

MP434

Management of Hay Production

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Cooperative Extension Service

University of Arkansas, U.S. Department of Agriculture, and County Governments Cooperating

Table of Contents

Introduction	1
Hay Testing and Interpretation of Results	1
Visual Appraisals of Hay Quality	3
Mowing, Wilting and Baling Hay Crops	4
Spontaneous Heating	8
DM Recovery in Heated Hays	12
Nutritional Characteristics of Heated Hays	12
Weathering Effects	16
Cautions for Fertilization	19
Other Toxic Substances in Hay	21
Summary	22

Introduction

The production and storage of hay is an integral component of most livestock enterprises in Arkansas. Some producers maintain a full line of hay equipment and produce large quantities of hay; others prefer to purchase hay to meet their needs. An understanding of the processes involved in harvesting and storing hay is critical to the success of hay feeding. This publication will discuss the management of hay production, measures or indicators of forage nutritive value, toxic substances in hays, hay sampling, hay analysis and ration formulation.

Hay Testing and Interpretation of Results

Hay Analysis. The first step in developing a hay feeding program that optimizes livestock production is to test all hay for nutrient value. Estimating the nutritive value of hay from book values or visual evaluation will lead to errors in feeding. This results in reduced animal performance, costly errors in under or overfeeding and loss of potential profit.

Nutrient composition data from the University of Arkansas Cooperative Extension Service Forage Database is used here to illustrate the variability in nutrient content of hays (Table 1). The database contains nutrient composition values for 2,979 samples of bermudagrass hay. The crude protein (CP) values of bermudagrass hays ranged from 3.7 to 23.7 percent, and total digestible nutrients (TDN) ranged from 40 to 81 percent. These data and other values shown in Table 1 indicate that it is futile to attempt to estimate the nutrient content of hay. **An efficient hay feeding program must start with hay analysis.**

A representative sample of the hay available for feeding should be submitted for analysis before the hay feeding period. The University of Arkansas Agricultural Services Laboratory will analyze samples submitted through Cooperative Extension Service offices, or samples may be sent to a private laboratory. In some cases, an analysis may be provided by a feed company.

A routine hay analysis usually includes (1) moisture or dry matter (DM) content, (2) CP and (3) analysis of structural plant fiber that may be reported as crude fiber, acid detergent fiber (ADF) or neutral detergent

Table 1. The percentages and ranges of dry matter (DM), crude protein (CP), total digestible nutrients (TDN), calcium (Ca) and phosphorus (P) of Arkansas hays (DM basis).

Hay	Number Samples ¹	DM Avg ² (Range) ³	CP Avg (Range)	TDN Avg (Range)	Ca Avg (Range)	P Avg (Range)
Alfalfa	364	88 (63-95)	18.5 (6.1-33.1)	61 (37-78)	1.25 (.56-2.07)	.31 (.19-.43)
Bahiagrass	173	88 (72-94)	9.6 (4.1-17.6)	57 (46-77)	.49 (.30-1.07)	.21 (.10-.32)
Bermudagrass	2,979	87 (61-97)	12.4 (3.7-23.7)	60 (40-81)	.51 (.10-1.21)	.28 (.08-.61)
Bluestem	57	87 (66-94)	9.4 (2.6-15.6)	56 (37-71)	.49 (.32-.64)	.28 (.18-.40)
Bromegrass	29	88 (79-93)	10.7 (3.9-27.4)	56 (50-65)	.63 (.45-.78)	.10 (.08-.12)
Clover	45	87 (68-93)	14.0 (6.1-21.3)	56 (31-66)	1.12 (.55-1.93)	.27 (.09-.50)
Dallisgrass	32	89 (80-94)	10.8 (6.3-20.4)	58 (42-79)	.55 (.51-.58)	.26 (.22-.30)
Fescue	906	87 (64-97)	11.2 (3.9-22.4)	54 (42-70)	.50 (.24-.85)	.30 (.11-.51)
Johnsongrass	123	85 (63-94)	11.0 (4.0-21.7)	62 (48-73)	.57 (.22-1.01)	.32 (.19-.48)
Legume/grass mix	200	87 (63-94)	12.6 (5.6-26.6)	55 (41-71)	.78 (.30-1.32)	.28 (.11-.47)
Mixed grass	2,376	87 (60-99)	11.1 (2.1-24.8)	53 (35-72)	.58 (.12-3.06)	.30 (.04-.66)
Orchardgrass	157	87 (62-95)	13.5 (6.3-23.6)	57 (45-68)	.51 (.16-.92)	.34 (.17-.49)
Ryegrass	195	87 (64-96)	11.8 (3.9-26.7)	56 (45-68)	.50 (.26-1.15)	.29 (.10-.53)
Sudangrass	254	84 (65-95)	11.6 (2.5-20.2)	62 (42-83)	.69 (.36-.96)	.31 (.21-.43)
Wheat	66	87 (68-93)	11.3 (4.4-19.4)	55 (38-68)	.43 (.36-.53)	.38 (.23-.48)

¹ Indicates the number of samples in the database which were averaged for CP and TDN values. Fewer samples were analyzed for calcium and phosphorus.

² Average value. Values for DM and TDN were rounded to the nearest whole number.

³ Range indicates the lowest and highest value observed. Range values for DM and TDN were rounded to the nearest whole number.

fiber (NDF). Most commonly, both ADF and NDF are reported; crude fiber is a remnant of the old proximate analysis system and is rarely used today. Concentrations of net energy or TDN are calculated using prediction equations based on CP and fiber levels. Mineral levels can be obtained from additional tests.

In most situations, cattle diets are formulated to meet requirements for CP and energy (TDN or net energy), assuming adequate feed intake. If a mineral deficiency, imbalance or toxicity is suspected, a mineral analysis should also be requested.

Hay Sampling. Inaccurate sampling of hay may lead to even greater errors than using average values from hay composition tables. A “lot” of hay is defined as the entire amount of hay cut from one field at one time. All hay in the lot should have been cut at the same stage of maturity, wilted under the same climatic conditions and stored such that weathering effects were the same. Each lot of hay should be sampled and analyzed independently.

Hay can be most accurately sampled using a bale core sampler. A minimum of ten core samples, one per bale, should be collected from each lot of hay. Core samples should be taken from the end of conventional rectangular bales and from the side of round bales and stacks. Angle the core sampling tool in an upward direction when sampling bales stored outside. This will avoid creating a passageway for water to enter the inside of the bale. In most Arkansas counties, county extension agents have sample bags, sampling equipment and information on obtaining hay samples for analysis.



Proper sampling technique for round bales.

Interpretation of hay analysis results. The results on a Feed Analysis Report should be evaluated relative to the nutrient requirements of the cattle that will be fed the hay. For example, the nutrient requirements of beef cattle are based on the animal’s weight, age, frame size, stage of production and expected performance.

A publication entitled *Beef Cattle Nutrition Series, Part 3: Nutrient Requirement Tables*, MP 391, is available at University of Arkansas Cooperative Extension Service offices. For beef cattle, hay tests results should be interpreted by using values in that publication.

For example, the following routine hay test shows nutrient values on an “as-fed” and DM basis. To determine whether the hay needs to be supplemented with either a CP or energy (TDN) supplement, use the DM basis column on the hay analysis report. A typical hay analysis follows.

HAY ANALYSIS

Chemical Composition	As-Fed Basis	DM Basis
Moisture12.0%	
DM88.0%	
CP	7.9%	9.0%
Total Digestible Nutrients	47.5%	54.0%

The CP and TDN requirements for 1,100-pound mature beef cows as shown in MP 391 are as follows:

NUTRIENT REQUIREMENTS

	Diet Nutrient Density, DM Basis	
	CP	TDN
Beef cows, 11 mo. since calving (last 1/3 pregnancy)	7.7%	52.1%
Beef cows, 2 mo. since calving, 20 lb peak milk	10.9%	60.4%

To properly interpret the hay analysis for a 1,100-pound mature beef cow at 11 months after calving (last 1/3 of pregnancy), compare the CP value of the hay on a DM basis to the nutrient requirement. The hay contains 9 percent CP, and the cow requires 7.7 percent. The hay has a higher level of CP than required. Therefore, no protein supplement is needed when this hay is fed free-choice to these beef cows during the last third of pregnancy. Likewise, the TDN value of the hay (54 percent) is greater than the TDN requirement (52.1 percent), so no supplemental energy is needed.

Supplementation is needed, however, for the lactating beef cow fed this hay. The requirements for CP (10.9 percent) and TDN (60.4 percent) are greater than the nutrients in the hay (9 percent CP and 54 percent TDN). Therefore, both supplemental protein and energy (TDN) would be required. In this case, the amount of supplement needed to meet the nutrient needs of the lactating cows could be determined with a computerized ration formulation program or by manual calculation. Other nutrient deficiencies (calcium, phosphorus, trace minerals, etc.) in hay can be determined by using the same procedure.

Using hay analysis results to match hay to cattle needs. Most cattle producers bale or purchase several

lots of hay for feeding their animals. Due to environmental conditions and other factors, hay quality often varies. Analysis can be used to designate the highest quality hay for the cattle with the highest nutrient needs and the lowest quality hay for animals with the lowest nutrient needs. By matching hay to the nutrient needs of cattle, hay is used more efficiently, overfeeding and underfeeding errors are reduced, less supplement is needed, cattle performance is usually improved and profit potential is increased.

Hay quality of different forage species. The primary forages used for hay throughout Arkansas are fescue, bermudagrass and mixed grasses. Several other forage species are used to a lesser extent (Table 1). Only two forages, bluestem and bahiagrass, had CP values that averaged below 10 percent. Alfalfa hay averaged over 14 percent CP. Generally, beef cows require a diet containing less than 12 percent CP, but growing cattle, especially lightweight calves, often need more than 12 percent CP. Lactating dairy cows usually need higher levels of CP than can be provided by many hays. The use of high CP hays by beef cattle generally results in inefficient use of protein.

In hays produced in Arkansas, energy (TDN) is the most common deficiency for beef cattle. The average TDN values shown for hays in Table 1 would often be satisfactory for beef cattle, but the lowest quality hays (at the bottom of the range) would need to be supplemented with TDN, especially for growing and lactating cattle.

Visual Appraisals of Hay Quality

Can the nutritive value of hay be estimated by simply looking at it? The short answer is **no!** Generally, the CP or TDN content of forages can't be estimated by visual appraisal alone. The only way to accurately determine the feeding value of a specific lot of hay is by a laboratory analysis. Even if the hay looks the same as another hay crop, it may have drastically different nutrient levels. Variation in nutritive value occurs from year to year, field to field and cutting to cutting due to weather, management and several other factors.

Unfortunately, laboratory results are often not available when you are buying hay. The seller may offer an assessment of the hay such as, "it was fertilized," or, "it is that new hybrid everybody wants," but these comments really tell you nothing about hay quality. Fertilization or forage variety do influence hay quality, but other factors have a greater effect. In the absence of a hay test, certain visual characteristics of baled hay can help assess relative quality. With experience, these factors can be judged to help sort different lots of hay into groups of poor, average or good quality. Characteristics that should be considered when visually

evaluating hay are forage maturity, condition, purity, color and smell. Once hay is purchased, it should be sampled and analyzed so that a feeding program can be developed.

Maturity. Forage maturity at harvest has greater influence on hay quality than any other single factor. Forages that become too mature before cutting have high concentrations of fiber that result in poor digestibility. Mature, high-fiber forages have lower CP and TDN levels than forages cut at less mature stages of growth. Some indicators of desirable forage maturity include:

- 1) the absence of seedheads and seed stems (mature blooms for legume hay);
- 2) small or fine stems;
- 3) a high percentage of leaf that is green compared to dead;
- 4) high leaf-to-stem ratio.

Condition. Hay condition refers to the leafiness and texture of the forage. Condition often reflects the harvest methods and conditions, as well as forage maturity. Desirable indicators of forage condition include:

- 1) a high leaf-to-stem ratio;
- 2) small, fine stems;
- 3) large leaves;
- 4) intact leaves with little evidence of shattering;
- 5) a soft feel or texture.

Legumes that are baled too dry will often have a large percentage of shattered leaves. Hay that is baled too wet is often very dusty or moldy; after storage, individual bale flakes also may be difficult to pull apart.

Purity. Hay purity is simply an observation of the relative proportion of weeds or foreign material in the hay. Certain weeds can decrease the nutritive value of the hay or be poisonous to livestock. Undesirable weeds easily can be established by feeding weedy hay purchased off the farm. High weed content can be the result of low soil fertility or other poor production practices. Foreign material such as dead forage matter, sticks and trash also can reduce hay quality and acceptability.

Color. Color probably has the biggest influence on sale price at hay markets and in private sales, and it easily biases visual appraisals. Although it can give an indication of harvest and storage conditions, **color is not a strong indicator of hay quality.** Yellow or bleached hay may indicate poor harvest conditions, advanced forage maturity or a lengthy storage period, but other factors should be considered before that conclusion is reached. Hay that is cut when wet may become bleached in the field, resulting in a yellow appearance. This can occur even though tests show it to be of good nutritive value. Hay that gets rained on during harvest may also become bleached in color. Additionally, research has

shown that hay can have better nutritive value if it is cut at the right stage of maturity and gets rained on than other hay that is harvested at a more mature growth stage without rain damage. Hay stored outside that is exposed to the sun also may become bleached; the outside of a bale may be yellowed or bleached while the interior of the bale may still be green. Conversely, hay that is bright green may have poor nutritive value if it was harvested at an advanced stage of growth. A brown color inside the bale that is coupled with a tobacco-like odor indicates that spontaneous heating has occurred.

Smell. The smell or odor of hay is affected by the concentration of moisture in the hay at baling. A typical fresh hay odor is desirable. Hay that smells musty or moldy was baled at higher than desirable moisture levels or became wet during storage. Some hays that are baled before they are adequately dried have a tobacco-like odor and are brown in color.

Differences in forage species. As a general rule, cool-season grasses have less fiber and higher concentrations of CP than warm-season grasses when they are compared at the same stage of growth. This quality difference is due to plant physiology and not management factors. Cool-season grasses include ryegrass, cereal grains, tall fescue, orchardgrass and smooth brome grass. Warm-season grasses include bermudagrass, bahiagrass, switchgrass and dallisgrass. Both cool- and warm-season grasses can have very good quality if harvested at the proper maturity. Generally, legumes have higher nutritive values than most grasses. Legumes include annual and perennial clovers, hairy vetch, lespedeza and alfalfa. Clover-grass mixtures will usually have higher nutritive value than grasses grown alone. Legumes also can improve the nutritive value of mixed hays harvested when the grass component is more mature than desired. Clover planted with fescue or ryegrass can lower nitrogen fertilizer costs and help to maintain good nutritive value if harvest is delayed.

Summary. To develop an economical feeding program, there is no substitute for hay analysis. In the absence of laboratory analysis, visual appraisal of hay can be useful in choosing good hay compared to poor hay. Hay with the best combination of desirable visual characteristics will generally be of good nutritive value, although a livestock ration can't be balanced from visual estimates. When visually appraising hay, more emphasis should be placed on maturity, condition and purity than on color or smell. Visual appraisal is learned by experience and by comparing visual observation with hay analysis results. Hay contests and field days are excellent opportunities to visually compare hay samples with results from laboratory analysis. **Visual appraisals should not be relied on for developing a livestock feeding program. Hay should be tested to determine actual forage quality.**

Mowing, Wilting and Baling Hay Crops

Harvest timing. No single factor affects the quality of hay or silage as much as the maturity of the forage when the mower is first pulled into the field (Table 2). As plants mature, stem is increased in the total forage mass, and therefore, the leaf-to-stem ratio is reduced. Increased proportions of stem usually result in higher concentrations of fiber (usually measured as NDF and ADF) and lower concentrations of CP and digestible DM. Unfortunately, the management of forage crops is complicated by the need to allow adequate initial growth, and either adequate regrowth or harvest intervals (depending on the crop) to maintain plant vigor and the health of the stand. Clearly, these competing management concerns require some compromise.

Table 2. Effects of maturity on forage quality¹.

Forage	CP	NDF	ADF	TDN
----- % of DM -----				
Alfalfa hay				
Early vegetative	23	38	28	66
Late vegetative	20	40	29	63
Early bloom	18	42	31	60
Midbloom	17	46	35	58
Full bloom	15	50	37	55
Bermudagrass hay				
Early vegetative	16.0	66	30	61
Late vegetative	16.5	70	32	54
15 - 28 days growth	16.0	74	33	55
29 - 42 days growth	12.0	76	38	50
43 - 56 days growth	8.0	78	43	43

¹ Nutrient Requirements of Dairy Cattle (1989).

For alfalfa, the general rule of thumb is to harvest before the crop reaches 1/10 bloom; however, the quality characteristics of alfalfa harvested at this growth stage may not allow producers to sell to top-dollar dairy markets. Bermudagrass should generally be harvested in intervals of about four weeks during the growing season. Individuals wishing to market or feed bermudagrass hay of the highest quality may reduce this interval by a few days, but haying intervals of less than 22 days are very rare. Tall fescue and other cool-season perennial forages should be harvested at the boot or early heading stages of growth. The interrelationships between maturity, concentrations of fiber (NDF) and digestibility for tall fescue are shown in Figure 1. The most rapid changes in fiber content and digestibility occur between the late boot and early bloom stages of growth. Weather permitting, producers should make every effort to harvest these crops at the best compromise between nutritive value and yield. The ideal harvest maturities for various forage crops are summarized in Table 3.

Figure 1. Digestibility and neutral detergent fiber (NDF) in Kentucky-31 tall fescue at various maturities.
 Source: C. S. Hoveland and N. S. Hill, University of Georgia.

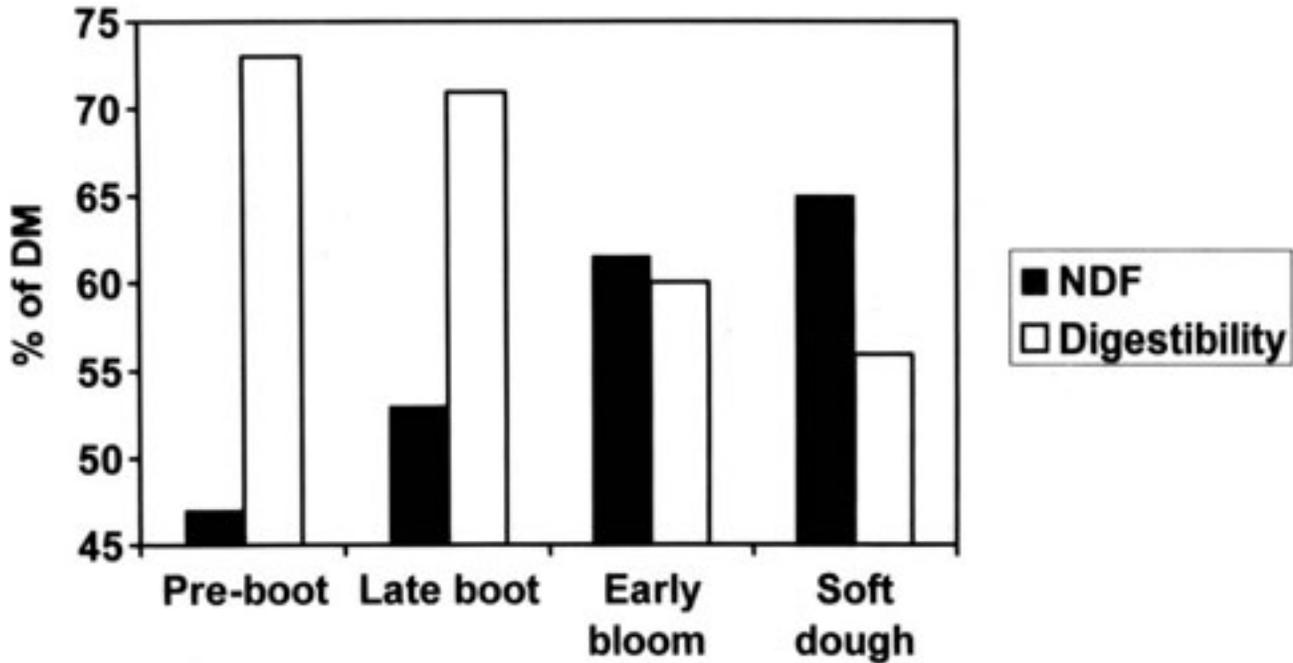


Table 3. Recommended growth stages or time intervals to harvest various hay crops¹.

Forage	Time of harvest
Alfalfa	First cutting: bud stage Second and later cuttings: 1/10 bloom First cutting following spring seeding: mid to full bloom
Orchardgrass, timothy or tall fescue	First cutting: boot to early heading Regrowth: four- to six-week intervals
Red, arrowleaf or crimson clovers	Early bloom
Sericea lespedeza	15 to 18 inches
Oats, barley, rye, ryegrass or wheat	Boot to early heading (nutritive value of rye will deteriorate much faster than other cereal grains after this growth stage is reached)
Annual lespedeza	Early bloom and before bottom leaves begin to fall off
Ladino or white clover	Cut at correct stage for companion grass
Hybrid bermudagrass	First cutting: 15 to 18 inches Second and later cuttings: every four to five weeks (intervals down to 22 days can be used for highest quality)
Birdsfoot trefoil	Cut at correct stage for companion grass
Sudangrass, sorghum-sudangrass and pearl millet	30 to 40 inches

¹Ball, et al., 1996; *Southern Forages*, 2nd ed., Potash and Phosphate Institute and Foundation for Agronomic Research, Norcross, GA.

Mowing and wilting. The mechanics of hay production should begin with a caution to check and service all equipment thoroughly during the weeks before haying season. It is impossible to calculate the tons of hay that have been damaged because of poorly maintained equipment that was not field ready at harvest time.

The goal during the wilting process is to eliminate water as quickly as possible. This conserves nutrients by limiting respiration within the forage mass. Generally, grasses wilt much faster than legumes. Some legumes are notorious for their slow drying rate; for instance, red clover dries even slower than alfalfa. For this reason, it is essential that alfalfa and other legumes be conditioned

when they are mowed. Normally, sickle-bar type mowers with conditioning rollers are used for this purpose. Generally, disc-type mowers are preferred for harvesting bermudagrass and other perennial grasses. Many grasses, such as bermudagrass, dry rapidly, and the conditioning step can often be omitted. When conditioning alfalfa hay, especially with roller-type conditioners, the risk of crushing blister beetles increases. Crushed blister beetles are lethal to horses consuming these forages; however, the stems of alfalfa plants dry so slowly that there is really no alternative to conditioning with either crushing rollers or a tine-type conditioner.

Summer annual grasses such as sudangrass, pearl millet and the sorghum-sudangrass hybrids should always be conditioned to increase the drying rate. In these forages, water can remain trapped in uncrushed stems long after the leaves are dry enough to bale. In contrast, conditioning rollers should be opened to a wide gap or disengaged when harvesting cereal grains with filling grain heads. By the soft-dough stage of growth, most of the nutritive value in these forages is associated with the grain head **and not the stover**. Therefore, an improperly adjusted conditioner that thrashes grain will greatly reduce the overall quality of the hay or silage.

Cutting height. The various mechanisms used by forages to convert carbon dioxide into sugars and then store these energy compounds to support regrowth after harvest have an important effect on forage management. Generally, plants that store their growth reserves underground, such as alfalfa, are unaffected by cutting height and can be mowed very short. In addition, plants that store growth reserves in stolons or “runners” that lay on the soil surface (bermudagrass and white or ladino clovers) typically are tolerant of close mowing or grazing heights. Many cool-season perennial forages, including smooth brome grass, orchardgrass and, to a lesser extent, tall fescue, are somewhat sensitive to extremely close mowing heights. These types of plants store their growth reserves in the stem bases. Removal of this part of the plant by mowing too close will limit the regrowth potential of these forages, resulting in thin stands. Leave at least 2 to 3 inches of stubble when harvesting these forages.

Some types of forages require much higher (6- to 8-inch) mowing heights. These forages include sudangrass, pearl millet, sorghum-sudangrass hybrids, johnsongrass and eastern gamagrass. For annuals such as sudangrass, pearl millet and the sorghum-sudangrass hybrids, clipping at shorter heights will slow the regrowth response after harvest. In addition, these forages are notorious for accumulating nitrates when growing conditions are stressful. Typically, nitrates are most likely to accumulate in the highest concentrations in the lower portions of the stem. Maintaining a mowing height of 8 inches or higher will encourage aggressive

regrowth and provide some help in reducing the risk of nitrate poisoning. Eastern gamagrass is a warm-season perennial that is extremely sensitive to close mowing heights. It is absolutely essential to leave at least 6 to 8 inches of stubble, measured from the top of the crown, when mowing this forage as a hay or silage crop.

Windrow width. If forages are to be baled as hay, they should be mowed in wide swaths to encourage drying. Dense, narrow windrows will not dry as fast; however, this can be used to slow wilting when alfalfa or other crops, such as cereal grains, are being harvested as silage and maintaining moisture in the windrow is essential. As the yields increase, the drying time required before baling increases regardless of windrow width.

Drying agents. Drying agents, such as sodium and potassium carbonate, that can be sprayed on alfalfa or other legumes at mowing are available. These products can reduce drying time, but the cost must be weighed against the likelihood of rainfall events. Drying agents do not usually enhance the drying time for cool-season grasses. This may occur because the leaf sheath prevents the drying agent from contacting the stem directly.

Mechanical manipulation. Unlike most grasses, alfalfa and other legumes should not be raked or tedded when the moisture content falls below 35 to 40 percent (Table 4). In addition, these processes should be as gentle as possible. The ground speed of the rake and the general aggressiveness of the raking mechanism should be reduced if leaves are obviously being shattered. Various mechanical processes that are improperly managed will greatly encourage leaf and DM losses in alfalfa and most other legume hays (Table 4).

Grasses and legumes, however, are fundamentally different. In grasses, both the leaf and stem have some structural function; therefore, they are more similar in quality than in legumes. In alfalfa, the function of the stem is almost entirely structural, while the leaf is extremely fragile and contains most of the metabolic machinery of the plant. Therefore, legume leaves are extremely high in nutritive value, relative to the stem tissues that are heavily lignified. In addition, the quality of legume leaves changes only marginally with maturity, but the quality of the stems will decrease rapidly. In contrast, the digestibility of leaves and stems both decrease markedly with maturity in most grasses. Therefore, it is necessary to conserve the extremely fragile leaves of legumes during the haymaking process to maximize the nutritive value of the hay.

Balers. Using the proper baler is important when producing quality alfalfa hay. Generally, large round balers should be avoided. Some studies have reported losses of 13 percent of DM and 21 percent of alfalfa leaves with these balers. Conventional rectangular balers or large square balers that use a plunger system

do a much better job of conserving leaves. The window of opportunity for baling alfalfa can be very short. Generally, alfalfa hay needs to be wilted to 20 percent moisture to prevent excessive spontaneous heating during storage; however, significant leaf loss will occur with any baler when the moisture content falls below this level. Preservatives are occasionally sprayed onto the forage at the baler in an effort to bale hay that is slightly wet, thereby conserving leaves. The most common of these preservatives is propionic acid, which can be effective in limiting the undesirable effects of respiration and spontaneous heating. These products generally permit the safe storage of hays that are marginally wet (probably < 30 percent moisture), and should not be viewed as a technique that allows producers to bale excessively wet hay.

Conservation of plant sugars. Plant sugars and other nonstructural carbohydrates are highly digestible; therefore, it is desirable to conserve these compounds during

Table 4. Alfalfa losses of DM and leaves during various haymaking operations.¹

Operation	% of DM Lost	% of Leaves Lost
Mowing	1	2
Mowing/conditioning:		
reciprocating mower, fluted rollers	2	3
disc mower, fluted rollers	3	4
disc mower, flail conditioner	4	5
Raking:		
at 70% moisture	2	2
at 60% moisture	2	3
at 50% moisture	3	5
at 33% moisture	7	12
at 20% moisture	12	21
Tedding:		
at 70% moisture	1	2
at 60% moisture	1	3
at 50% moisture	3	5
at 33% moisture	6	12
at 20% moisture	11	21
Baling, pickup + chamber		
at 25% moisture ²	3	4
at 20% moisture	4	6
at 12% moisture	6	8
Baling at 18% moisture:		
conventional rectangular baler		
with ejector	5	8
round baler, variable chamber	6	10
round baler, fixed chamber	13	21

¹ Source: R. E. Pitt. *Silage and Hay Preservation*. Northeast Regional Agric. Engr. Service. NRAES-5. Ithaca, NY. Data compiled from: Kjølgaard [Trans. ASAE 22:464-469 (1979)]; Hundtoft [Extension Bulletin 364, Cornell University (1965)]; and Rotz [DAFOSYM: The Dairy Forage System Model. USDA- ARS (1989)].

² Requires a preservative for safe storage.

the haying process. Generally, perennial cool-season grasses have higher concentrations of nonstructural carbohydrates than either legumes or perennial warm-season grasses. Lush, immature forages usually have relatively low concentrations of sugars. Forages mowed late in the afternoon will have higher concentrations of plant sugars than those harvested in the morning; however, specific attempts to harvest sugars by postponing mowing until late afternoon are not necessarily advised except under arid drying conditions.

Nonstructural carbohydrates can be lost at several points during the haying process, and a large percentage of these compounds are lost even when weather conditions are ideal. During the wilting process, sugars are consumed (as an energy source) as plant cells try to continue functioning while the forage dries in the swath. This respiratory activity within plant cells is usually a minor cause of DM loss after the plant reaches about 40 percent moisture. Air temperature also affects respiration because enzymatic activity is increased at higher temperatures; however, this relationship is confounded because higher temperatures also increase drying rate. It is undesirable for mowed hay to remain in the swath for prolonged periods under poor drying conditions (high humidity, fog, etc.), even in the absence of rain. This will always result in poor recovery of nonstructural carbohydrates.

Rain damage. Unfortunately, research trials that describe the effects of rain on drying forage crops are quite limited. Most of this work has been confined to alfalfa and other legumes (Tables 5 and 6). Generally, rain will leach soluble nutrients (primarily sugars) from hay, resulting in DM loss, increased concentrations of fiber and decreased energy levels in the forage. The effects of rainfall on three legumes are shown in Table 5. These results illustrate the effects of leaching only; shattered leaf fragments were included in the analysis. When leaf shatter is also considered, quality depression and DM losses can be severe. Digestibility decreased from 72.7 to 49.3 percent and from 62.3 to 36.0 percent in response to a 2.4-inch rain event on dry alfalfa harvested at late bud stage and first flower, respectively (Table 6). Based on the few available research studies, the effects of rainfall appear to be more severe when the forage is dry. Generally, the effects of rainfall on drying grasses remain poorly defined; however, cool-season grasses contain large concentrations of sugars and other nonstructural carbohydrates that are water soluble and easily leached. Therefore, concentrations of less digestible structural plant fiber will likely increase after rainfall events. Leaf shatter that occurs as a result of rainfall is usually less of a problem with grasses than with legumes.

Table 5. Effects of rainfall and forage type on nutritive characteristics of three legumes. Analysis includes shattered leaf fragments.¹

Treatment	% Leaf	Crude Protein	NDF ²	ADF	Lignin	TNC	Forage Digestibility
----- % of DM -----							
Alfalfa							
Control	56.8	15.5	32.3	25.9	5.3	12.2	71.5
Wet 48 hours ³	53.5	18.7	34.1	27.4	5.5	10.7	71.0
Wet 24 and 48 hours ⁴	45.6	18.2	38.4	29.9	6.0	8.0	69.2
Red Clover							
Control	92.7	14.6	29.1	21.6	3.2	15.7	75.8
Wet 48 hours	97.0	16.9	32.7	24.1	4.0	12.7	72.6
Wet 24 and 48 hours	96.8	17.5	39.9	28.9	4.8	5.2	67.0
Birdsfoot trefoil							
Control	52.9	13.7	31.0	24.6	5.9	15.2	71.3
Wet 48 hours	48.1	13.9	36.0	29.6	7.1	13.4	70.2
Wet 24 and 48 hours	47.1	15.2	40.8	32.1	7.8	9.6	66.4

¹ M. Collins, *Agronomy Journal* 74:1041-1044 (1982).

² Abbreviations: NDF, neutral detergent fiber; ADF, acid detergent fiber; and TNC, total nonstructural carbohydrates.

³ Artificial rainfall amount was 1.0 inch at 48 hours.

⁴ Two applications of 1.0 inch of water at 24 and 48 hours.

Table 6. Effects of rain and plant maturity on alfalfa quality. Shattered plant matter was not included in the analysis.¹

Maturity	No Rain	Rain ²	Rain on Dry Hay ³
----- % of DVM -----			
Crude protein			
Late bud	26.3	24.6	23.1
First flower	18.1	13.9	15.6
Digestibility			
Late bud	72.7	57.2	49.3
First flower	62.3	39.2	36.0
TNC⁴			
Late bud	4.65	2.00	1.21
First flower	4.46	1.89	0.98
NDF			
Late bud	32.4	45.4	54.8
First flower	42.2	64.1	69.8
ADF			
Late bud	27.5	38.5	46.2
First flower	36.4	53.0	58.4
Lignin			
Late bud	5.5	9.7	11.5
First flower	9.1	13.8	16.6

¹ M. Collins, *Agronomy Journal* 75:523-527 (1983).

² 1.6 inches of rain during curing

³ 2.4 inches of rain on dry hay

⁴ Abbreviations: TNC, total nonstructural carbohydrates; NDF, neutral detergent fiber; and ADF, acid detergent fiber.

Spontaneous Heating

Introduction. The negative consequences of baling hay before it is adequately dried are widely known to producers. Frequently, these problems are created by uncooperative weather conditions that prevent forages from drying (rapidly) to moisture contents that allow safe and stable storage of harvested forages. Negative consequences associated with baling hay before it is adequately dried include molding, spontaneous heating and undesirable changes in forage nutritive value.

Mechanisms. Spontaneous heating is the most obvious result of plant and microbial respiration within the hay bale. Respiration is the process in which plant cells and different microorganisms consume sugars in the presence of oxygen to yield carbon dioxide, water and heat:

plant sugars + oxygen → → → → carbon dioxide + water + heat

This process causes the internal temperature of any hay bale to increase and ultimately lowers the energy content and digestibility of the forage. Spontaneous heating actually helps to dry the hay because it encourages the evaporation of water. Many factors contribute to the extent of heating. These include:

- 1) moisture content at baling;
- 2) bale type;
- 3) bale density;

- 4) environmental factors, such as relative humidity, ambient temperature and air movement;
- 5) storage site;
- 6) use of preservatives.

Usually the extent of heating that occurs in any hay bale is a good indicator of the undesirable changes in nutritive value that may be observed after storage.

Figure 2 shows the typical patterns of spontaneous heating that occur over time in storage for conventional rectangular alfalfa hay bales made at 30 and 20 percent moisture. Beginning immediately after baling, the internal bale temperature rises due to respiration of both plant cells and microbes associated with the plant in the field. This heating usually lasts less than five days. Following a short period in which internal bale temperatures normally decrease (at 4 to 5 days post-baling), a prolonged period of heating begins that can last several weeks. This heating is the result of respiration by storage microorganisms. The hay bales made at 30 percent moisture maintained a higher internal bale temperature than the drier hay (20 percent moisture) for about 25 days. Similar trends can be observed for characteristics of spontaneous heating in bermudagrass hays (Figure 3).

Bale size and density also have a positive effect on heating in hay packages. However, the amount of heat developed per unit of DM is independent of bale density.

This suggests that bale density increases spontaneous heating simply because more hay is packaged within the bale. Larger and denser packages also tend to have higher internal bale temperatures because the heat produced is more difficult to dissipate.

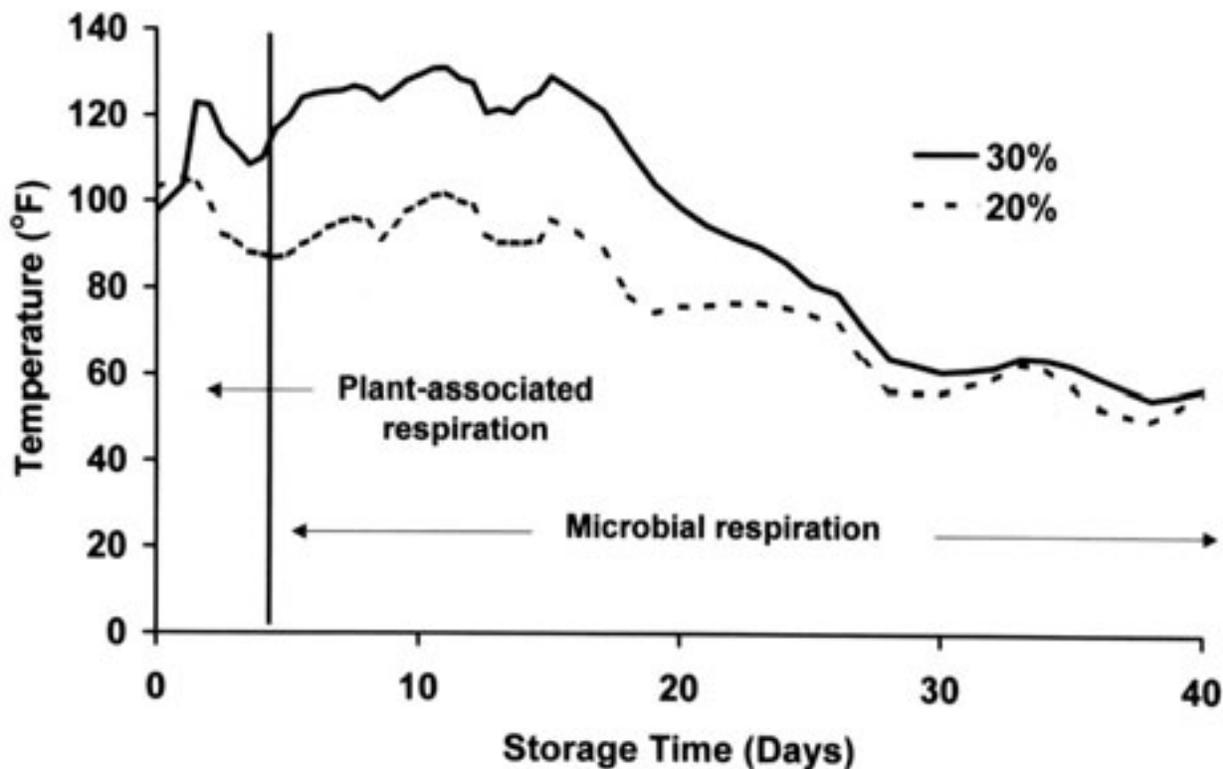
Measuring spontaneous heating. Under research conditions, spontaneous heating usually is not measured simply as internal bale temperature. The concept of heating degree days (HDD) is often used as a single index that incorporates both the magnitude and duration of heating during the entire storage period. Heating degree days usually are calculated by subtracting 86°F (30°C) from the daily internal bale temperature; these differences are then summed over all days in storage. An example of how HDD are calculated is summarized below:

Example:

Day	Bale Temperature, °F	Degrees > 86°F
1	108	22 (108-86)
2	104	18 (104-86)
3	115	29 (115-86)
3-day total		→ 69

This concept is often used to limit effects of ambient air temperature and because negative changes in forage nutritive value are most noticeable when internal bale

Figure 2. Typical patterns of spontaneous heating in conventional rectangular bales of alfalfa hay packaged at 30 and 20% moisture and stored in small stacks in Manhattan, KS. Source: W. K. Coblenz.



temperatures exceed 86°F. Heating degree days can be viewed as a relative measure of the heat produced within each bale. Heating degree days totaling 150 or less are indicative of relatively minimal spontaneous heating; conversely, totals in excess of 800 HDD are indicative of hay that was baled excessively wet, probably at about 30 percent moisture.

Of all the factors that affect spontaneous heating, moisture content at the time of baling is the most important. Figure 4 summarizes several alfalfa hay experiments conducted in Kansas. The relationship between moisture content and HDD is quite close ($r^2 = 0.902$). A one percentage unit increase in the moisture content of the forage at baling results in 56 HDD. A similar relationship was observed for bermudagrass hay baled in Fayetteville (Figure 5). In that study, about 43 HDD were accumulated for each increase of one percentage unit in the moisture content at baling. Regardless of the forage type, the level of heating that occurs is primarily driven by moisture content at baling, and this relationship is linear (HDD increases at a constant rate with bale moisture).

These studies were all conducted with conventional small rectangular bales. While it is generally assumed that similar relationships between moisture content and spontaneous heating exist in large round bales, there is limited documented research to support this. Typically,

the recommended moisture content at baling for larger, round hay bales is lower than is necessary for conventional rectangular bales. A good rule of thumb for maintaining acceptable storage in conventional rectangular hay packages is to bale hay at 20 percent moisture or less; however this guideline is often reduced to 16 to 18 percent moisture for larger hay packages.

A recent study conducted with mixtures of orchardgrass and alfalfa at the University of Tennessee (Montgomery et al., 1986; *J. Dairy Sci.* 69:1847-1853) measured the internal bale temperature of 1,373-pound round bales made at 24 percent moisture during a 96-day storage period. These results were compared with those of 25-bale stacks of the same material baled as conventional rectangular bales. Maximum internal bale temperatures for both bale types occurred at about the same time (11 to 12 days of storage); however, the peak internal bale temperature for the round bales was about 190°F compared to only 104°F for the conventional rectangular bales. Internal bale temperatures in round bales can reach levels comparable to those in the University of Tennessee study through the respiratory processes of plant cells and microorganisms. However, higher temperatures are caused by oxidative chemical reactions that may occur as long as 30 days after baling. Clearly, large round bales are more prone to heat

Figure 3. Typical patterns of spontaneous heating in conventional rectangular bales of bermudagrass hay packaged at 31, 27 and 17% moisture and stored in small stacks in Fayetteville, AR. Source: W. K. Coblenz.

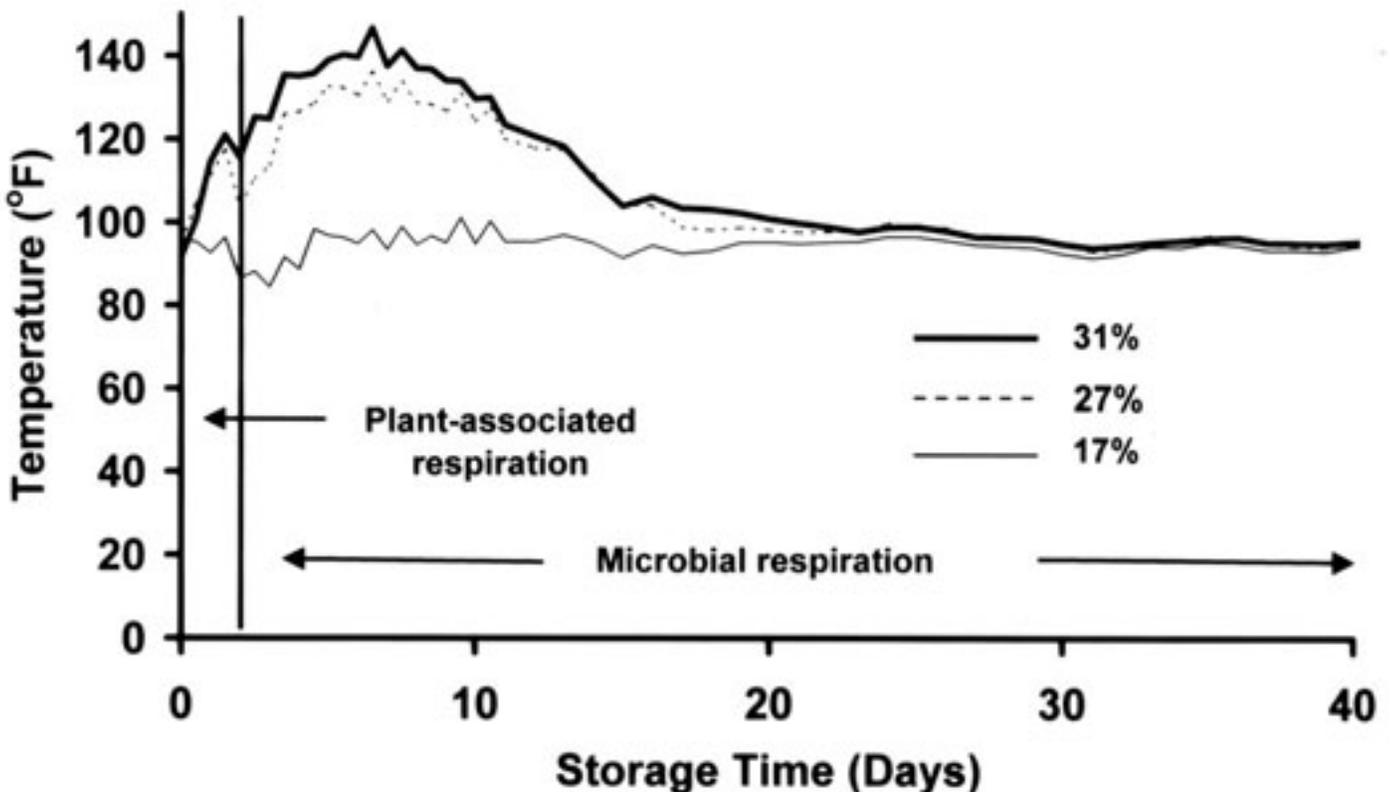


Figure 4. Relationship between heating degree days > 86°F (HDD) accumulated in conventional rectangular bales of alfalfa hay (■) and the concentration of moisture in the bale at packaging. Heating degree days can be interpreted as a single number that represents both the magnitude and duration of heating within the bale. Source: W. K. Coblenz.

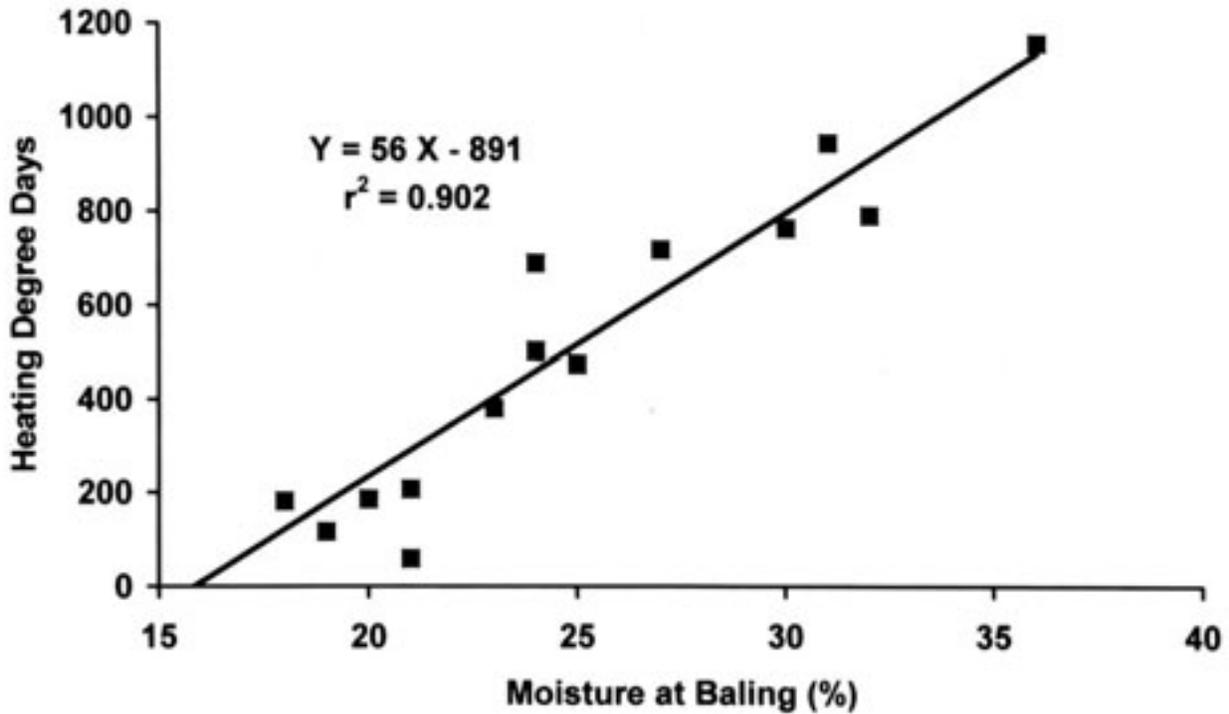
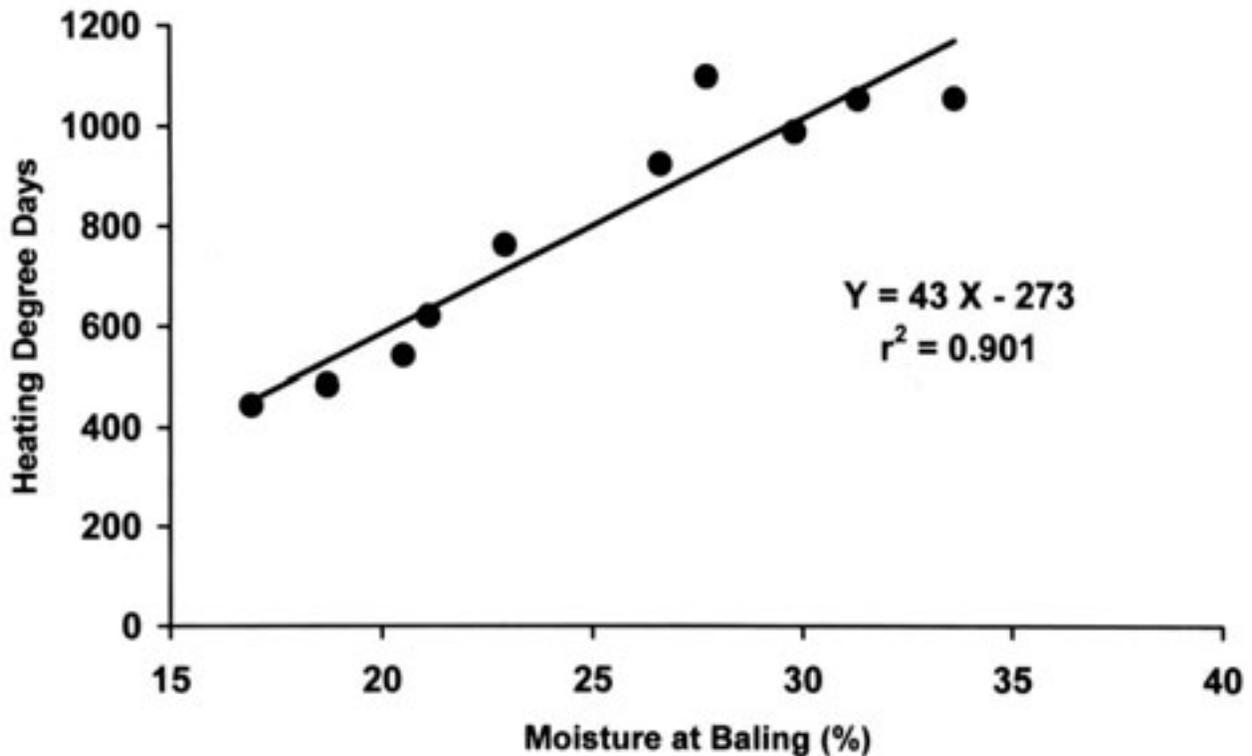


Figure 5. Relationship between heating degree days > 86°F (HDD) accumulated in conventional rectangular bales of bermudagrass hay (●) and the concentration of moisture in the bale at packaging. Heating degree days can be interpreted as a single number that represents both the magnitude and duration of heating within the bale. Source: W. K. Coblenz.



spontaneously and have a higher risk of combustion. Spontaneous combustion is thought to occur when internal bale temperatures reach about 340°F. Normally, this does not occur in the center of the stack because lower concentrations of oxygen may limit temperature increases and make combustion less likely. It is more commonplace to observe spontaneous combustion near the outside of the stack where concentrations of oxygen are higher.

DM Recovery in Heated Hays

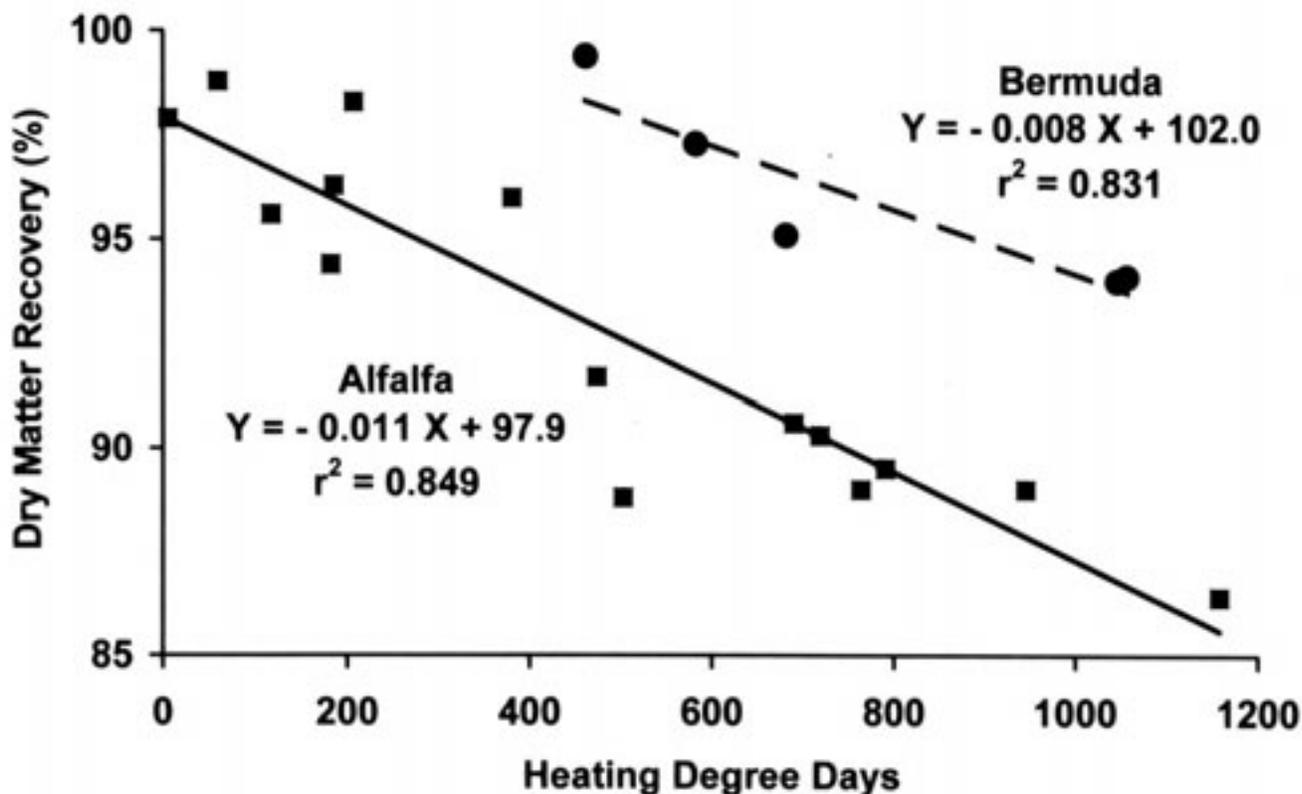
Dry matter is lost whenever heating occurs in hay bales. Dry matter losses occur in virtually all hay packages, but these losses are relatively minor without evidence of heating. Most of the DM that is lost during hay storage is nonstructural carbohydrate (plant sugars) that are respired to carbon dioxide, water and heat. Losses of DM will increase with increased moisture content at baling and subsequent spontaneous heating. Figure 6 summarizes DM losses in conventional rectangular alfalfa and bermudagrass hay bales over several experiments. For both hay types, about 1 percent of the initial DM in the bale is lost for every 100 HDD measured during storage. In the alfalfa hay, some DM loss

(about 2 percent of the initial DM) occurred even when no HDD were measured during the storage period. This occurred because some respiration takes place when internal bale temperatures are below 86°F. For bermudagrass hay, losses of DM also are related closely to the maximum internal bale temperature recorded during the storage period (Figure 7). These data indicate that bermudagrass hay packaged in conventional rectangular bales will lose 1.3 percent of the initial DM in the bale for every increase of 10°F in the maximum internal bale temperature. It is important to note that Figures 6 and 7 both display data that was collected from conventional rectangular bales. Although it is assumed that these trends are similar in large round bales, these relationships cannot be applied directly to larger hay packages. Generally, DM losses associated with spontaneous heating are greater in larger hay packages.

Nutritional Characteristics of Heated Hays

Plant sugars. During the spontaneous heating process, sugars are oxidized. This results in increased concentrations of more stable plant components such as structural fiber (NDF, ADF) and, to a lesser extent,

Figure 6. Relationship between dry matter recovery after storage and heating degree days > 86°F (HDD) for conventional rectangular bales of alfalfa (■) and bermudagrass (●) hays made in Manhattan, KS, and Fayetteville, AR, respectively. Source: W. K. Coblenz.



protein. This results in a decrease in the energy content and digestibility of the forage. As a standing crop, the concentrations of nonstructural carbohydrates in alfalfa can exceed 20 percent of the total plant DM. Even when alfalfa is wilted under excellent drying conditions, the concentrations of nonstructural carbohydrates can fall to less than 8 percent of DM by the time the forage is baled. This occurs as a result of unavoidable plant respiration during the wilting process. During storage, alfalfa continues to lose nonstructural carbohydrates to microbial respiration. Hay packaged at 30 percent moisture has about half the concentration of nonstructural carbohydrates at the end of a 60-day storage period as hay packaged at 20 percent moisture. This is due to the greater heating that occurs in hay made at 30 percent moisture. The time interval when concentrations of nonstructural carbohydrates fall most rapidly (0 to 12 days) coincides with the period of most intense heating in hay bales (Figure 2). During this period of intense spontaneous heating, plant sugars in all hays are oxidized as a fuel source for rapidly proliferating microorganisms in the hay. Ultimately, this negatively affects the nutritive value of the hay because sugars are among the most digestible components of any forage.

Fiber components. Forage fiber components, such as NDF, ADF, crude fiber, lignin and ash, remain

relatively stable during bale storage. These components essentially comprise the cell wall or structural portion of forages and are the least digestible parts of the plant. The NDF concentration of a forage is equated with the concentration of cell wall within the forage; low NDF concentrations normally indicate high nutritive value. The primary energy source for the respiratory processes in hay bales are nonstructural carbohydrates, or plant sugars. When hay bales heat spontaneously, concentrations of NDF, ADF and other fiber components increase. This is not because more plant fiber is actually constructed. The mechanism is indirect; as more plant sugars and other cell solubles are consumed during microbial respiration, the concentrations of the fiber components increase.

Recent research with alfalfa hay baled at 30 percent moisture showed that concentrations of NDF increased rapidly between 0 and 12 days of storage (the period of active respiration and high internal bale temperatures), but were relatively stable after 12 days (Figure 8). Higher concentrations of NDF were reached in the hay baled at 30 percent moisture because of the increased spontaneous heating that occurred in this hay. Similar relationships have been observed in bermudagrass hays made in Fayetteville, Arkansas, during the summers of 1998 and 1999.

Figure 7. Relationship between DM recovery after storage and the maximum internal bale temperature for conventional rectangular bales of bermudagrass hay (●) made in Fayetteville, AR, in 1998. Source: W. K. Coblenz.

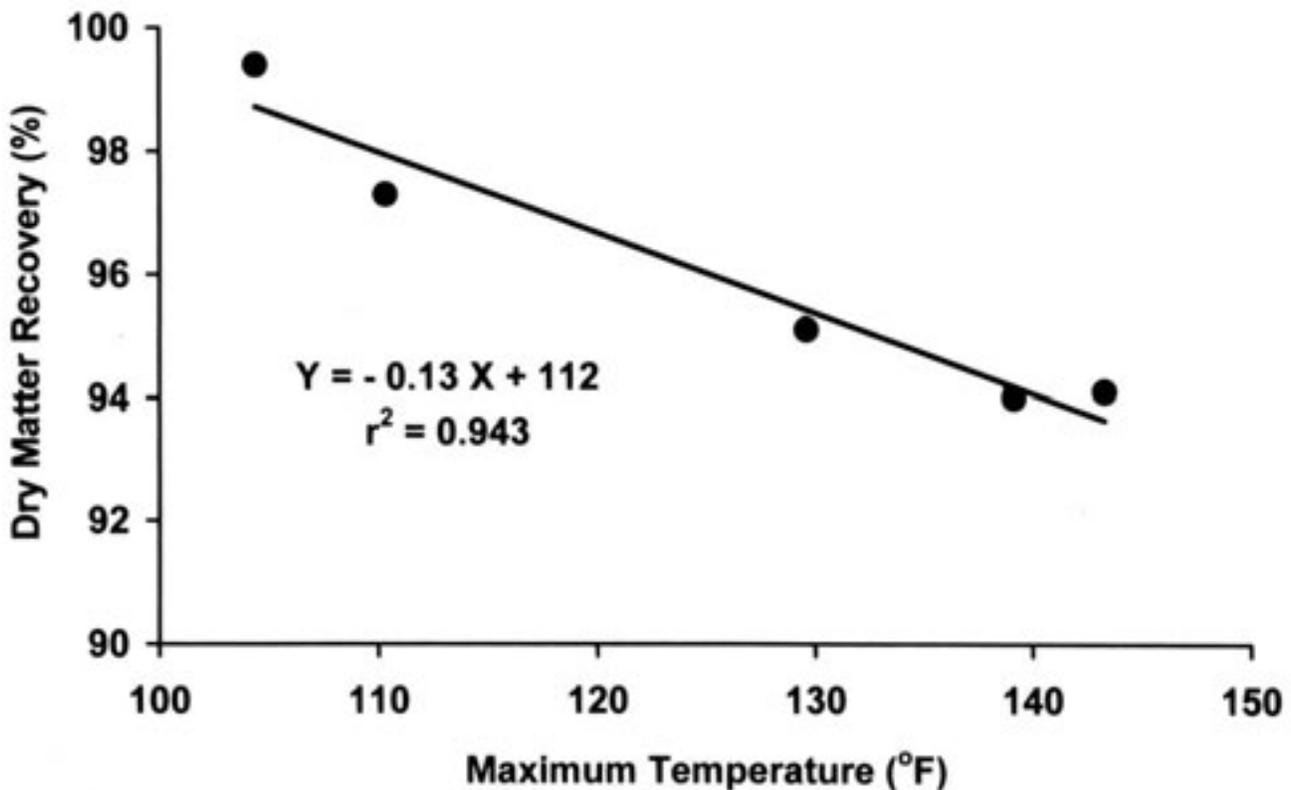


Figure 8. Relationship between the concentration of NDF and storage time for alfalfa hay packaged in conventional rectangular bales at 30 (—) and 20 (---) percent moisture in Manhattan, KS. Source: W. K. Coblenz.

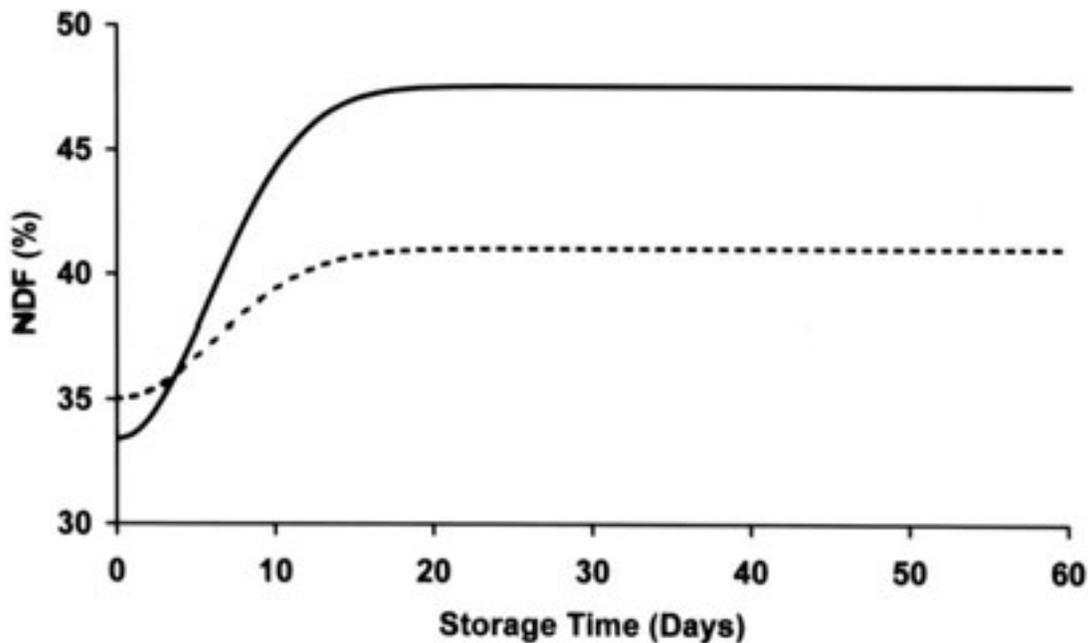
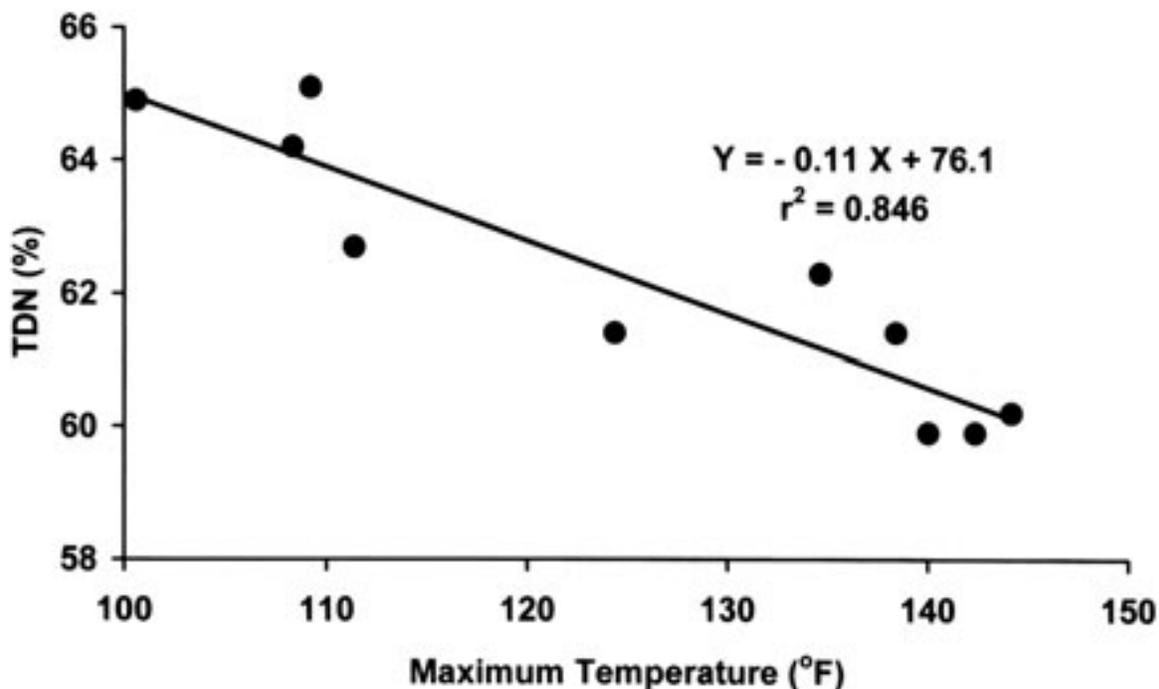


Figure 9. Relationship between energy content (TDN) and the maximum internal bale temperature for conventional rectangular bales of bermudagrass hay (●) made at Fayetteville, AR, in 1998. Source: W. K. Coblenz.



Total digestible nutrients (TDN). The concentration of TDN (or energy) in a forage is often predicted from equations on the basis of concentrations of fiber (ADF and/or NDF). As the concentrations of NDF and ADF increase, TDN usually declines. Any process (such as spontaneous heating or rain damage) that affects the concentrations of fiber components in a forage will often

have a noticeable effect on the TDN content. In Arkansas, the TDN content of warm-season grasses is predicted from an equation that utilizes the concentrations of NDF, ADF and CP. Figure 9 illustrates the relationship between estimated TDN and the maximum internal bale temperature during storage for bermuda hay baled in conventional packages. The TDN content declined by

1.1 percentage units for every increase of 10°F in the maximum internal bale temperature.

Digestibility. Most measures of forage nutritive value are affected negatively by spontaneous heating. Digestibility is no exception. As nonstructural carbohydrates and other highly digestible compounds within the forage plant are lost to respiration, concentrations of less-digestible plant components (particularly fiber components) increase noticeably. This often decreases the digestibility of the forage. For bermudagrass hay made in Fayetteville in 1998 (Figure 10), the effects of heating on forage digestibility appeared to be minimal when the internal bale temperature did not exceed 120°F. However, as the internal bale temperature increased above 120°F, forage digestibility decreased dramatically. In this study, forage digestibility dropped by about 14 percentage units when the maximum internal bale temperature exceeded 140°F.

Crude Protein. Concentrations of CP are not stable during bale storage. Generally, the observed changes in concentrations of CP are somewhat dependent on time since baling. In the short term (< 60 days), CP content may actually increase in a similar manner to that described for fiber components; however, CP can also be used as a fuel for microbial respiration, particularly after supplies of plant sugars are exhausted. Table 7 shows the effects of spontaneous heating on the CP concentration of

bermudagrass hay bales sampled after 60 days in storage. Although spontaneous heating has positive short-term effects on concentrations of CP, this should not be viewed as a justification for baling hay before it is dry.

The long-term effect of spontaneous heating during bale storage is to decrease CP content. Concentrations of CP are often reduced by 0.25 percentage units per

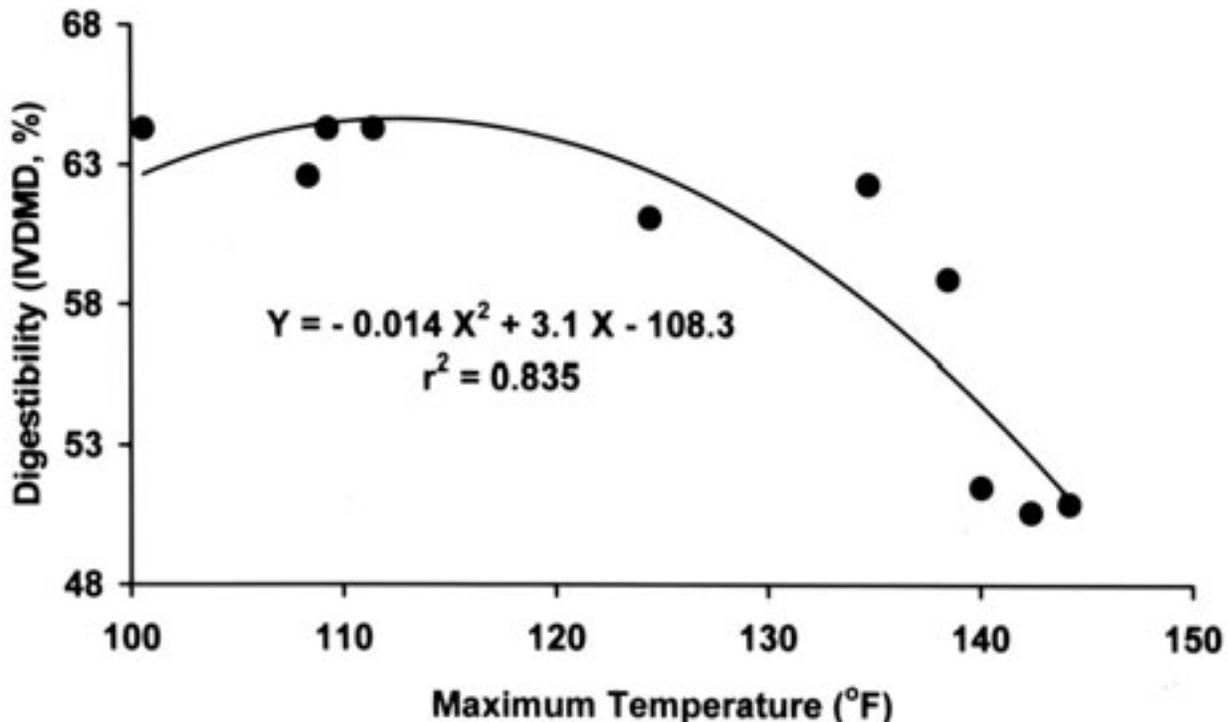
Table 7. Concentrations of crude protein (CP) for bermudagrass hay bales made from the same field and sampled after 60 days of storage at Fayetteville, AR, during 1998.¹

Initial Moisture Content	HDD ²	Maximum Temperature	CP
%		°F	%
31.3	1,055	144	15.3
33.6	1,057	142	15.7
27.7	1,100	140	15.0
29.8	990	138	15.0
26.6	925	135	15.8
22.9	763	124	14.2
21.1	621	111	14.0
20.5	542	109	15.4
16.9	445	101	14.2
18.7	484	108	14.5

¹ Source: W. K. Coblenz

² HDD = heating degree days > 86°F.

Figure 10. Relationship between digestibility and the maximum internal bale temperature for conventional rectangular bales of bermudagrass hay (●) made at Fayetteville, AR, in 1998. Source: W. K. Coblenz.



month of long-term storage due to volatilization of ammonia and other nitrogenous compounds; however, this loss is unlikely to continue indefinitely. Therefore, the concentrations of CP can increase in response to spontaneous heating during short-term storage (< 2 months) but decrease thereafter. The same forage sampled at different points in time can have noticeably different concentrations of CP that are not associated with laboratory errors.

Heat-damaged protein. Heat can damage forage proteins. Unlike fiber components, concentrations of heat damaged protein increase by direct mechanisms during bale storage. This causes forage protein to become indigestible when consumed by ruminants. Moisture content, the magnitude and duration of spontaneous heating and forage type all affect the amount of heat damage that may occur to forage proteins. Moisture plays a critical role in this process in two ways. First, it has a catalytic effect. This is the reason proteins in silages are more susceptible to heat damage than proteins in forages conserved as hay. Secondly, the moisture within the hay at baling stimulates spontaneous heating, which subsequently increases the probability of heat damage.

A positive linear relationship between heat damaged protein and spontaneous heating exists for both alfalfa and bermudagrass hay. All forages have some indigestible protein that is inherently unavailable to livestock. This fraction is small in most standing forages or unheated hays. Concentrations of indigestible protein in unheated alfalfa can range between 3 and 6 percent of all the protein in the forage. Typically, the indigestible protein in unheated warm-season grasses represents a higher percentage of the total forage protein. It can be higher than 20 percent in dormant forages. The concentrations of heat damaged protein increase at a rate of about 0.4 percentage units per 100 HDD in alfalfa hay, which is about half the rate observed for bermudagrass hay (0.8 percentage units per 100 HDD). Grass hays are typically more susceptible to this type of damage than alfalfa or other legumes. Ruminant nutritionists usually consider alfalfa hay to be seriously heat damaged when concentrations of heat damaged protein exceed 10 percent of all forage protein.

Other management factors, such as large round balers or higher-density hay packages, will increase the possibility of spontaneous heating and the probability of heat damage to forage protein. Even though concentrations of heat damaged protein increase by mechanisms different than those for NDF and ADF, most increases in concentrations of heat damaged protein still occur early in the storage period (< 20 days).

Ruminal protein digestibility. Considerable research effort has been devoted to assessing the ruminal digestibility of forage protein. This is the proportion of forage protein that is broken down or digested in the rumen. Forage protein that escapes the rumen intact is often referred to as “bypass protein.” Much of this research effort has been centered around efforts to improve dairy production. High-quality forages, such as alfalfa, frequently have high concentrations of CP, but this protein is rapidly degraded in the rumen and inefficiently utilized by dairy cows and other livestock. Spontaneous heating limits both the rate and amount of forage protein digested in the rumen. While this may provide some benefit with respect to nitrogen retention and utilization, it should not be viewed as a justification for intentionally allowing forages to heat in the bale.

Digestion of protein in the rumen is naturally less rapid for warm-season grasses, such as bermudagrass. This natural resistance to ruminal digestion is associated with the differences in plant anatomy between warm- and cool-season plants. Unlike alfalfa and other legumes, it is not necessarily desirable to slow the rate of ruminal digestion of protein in warm-season forages. However, spontaneous heating will have the same effect on warm-season hays that it does on alfalfa.

Weathering Effects

Introduction. Spontaneous heating is not the only factor that can affect the nutritional value of stored hay. Over the last two decades, large round bales generally have replaced small rectangular bales as the preferred type of hay package largely because of the reduced requirement for labor. Many of these round bales are stored outside without any protection against the weather. The weathering of the outside layer can have a major impact on the nutritional characteristics and DM recovery of hay. It also may result in greater refusal and reduced intake by livestock.

Weathering is partially a physical process caused by the leaching of soluble forage nutrients during rainfall. Since most soluble compounds in forages are highly digestible, it is desirable to limit these losses during storage. A second type of weathering is the result of microbial activity that increases under moist, warm conditions. Infrequent heavy rains are likely to have less impact on weathering hay bales than smaller, more frequent, rainfall events. Losses are generally reduced in arid climates and in northern climates with severe winters because the environmental conditions are less favorable for microbial activity. Within any specific environment, DM losses are nearly proportional to storage time.

Crop factors. Some crops are naturally more resistant to weathering. Generally, fine-stemmed, leafy, weed-free crops, such as bermudagrass or tall fescue, form an excellent thatch that sheds water. Other crops with large, coarse stems do a poorer job of shedding water. Good examples of these types of forages include sudangrass, pearl millet, sorghum-sudangrass hybrids and johnsongrass. Water can easily penetrate bales made from these forages and accelerate the weathering process. Hays with coarse-stemmed weeds also do a poor job of shedding water and weather quicker than weed-free hays.

Bale size and density. Dense, uniform hay packages will limit weathering losses compared to loosely baled hay packages. Bales that have 10 pounds of hay per cubic foot in the outer layer will help to reduce penetration by rain. The density of the inner core is less important than the outer layer. Bale density can be increased by raking hay swaths into smaller windrows and reducing the ground speed of the baling tractor. These practices will result in more layers per bale and a greater overall bale density. Unfortunately, this also will increase leaf shatter in legume hays. While baling dense hay packages will help to limit weathering effects, it also will increase the likelihood of spontaneous heating. Therefore, every effort should be made to reduce the forage moisture content to 18 percent or less before baling. It should also be noted that larger hay packages have lower percentages of weathered forage than smaller hay packages; however, larger and more expensive tractors are often required to handle larger hay packages.

Limiting hay/soil contact. It is easy to overlook the importance of the bottom of the bale when discussing weathering losses. Some reports suggest that approximately 50 percent of the storage losses in hays stored outside occur at the hay/soil interface. This occurs because the dry hay acts as a wick, drawing moisture from the soil. Depending on the site, air movement may not be as great around the hay/soil interface as it is around the top of the bale. These factors combine to

produce a moist environment at the bottom of the bale that is more favorable to microbial activity.

There are many ways to limit contact between hay and soil. Wooden pallets, railroad ties, pipe, tires and telephone poles can all be used to support hay bales and prevent contact with the soil. Ideally, any base should allow some air movement under the bales to facilitate drying. Crushed rock can be used as a base to limit contact with the soil. Crushed rock that is 1 to 3 inches in diameter and piled 4 to 8 inches deep should not trap water but should channel it away from the bales. Crushed rock also has the added advantage of lasting many seasons and repair of the storage site is simple. If bales must be placed directly on the ground, select a well-drained site with a sandy soil type.

Any site selected for the storage of hay bales should be in a sunny, breezy, well-drained area, possibly near the top of a slope. Bales should be oriented in rows that run up and down the sloping area, preferably with a southern exposure. Rows of bales oriented perpendicular to a sloping surface will trap moisture following rainfall. Rows of bales should be positioned with the flat ends of each bale butted together. The rounded sides of adjacent rows should not touch each other. There should be about 3 feet between adjacent rows to insure good air circulation and penetration of sunlight. Bales should not be stored under trees or ever rest in standing water. It is best to select a site that has no objects that will attract lightening, and the posting of no smoking signs may remind others that a hay crop represents a serious investment of time and money. It is also a good idea to have multiple storage sites. This will reduce the risk of a fire destroying an entire hay supply at one time.

Effects of storage method on losses of DM. Several studies have attempted to quantify storage losses of DM in large round bales. Table 8 summarizes a recent study with tall fescue conducted at the University of Kentucky. Four combinations of wrapping and storage methods were evaluated. These included 1) bales wrapped with

Table 8. Depth and volume of weathered layer and DM losses from tall fescue round bales stored inside and outside with different binding materials.¹

Treatment	Dept of Weathered Layer	Weathered Layer as Percentage of Bale Volume	Actual DM Loss	DM Loss With All Weathered Layer Considered Lost ²
	inches	-----%		
Plastic mesh wrap/ground	2.1	13.6	10.6	23.3
Solid plastic wrap/ground	0.6	3.9	3.6	7.8
Sisal twine/ground	4.4	26.8	18.2	34.1
Sisal twine/inside	0	0	5.7	5.7

¹ Collins, et al., 1995; *Journal of Production Agriculture* 8:507-513.

² Entire weathered layer considered to be unrecovered DM.

two layers of plastic mesh and stored outside, 2) bales wrapped with two layers of solid, 1.5-mil, self-adhesive wrap and stored outside, 3) bales tied with sisal twine spaced at 4-inch intervals and stored outside and 4) bales tied in the same manner as #3 but stored inside. Bales stored outside were positioned in a north-south orientation with 3 feet between adjacent bales. The storage site had a 5 to 7 percent slope. Bales stored inside were placed in a well ventilated structure that provided protection from the weather. All bales were stored for one year before sampling and analysis.

Twine-tied bales stored inside and solid plastic-wrapped bales lost relatively small amounts of DM (< 6 percent). This amount of DM loss is comparable to that observed in several other studies for round bales stored inside. Plastic mesh-wrapped and twine-tied bales stored outside lost considerably more (> 10 percent) of the total DM; however, the twine-tied treatment appeared to be the least desirable (18.2 percent DM loss). It is important to note that a relatively shallow (4.4 inches) weathered layer accounted for 26.8 percent of the total bale volume for twine-tied bales stored outside. Bales in the Kentucky trial measured 4 by 4.5 feet. Generally, the weathered layer in smaller bales will account for a larger

portion of the total bale volume than a weathered layer of comparable depth in larger bales. However, even relatively shallow weathered layers can account for very large portions of the total bale volume. This suggests that producers are losing far more DM and nutritive value than they may realize.

Effects of storage method on nutritive value. In the University of Kentucky study, storage treatment had a large effect on the nutritive value of the exterior weathered layer after the one-year storage period (Figures 11 and 12). Concentrations of CP (Figure 11) were approximately two percentage units higher in the exterior weathered layer of bales wrapped with plastic mesh or sisal twine and stored on the ground than in the unweathered interior of the same bales. For bales wrapped in solid plastic and stored on the ground, concentrations of CP were a little more than half a percentage unit higher in the exterior weathered layer than in the unweathered interior of the same bales. There was essentially no difference between the weathered exterior and the unweathered interior for tall fescue hay bales stored inside. Elevated concentrations of CP in the weathered layer also can be observed in alfalfa hay (Table 9). These observations indicate that CP is more stable during the

Table 9. Forage quality of the interior and exterior portions of alfalfa round bales stored outside.¹

Portion of Bale	CP	ADF	Digestibility
	----- % of DM -----		
Unweathered	18.9	38.6	61.4
Weathered	19.4	45.8	46.9

¹ Anderson, et al., *Transactions of the American Society of Agricultural Engineers* 24:841-842 (1981).

Figure 11. Concentrations of crude protein (CP) in weathered and unweathered layers of tall fescue hay packaged in large round bales in Kentucky. Source: Collins, et al., 1995; *Journal of Production Agriculture* 8:507-513.

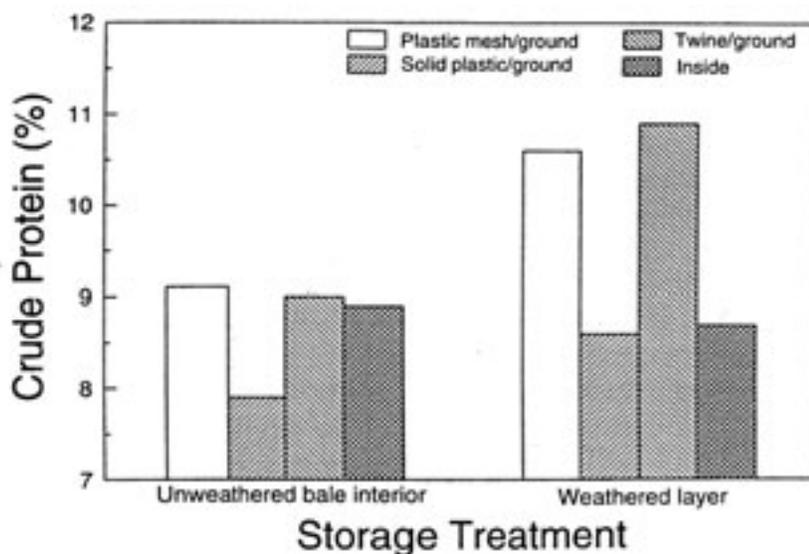
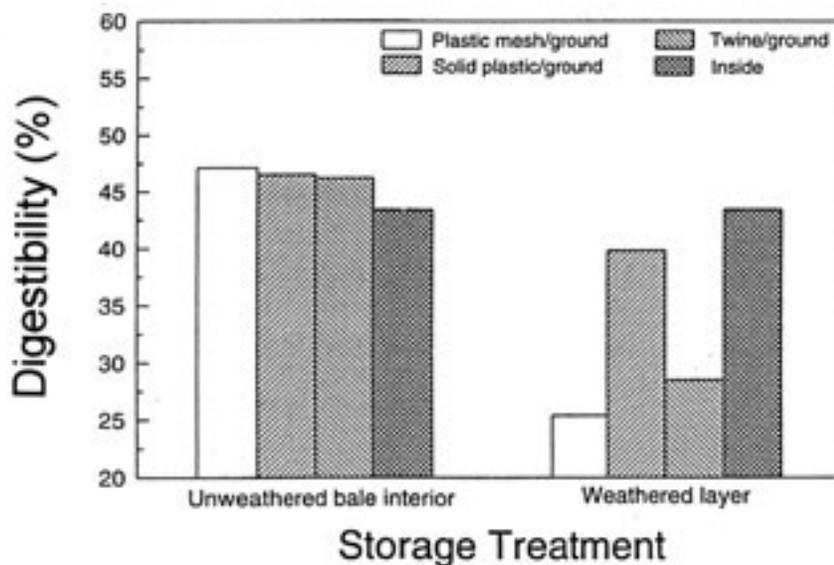


Figure 12. Digestibility of weathered and unweathered layers of tall fescue hay packaged in large round bales in Kentucky. Source: Collins, et al., 1995; *Journal of Production Agriculture* 8:507-513.



weathering process than other plant components (especially sugars), and that CP increases over time in the weathered layer because less stable plant components that are usually highly digestible are lost by leaching, oxidation or other processes.

Generally, the effects of weathering can be expected to increase the concentrations of fiber components (NDF, ADF, cellulose, hemicellulose and lignin) and reduce digestibility. The effects of weathering on the digestibility of tall fescue hay in the University of Kentucky study were quite substantial (Figure 12). The digestibility of the weathered layer for bales tied with plastic mesh or sisal twine and stored outside on the ground was reduced by about 22 and 18 percentage units, respectively, relative to the digestibility of the unweathered interior core of these same bales. For bales wrapped in solid plastic and stored outside on the ground, the digestibility of the weathered layer was reduced by about 6 percentage units relative to the unweathered core. There was essentially no change for bales stored inside. In a separate study, the digestibility of the weathered exterior layer for large round bales of alfalfa was 14.5 percentage units lower than the unweathered interior core (Table 9).

These findings indicate that the nutritive value of the weathered exterior layer of hays stored outside can be substantially poorer than the unweathered interior core of the bale. The effects of weathering on the bale as a whole will depend on the magnitude of changes in nutritive value between the unweathered and weathered portions, and the depth of the weathered layer. Simple management techniques should be used to limit weathering in hays stored outside. In general, it is much

easier to justify expenditures, such as storage barns or sheds, to protect baled hays when the initial quality of the forage is high.

Cautions for Fertilization

Depletion of soil-test potassium. Some cautions are advised with respect to fertilization strategies for hay production. Although hay production is commonly driven by nitrogen fertilization from commercial sources or animal waste, it is important to remember that other nutrients are removed from the soil in addition to nitrogen. Placing fields with high levels of soil-test phosphorus in continuous hay or silage production is the most commonly suggested method for reducing soil-test phosphorus. This hay or silage should then be fed on other sites that are low in soil-test phosphorus. While this method is effective in reducing the available phosphorus loads in the soil, it will also reduce levels of potassium. This is of critical importance and must be addressed with potassium from commercial sources. Bermudagrass has a critical need for potassium. It is particularly important with respect to winter hardiness. Bermudagrass stands that are managed with continual fertilization with nitrogen but without any attention to potassium levels in the soil are prime candidates for winterkill and other problems.

These problems can surface rapidly. Table 10 illustrates this point. Bermudagrass from a high soil-test phosphorus site was fertilized with varying rates (0, 50, 100, 150, 200, 250, 300 lbs N/acre) of ammonium nitrate (34-0-0) and clipped on three dates during 2000. No other fertilizer was applied. The last waste

Table 10. Levels of soil test potassium on three dates in response to nitrogen fertilization and hay production (three harvests) on a high soil-test phosphorus site (571 lbs/acre) with a recent history of animal waste application. Source: W. K. Coblenz, J. L. Gunsaulis and M. B. Daniels.

N Fertilization Rate	Yield	Soil Test K (May 2000)	Soil Test K (November 2000)	Soil Test K (May 2001)
lbs N/acre	lbs/acre	----- lbs K/acre -----		
0	9,692	511	370	325
50	10,310	506	375	306
100	11,198	442	367	293
150	11,684	480	343	318
200	12,467	524	350	316
250	12,564	495	347	301
300	12,532	514	372	291

application on this site was in 1999. In May 2000, soil tests indicated that potassium levels were considerably in excess of soil test recommendations, which is not unusual for sites with long histories of animal waste application. However, after one year of production (May 2001), levels of soil test potassium had fallen well below recommended levels, and supplemental fertilization was required. This was true at all levels of nitrogen fertilization. This response is much more rapid than is normally observed in attempts to “mine” phosphorus from these sites. Soils should be tested regularly to maintain acceptable levels of potassium in bermudagrass hay fields.

Nitrates. Certain forage crops (sorghum-sudangrass hybrids, sudangrasses, johnsongrass and others) are known to accumulate nitrates, particularly under stressful growing conditions. These crops should be fertilized conservatively with nitrogen fertilizer sources. Split applications are probably preferably to a single, larger application, but this will not insure acceptable nitrate levels in the forage. If possible, forages should be tested before mowing, grazing or feeding, especially if the climate conditions are stressful for plant growth. Consult with your county extension agent about submitting samples.

Nitrate poisoning can affect several species of livestock, including cattle, sheep and goats. It usually occurs after prolonged periods of cloudy, overcast days, and drought. Application of 2,4-D, plant diseases and soil nutrient imbalances may also cause these plants to accumulate nitrates. Nitrate toxicity typically occurs in cattle on a low plane of nutrition (low quality forages, not enough energy). Hungry, stressed cattle will usually consume more hay and become exposed to high levels of nitrates over a short period of time.

Nitrate itself is not especially toxic to cattle. It is normally converted to ammonia in the rumen and then

incorporated by bacteria into microbial protein. Nitrate poisoning is caused by the accumulation of nitrite, an intermediate compound in this process. Nitrite absorbed in the blood affects oxygen-carrying capacity and can result in asphyxiation. There may be no clinical signs other than sudden death. If exposure is observed early enough, one may observe rapid breathing, restlessness, weakness, difficult breathing or convulsions. Treatment at this point is often unrewarding.

If samples are high in nitrates, the hay can often be fed safely, but it should be done with caution. Dilute the high nitrate hay with other hay that is low or free of nitrates. It is also important to make sure the cattle are gradually exposed to high nitrate hay. Maintaining a lower pH in the rumen will help to limit the accumulation of the nitrite intermediates. Feeding concentrate supplements with hays known to be high in nitrates will lower rumen pH and help to prevent the buildup of nitrites. Finally, water sources should be considered when managing high nitrate hays. Ponds, shallow wells and streams that collect drainage may accumulate high levels of nitrates. The effects of nitrate levels in forages, other feeds and water are additive; therefore, offering cattle water from deep wells or verifying that other water sources are low in nitrates may limit the risk of nitrate poisoning.

If nitrates are known or suspected to be high before the forage has been mowed, a couple of options are available that will subsequently reduce nitrate levels in the conserved forage. Most nitrates accumulate in the lower part of the stem; therefore, elevating the cutting height of the mower will reduce nitrate levels. Typically, nitrate levels are not reduced during the wilting or haymaking processes, but fermentation into silage will often cut nitrate levels by 50 percent. Producers who possess the equipment necessary to make silage can use this technique as an effective management tool when nitrate levels in the forage are known to be high.

Other Toxic Substances in Hay

When most people think of hay quality, they normally are considering its nutritional value for livestock. Another important, and sometimes overlooked, consideration is the presence of undesirable substances in hay which will affect livestock performance and, in a worst-case scenario, may result in death. In this section, these undesirable substances, the conditions under which they are produced and their effects on livestock are discussed.

Molds. The majority of mold contamination occurs in the field before harvest. A certain amount may occur secondarily during less than optimal storage conditions. The presence of molds may not always be obvious, and the signs observed in livestock may look similar to those observed for many other problems. Whether mold growth occurs early or late in the growing season depends on climate conditions. Typically mold production will be enhanced if there is stress during the early growing season, or when there are hot days followed by cool nights (promoting heavy condensation). Good observational skills and forage sampling techniques will reduce the risk of these health problems.

Most molds are harmless to livestock; however, their presence in feedstuffs causes decreased palatability and digestive problems. The molds that are of primary concern are those that produce toxic products known as mycotoxins. These mycotoxins can affect many of the animal's body systems. They interfere with many of the digestive enzymes and result in impaired growth and muscle formation. In addition, they can have detrimental effects on reproductive hormones, thereby resulting in impaired fertility, abnormal libido and decreased milk production. Mycotoxins can have adverse effects on the cells in the blood stream and can result in anemia and increased susceptibility to disease. Finally, they can affect the respiratory and nervous systems. These potential effects on multiple bodily functions make it difficult to pinpoint what might be wrong with the animal. This can have serious economic consequences.

There are several circumstances that would indicate there might be a mycotoxin problem. Frequently, only a few animals are affected rather than the entire herd. Outbreaks also may appear to be seasonal and often are associated with a particular climatic sequence. In addition, the treatment of affected animals with drugs and antibiotics often seems to be ineffective. There also may be evidence of fungal activity when the hay is examined. The level of mycotoxins can be quite uneven throughout the forage sample; therefore, it is important to take several samples from the same bale.

Fescue toxicity. The association of the fungus *Neotyphodium coenophialum* with tall fescue has a positive effect on plant persistence, but the negative effects of the toxins produced by this fungus can have a detrimental effect on livestock performance. Some estimates report losses of up to one billion dollars per year. The amount of fungal infection can vary widely from one pasture or hay field to another.

Fescue toxicity in cattle manifests itself in one of three ways: fescue foot, poor performance (summer slump) and fat necrosis. In mares, reproductive problems include prolonged gestation, abortions, birthing difficulty, thickened placentas, lack of milk production, large and weak foals and high foal mortality.

Fescue foot usually occurs in the late fall or winter but can occur at any time of the year. The animal will often lose weight and become lame on the hind limbs, and there may be gangrene of the feet, tail and tips of ears. Early signs may include a tendency to shift weight from one hind foot to the other and a slight arching of the back. Animals will eventually become unthrifty and reluctant to move.

In cattle, poor performance is the most common of the three effects. This is where most of the economic losses occur. The effects on cattle include weight loss, decreased milk production, reproductive problems, rough hair coat, diarrhea, elevated body temperature, increased respiration rate and excess salivation. Cattle with summer slump spend less time grazing and more time in the shade or in farm ponds.

Fat necrosis is characterized by accumulation of hard necrotic fat in the abdominal or pelvic cavity. There usually are no notable clinical signs. Fat necrosis has usually been associated with long-term ingestion of endophyte-infected fescue that has been heavily fertilized with nitrogen or poultry litter. One might observe digestive disturbances such as chronic bloating, decreased rumen function, reduced feed intake, weight loss and decreased amounts of feces. Some animals may become emaciated and die, others may just become poor performers. Large masses of fat in the pelvic cavity may also cause calving problems.

Animals with suspected fescue toxicosis can be removed from the infected pasture or switched to non-infected hays. Many animals exhibiting poor performance will gradually return to normal when an alternative forage is supplied. Providing other types of hay or pasture and a grain supplement can reduce the effects of the toxins produced within endophyte-infected forages. Generally, diluting the infected fescue in the diet is an

effective management technique. Brahman and Brahman-cross cattle normally exhibit better tolerance of the combined effects of the toxins produced by the endophytic fungus and heat stress than other breed types. Endophyte-infected forages cut for hay will have lower levels of toxins if they are harvested early in the spring. Normally, the levels of toxins in these forages are reduced substantially during the wilting process prior to baling. After the initial curing process, concentrations of toxins in stored hay are relatively stable and decrease at very slow rate over time. Ensiling these forages is usually not as effective in reducing the concentrations of toxins produced by the endophyte.

Blister beetles. Alfalfa and other clovers may attract blister beetles. They may be found throughout the United States but are most frequently observed in the midwestern United States. The beetles tend to swarm when the hay or nearby weeds are in bloom. Mower-conditioners that cut and crimp the hay with conditioning rollers will trap dead beetles within the windrow or swath.

These beetles produce cantharadin, which is a potent toxin that causes severe irritation and necrosis of any mucus membranes that it comes in contact with. The beetles retain their toxicity in dry hay. All classes of animals that eat forages may be affected; however, most cases have been reported in horses. Animals may become severely dehydrated and will usually die from kidney failure and shock. The intestines and urinary tract are severely damaged. Animals with blister beetle poisoning should have the hay removed from the diet. The hay should be destroyed because the toxicity does not lessen with time. If it is not too far advanced, animals can be treated for kidney failure and shock. The outcome, however, is usually not successful.

The risk of blister beetle toxicosis can be reduced by certain management techniques. Normally, the first harvest of alfalfa each year is relatively safe. Blister beetles are attracted to flowering legumes; therefore, harvesting at bud stage or at first flower will reduce risks relative to waiting until full bloom. Some pesticides that are routinely applied to control alfalfa weevil and potato leafhopper have labeled effectiveness against blister beetle. Consult the label for detailed information. It would be helpful if alfalfa and clover hays could be dried without conditioning rollers that kill beetles and gather them in the windrow, but these crops have notoriously slow drying rates and this approach is not really practical. Ultimately, it is very difficult to guarantee the absence of blister beetles in alfalfa hay. Buyers are well advised to view such claims with skepticism.

Submitting samples for toxin analysis. The care used in collecting the sample of hay for laboratory analysis has a direct effect on the accuracy of the

analysis. Many times this may not be possible, since all of the hay has already been fed. At least one quart of forage should be submitted, cut to a length of 3 inches or less. It is best to sample several areas of the bale that do not appear to have visual defects, as well as those that have visual defects (i.e., mold). Consult with your county Extension agent about where to submit these samples and how to package them for mailing to the laboratory. Make sure everything is labeled properly. The cost of the analysis may vary depending on what tests are run on the sample.

Summary

- 1) Whether purchased or home-grown, it is always best to test hay for nutritive value and balance livestock rations on this basis.
- 2) Color is not a good predictor of forage nutritive value. Place emphasis on maturity, condition and purity when making visual appraisals.
- 3) Visual appraisals should not be relied on for developing a livestock feeding program. Hay should be tested to determine actual forage nutritive value.
- 4) Harvest forage crops at the correct maturity. No factor affects forage nutritive value more than the maturity of the crop at harvest.
- 5) Use appropriate haymaking techniques. Hay should be baled at 18 and 20 percent moisture for large round and conventional rectangular bale packages, respectively.
- 6) Generally, the unrelated processes of rain damage to wilting forages, spontaneous heating and weathering will all reduce DM recovery, sugar content, digestibility and the energy value (TDN) of the forage. Conversely, the concentrations of the most stable components of the plant are increased by these processes, resulting in elevated concentrations of NDF, ADF and lignin.
- 7) The availability of forage proteins to livestock can be reduced by spontaneous heating during bale storage.
- 8) Use good management techniques when storing large round bales outside. Specifically, try to maximize drainage away from the storage area, maintain air movement around the bales, and limit bale/soil contact.
- 9) Do not be deceived by what appears to be relatively shallow weathered layers in hays stored outside. Weathered layers of 4 to 6 inches can account for 20 to 30 percent of the bale volume and may cause producers to greatly underestimate their losses.

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Printed by University of Arkansas Cooperative Extension Service Printing Services.

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MP434-PD-8-07RV