Fact Sheet 001
July 1997

NUTRITION ADVISORY GROUP
HANDBOOK

HAY QUALITY EVALUATION[a]

Author
Duane E. Ullrey, PhD
Animal Science
Michigan State University
East Lansing, MI 48824

Reviewers
Susan D. Crissey, PhD
Brookfield Zoo
Chicago Zoological Society
Brookfield, IL 60513

Mark S. Edwards, PhD
Zoo & Wild Animal Park
Zoology Society of San Diego
San Diego, CA 92112

Milo B. Tesar, PhD
Crop & Soil Science
Michigan State University
East Lansing, MI 48824

Hay is the foundation of dietary husbandry for most captive herbivores, and its quality determines the need for other feeds. Quality can be high, low, or in between, but standards that are appropriate for hay fed to lactating dairy cows may be different than standards for hay fed to mature elephants. Hay that is high in protein and low in fiber is usually the most expensive and may be rated of best quality for supporting rapid growth or high levels of production in farm animals. However, considering the numbers of species and life stages of herbivores that must be fed in zoos, hays that meet their various nutrient and functional requirements at reasonable cost may be most appropriate for the task. In most zoos, two or three different hays will be required, and realistic purchasing specifications should be developed that are consistent with the needs of herbivores in the zoo collection and the local availability of hay types.

Environmental factors influencing plant growth and hay quality include temperature, daylength, light intensity, water supply and distribution over time, fertilization, and soil type. Hay quality is further influenced by plant species, stage of maturity when cut, leafiness, color, stem size and brittleness

[a] Adapted in part from material prepared by D.A. Rohweder, Professor of Agronomy, University of Wisconsin, Madison, WI; R.W. Taylor, Professor of Plant and Soil Sciences, University of Delaware, Newark, DE; J.E. Moore, Professor of Animal Science, University of Florida, Gainesville, FL; and M.B. Tesar, Professor of Crop and Soil Sciences, Michigan State University, East Lansing, MI.

(lignification), foreign material, and the effects that these factors have on chemical composition, palatability, and digestibility.

Environmental circumstances during harvest and post-harvest storage are important, as well. Hay harvest commonly includes cutting, crimping, and partial drying in swaths exposed to sunlight in the field. Crimping crushes plant stems at intervals and speeds their drying to a rate approximating the drying rate of leaves. Otherwise, the leaves may become so dry and brittle, before stem moisture levels decline significantly, that leaf loss will be excessive during subsequent raking and baling. Drying time in the field depends upon temperature and humidity, but under ideal conditions should be sufficient to permit raking into windrows within a few hours to a day. Additional drying in windrows to moisture levels safe for baling and storage may require another day or two. High humidity or rainfall during these periods delays the process and may lower the quality of the final product.

If hay quality at the time of baling is to be sustained, it should be stored off the ground and under cover. In general, purchased hay should be green, leafy, have fine, pliable stems, and be free of weeds, insects, mold, soil, twine, and wire. Descriptions of the visual appearance of legume and grass hays cut at different stages of maturity, concentrations of protein and fiber in hay dry matter, and quality standards assigned by the Hay Market Task Force of the American Forage and Grassland Council (P.O. Box 94, Georgetown,TX 78627, 800-944-2342) are presented in Tables 1 and 2.[1]

Factors Affecting Hay Quality

Plant species. Forages that are suitable for harvest as hays and that are of importance in the commercial hay trade include the perennial legume alfalfa (*Medicago sativa*) and the shorter-lived common red clover (*Trifolium pratense*); the perennial grasses bermudagrass (*Cynodon dactylon*), timothy (*Phleum pratense*), smooth bromegrass (*Bromus inermis*), tall fescue (*Festuca arundinacea*), orchardgrass (*Dactylis glomerata*), perennial ryegrass (*Lolium perenne*), and reed canarygrass (*Phalaris arundinacea*); and the annual sudangrass (*Sorghum sudanense*). Oats (*Avena sativa*), an annual usually raised for grain, is sometimes cut for hay when it is green and the seeds are in the late-milk to early-dough stage. Of course, some plants are best adapted to certain regions. For example, bermudagrass is a heat-tolerant southern grass, whereas timothy is a cool-weather northern species.

Legumes have a symbiotic relationship with atmospheric nitrogen-fixing bacteria that live in root nodules and that make legumes independent of nitrogen fertilization. As a consequence, legume hays commonly have higher concentrations of crude protein than grasses. In addition, legume hays usually are higher than grasses in their concentrations of pectins, lignin, and calcium, and are lower in neutral detergent fiber (NDF) and cellulose. At comparable stages of maturity, legume and grass hays are about equal in concentrations of acid detergent fiber (ADF).

Crude protein concentrations in grass hays are very responsive to the amount of available nitrogen in the soil during plant growth. When heavily fertilized with nitrogen, immature grasses may have crude protein concentrations as high or higher than legumes. When soils are nitrogen poor and grasses growing on those soils are mature at harvest, crude protein may drop to as low as 4% of dry matter. Legume hays are generally more palatable than grasses as they mature, tend to be consumed in greater amounts, and are fermented more rapidly in the gastrointestinal tract than grasses of comparable maturity.

Stage of maturity. First cuttings of perennial forages are made as early as March in the southern United States and as late as June in the North. The length of the growing season, the forage species, and the availability of water from rainfall or irrigation (and nitrogen fertilization of grasses) greatly influences the number of hay cuttings per year. Depending upon environmental conditions, it takes about 6 wk after harvest for sufficient regrowth to justify the next cutting, which for most hay producers must yield a minimum of 1 T per acre. Alfalfa in the North is generally cut three times, whereas there may be up to eleven cuttings per year in irrigated areas of the Southwest. Regrowth of grasses generally is less vigorous than that of alfalfa, and seldom are there more than two cuttings in the North, four in the South, and four to six in the Southwest, where irrigation is used. The date of cutting is commonly selected to maximize the yield of digestible nutrients.

The stage of maturity at which hay is harvested is more easily determined before cutting than afterward. Since the hay purchaser seldom has the opportunity to observe harvest of the hay to be purchased, the following points may be helpful.

Alfalfa hay cut in the *bud stage* has buds at the end of the stems, and purple flower petals are absent. It is usually very leafy, and the stems are rather fine and pliable. Alfalfa hay cut in the *early-bloom stage* has buds, some purple flowers, and stems that are larger than in the bud stage. At the *full-bloom stage*, alfalfa hay has many blossoms, fewer leaves, and distinctly larger, woody stems. Alfalfa hay cut *post-bloom* has seed pods, few leaves, and large stems. It should be noted that the first cutting usually has larger stems than do subsequent cuttings, but these large stems are often softer and less lignified than the thin but stiff stems of regrowth during the high temperatures of summer.

Common red clover progresses through similar stages as it matures, but the flowers are red, and stems thicken earlier.

Yields of digestible nutrients of legumes generally are optimized when alfalfa hay is cut in the *late-bud* to *early-bloom stage* and common red clover hay is cut in the *early-bud* to *mid-bud* stage.

The stage of maturity at which grasses are first cut for hay can be determined by examining the seed heads. First-cutting bermudagrass, tall fescue, orchardgrass, and reed canarygrass should be cut *in the boot* (head is just emerging from the leaf roll) to the *early-heading stage*.

First-cutting timothy, smooth bromegrass, perennial ryegrass, and sudangrass should be cut in the *early-heading stage*. If these grasses are cut before full bloom, no ripe seeds will be present, parts of the flower can be seen, and unless weather damaged, they should have considerable green color. When these grasses *mature*, plump, brown seeds are present, separating easily from the whitish, dry glumes (or chaff). The stems and heads are usually yellowish-brown, and there are many brown leaves.

Regrowth of perennial grasses is principally vegetative, and seed heads will not be apparent in second or subsequent cuttings. Regrowth of the annual, sudangrass, is also mostly vegetative, but some sead heads will be seen when plants reach 2-4 ft in height before cutting.

Alfalfa-grass mixtures should be cut according to the maturity of the alfalfa, i.e., when alfalfa is in the *late-bud* to *early-bloom stage*. Common red clover-grass mixtures should be cut in the *early-bud* to *mid-bud stage*.

Leafiness. Leafiness is important since leaves are higher than stems in protein, minerals, and vitamins, and stems are higher in poorly-digestible fiber. Leafiness declines as plants mature. The lower most mature leaves die and fall from the plant and stems get proportionately larger. Leaf loss during raking

and baling also reduces quality. This is a particular problem with weather-damaged hay or if the hay is raked or baled when it is too dry. Legumes lose their leaves more readily than grasses. Even if the leaves are incorporated into the bales, when the bales are opened and fed, large losses of leaves to the ground occur.

Very leafy alfalfa hay may have 65 to 70% leaves compared to 10 to 15% for alfalfa hay with major leaf loss. A high proportion of leaf to stem is more significant for legume hay than grass hay because leaves of legumes maintain their quality relative to stems as plants mature whereas both leaves and stems of grasses decline in quality.

Color. Color is an indication of how the hay was handled and stored. It should approach the green color of the immature plant in the field. This color may be lost by bleaching in the sun, rain during curing, fermentation in the bale (because it was too wet), or because the plants were too mature when cut.

Hay that has been sun-bleached in the bale is a light golden-yellow only on the exposed surface, and the unexposed interior remains green. Such hay need not be discriminated against as seriously as hay that has been exposed to rain or heavy fog during curing and that is discolored to the interior of the bale. Such discoloration may be associated with significant nutrient loss due to leaching of water-soluble nutrients and destruction of oxygen-sensitive compounds such as chlorophyll, which accounts for the green color, and ?-carotene, which is a source of vitamin A activity.

When stored for periods greater than one year, hay of good quality initially, with no evidence of mold, may become brown, dry, and dusty, with ?-carotene concentrations less than 10% of starting values. This hay might be used for large adult herbivores in an emergency, but such use should be avoided, if possible, due to nutrient loss and undesirable respiratory effects.

Brown hay with white or gray discoloration and a musty odor (odor of mold) may have been baled when it was too wet. Fermentation, heating, and molding have occurred, and the flakes of hay may be caked together and difficult to separate. Such hay should not be used.

Stem size and brittleness. In general, large stem size means that mature plants were harvested and leaves have been lost. However, small stems are not always desirable. Regrowth of alfalfa during midsummer, following one or more earlier cuttings, may be influenced by unusually hot weather, resulting in small, brittle stems with a high degree of lignification. Since lignin can not be digested, the hay may be less digestible than expected even though the alfalfa plants that were cut were relatively young. If stems are small but not particularly brittle, undue lignification probably did not occur. Thus, digestibility should be normal.

Foreign materials and toxins. Foreign materials may be injurious because of specific toxins or the likelihood of trauma, or they may simply be items that won't be eaten and, thus, represent waste. Soil contamination is undesirable, but is unlikely to cause serious illness. Wire and plastic twine can cause gut damage; and contamination with bird droppings can lead to disease.

A number of weeds, such as mustard (*Thelypodium lasiophyllum*) and yellow rocket (*Barbarea vulgaris*), are not relished by herbivores but are not particularly toxic. Poisonous plants, such as tansy ragwort (*Senecio jacobaea*) that contains an alkaloid causing irreversible liver damage, or sharp-bearded weedy grasses, such as yellow foxtail (*Setaria lutescens*) and squirreltail

barley(*Hordeum jubatum*), and grasses that have a sharp point at the base of the seed, such as needlegrass (*Stipa* spp.), can do obvious harm to the oral cavity and gastrointestinal tract.[2,4]

Blister beetles, members of the Meloidae family, are sometimes found in alfalfa hay during hot weather (seldom seen at first cutting) in the central or southwestern United States. Adult blister beetles are plant eaters that have soft, elongate bodies, about 3/8-1 1/8" long, depending upon species. The beetles will normally leave alfalfa plants during harvest, unless injured and unable to do so. Both live and dead blister beetles contain a potent irritant, cathardin, that is particularly dangerous for equids and infrequently affects ruminants. Cathardin produces redness and ulcers of the mouth, esophagus, stomach, and intestinal tract, and nephritis and cystitis (inflammation of the kidneys and bladder).[3]

Tall fescue is a cool-season perennial grass that is frequently infested with an endophytic fungus (*Acremonium coenophialum*) that produces a vasoconstricting toxin. Affected ruminants and horses may exhibit poor growth, fever, excessive salivation, lameness, impaired reproduction, reduced milk production, and necrosis and mineralization of peritoneal fat. These hard fat masses may cause clinical disease when they compress the intestine or ureters or obstruct the birth canal.[3]

Odor. The smell of new-mown hay is the standard for comparison. Mustiness (and presence of mold) or a fermented or putrified odor usually indicate that quality has been adversely affected by weather damage or storage at excessive moisture levels.

Chemical composition. Concentrations of dry matter (DM) or, conversely, moisture, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin, calcium (Ca), and phosphorus (P) are important, practical indicators of hay quality. Regular analysis of hay for these components helps ensure that expected specifications will be met. Concentrations of these components in alfalfa, common red clover, and grass hays are shown in Table 3.[5,6] Concentrations of sodium, trace elements, and certain vitamins can be determined, and this information would be useful, but the assays are costly, and adequate supplies of these nutrients can be assured by use of nutritionally complete feeds.

Moisture in hay purchased during the growing season should generally be <14% for safe storage in humid regions. In arid regions, moisture may be as high as 17% in alfalfa hay during the growing season, and this higher level may be associated with less leaf loss during handling and feeding. Hay out of storage in winter and spring more typically contains 8 to 12% moisture. Valid comparisons of the composition of different hays can be made only after conversion of nutrient and fiber concentrations in hays containing moisture to a dry matter basis.

Sampling Hay for Analysis

Analytical data will be of limited value if the sample analyzed is not representative of the hay. Thus, sampling techniques are very important. Each lot of hay should be sampled. A "lot" of hay is defined as hay harvested on a single occasion from the same field, involving the same species, and subject to the same environmental conditions during harvest and storage. It should be noted that some lots of hay will include bales that differ in appearance from the rest even though the lot conforms to the above definition. This may be a consequence of differences in soil type, fertility, and drainage within a field and the effects of those differences on the predominance of plant species and their growth.

Fifteen to 20 cores from the lot should be collected and composited, using a hay probe with a minimum cutting diameter of 1/2" and a minimum sampling length of 12". The Multi-Forage Sampler™ and the Penn State Forage Sampler™ are useful hay probes. The Multi-Forage Sampler™ can be used quite easily without electrical power. The Penn State Forage Sampler™ can be used with a hand brace but is best powered by a 1/2" or larger electric drill. Cores should be taken to full depth of the sampler from the center of the end of randomly selected rectangular bales or coincident with the radius of randomly selected round bales.

The 15 to 20 cores should be mixed together and the composite (weighing 1/2 to 1 lb) placed in an airtight plastic bag (such as a freezer-weight Ziploc™ bag; DowBrands L.P., P.O. Box 68511, Indianapolis, IN 46268-0511) and shipped to a certified laboratory for "wet chemistry" analysis.

Sources of hay probes.

Multi-Forage Sampler™
Star Quality Samplers
5719-114A Street
Edmonton, Alberta T6H 3M8
403-434-3367

Penn State Forage Sampler™
NASCO
901 Janesville Avenue
Fort Atkinson, WI 53538
800-558-9595

Forage testing laboratories with demonstrated expertise. Because analytical laboratories differ in the quality of service they offer, it is important to identify those that use Association of Official Analytical Chemists (AOAC)-approved techniques. The author and reviewers of this paper have experience with the three laboratories listed below and have found them reliable and reasonable in cost. A list of other approved forage testing laboratories may be obtained from the National Forage Testing Association, P.O. Box 371115, Omaha, NE 68137 (402-333-7485).

Northeast DHIA Forage Lab
730 Warren Road
Ithaca, NY 14850
607-257-1272

OARDC-REAL
1680 Madison Avenue
Wooster, OH 44691
216-263-3760

Woodson-Tenent Labs
3507 Delaware St
Des Moines, IA 50313
515-265-1461

Near infrared reflectance spectrophotometry (NIRS) is not recommended for the variety of forages purchased from various locations by zoological parks. NIRS is a nondestructive means of correlating spectra of hays of unknown composition with spectra of standard samples whose composition is known. The spectra do not have an absolute relationship to specific chemical compounds, and about 50 samples of a hay type of known composition are required for adequate calibration of the instrument. Analysts using NIRS can supply answers quickly, but the validity of those answers should be confirmed before routine acceptance of the technique.

When Hay Doesn't Measure Up

When hay is ordered, hay providers should be clearly informed of the specifications that are required. In addition, agreement should be reached in advance concerning actions to be taken if specifications are

not met. Hay should be visually inspected before delivery is accepted. Hay that is moldy or infested with blister beetles, poisonous plants, or other dangerous substances should be immediately rejected. Identification of other quality factors may require a more extended examination.

While there is a general relationship between physical appearance and chemical composition, it is particularly difficult to predict crude protein concentration and dry matter digestibility of grass hays. Hays that, after analysis, prove to be low in crude protein and high in indigestible fiber might be exchanged for a more suitable product, or alternatively, a price adjustment might be made. However, use of hays that do not meet specifications requires supplemental feeds that compensate for their deficiencies. In any case, there are certain nutrients such as iodine, cobalt, and selenium that may be regionally deficient or nutrients such as sodium that tend to be low in all hays. Thus, evaluation of hay quality should always be complemented by consideration of the nutrient requirements of specific herbivores and the means necessary to meet those needs.

Additional Suggestions

Establish a working relationship with the forage specialist at your state's College of Agriculture and with your county or parish Cooperative Extension Service. With their help, perhaps through demonstrations or workshops, identify the types of hay that are available within a practical transport distance, and determine whether there are likely to be special problems requiring your attention, such as the presence of poisonous plants or regional deficiencies or excesses of certain minerals. Select hays required to meet your needs and attempt to locate honest producers or brokers that can reliably deliver hays that meet your specifications at a reasonable cost. Develop specifications for the hays you want to buy that will meet the needs of the herbivores you propose to feed, but keep the specifications realistic so potential hay suppliers will be eager to work for your business.

Literature Cited

[1]Baylor, J.E., and D.E. Rohweder. 1979. Implementation of new hay standards in the U.S. --- Where are we? Report from the AFGC Hay Market Task Force. Proceed. Ann. Meet. American Forage and Grassland Council, Little Rock, AK. Pp. 47-57.

[2]Cheeke, P.R., and L.R. Shull. 1985. Natural Toxicants in Feeds and Poisonous Plants. AVI Publishing Co., Westport CT.

[3]Fraser, C.M., J.A. Bergeron, A. Mays, and S.E. Aiello. 1991. The Merck Veterinary Manual. Merck & Co., Inc., Rahway, NJ.

[4]Kingsbury, J.M. 1964. Poisonous Plants of the United States and Canada. Prentice-Hall, Englewood Cliffs, NJ.

[5]National Research Council. 1989. Nutrient Requirements of Dairy Cattle. National Academy Press, Washington, DC.

[6]National Research Council. 1996. Nutrient Requirements of Beef Cattle. National Academy Press, Washington, DC.

Table 1. Description of legume hays cut at different stages of maturity and quality standards assigned by the Hay Market Task Force of the American Forage and Grassland Council.[1]

Stage of maturity	Definition	Description	Composition of DM, %			Quality standard[a]
			CP	NDF	ADF	
Prebloom	Bud to 1st flower; from start of stem elongation to just before blooming.	40-50% leaves; green; <5% foreign material; no mold or dust.	>19	<40	<31	Prime
Early bloom	Early to mid-bloom; start of bloom to1/2 of plants in bloom.	35-45% leaves; light green to green; <10% foreign material; no mold or dust.	17-19	40-46	31-35	1
Mid-bloom	Mid- to full bloom; ½ or more of plants in bloom.	25-40% leaves; yellow green to green; <15% foreign material; no mold or dust.	14-16	47-53	36-40	2
Full bloom	Full-bloom and beyond.	<30% leaves; brown to green; <20% foreign material; no mold or dust.	11-13	54-60	41-42	3

[a]The quality standards also apply to mixed legume-grass hays that conform to the indicated ranges for crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF).

Table 2. Description of grass hays cut at different stages of maturity and quality standards assigned by the Hay Market Task Force of the American Forage and Grassland Council.[1]

Stage of maturity	Definition	Description	Composition of DM, %			Quality standard[a]
			CP	NDF	ADF	
Prehead	Late vegetative to early boot; start of stem elongation to just before heading; 2-3 wk growth.	50% or more leaves; green; <5% foreign material; no mold or dust.	>13	47-53	36-40	2
Early head	Boot to early head; from inflorescence just emerging to ½ inflorescences in anthesis; 4-6 wk growth.	40% or more leaves; light green to green; <10% foregn material; no mold or dust.	11-13	54-60	41-42	3
Head	Head to milk; ½ or more inflorescences in anthesis; seeds formed but soft and immature; 7-9 wk growth.	30% or more leaves; yellow green to green; <15% foreign material; no mold or dust.	8-10	61-65	43-45	4
Posthead	Dough to seed; seeds doughlike to hardened as at harvest; >10 wk growth.	30% or more leaves; brown to green; <20% foreign material; slight musty odor; some dust.	<8	>65	>45	5

[a]The quality standards also apply to mixed legume-grass hays that conform to the indicated ranges for crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF).

Table 3. Concentrations of crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin (Lig), calcium (Ca), and phosphorus (P) in alfalfa, clover, and grass hays.[5,6]

		Composition of DM, %					
Species	Stage of maturity	CP	NDF	ADF	Lig	Ca	P
Alfalfa	Early vegetative	23.0	38	28	5	1.80	0.35
Alfalfa	Late vegetative	20.0	40	29	7	1.54	0.29
Alfalfa	Early bloom	19.9	39	32	8	1.63	0.21
Alfalfa	Midbloom	18.7	47	37	9	1.37	0.22
Alfalfa	Full bloom	17.0	49	39	10	1.19	0.24
Bermudagrass	Early vegetative	16.0	66	30	4	*	*
Bermudagrass	Late vegetative	16.5	70	32	4	*	*
Bermudagrass	15-28 d regrowth	16.0	74	33	4	0.40	0.27
Bermudagrass	29-42 d regrowth	12.0	76	38	6	0.32	0.20
Bermudagrass	43-56 d regrowth	8.0	78	43	7	0.26	0.18
Bromegrass	Late vegetative	16.0	65	35	4	0.32	0.37
Bromegrass	Midbloom	14.4	58	37	*	0.29	0.28
Bromegrass	Late bloom	10.0	68	43	8	0.30	0.35
Clover, red	Unstated[a]	15.0	47	36	*	1.38	0.24
Fescue	Early vegetative	12.4	57	32	3	0.51	0.36
Fescue	Late vegetative	10.5	64	36	4	0.40	0.34
Fescue	Early bloom	9.5	72	39	5	0.30	0.26
Oat	Boot	17.5	58	35	4	*	*
Oat	Head emerging	14.0	62	39	6	*	*
Oat	Immat seed (dough)	9.5	63	38	9	0.32	0.25
Orchardgrass	Early bloom	12.8	60	34	5	0.27	0.34
Orchardgrass	Late bloom	8.4	65	38	9	0.26	0.30
Sudangrass	Full bloom	8.0	68	42	6	0.55	0.30
Timothy	Late vegetative	17.0	55	29	3	0.66	0.34
Timothy	Early bloom	10.8	61	35	4	0.51	0.29
Timothy	Midbloom	9.1	67	36	5	0.48	0.22
Timothy	Full bloom	8.1	64	38	6	0.43	0.20
Timothy	Late bloom	7.8	70	40	7	0.38	0.18
Timothy	Immat seed (milk)	7.0	71	41	8	0.28	0.18

[a]Probably midbloom.

*Value not determined.