NUTRITION ADVISORY GROUP HANDBOOK

ELEPHANTS: NUTRITION AND DIETARY HUSBANDRY[1]

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Elephants are the largest extant herbivores on earth. Although the average weight of adult Asian elephants *(Elephas maximus)* tends to be less than that of adult African elephants *(Loxodonia africana)* in the wild their weight ranges overlap (Asian, 1,800-5,000 kg [4,000-11,000 lb]; African, 1,800-6,000 kg [4,000-13,000 lb])[33] and are influenced by age, sex, health, and food supply.[1,19] Their nutrient needs have been studied very little. With the exception of energy requirements for basal metabolic functions and for maintenance,[3] nutrient needs of elephants have been largely inferred from field studies of food plants and extrapolation of data from the horse.

Digestive Tract Morphology and Physiology

One of the most obvious and unique physical features of the elephant is its elongated upper lip and nose, forming a muscular trunk capable of reaching from ground level to high branches in its search for food. Although strong enough to lift an entire tree, the trunk is delicately prehensile and can be used to pick a single grass inflorescence. Food is transferred to the mouth where there is a large grinding tooth in wear on each side of the upper and lower jaw. Unlike the horse, the elephant has no canines or lower incisors, and the upper incisors, when present, have been modified to form [1][2] tusks. The grinding teeth do not succeed each other vertically, as in most mammals, but migrate forward from the back of the jaw. As the foremost tooth wears down, it is pushed out, often breaking off in transverse plates. Transverse ridges on the teeth produce an occlusal grinding surface that is particularly important for reducing siliceous or highly lignified foods to a more digestible particle size. If a tooth erupts at an improper angle, or wears unevenly, grinding surfaces may not meet, and the physical form of the diet may need to be altered to assist in the particle size reduction normally accomplished by chewing.[28]

Chewed food, mixed with saliva, passes down the esophagus to a simple stomach, connected, in turn, to the small intestine, which then joins with the colon. At this latter juncture there is a cecum of considerable proportions. The colon is sacculated but not compartmentalized, and the majority of the digesta is located in the proximal two-thirds. The average wet weight of digestive tract contents found in 10 wild African elephants in the Kruger National Park of South Africa was 415 kg (915 lb).[40] Similar values were found in Kenya where three adult elephants had an average digesta weight of 487 kg (1,074 lb).[4] Two-thirds to three-quarters of the wet digesta were found in the cecum and colon, where microbial fermentation is particularly prominent.

Digestion of protein begins in the stomach and continues in the small intestine, where fat and carbohydrate are also being broken down to absorbable forms. The cecum and colon are inhabited by anaerobic bacteria and protozoa similar to those found in the rumen and reticulum of the ruminant. Anaerobic bacteria and protozoa have also been found in the small intestine, although concentrations of protozoa are lowest in the duodenum and increase in the more distal jejunum and ileum.[39] These microorganisms digest plant fiber (principally cellulose and hemicellulose) that otherwise could not be used, since elephants, like other herbivores, have no fiber-digesting enzymes of their own. Microbial fermentation of fiber, other incompletely digested compounds, and lactic acid formed in the upper tract results in production of volatile fatty acids that can be absorbed and used for energy.

These digestive processes, and the finding that elephants have a rapid gut transit time (11-46 br),[2,3,13,27] are consistent with a digestive system designed to deal most effectively with young and tender plant parts but with the capacity for high throughput and the ability to partially digest plant fiber for energy, courtesy of the symbiotic microorganisms inhabiting the hind gut. Digestibility of the dry matter in wild diets consumed by free-ranging African elephants has been estimated to be 30-45%.[20] Digestibility of the dry matter in timothy *(Phleum pratense)* hays consumed by captive African elephants was variously estimated to be 45-46%[12] or 35-39%.[29] In another study with captive Asian and African elephants fed grass hay, dry matter digestibility was 3 8-43%.[13]

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1 Adapted in part from Ullrey, D.E. 1991. Dietary husbandry of the elephant Unpublished, manuscript, Michigan State University, East Lansing, MI; and Crissey, S.D., and H.F. Hintz. 1997. Protein nutrition of elephants. Elephant Managers News Letter.

2 Numbers in [ ] = pages of the original fact sheet

Natural Dietary Habits

Numerous studies on feeding habits of African and Asian elephants indicate that they are generalist feeders, consuming a large number of plant species but with wide variations regionally and seasonally in the proportions of grasses, sedges, forbs, shrubs, and trees. Fruits, bulbs, plant bases, and roots also are consumed. Both browsing and grazing are practiced, but elephants tend to take plant types in proportion to their availability.[10] Browsing is commonly defined as consumption of forbs and the tender shoots, twigs, and leaves of trees and shrubs, whereas grazing is the consumption of grasses and sedges. Free-ranging African elephants select relatively young plant parts if food supplies are not excessively restricted by drought overpopulation, or habitat [2] degradation. [11,18,19,32,42] In many bushland or forested habitats, browse consumption predominates during much of the year, although grass consumption increases greatly when its growth is promoted by rainfall.[42] When African elephants are confined to savannah habitats, a large portion of the diet is grass, perhaps a consequence of elephant- and fire-induced conversion of woodland into grassland.[17] It has been estimated that the proportion of browse in elephant diets in Amboseli Park, Kenya, dropped from 75% in the early 1970s to 40% in the late 1980s, a period of just such a habitat conversion.[16]

The feeding habits of African elephants were studied in the Ngorongoro Crater, Tanzania, during 1984 and 1985.[15] At this time, most of the Crater floor was grassland, with small areas of forest and swamp. At least 36 plant species were consumed, ranging from large trees to small herbs. Mostly tree, shrub, and forb browse, along with sedges, were eaten during the dry season, whereas forbs, sedges, and grasses predominated in the diet during the wet season. The plant parts eaten were mostly shoots, leaves, and floral parts (infloresences) during the wet season, and only occasionally bark, wood, and twigs, mostly during the dry season. The forest race of African elephants *{Loxodonta africana cyclotis)* living in the rain forest of the Ivory Coast was found to consume up to 29 species of fruiting bodies in January, the fruiting season. However, these fruiting bodies are greatly different in composition from the commercial fruit consumed by humans. A wide variety of plants (67 species identified) was fed on at other times. The parts consumed included leaves, twigs, whole branches, and bark. Some grass from open spaces in the forest floor also was eaten, but its proportion in the diet was low.[21] Heavy use of fruit and browse by the forest elephant, and minimal use of grass, also was observed in the Bia National Park in western Ghana.[32]

A study of free-ranging Asian elephants in wild regions of southern India established that 112 plant species were eaten, although just 25 species accounted for about 85% of the elephants' intake. In short-grass zones, both during the dry and wet seasons, about 85-90% of the diet was browse. Grazing was restricted to sedges and grasses along streams. In mixed tall grass and browse forests, there was slightly more grazing than browsing during the dry months, but after the first rains, the new growth of grass promoted significantly more grazing.[35]

Amounts of Food Eaten

Daily food intake of the wild African elephant has been estimated from the weight of stomach contents or by extrapolating from feeding rate and time. Both methods have produced estimates of daily dry matter intake by adults of about 1.0-1.5% of body weight.[5,24] Using similar methods with wild adult Asian elephants, daily dry matter intakes have been estimated to be 1.5-1.9% of body weight.[35] Dry matter intakes, relative to body weight are influenced by dry matter digestibility,[20] environmental circumstances, and the productive functions being supported (e.g., maintenance, growth, lactation), and it is unlikely that these different ranges represent species differences. Daily dry matter intakes of timothy hay by two captive 6-yr-old female African elephants, measured for one 7-day period in summer and a second 7-day period in winter, were 1.4-1.6% of body weight.[29] In another study, daily dry matter intakes of captive Asian and African elephants fed grass hays were 1.3 and 1.7% of body weight respectively.[13] [3]

Nutrient Intakes in the Wild

While field observations are not sufficient to set minimum nutrient requirements, an analysis of plant parts eaten can help define usual nutrient intakes in wild diets. These vary in nutrient concentration over time much more than would be expected for diets fed in captivity. Presumably nutrient reserves accumulated during periods of plenty help compensate for periods when nutrients are in short supply. Please note that all nutrient and fiber concentrations in this document are expressed on a dry matter (DM) basis.

Protein

Browse species eaten by African elephants in the Wankie National Park in Rhodesia (now Zimbabwe) in February had crude protein (CP) concentrations from 8-24%, with the majority containing from 12-18%. Most grasses at that time contained 3-6%, although *Panicum maximum* and *Cynodon dactylon* had 10 and 12% CP, respectively.[42] In this region, rain falls mainly from late October to early April. Generally, plants have their highest protein concentration at their first flush of growth. For most browse species in Wankie Park, this occurs in late September and October, whereas, grass species tend to flush in late November or early December. High CP concentrations (most 8-18%, some to 30%) also were found in vegetation consumed by elephants during the wet season in the Tsavo Royal National Park of Kenya. During the dry season, grasses contained 5-7% CP, but legumes and forbs eaten by elephants still contained 10-12% CP.[2]

When a 10-yr-old male African elephant was released from a stockade and allowed to roam freely in the Tsavo National Park, Kenya, and food selections were observed during 12 daylight hours in May, parts of 64 plant species were consumed. These included trees, shrubs, forbs, sedges, and grasses, and CP concentrations ranged from 6-23% in the parts eaten of the 59 species that were analyzed. Concentrations of CP were 10% or greater in 47 of these species.[9]

The leaves of 11 browse plants consumed by wild Asian elephants during the wet season in southern India contained 13-26% CP, whereas leaves of the wild grass, *Themeda cymbaria,* contained 9-10% CP. During the dry season, browse leaves contained 6-18% CP, and grass leaves contained 3% CP. Bark of the browse, *Grewia tiliaefolia,* contained 4% CP during the wet season, and basal portions of the grass, *T. cymbaria,* contained 2% CP during either the wet or dry season.[35]

Minerals

Browse species eaten by wild African elephants during February in Wankie National Park in Zimbabwe contained 0.35-2.47% calcium (Ca) and 0.11-0.33% phosphorus (P). Grasses contained Ca concentrations of 0.41-0.66% and P concentrations of 0.09-0.20%.[42] Similar ranges (0.37-3.61% Ca; 0.08-0.36% P [one forb had 0.58% P]) were found in the parts of 59 plant species eaten by a male African elephant released into the Tsavo National Park.[9]

Bark and leaves of browse eaten by Asian elephants in southern India contained 0.25-5.72% Ca and 0.08-0.21% magnesium (Mg) during the wet season and 1.77-3.74% Ca and 0.07-0.14% Mg during the dry season. Grass leaves during the wet season contained 0.19-0.46% Ca and 0.06-0.08% Mg. Phosphorus concentrations were not reported.[35]

Sodium (Na) concentrations in the leaves of 12 tree species favored by elephants in Kasungu National Park, Malawi, ranged from 0.10-1.25%.[13] Concentrations of Na in the browse [4] and grass eaten by the male elephant that was observed in the Tsavo National Park ranged from 0.01-1.67%.[9]

With the exception of values for potassium (K), ranging mostly from 0.25 to 2.5% of DM in browse leaves, sedges, and grasses,[9,13] few data on other minerals are available. Samples of grass *(Saccharum arundinecium)* eaten by Asian elephants in Nepal during the cool-dry season contained 296 ppm iron (Fe), 39 ppm copper (Cu), 29 ppm manganese (Mn), 52 ppm zinc (Zn), and 0.12 ppm selenium (Se). Browse stems and twigs of *Bombax ceiba* contained 368 ppm Fe, 11 ppm Cu, 19 ppm Mn, 27 ppm Zn, and 0.11 ppm Se. Leaves of this species contained 429 ppm Fe, 13 ppm Cu, 37 ppm Mn, 20 ppm Zn, and 0.46 ppm Se. Browse stems and twigs of *Ficus religiosa* contained 152 ppm Fe, 13 ppm Cu, 16 ppm Mn, 22 ppm Zn, and 0.43 ppm Se, whereas leaves contained 313 ppm Fe, 10 ppm Cu, 32 ppm Mn, 20 ppm Zn, and 0.17 ppm Se.[31]

Vitamins

Concentrations of vitamins in plants being eaten by wild elephants appear not to have been analyzed. However, α-tocopherol concentrations in plants eaten by black rhinoceroses *(Diceros bicomis)* in Zimbabwe and Kenya have been reported to range from 4-421 mg/kg.[7] Unfortunately, this issue has been confused by a more recent report, apparently on some of the same plants, that vitamin E concentrations might be 50-150 IU/kg.[6]

Fiber Intakes in the Wild

The proximate analytical system includes a method for determining crude fiber, originally intended to represent the organic fraction of plant cell walls that is not digested by mammalian enzymes. Thus, crude fiber should be either indigestible or digested only by symbiotic microorganisms that live in digestive tract compartments such as the rumen and reticulum of ruminants or the cecum and colon of horses and elephants.

The association of crude fiber with lowered digestibility accounts for the common characterization of fiber as a negative component of animal food. However, in animals that have evolved as herbivores, the physicochemical characteristics of dietary fiber play an important role in normal gastrointestinal function. The amount and form of digesta reaching the lower gut of the elephant influences the character of the fermentation occurring there, and may affect the rate at which fermentation products are produced and absorbed and the rate at which undigested residue is excreted. When dietary fiber concentrations are low and concentrations of rapidly fermented materials, like starch, are high, fermentation rates will be accelerated, gut motility will change, the bowel can become distended with gas, and abdominal pain may result.

Crude fiber concentrations in the leaves of trees used by African elephants in the Kasungu National Park, Malawi, ranged from 13-62%.[10] Browse, sedge, and grass consumed by an elephant in the Tsavo National Park, Kenya, contained 21-49% crude fiber.[9] Crude fiber concentrations in whole grasses, grass bases and tops, browse stems and leaves, and in herbs consumed by elephants in the Queen Elizabeth National Park, Uganda, ranged from 13-47% (recalculated from data expressed on an ash-free basis).[19] The average crude fiber concentration in palm *(Caryota urens)* leaves consumed by Asian elephants in the Kerala Forest, India, was 24%.[22] [5]

Unfortunately, the crude fiber determination includes an analytical error that varie : magnitude with the type of plant material being analyzed. Although oversimplified, the principe error relates to underestimation of the concentrations of hemicellulose and lignin (thuT underestimating plant cell wall). Despite this error, the use of crude fiber analysis persists, largely because of the simplicity of the procedure and the large amount of published crude fiber data.

Alternative analyses for neutral detergent fiber (NDF), acid detergent fiber (ADF), and lignin have been developed, that more accurately characterize those plant cell wail fractions that are difficult to digest[41] Concentrations of these fractions can not be directly compared with crude fiber values, although crude fiber tends to be lower than ADF and higher than lignin when these analyses are conducted on the same sample. Neutral detergent fiber includes lignin, cellulose, and hemicellulose, whereas ADF includes lignin and cellulose. Hemicellulose can be estimated by subtracting ADF from NDF. This analytical system has been used to characterize fiber concentrations in plants consumed by African elephants in a private game reserve bordering the Kruger National Park in South Africa, and averages of 62% NDF, 48% ADF, and 15% lignin were found.[20]

Diets for Captive Elephants

Hays

Since captive elephants are totally dependent upon food provided by their keepers, it is important that their diet contain all required nutrients in sufficient quantities and in usable forms. Hays of various types generally constitute the foundation of feeding programs for elephants in North America. Grass hays are commonly used, although they vary greatly in nutrient content, and many elephants may benefit from a combination of grass and legumes. Hays that are dusty, moldy, or infested with blister beetles, poisonous plants, or other dangerous substances should never be used.

Nutrition Advisory Group (NAG) Fact Sheet 001 (Hay Quality Evaluation) includes a description of various hay types, the regions where hays are grown, and the factors that influence composition. In brief, the perennial grasses grown for hay in the northern temperate zone include timothy *(Phleum pratense),* smooth bromegrass *(Bromus inermis),* and orchardgrass *(Dactylis glomerata).* Tall fescue *(Festuca arundinacea)* is grown in the Southeast and Pacific Northwest. Bermudagrass *(Cynodon dactylon)* is a warm-season grass, common in the South. Sudangrass *(Sorghum vulgare) is* an annual warm-season grass that can be grown even in the North during the summer, and that is sometimes made into hay. Hay also may be made from oats *(Avena sativa)* if cut in the late-milk to early-dough stage before the seed heads fully ripen. The composition of grass hays can vary widely, dependent largely upon soil fertility and stage of maturity when cut. For example, bermudagrass hay that has not been fertilized with nitrogen and is cut when mature, may have only 4% CP, whereas properly fertilized bermudagrass cut at the early heading stage, or before, may have up to 14% CP. Perennial legumes, such as alfalfa *(Medicago sativa)* and common red clover *(Trifolium pratense)* have relatively high CP concentrations because of the nitrogen-fixing bacteria that live in their root nodules.

Mixed hays, such as alfalfa-bromegrass or alfalfa-timothy, are particularly useful because the species in the mix complement each other in the nutrients they individually supply. Such mixes are agronomically productive and are widely available in the northern United States and in Canada. [6]

Where such mixes are not available, it is often possible to purchase alfalfa hay that can be fed in desired proportions with locally produced grass hay.

Nutrient concentrations in some typical hays that have been used for elephants are shown in Table 1. Most useful are analytical data on the actual hays to be used. Routine analyses of purchased hays for DM, CP, NDF, ADF, lignin, Ca, and P are recommended.

The data in Table 1 reveal that, regardless of the hay chosen, several nutrients are likely to be in short supply. As previously noted, the nutrient requirements of the elephant have not been defined. However, the similarities in digestive strategies of the elephant and the horse suggest that the nutrient needs of the former might reasonably be compared to the nutrient requirements of the latter.[23] When this is done for typical hays, deficiencies of several nutrients are apparent. Protein concentrations are low in many grass hays compared to the needs of growing young, pregnant and lactating females, and breeding males. Some of the poorer grass hays are too low in protein for maintenance of adults, but these conclusions should be based on analysis.

Calcium concentrations tend to be high in legumes and low in grass hays, whereas P and Na tend to be low in both grass and legumes. Dependent upon the region where grown, low concentrations of I, Co, Se, Zn, and Cu may be seen. Vitamin A (from β-carotene) and vitamin E can be inadequate if the hay has few leaves or is badly weathered, and concentrations of both nutrients decline with storage time.

Although daily digestible energy (DE) requirements are commonly met by allowing elephants to consume hay until their appetites are satisfied, fiber concentrations in mature grass hays may be so high and DE concentrations so low that gut fill will physically restrict intakes below the needs of young, growing elephants or of lactating females.

Thus, supplements to hay must be formulated to ensure that intakes of specific nutrients and of DE will be sufficient. Proposed minimum nutrient concentrations (DM basis) in elephant diets, based largely on extrapolation of nutrient requirements of horses,[23] are presented in *Table 2.*

Pellets

Pelleted feeds can be useful in correcting the inadequacies of hay. Formulas for three types of pellets are given in Table 3. The first and second have been designated ADF 16 and ADF25 for the percentages of acid detergent fiber they contain. Please note that these designations do not refer to particular commercial feeds, and manufactured products that have been given these names may or may not have the same formulas and specifications. ADF16 is lower in fiber but higher in CP and DE, whereas ADF25 is lower in DE but higher in fiber, Ca, P, and Na. Most other nutrient levels are similar. These differences allow for some manipulation of DE and nutrient supplements to hays of different qualities for elephants with different needs, but either pellet can be useful and important when feeding growing young elephants,[36] adults with missing or misshapen teeth,[28] females in the last third of gestation, or lactating females. To avoid digestive upsets, the introduction of either pellet into the diet should be gradual (increasing slowly over 2 wk), and the amount fed should be appropriate to need but should not exceed

50% of total dietary DM.

The third pellet has been designated Herbivore Supplement (likewise, not a commercial product) and is designed to be used in more limited amounts, providing a little extra DE and protein but primarily ensuring that dietary levels of minerals and vitamins will be adequate. The amount [7] fed generally would be in the range of 10-25% of dietary DM, and this upper level should not be exceeded to avoid mineral excesses.

Nutrient specifications for these three pellets are given in Table 4. If well-chosen and combined, ingredients other than those shown in Table 3 can be used to formulate these pellets. Pellet diameters of 1.3-1.9 cm (0.5-0.75 in) are reasonable, although elephants can successfully pick up pellets as small as 0.5 cm (0.20 in) in diameter.

As with all feeds, appropriate storage conditions are important to retain product quality. Insect and rodent control measures should be in place, and air-conditioned storage may be particularly important in hot, humid environments. Purchased supplies should not exceed the amounts needed over a 4- to 6-mo period, assuming ideal storage conditions.

Combinations of Hay and Pellets

When ADF16 or Herbivore Supplement are used in typical amounts with various hays, the dietary nutrient concentrations shown in Tables 5 and 6 will result. The data provided are sufficient to make comparable calculations using ADF25, but these calculations have not been included in this document

The proportions of grass hay and ADF16 in Table 5 are 70 and 30%, respectively. Except for low-protein bermudagrass, these combinations meet the nutrient requirements for much of the elephant life cycle. When bermudagrass contains only 4% CP, protein concentrations in the total diet will be inadequate, for all but adult maintenance. Nutrient levels could be improved and still permit use of this low protein hay by feeding 60% bermudagrass, 30% ADF16, and 10% Herbivore Supplement Crude protein concentrations will be increased from 9 to 11%, with comparable increases in other nutrients.

In Table 6, grass hay, alfalfa hay, and Herbivore Supplement are used in proportions of 70, 20, and 10%, respectively. This combination might be used when seeking supplemental minerals and vitamins, primarily, and the extra digestible energy provided by supplemental ADF16 is not needed. Costs would also tend to be lower than when ADF16 is used in larger amounts. However, as before, the use of low-protein bermudagrass as the grass hay in the mix results in dietary protein concentrations that are adequate only for maintenance. By doubling the percentage of Herbivore Supplement (increased to 20%) and removing a like percentage of bermudagrass (reduced to 60%), CP concentrations could be increased from 9 to 11%.

Thus, it is apparent that appropriately formulated pellets can be used in a variety of ways to correct the deficiencies of forage. However, if those deficiencies are extreme, it may be more cost effective to buy and use only hays that meet Quality Standard 4 or higher of the Hay Market Task Force of the American Forage and Grassland Council (see NAG Fact Sheet 001, 1997, Hay Quality Evaluation).

Other Supplements

Assuming that pellets are compounded and used as described, other nutrient supplements should not be needed. However, it has been suggested that biotin supplements improve foot health, and that zinc supplements may be needed to ensure normal immune function. Also suggested is that large doses of a water-soluble derivative of vitamin E protect more effectively, than the usual [8] vitamin E compound added to feeds (d,l-α-tocopheryl acetate), against myopathies and other expressions of oxidative damage to cells.

Biotin.

Pharmacokinetic data (used to estimate absorption, use, and excretion) generated by giving single oral doses of biotin to horses indicate that only 1% of the dose is absorbed, and about half of that is excreted in the urine. The pharmacokinetic curves produced by single oral doses of biotin given to Asian elephants are the same shape as in horses.[19] Data on urinary biotin excretion are not available, but it is reasonable to believe that elephants also absorb and retain very small amounts of biotin. Anecdotal reports of improvements in foot health associated with biotin supplementation of horses or elephants are almost invariably confounded by improvements in foot husbandry. Considering the evidence of biotin synthesis in the digestive tract of horses, the similarity of the elephant digestive tract, and the difficulty in demonstrating biotin deficiency in any species fed natural diets without use of an antibiotic or sulfa drug to limit microbial synthesis in the intestine, it is surprising that responses to biotin supplements have been noted. It is doubtful that this issue will be resolved until an adequate double-blind study is conducted, in which the person administering oral biotin or a placebo does not know which is which, and likewise, the person scoring foot health does not know which animals received biotin and which received the placebo.

It is implausible that the application of biotin-containing products (ointments) to the foot or toenails will result in improvement.

Vitamin E.

With respect to vitamin E requirements, serum concentrations of α-tocopherol in captive elephants responded markedly (rising from 0.1 to 0.4 mg/ml) to a large oral dose (4.8 IU/kg body weight) of water-soluble vitamin E (d-α-tocopheryl polyethylene glycol succinate [TPGS]) compared to little response from equal or higher doses of d-α-tocopherol or d-α-tocopheryl acetate. When TPGS was provided at 6.6 IU/kg body weight, serum a-tocopherol concentrations rose to about 1 mg/ml.[25,26] Death of a 17-mo-old Asian elephant was previously reported when plasma concentrations of α-tocopherol in this animal and others in the herd were undetectable (<0.1 mg/ml). When estimated daily vitamin E intakes were doubled (from about 0.6-0.8 to 1.0-1.6 IU/kg body weight), using d,l-α-tocopheryl acetate, plasma α-tocopherol concentrations 3 yr later ranged from 0.2-0.6 mg/ml.[8] Seven African and six Asian elephants at the San Diego Wild Animal Park were fed about 27 kg (60 lb) of sudangrass hay, 14 kg (30 lb) of alfalfa hay, and 4.5 kg (10 lb) of an herbivore supplement each day. The supplement contained 2,000 IU vitamin E/kg either in the form of d,l-α-tocopheryl acetate or as TPGS. Both treatments provided about 200 IU of supplemental vitamin E/kg diet or about 2.25 IU/kg body weight After 5 wk, the three African and three Asian elephants receiving d,l-α-tocopheryl acetate had serum α-tocopherol concentrations of 0.49 mg/ml, whereas the four African and three Asian elephants receiving TPGS had serum α-tocopherol concentrations of 0.70 mg/ml. The values were about the same after 8 wk, 0.49 and 0.67 mg/ml, respectively.[38] Although it is commonly believed that serum or plasma tocopherol concentrations may be used to assess vitamin E status, there is increasing evidence that assays of single serum samples are poorly related to vitamin E concentrations in critically important tissues. In addition, individual elephants (and horses), who are eating the same diet and who are within the same age class, have had their plasma repeatedly analyzed and have been shown to have individually characteristic plasma α-tocopherol concentrations that may vary 1.5-2 fold from plasma α-tocopherol concentrations of other individuals.[31,37] These individually characteristic differences between elephants in plasma α-tocopherol concentrations, coupled with values that are typically low and within one order of [9] magnitude of the analytical detection limit, introduce an uncertainty into the determination that suggests results of a single assay should be interpreted with caution.

Zinc.

A captive Asian elephant fed timothy hay, oat grain, carrots, lettuce, and pellets was reported to exhibit hyperkeratosis and a poor inflammatory response in infected vesicles above the toenails. A presumptive diagnosis of immunodeficiency, secondary to zinc deficiency, was made when an improvement was noted following administration of a zinc carbonate supplement.[30] The concentration of zinc in dietary DM was reported to be 22 mg/kg before supplementation and 54 mg/kg afterward. Unfortunately, it isn't clear whether these were analyzed or calculated values, and if calculated, whether consideration was given to missing values for zinc in some dietary ingredients. In addition, dietary zinc concentrations given in the text of this report differed from those in the tables.

It is noteworthy that 88 young African elephants (<2-9 yr initially), housed in dirt lots with small areas of mud (man-made in dry weather), fed bermudagrass hay, alyceclover *(Alysicarpus vaginalis)* hay, and ADF16, and subjected to regular veterinary examination for 6 yr, grew normally and showed no signs of biotin, vitamin E, or zinc deficiency.[18]

Bran, oats, and colic

As with horses, bran, oats, corn, and other grains were traditionally used in feeding programs for elephants, and some zoos continue this practice. With the appropriate use of nutritionally complete pelleted feeds and adequate amounts of fiber from good quality hays, the benefits of bran may be overstated, and, indeed, excessive use of bran for the horse has been associated with nutritional secondary hyperparathyroidism, due to bran's high phosphorus content and a marked inverse Ca:l ratio. The use of whole grains, once necessitated by the unavailability of nutritionally complete pelleted feeds, is, likewise, no longer required. Upon occasion, bran has been used as a carrier for liquid medications, and different carriers may be required for medications in other forms. Because elephants are reluctant to consume unfamiliar foods, it is appropriate to offer potential medicant carriers periodically so they will be consumed when needed. However, it should not be necessary to offer such items continuously.

Bran from wheat or rye consists primarily of the seed coat, containing most of the seed fiber, and the gluten cell layer, containing protein. It has been suggested that use of bran may prevent colic in elephants. Horses and elephants are not "meal-eaters", but have evolved to consume large amounts of food throughout the day. Bran, when offered along with pellets as part of a meal, provides a bolus of high fiber material to the gut. By contrast, consumption of properly selected hay throughout the day better simulates the natural feeding strategy of elephants and provides fiber continuously over a longer period.

Colic is a general term for abdominal pain that may be chronically intermittent or may have a sudden, acute onset. Colic in horses has been attributed to parasites, behavioral problems, and a number of poor husbandry and feeding practices, including stress due to changes in routine, insufficient roughage of appropriate quality, rapid consumption of grains or pelleted feed, sudden changes in amounts or types of feeds/roughage, and lack of continuously available fresh, clean water. Elephants, like many humans, appear to be more comfortable when their lives are governed by a predictable routine. Considering the nature of their digestive tract and the composition of foods in the wild, hay should form the base of the captive diet. Nutrient concentrations important of course, but fiber intakes should be sufficient to ensure normal gut function. When [10] 3rd-cutting orchardgrass hay with an ADF concentration of about 24% was fed to adult elephants digestive upsets occurred. However, when hays with 30% or more ADF were fed, no tendencies for colic to develop have been noted (M.E. Allen, personal communication). Some believe that regular exercise promotes normal gut motility. Although exercise is difficult to promote in the typically small elephant exhibit, distribution of hay among several feeding locations encourages movement and may provide some behavioral stimulation. Rapid consumption of more concentrated foods, such as pellets, can be controlled by keepers. Any changes in the amounts or types of roughage and other foods offered should be made gradually (over 1-2 wk) to allow for adaptation by intestinal microorganisms. Although some zoos do not provide water continuously for elephants, with the present substantial knowledge of factors predisposing to colic, it is advised that this practice be changed.

Because exhibit areas are small, and food requirements can generally be met by short bouts of eating, there are long periods of inactivity during which aberrant behavior may develop in a few elephants. This may include consumption of sand or other exhibit substrates, resulting in intestinal impaction. Some zoos have used decomposed granite on ground surfaces which, when consumed, tends to form a stable concretion that is more likely than sand to obstruct the intestinal tract, because it does not break apart readily. Additions of wheat bran or sugar beet pulp to the diet have been attempted as a prophylactic measure, with uncertain results. Mineral oil has been used as well, but its prolonged use will seriously impair absorption of fat-soluble vitamins. It may be most appropriate to thoroughly review and correct husbandry, restrict access to consumable substrates, if feasible, and observe elephants regularly for signs of abnormal behavior. Depression, failure to eat, changes in the odor, appearance (e.g., presence of substrate), and volume of feces, changes in the pattern of defecation (commonly about every 2 hr, but individuals have a characteristic pattern), stretching in a "saw-horse" stance, elevation of the head, and rolling, are colic danger signs. Forced exercise may be helpful in restoring normal gut motility and relieving pain.

Produce

Many zoos continue to offer produce to large herbivorous animals. When used in small amounts, fruits and vegetables are not harmful and may help when shifting or medicating elephants. However, other palatable products, such as leaf-eating primate biscuits can be used in small amounts (a few cubes), as an enticement to shift, at appreciably less cost. At one major U.S. zoo that still feeds apples, carrots, and leafy greens, 49% of the cost of the elephant diet was due to produce, whereas those high-cost, high-moisture foods contributed 5% of diet dry matter. Clearly, the nutrient contribution of produce was negligible, but its cost was not.

Recommendations

1. Analyze hays for dry matter, crude protein, neutral detergent fiber, acid detergent fiber, lignin, calcium, and phosphorus in a laboratory with demonstrated expertise.
2. Use grass hay or a mixture of grass and legume hays, of known composition, as the base for elephant diets.
3. Using analyzed and published nutrient concentrations, determine the need for supplemental sources of energy, protein, minerals, and vitamins. [11]
4. When hay mixtures are not adequate to meet digestible energy, protein, mineral, and vitarrun needs, consider adding a formulated pellet similar to ADF16.
5. When hay mixtures are principally deficient in minerals and vitamins, consider adding a formulated pellet similar to the Herbivore Supplement
6. Provide water and grass hay ad libitum, and add legume hay and ADF16, ADF25, or Herbivore Supplement in amounts proportional to estimated need. Note that grass hay to be fed ad libitum should have 30% or more ADF to avoid problems with colic.
7. Make all dietary changes gradually (over 1-2 wk) to avoid digestive upsets.
8. Observe elephants regularly and conscientiously.

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[14]

Table 1.

Composition (DM basis) of hays used for elephants.[3]

Nutrient	Alfalfa	Bermudagrass	Oat	Sudangrass	Timothy
Number	4	4	2	3	3
DM, %	90-93	87-91	91-92	82-93	84-88
CP, %	15-19	4-14	9-10	7-8	5-9
NDF, %	39-46	80-81	59-66	62-70	67-70
ADF, %	30-34	39-43	33-36	36-49	36-44
Lignin, %	7-9	8-10	5-6	3-6	5-9
Crude fiber, %	23-26	30-34	28-31	28-3S	30-34
Lysine, %	0.74-0.84	0.19-0.67	*	*	*
Ca,%	1.15-1.74	0.29-0.97	0.24-0.32	0.55-0.86	0.39-0.48
P,%	0.23-0.31	0.13-0.34	0.22-0.24	0.17-0.24	0.13-0.22
Na.%	0.01-0.42	<0.01-0.04	0.19-3.27	<0.01-0.06	0.01-0.18
K,°/o	1.61-3.18	0.79-2.49	1.34-1.52	1.41-2.07	1.24-1.61
Mg, %	0.15-0.37	0.11-0.34	0.31-0.31	0.18-0.53	0.10-0.16
Fe, ppm	48-547	20-99	156-263	67-1,870	130-170
Cu, ppm	9-12	4-8	8-9	7-10	5-5
Mn, ppm	25-62	49-112	54-65	29-59	25-25
Zn, ppm	13-31	11-31	24-40	26-30	10-43
Se, ppm	0.05-1.49	0.02-0.16	0.18-0.27	0.15-0.48	0.17-0.17
Carotene, ppm	52-59-	20-97	6-20	5-58	11-45
Vit D, IU/kg	1,409-1,583	*	*	*	2,000-2,300
Vit E, IU/kg	52-59	*	*	*	50-63

* Value not determined [15]

3 Proximate and mineral analyses from Comparative Nutrition Laboratory, Mich. State Univ.

Table 2.

Proposed minimum nutrient concentrations (DM basis) in elephant diets based largely extrapolation from nutrient requirements of horses.[23]

Nutrient	Maintenance, breeding, early pregnancy	Late pregnancy	Lactation	Growth of juveniles
Crude protein, %	8-10[a]	12	12-14[b]	12-14[c]
Lysine, %	0.3	0.4	0.4-0.5	0.5-0.6
Calcium, %	0.3	0.5	0.5	0.5-0.7
Phosphorus, %	0.2	0.3	0.3	0.3-0.4
Magnesium, %	0.1	0.1	0.1	0.1
potassium, %	0.4	0.4	0.5	0.4
Sodium, %	0.1	0.1	0.1	0.1
Sulfur, %	0.15	0.15	0.15	0.15
Iron, ppm	50	50	50	50
Copper, ppm	10	10	10	10
Manganese, ppm	40	40	40	40
Zinc, ppm	40	40	40	40
Cobalt, ppm	0.1	0.1	0.1	0.1
Iodine, ppm	0.6	0.6	0.6	0.6
Selenium, ppm	0.2	0.2	0.2	0.2
Vitamin A, IU/kg	3,000	3,000	3,000	3,000
Vitamin D, IU/kg	800	800	800	800
Vitamin E, *TV/kg*	100	100	100	100
Thiamin, ppm	3	3	3	3
Riboflavin, ppm	3	3	3	3

[a] Adult maintenance, 8% CP; breeding bull, pregnant cow (1st twcnthirds of pregnancy), 10% CP.

[b] First yr of lactation, 14% CP; 2nd yr of lactation, 12% CP.

[c] Weanling, 14% CP; 3-yroId, 13% CP; 4-yr-old to 12-yr-old, 12% CP.

[16]

Table 3.

Formulas for ADF16, ADF25, and Herbivore Supplement (percentage by weight).[a]

Ingredient	ADF16	ADF25	Herbivore Supplement
Alfalfa meal, dehydrated (17% CP)	31.9	59.7	20.0
Wheat middlings	29.8	31.6	36.3
Com grain	19.0	—	^___
Soybean meal, dehulled, solvent extr. (48% CP)	11.0	—_	30.0
Cane molasses	5.0	5.0	5.0
Soybean oil	1.0	1.0	2.0
Mono-dicalcium phosphate (16% Ca, 21% P)	1.0	—	2.0
Sodium tripolyphosphate (31% Na, 25% P)	—	***1.5***	—
Calcium carbonate (38% Ca)	—	—	0.8
Salt	0.6	0.5	2.0
Trace mineral premix[b]	0.1	0.1	0.3
Vitamin premix[c]	0.4	0.4	1.2
Choline CI premix (60% choline)	0.1	0.1	0.3
Mold inhibitor (50% propionic acid on verxite)[d]	0.1	0.1	0.1
	100.0	100.0	100.0

[a] These designations do not refer to particular commercial feeds, and manufactured products that have been given these names may or may not have the same formulas and specifications.

[b] Contains per kg: 50 g Fe, 10 g Cu, 45 g Mn, 90 g Zn, 0.1 g Co, 0.8 g I, and 0.2 g Se.

[c] Contains per kg: 1 g riboflavin, 5 g pantothenic acid, 10 g niacin, 5 mg vitamin B,2, 1,250,000 IU vitamin A, 300,000 IU vitamin D_3, and 75,000 IU vitamin E.

[d] MonoProp®, Anitox Corp., Buford, GA.

[17]

Table 4.

Nutrient specifications for ADF16, ADF25, and Herbivore Supplement (concentration).[a]

Nutrient[b]	ADF16	ADF25	Herbivore Supplement
Crude protein, min. %	17	15	23
Lysine, min. %	0.8	0.7	1.2
Acid detergent fiber, min. %	13	21	10
Acid detergent fiber, max. %	17	26	14
Crude fat, min. %	3	3	3
Linoleic acid, min. %	1	1	1.5
Ash, max. %	8	11	12
Calcium, min. %	0.65	0.85	1.20
Calcium, max. %	1.00	1.20	1.50
Phosphorus, min %	0.65	0.75	0.90
Magnesium, min. %	0.20	0.25	0.25
Sodium, min. %	0.25	0.50	0.80
Potassium, min. %	1.20	1.50	1.50
Sulfur, min. %	0.20	0.20	0.25
Iron, min, ppm	150	200	300
Copper, min, ppm	20	20	35
Copper, max. ppm	30	30	50
Manganese, min, ppm	90	90	150
Zinc, min, ppm		120	120
Cobalt, min. ppm	0.3	0.3	0.4
Iodine, min. ppm	0.8	0.8	2.0
Selenium, min. ppm	0.3	0.4	0.8
Tm'amin, rain, ppm	5	5	7
Riboflavin, min. ppm	9	9	15
Pantothenic acid, min ppm	30	30	75
Niacin, min. ppm	50	50	180
Biotin, mux ppb	250	250	300
Vitamin B,$_2$, min. ppb	20	20	60
Choline, min. ppm	1,500	1,500	3,500
ß-Carotene, min, ppm	30	50	20
Vitamin A, min. IU/kg	5,000	5,000	15,000
Vitamin D_3, min IU/kg	1,200	1,200	3,600
Vitamin E, min. IU/kg	300	300	900

[a] These designations do not refer to particular commercial feeds, and manufactured products that have been given these names may or may not have the same formulas and specifications.

[b] Min. = minimum; max. = maximum; ppm = parts per million = mg/kg; ppb = parts per billion = µg/kg.

[18]

Table 5.

Nutrients (DM basis) in diet of 70% designated grass hay and 30% ADF16.[a]

Nutrient	Bermuda (4% CP)	Bermuda (11% CP)	Sudan (7% CP)	Timothy (9% CP)
DM, %	89	88	92	89
CP, %	9	14	11	12
ADF, %	32	34	33	30
Ca,%	0.48	0.65	0.65	0.61
P,%	0.38	0.44	0.38	0.38
Na,%	0.10	0.13	0.12	0.22
K,%	1.14	1.39	1.95	1.61
Mg, %	0.17	0.24	0.27	0.20
Fe, ppm	111	148	124	197
Cu,ppm	12	14	15	12
Mn, ppm	84	67	62	50
Zn, ppm	68	55	66	76
Se, ppm	0.18	0.26	0.34	0.26

[a] By analysis; ppm = parts per million = mg/kg.

Table 6.

Nutrients (DM basis) in diet of 70% designated grass hay, 20% alfalfa hay (17% CP), and 10% Herbivore Supplement[a]

Nutrient	Bermuda (4% CP)	Bermuda (11 % CP)	Sudan (7% CP)	Timothy (9% CP)
DM, %	89	88	92	90
CP, %	9	14	11	13
ADF, %	34	37	35	32
Ca,%	0.60	0.77	0.76	0.72
P,%	0.32	0.38	0.33	0.32
Na,%	0.18	0.25	0.28	0.22
K,%	1.47	1.72	2.26	1.94
Mg, %	0.18	0.25	0.28	0.22
Fe, ppm	181	218	191	266
Cu, ppm	12	13	15	11
Mn, ppm	80	63	58	46
Zn, ppm	65	52	63	73
Se, ppm	0.17	0.25	0.33	0.25

[a] By analysis; ppm = parts per million = mg/kg.

[19]