Kentucky Equine Research®

World Leaders In Equine Nutrition

Advances in Equine Nutrition

Volume I

Edited by

J.D. Pagan

NUTRIENT DIGESTIBILITY IN HORSES

JOE D. PAGAN
Kentucky Equine Research, Inc., Versailles, Kentucky, USA

Introduction

Many equine nutrient requirements are based on certain assumptions about how well horses digest and absorb nutrients. Unfortunately, a great many questions remain unanswered about nutrient digestibility in horses. How well do horses utilize different sources of nutrients? What nutrients interact with one another to affect digestibility?

Over the past five years, Kentucky Equine Research has conducted dozens of digestibility trials to evaluate different types of feeds and feed ingredients for horses. This paper will present a summary of the data collected in these various experiments. Together, these data represent one of the most comprehensive digestibility studies ever conducted in horses. Hopefully, the results of these studies will help refine the various nutrient requirements currently being used for horses and improve the precision with which horse feeds are formulated.

Materials and methods

Kentucky Equine Research uses a standardized experimental design to measure digestibility in horses. In this design, four mature horses are fed different experimental diets in a Latin square design (either 2x2 replicated or 4x4) over four collection periods. Each period consists of a 3 week adjustment period followed by a 5 day total fecal collection. The week before and during the 5 day collection period, the horses are housed in specially designed stalls that allow the complete and separate collection of urine and feces. While housed in these stalls, the horses are hand walked twice daily.

During the collection period, daily feed intake and total fecal output are measured. Subsamples of daily feed and feces are taken and frozen. These subsamples are dried and composited for chemical analysis. Both feed and feces are analyzed for dry matter, crude protein, ADF, NDF, crude fiber, fat, calcium, phosphorus, magnesium, potassium, zinc, copper, manganese, and ash. Digestibilities are calculated for each nutrient measured.

Table 1. AVERAGE NUTRIENT CONCENTRATIONS OF DIETS STUDIED (100% DRY MATTER BASIS)

Nutrient	*Average concentration*	*Standard deviation*	*Maximum*	*Minimum*
Crude protein	13.1 %	2.6 %	20.4 %	9.6 %
ADF	28.8 %	4.6 %	40.6 %	20.6 %
NDF	46.9 %	5.4 %	57.4 %	38.3 %
Hemicellulose	18.1 %	4.7 %	24.1 %	6.0 %
Crude fiber	22.8 %	3.9 %	31.8 %	15.4 %
Soluble CHO	28.9 %	5.0 %	36.9 %	18.3 %
Fat	3.6 %	0.8 %	5.5 %	2.1 %
Calcium	0.89 %	0.24 %	1.50 %	0.55 %
Phosphorus	0.39 %	0.09 %	0.58 %	0.20 %
Magnesium	0.22 %	0.03 %	0.29 %	0.17 %
Potassium	1.63 %	0.54 %	3.29 %	0.98 %
Iron	287 ppm	119 ppm	753 ppm	127 ppm
Zinc	84 ppm	38 ppm	147 ppm	20 ppm
Copper	22 ppm	8 ppm	38 ppm	7 ppm
Manganese	83 ppm	29 ppm	127 ppm	29 ppm
Ash	7.45 %	1.53 %	11.62 %	5.99 %

Thirty different diets (120 observations) have been evaluated using this design. These diets have ranged from pure alfalfa hay to a combination of sweet feed and fescue hay to pelleted concentrates fed with timothy hay. Table 1 lists the average concentration of each nutrient measured along with the standard deviation, maximum and minimum ranges. The majority of horses used in these studies have been Thoroughbreds, although Quarter horses, Appaloosas, and Warmbloods have also been included. Most of these horses have averaged between 1,100 and 1,320 lbs of body weight (500-600 kg). Because of the tight range of body weights of the experimental horses, all data are presented as total daily intakes rather than as a function of body weight.

Each experiment was conducted for a specific purpose, such as to evaluate the effect of adding distillers dried grains to horse feeds or to determine the effect that pelleting has on alfalfa hay, but for the purpose of the present study, all data have been combined into one data base.

As table 2 illustrates, these combined experiments represent a wide range of nutrient intakes for mature horses. While a variety of different feed ingredients were used in these studies, these data are only representative of forages and concentrates from a temperate environment. Tropical forages may behave differently because they contain inhibitory substances not found in temperate forages. (For a more detailed discussion of these factors, see the paper *Forages for Horses: More Than Just Filler).*

Table 2. AVERAGE NUTRIENT INTAKES OF DIETS STUDIED

Nutrient	*Average concentration*	*Standard deviation*	*Maximum*	*Minimum*
Dry matter	7,119 grams	1,464 grams	10,541 grams	4,777 grams
Crude protein	946 grams	326 grams	1,808 grams	572 grams
ADF	2,097 grams	709 grams	4,266 grams	984 grams
NDF	3,371 grams	927 grams	5,427 grams	1,968 grams
Hemicellulose	1,275 grams	411 grams	2,191 grams	393 grams
Soluble CHO	2,007 grams	285 grams	2,627 grams	1,195 grams
Fat	254 grams	66 grams	469 grams	144 grams
Calcium	64 grams	27 grams	158 grams	33 grams
Phosphorus	28 grams	9 grams	57 grams	13 grams
Magnesium	16 grams	5 grams	27 grams	9 grams
Potassium	119 grams	53 grams	269 grams	47 grams
Iron	2,059 mg	1,250 mg	7,912 mg	773 mg
Zinc	567 mg	216 mg	885 mg	131 mg
Copper	149 mg	57 mg	282 mg	46 mg
Manganese	572 mg	201 mg	1,179 mg	210 mg
Ash	540 grams	199 grams	1,136 grams	299 grams

Nutrient digestibility

Nutrient digestibility can be expressed in two different ways. One way is as apparent digestibility. Using this calculation, the amount of a specific nutrient that is recovered in the feces is subtracted from the total daily intake of that nutrient. The amount that disappeared (intake - feces) is divided by the total daily intake to produce a percentage of intake. Table 3 shows the apparent digestibilities of the various nutrients measured. Apparent digestibility is a fairly crude way to evaluate digestibility since it only measures the total amount of a particular nutrient in the feces. There are two possible sources of these fecal nutrients. Some of the nutrient could be the undigested residue left from the feed, but some may have actually been excreted into the digestive tract from the horse's system or it might have sloughed off the intestinal wall. The fecal substances that originate from inside the horse are considered *endogenous* in nature and they result in an underestimation of *true* nutrient digestibility.

To overcome the interference of endogenous losses in the determination of digestibility, a statistical procedure called a Lucas test can be utilized. In this test, a range of nutrient intakes are studied. The amount of nutrient that is digested is regressed against its corresponding level of intake. This procedure is illustrated in figure 1. If there are real endogenous losses associated with a particular nutrient, then the calculated level of nutrient digested at a nutrient intake of zero will be a negative number. The slope of the regression line represents the *estimated true digestibility* for the nutrient. If the regression line intersects the vertical axis at or above zero, then there are no endogenous losses for that particular substance. For example, a horse would not be expected to have an endogenous loss of plant fiber (ADF or NDF). With these types of nutrients, apparent and true digestibilities should be fairly similar.

Table 3. AVERAGE APPARENT DIGESTIBILITIES OF DIETS STUDIED

Nutrient	*Apparent digestibility*	*Standard deviation*
Dry matter	62 .0 %	4.6 %
Crude protein	71 .0 %	5.2 %
ADF	39.9 %	7.9 %
NDF	45.4 %	5.7 %
Hemicellulose	51.9 %	10.6 %
Crude fiber	43.4 %	14.5 %
Soluble CHO	88.6 %	5.2 %
Fat	58.4 %	19.2 %
Calcium	44.0 %	14.3 %
Phosphorus	8.9 %	9.8 %
Magnesium	37.4 %	9.1 %
Potassium	75.4 %	9.2 %
Zinc	9.4 %	11.0 %
Copper	30.1 %	11.6 %
Manganese	8.9 %	13.9 %
Ash	43.3 %	12.7 %

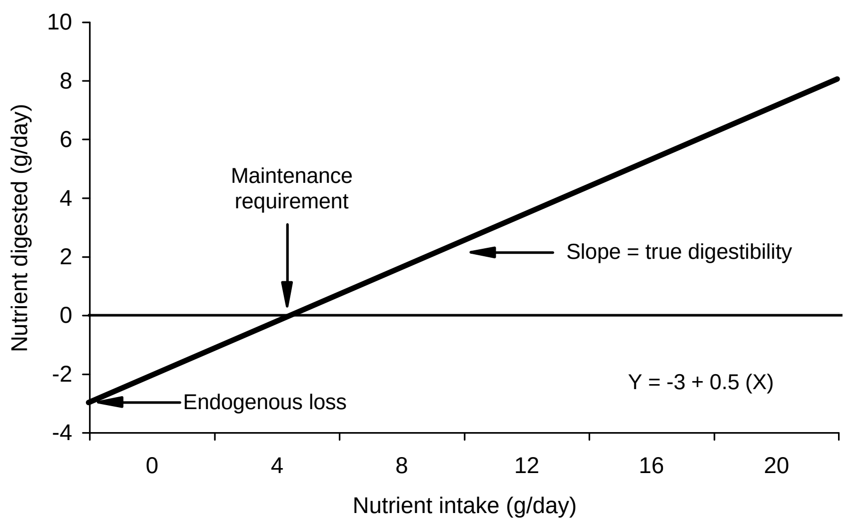

Figure 1. Lucas test for determining true digestibility and endogenous fecal losses

Table 4 contains the results of the Lucas tests for each nutrient measured. Most of the minerals measured had negative intercepts that were significantly different from zero, indicating that there are endogenous fecal losses for these nutrients. The slopes of the regression lines for the various minerals indicate that there is a great deal of difference in their true digestibilities. Calcium and potassium are readily digested from most equine diets, with estimated true digestibilities of about 75%. Magnesium true digestibility equals about 52%, while the estimated true digestibility of phosphorus is considerably lower (25%). The true digestibilities of the trace elements zinc, manganese and copper average 20.8%, 28.5% and 40.0%, respectively. The sources of trace minerals used in these diets were either from the naturally occurring mineral in the feed ingredients or added inorganic sources. The true digestibility of organic sources of these minerals is currently being investigated.

Table 4. ESTIMATED TRUE DIGESTIBILITIES AND ENDOGENOUS LOSSES FOR EACH NUTRIENT MEASURED.

Nutrient	*Apparent digestibility*	*Endogenous loss*	*Endogenous loss real*[a]	*R^2*
Crude protein	86.1%	143.3g/d	yes	0.96
ADF	40.2 %	12.4 g/d	no	0.85
NDF	45.0 %	-112.3 g/d	no	0.85
Hemicellulose	54.2 %	26.8 g/d	no	0.87
Soluble CHO	97.4 %	179.3 g/d	yes	0.85
Fat	55.7 %	-7.4 g/d	no	0.30
Calcium	74.7 %	17.4 g/d	yes	0.94
Phosphorus	25.2 %	4.7 g/d	yes	0.33
Magnesium	51.8%	2.2 g/d	yes	0.76
Potassium	75.3 %	1 g/d	no	0.94
Zinc	20.8 %	54 mg/d	yes	0.57
Copper	40.0 %	38 mg/d	yes	0.71
Manganese	28.5 %	110 mg/d	yes	0.40
Ash	67.8 %	121 g/d	yes	0.81

[a] intercept of regression equation significantly different from zero ($p<0.05$)

The true digestibility of protein in these various diets averaged 86.1%. Most of the diets studied had protein digestibilities close to this level with the exception of a high quality alfalfa hay from Arizona which was higher.

Regression analysis of fiber digestibility showed that these components did not produce endogenous losses. Estimated true digestibilities of ADF, NDF and hemicellulose were 40.2%, 45.0%, and 54.2%, respectively. Interestingly, low fiber intakes resulted in lower fiber digestibility than when high levels of fiber were being fed. Perhaps the fiber from grains (which represented a greater proportion of total at the low fiber intakes) was less digestible than the fiber from forages.

Energy content

The energy content of the various rations was calculated as percent total digestible nutrients (TDN %). TDN was calculated as: digestible crude protein + (digestible crude fat x 2.25) + digestible neutral detergent fiber + digestible soluble carbohydrate. Soluble carbohydrate (CHO) = 100-crude protein (CP)-ether extract (EE)-neutral detergent fiber (NDF)-ash. TDN averaged 61.4% for all of the diets measured with a range from 46.9% to 61.0%. TDN or digestible energy (DE) are useful values to calculate for a horse ration. Since these values are by nature biological assays, it would be impossible to directly determine these values for every feed. From the present study, regression equations have been developed that allow the calculation of TDN (or DE) from analyses routinely performed on horse feed and forage. TDN and DE are really interchangeable units of digestible energy since the heat of combustion of protein and carbohydrate are similar and the heat of combustion of fat is already accounted for in the equation used to calculate TDN. Therefore, to calculate DE as kcal/kg, simply multiply TDN% X 4400 or DE as kcal/lb, multiply TDN X 2000.

The most complete equation to estimate DE is: DE (kcal/kg DM) = 2,118 + 12.18 (CP%) -9.37 (ADF%) - 3.83 (hemicellulose %) + 47.18 (fat %) + 20.35 (NSC) - 26.3 (Ash %) (R^2=0.88). Notice that as protein, fat and soluble CHO increase, DE increases. As fiber and ash increase, DE decreases. This agrees well with what we know about the energy density and digestibility of these various components in horse feeds. It should also be remembered that these equations were developed with either all forage diets or mixtures of forage and concentrate. These equations tend to overestimate the energy density of straight grains, possibly because of the differences in fiber digestibility mentioned above.

Nutrient interactions

Table 4 contains the R^2 for each regression equation that was used to calculate true nutrient digestibility. R^2 describes how well the equation reflects the relationship between nutrient intake and disappearance. An R^2 of 1.0 means that the regression line perfectly describes the relationship between the two parameters measured. The closer R^2 gets to 0, the less related are the two values in the regression. R^2 for protein, calcium and potassium were quite high (0.94). This indicates that these nutrients were digested with only minor interference from other substances in the feed. Other nutrients like phosphorus, manganese and zinc had low R^2 (<0.60), indicating that there were other factors besides nutrient intake that significantly affected their digestibility.

Nutrient requirements

The maintenance requirements of calcium, phosphorus, magnesium, zinc, copper, and manganese can be calculated by dividing the mineral's daily endogenous loss by its estimated true digestibility. For example, the endogenous calcium loss averaged 17.4 grams/day and the estimated true digestibility of calcium equaled 74.7%. Therefore, to replace all of the fecal calcium losses and maintain the horse in zero calcium balance, a daily intake of 23.3 grams (17.4/0.747) would be required. Table 5 contains these maintenance estimates along with the 1989 NRC recommendations for the same minerals. The estimates of maintenance requirements from this study for calcium and phosphorus are very similar to NRC requirements. In this study, however, endogenous calcium losses were higher than estimated by the NRC, but so was true digestibility. These two factors combined resulted in the same daily requirement. Conversely, endogenous phosphorus losses were slightly lower than estimated in the NRC, but so was true phosphorus digestibility. Again, the two factors combined netted the same daily requirement.

Table 5.
MINERAL REQUIREMENTS FOR MATURE HORSES

Mineral	*Requirement estimated from present study*		*1989 NRC requirement (500-600 kg)*	
Calcium	23.3	grams/day	20-24	grams/day
Phosphorus	18.5	grams/day	14-17	grams/day
Magnesium	4.2	grams/day	7.5-9.0	grams/day
Zinc	257	mg/day	328-388	mg/day
Manganese	385	mg/day	328-388	mg/day
Copper	95	mg/day	82-97	mg/day

Daily requirements for zinc were slightly lower than estimated by the NRC, but manganese and copper requirements were remarkably similar. The NRC did not use this method of calculation to arrive at its requirements for the trace minerals. Instead, it either used data from studies with cattle (manganese) or studies that determined the amounts of copper and zinc necessary to prevent deficiency symptoms.

These mineral requirements are only appropriate for mature horses at rest. Requirements for growth, pregnancy and lactation will certainly be higher. It remains to be determined how exercise affects the requirements for many of these nutrients.