. The apparent digestibility (aD) of GE was calculated as

$$aD_{GE}(\%) = \frac{GE_{Feed} - GE_{Feces}}{GE_{Feed}} \times 100$$

In the same way, the absorption coefficients for minerals were calculated.

We performed regression analyses on the mineral intake and output data to estimate the endogenous fecal losses of a mineral by extrapolation to zero intake. The statistical calculations were performed with SPSS 9.0 software (SPSS, Chicago, IL), and the significance level was set to $\alpha = 0.05$.

RESULTS

The general health of the animals during the study period did not seem to be compromised. As judged by the prominence of the hip bones and the lumbar vertebrae, no animal appeared to lose weight during the study period. Animal 2 came into heat during the second trial period. In this period, her food intake was particularly low, as was that of the bull at the same facility (animal 1).

The DM intake values are recorded in Table 3. Animals 1, 3, 4, and 11 increased their roughage intake when they were switched from diet RC to diet R. In contrast, animals 2, 8, 9, and 10 did not increase their roughage intake when they were switched to diet R. DE intake was higher on diet RC at facility A and D, but not at facility B. DE intake ranged from 0.27 to 0.99 MJ/kg metabolic BW ($BW^{0.75}$) (Table 3). It was above 0.60 MJ/kg $BW^{0.75}$ in eight of 11 animals on ration RC, and in two of eight animals on ration R.

The water balance and the urinary Cr and Ca concentrations are recorded in Table 4. Data for mineral intake and fecal output are listed in Table 5. There was a significant correlation between the Ca intake (in g/kg BW) and the urinary Ca:Cr ratio (Pearson correlation $r = 0.52$, $P = 0.022$). The apparent P absorption increased with an increasing dietary P content ($r = 0.82$, $P < 0.001$). The linear relationships between the mineral intake and fecal output, expressed on a mg/kg BW basis, were all highly significant (Table 6).

DISCUSSION

Energy Supply

Since no direct data on the energy requirement of rhinoceroses are available, we estimated this requirement using standard values generally applied to mammals. According to the allometric Kleiber equation, the basal metabolic rate (BMR) = 293 kJ/kg $BW^{0.75}$/day. The resulting energy value is the energy expenditure (basal heat production) required for basal functions, such as respiration and heartbeat in a resting animal in a thermoneutral environment. Since the BMR does not equal maintenance requirements, BMR is usually multiplied by a factor of 1.5–2 to

TABLE 4. Daily water intake by drinking, by feeds and total, fecal water excretion, urinary creatinine and calcium content

Animal	Diet	Drinking water kg	Food water kg	Totalwater kg	Fecal water kg	Urinary creatinine Mmol/L	Urinary Ca g/kg ww
1	RC	2.7	1.2	3.9	2.1	–	
1	R	3.8	0.1	3.9	2.1	–	
2	RC	2.1	1.1	3.1	1.6	–	
2	R	2.0	0.0	2.1	1.1	36.94	2.36
3	RC	5.4	0.8	6.2	2.7	8.95	2.36
3	R	4.1	0.5	4.6	2.4	–	
4	RC	3.0	0.7	3.7	2.0	9.81	2.40
4	R	3.0	0.4	3.4	1.6	16.24	1.72
5	RC	3.0	0.8	3.9	2.6	15.27	3.85
6	RC	3.4	0.8	4.2	2.6	–	
7	RC	3.2	0.8	4.0	1.8	29.19	7.84
8	RC	NM	0.1	NM	2.0	15.96	3.83
8	R	NM	0.1	NM	2.1	23.60	4.00
9	RC	NM	0.1	NM	2.0	–	–
9	R	NM	0.1	NM	1.8	–	–
10	RC	NM	0.1	NM	1.7	–	–
10	R	NM	0.1	NM	1.8	–	–
11	RC	NM	0.1	NM	1.4	6.94	1.85
11	R	NM	0.1	NM	1.8	17.42	3.81

NM, not measured; WW, wet weight.

TABLE 5. Daily mineral intake (in) and fecal excretion (out)

		Ca (g)		P (g)		Cu (mg)		Fe (mg)		Zn (mg)	
Animal	Diet	In	Out	In	Out	In	Out	In	Out	In	Out
1	RC	135.89	26.86	54.58	59.26	283	258	6004	5628	1546	1570
1	R	60.74	12.77	37.71	39.82	115	106	3147	6233	373	537
2	RC	109.41	26.33	39.55	46.72	242	218	4263	4444	1362	902
2	R	30.97	7.26	19.23	19.81	59	40	1605	2250	190	198
3	RC	151.61	53.41	96.65	90.00	524	458	5066	5575	1986	1744
3	R	67.96	22.75	65.11	60.26	126	131	1082	2197	612	594
4	RC	129.44	33.40	81.14	69.97	728	413	4066	4443	2099	1660
4	R	46.42	18.49	46.09	46.47	88	80	763	2276	405	451
5	RC	136.40	46.79	69.35	62.99	157	135	3158	4336	950	1140
6	RC	114.27	45.03	56.71	53.29	133	119	2577	3154	705	787
7	RC	83.04	32.15	41.04	43.45	100	87	1899	2685	547	672
8	RC	191.82	40.76	65.71	66.43	149	126	1037	1716	1224	932
8	R	101.68	20.47	21.78	37.39	94	95	437	1106	520	389
9	RC	198.77	42.35	63.95	76.02	154	137	1001	2568	1169	759
9	R	104.83	18.13	22.46	35.81	97	76	450	1013	536	306
10	RC	214.80	35.95	68.23	48.52	166	107	1066	1103	1242	656
10	R	116.54	25.30	24.96	37.81	108	95	500	934	596	375
11	RC	131.14	33.53	48.69	45.40	102	95	776	1248	928	527
11	R	76.21	24.45	16.33	37.34	71	93	327	2791	390	501

TABLE 6. Linear regression analysis of daily mineral intake (x) and fecal excretion (y) on a mg/kg bodyweight basis according to $y = ax + b$

Mineral	a	b	r^2	*P*
Ca	0.17	5.10	0.56	<0.001
P	0.64	10.00	0.80	<0.001
Cu	0.60	0.02	0.91	<0.001
Fe	0.82	0.62	0.76	<0.001
Zn	0.70	0.06	0.80	<0.001

calculate maintenance metabolizable energy (ME) requirements in captivity [Kirkwood, 1991, 1996; Robbins, 1993]. This translates into a maintenance requirement of 0.44–0.59 MJ ME/kg $BW^{0.75}$/day. Since the proportion of ME in dietary DE has not been determined in rhinoceroses, we used literature values to make the transfer calculation. According to a literature survey across many non-ruminant herbivores [Robbins, 1993], ME is 92.7% of DE. Using data collected by Reid and White [1978], Pagan and Hintz [1986] concluded that ME ranged between 85–94% of DE in horses. Assuming an average of 90%, this translates into a maintenance energy requirement of 0.49–0.66 MJ DE/kg $BW^{0.75}$/day. This range correlates well with the allometric equation used by Meyer and Coenen [2002] to determine horse maintenance requirements (0.6 MJ DE/kg $BW^{0.75}$/day), which we used to evaluate measured DE intake in the Indian rhinoceroses.

The results show that at facilities B and D, some animals were ingesting DE at levels far above the expected requirement. This was not the case at facilities A and C, where the roughage fed to the animals had lower energy digestibility. However, only at facility C was roughage of low digestibility deliberately chosen (straw); a hay of higher digestibility could have led to high energy intakes at facility A as well. Even on the roughage-only diet (diet R), one animal each from facilities B and D ingested distinctly more than 0.6 MJ DE/kg $BW^{0.75}$/day. It is important for the validity of this evaluation to obtain correct BW estimates. In the present study, the BWs of animals from facility D were determined by weighing, and it is in this group that the highest relative DE intakes were observed. The BWs of the other animals were estimated by one observer by comparison with the weighed animals, and these estimates were consistently higher than the weights of the actually weighed animals. Thus, an overestimation seems more likely than an underestimation. An overestimation of the BWs of the other animals would mean that the relative DE intakes of these animals are still underestimated.

These results indicate that the conventional practice of feeding a restricted amount of concentrates (and produce) but an ad libitum amount of roughage should be reassessed. Given the high incidence of both leiomyomas and foot lesions, both of which may be exacerbated (if not triggered) by excessive BW, restricted feeding of both concentrates and roughage seems reasonable. It is well known that domestic horses ingest more energy than necessary and gain BW when offered a concentrate food ad libitum [e.g., Westervelt et al., 1976], and that this also can occur on a roughage-only ad libitum diet. Moore-Colyer and Longland [2000] reported energy intakes above the calculated requirements, and associated BW gains in horses on a roughage-only ad libitum diet. Other authors observed energy intakes above the calculated requirements on roughage-only ad libitum diets in horses and donkeys

[Cymbaluk et al., 1989; Cymbaluk, 1990; Doreau et al., 1992; Hyslop et al., 1998; Pearson et al., 2001]. Although a restricted allocation of roughage is usually employed for domestic horses [Meyer and Coenen, 2002], ad libitum roughage feeding is, to our knowledge, common practice in many zoological institutions. Dierenfeld et al. [2000] demonstrated that an unrestricted food intake can lead to obesity in rhinoceroses, and therefore recommended that these animals should be weighed regularly. Kiefer [2002] measured DE intakes in captive adult white rhinoceroses (*Ceratotherium simum*) on a diet of concentrates and hay of 1.1 MJ/kg $BW^{0.75}$/day. Similarly, Clauss et al. [2003] measured DE intakes in captive adult female Asian elephants (*Elephas maximus*) on a diet of restricted oats and ad libitum hay of 0.61–0.79 MJ/kg $BW^{0.75}$/day. Ange et al. [2001] reported that captive female Asian elephants are often distinctly heavier than free-ranging specimens, with an average difference of 600–700 kg. Hatt and Liesegang [2001] reported problems with overweight in a group of Asian elephants that were ameliorated by reducing the amount of food given, including straw in the roughage, increasing fiber content in the concentrate formula, and weighing the animals regularly. Similar reports do not yet exist for captive rhinoceroses. It seems advisable to include the routine use of scales in husbandry guidelines for captive rhinoceros management.

Finally, it should be noted that apart from the low energy intakes in the animals at facility A on diet R, animal 11 at facility D had a remarkably low energy intake on the roughage-only diet. This may be explained by the old age of this animal, although it was not the oldest among the animals studied (Table 1). The case of this animal underlines the necessity of monitoring each animal individually (ideally, by obtaining actual BWs).

Water

For maintenance under moderate environmental temperatures, horses ingest approximately 30–50 mL water/kg BW/day [Meyer, 1992]. With averages for the different facilities and rations ranging from 30 to 49 mL of water intake (from food and drinking water) per kg BW per day, the Indian rhinoceroses of this study were exactly within the range given for horses. This represents a water intake of 3.4–5.2 L/kg of ingested DM. The fecal water losses in the Indian rhinoceroses ranged between 16–36 mL/kg BW/day, which again are close to the values Meyer [1992] reported for horses (20–30 mL/kg BW/day). The correspondence between the Indian rhinoceros and horse data, regardless of a three- to eightfold BW difference, suggests that water intake scales linearly with BW.

The amount of water not excreted via the feces (i.e., available for urinary excretion, and for imperceptible losses by evaporation and expiration) was 11–25 mL/kg BW/day. This calculation does not account for water endogenously produced by metabolic oxidation. Meyer and Stadermann [1990] determined a correlation between the urine volume in domestic horses (y; in mL/100 kg BW/h) and the urinary Cr concentration (x; in mg/dl) according to the equation $y = 24.3 + (14{,}067/x)$. The urinary Cr concentrations and the amounts of ingested water not excreted in the feces of the Indian rhinoceroses are depicted as dots in Fig. 1 in comparison to this equation. In general, there is no substantial deviation from the horse data. The fact that the rhinoceros values are mostly below the horse curve may be due to the missing values from metabolic body water in the balance.

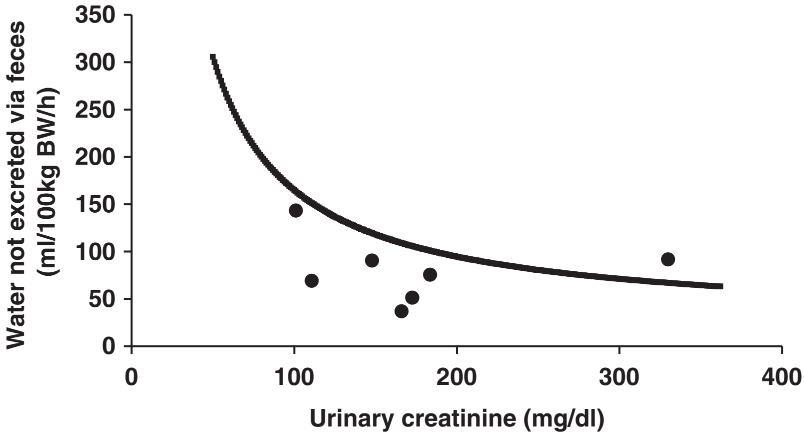

Fig. 1. Comparison between urinary Cr concentration and the amount of ingested water not excreted via the feces in the Indian rhinoceroses (dots). The curve indicates the relationship between the urininary Cr concentration and the urine volume in horses [Meyer and Stadermann, 1990].

Mineral Metabolism

Calcium (Ca)

The apparent absorption coefficient for Ca was 60–83% in the present study. Meyer and Coenen [2002] reported average coefficients of 60% in domestic horses, and Clauss et al. [2003] measured coefficients of 40–60% in elephants. Data from Cymbaluk and Christison [1989], Cymbaluk [1990] and Pagan [1998] indicate that in horses, apparent Ca absorption increases with an increasing dietary Ca:P ratio. Such a correlation was evident in the present study as well.

According to the regression analysis, endogenous fecal Ca losses in this collection of Indian rhinos were 5.1 mg Ca/kg BW/day. Meyer and Coenen [2002] reported 30 mg/kg BW/day for horses, and from data collected by Clauss et al. [2003], 6.6 mg/kg BW/day can be calculated for Asian elephants. These data suggest that endogenous fecal Ca losses in general do not scale isometrically to BW; they also indicate that the Ca requirements of rhinoceroses can be met by diets that are appropriate for horses. The increase in urinary Ca content (expressed as the Ca:Cr ratio) with increasing Ca intake suggests that Indian rhinoceroses absorb a large proportion of dietary Ca from the intestines and excrete the surplus via the kidneys, in a manner similar to that of horses [Schryver et al., 1970; Caple et al., 1982; Meyer and Stadermann, 1990] and rabbits [Cheeke and Amberg, 1973]. The clinical relevance of this finding is debatable. In theory, it is conceivable that the urinary tract of rhinoceroses could be overloaded by a more than appropriate dietary Ca supply, and hence (as previously described for rabbits [Kienzle, 1991; Kamphues, 1991; Wenkel et al., 1998] and horses [Holt and Pearson, 1984; Mair and Osborn, 1986; Laverty et al., 1992]) Ca-containing uroliths could form and cause obstructions. However, associated clinical findings have not been described in any rhinoceros species, which could be due to the comparatively large anatomical structure of the urinary tract in these animals. Interestingly, Ippen and Henne [1991] found a high incidence of renal disease with uroliths in captive wild equids.

Phosphorus (P)

The apparent absorption coefficient for phosphorus was between −129% and 29% in the present study. On average, horses achieve an apparent P absorption of 40% [Meyer and Coenen, 2002]. Clauss et al. [2003] measured coefficients of 10–30% in Asian elephants. Our regression analysis indicated endogenous fecal P losses of 10.0 mg/kg BW/day in the rhinoceroses. Meyer and Coenen [2002] report losses of 12 mg/kg BW/day for horses, and according to the data of Clauss et al. [2003], Asian elephants have losses of 6.4 mg P/kg BW/day.

Negative apparent absorption coefficients for P have been noted for roughage-only diets in horses and elephants [Cymbaluk and Christison, 1989; Cymbaluk, 1990; Clauss et al., 2003]. Concentrate feeds usually contain more available P compared to roughage feeds; accordingly, apparent P absorption coefficients were higher on rations with concentrates at facilities B and D, and on rations with concentrates for elephants [Clauss et al., 2003]. In horses, the apparent P absorption increases with an increasing dietary P content [Schryver et al., 1971; Cymbaluk and Christison, 1989; Pagan, 1998], and a similar correlation was evident in the Indian rhinoceroses.

Copper (Cu), iron (Fe), and zinc (Zn)

According to the regression analysis, the hypothetical endogenous losses of the Indian rhinoceroses are 19.9 μg Cu/kg BW/day, 617.8 μg Fe/kg BW/day, and 62.2 μg Zn/kg BW/day. On a 100 kg BW basis, they are 2.0 mg Cu/100 kg BW/day, 62 mg Fe/100 kg BW/day, and 6.2 mg Zn/100 kg BW/day. According to Meyer and Coenen [2002], a mineral supplementation for maintenance of 10–15 mg Cu/100 kg BW/day, 100 mg Fe/100 kg BW/day, and 50 mg Zn/100 kg BW/day is recommended for horses. These results indicate that Indian rhinoceroses receiving diets in accordance with recommendations for horses should be adequately supplemented.

Ration Adequacy

Using recommendations for horses (5 g Ca/100 kg BW/day, 3 g P/100 kg BW/day, 10 mg Cu/100 kg BW/day, 100 mg Fe/100 kg BW/day, and either 50 mg Zn/100 kg BW/day [Meyer and Coenen, 2002] or 100 mg Zn/kg BW/day [Kamphues et al., 1999]), we evaluated the adequacy of the different rations. Generally, the roughage-only diets (ration R) were deficient for all measured minerals, with the exception of the diets for animals 8–10 at facility D that were deficient in all minerals except Ca. Evidently, mineral supplementation of roughage diets is often necessary. According to the recommendations of Meyer and Coenen [2002], the regularly-fed diets (ration RC) were adequate in all measured minerals at facility B only. At facility A, the diet was marginally deficient in P. At facility D, all diets were deficient in Cu and Fe, and one diet was deficient in P. At facility C, all diets were deficient in Cu and Zn, one was also deficient in P, and one was deficient in all measured minerals. However, if one follows the higher recommendations of Kamphues et al. [1999] for Zn, all of the regular zoo diets (with the exception of that of animal 4 at facility B) were deficient in this element.

If the recommendations of Lintzenich and Ward [1997] for an adequate ration composition in g/kg feed (transferred to a DM basis) are used for such an evaluation (using their white rhinoceros recommendation), again the roughage-only diets were deficient in Cu and Zn, and (at facility D) P and Fe. Of the regular zoo diets, the one at facility C was deficient in Cu and Zn, and the one at facility D was deficient in Cu.

Especially with regard to the hypothetical involvement of a low Zn supply in chronic foot problems, an adequate mineral supply is warranted. The hypothetical endogenous fecal Zn losses estimated by regression analysis suggest that a recommendation of 50 mg/kg BW/day or 40 mg/kg dietary DM should be sufficient, and higher supplementation levels may be unnecessary. Roughage diets should be supplemented with minerals. With respect to the potential for unnecessary energy intake, as documented above, such a supplementation could be achieved by a mineral feed that does not contain high-energy ingredients, such as starch or sugars. In any case, intake of the final diet should be restricted and recorded periodically to permit calculation of energy and nutrient intakes.

CONCLUSIONS

1. The amount of DE ingested by Indian rhinoceroses on conventional zoo diets and roughage-only ad libitum diets indicates that excess energy intakes do occur. This is in accord with literature reports on energy intakes exceeding maintenance requirements in horses on ad libitum roughage diets. In large hindgut fermenters, both concentrates and the roughage portion of the diet should be fed in a restricted way, and BW should be monitored regularly.
2. Water intake and excretion patterns in Indian rhinoceroses are similar to those documented in domestic horses.
3. The hypothetical endogenous fecal losses for Ca, P, Cu, Fe, and Zn obtained by regression analysis indicate that the maintenance requirements of these minerals should be met in Indian rhinoceroses by diets that meet recommendations for domestic horses.
4. Our analysis of four conventional zoo diets indicates that zoo rations should be controlled by a ration calculation that includes mineral levels to ensure that the animals are receiving adequate mineral nutrition.

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