In some areas of the country, producers store a substantial portion of their forage for winter feeding as silage or haylage. However, hay remains the most popular storage method for forage. Hay stores well for long periods and is better suited to cash sale and transportation than silage. Mechanical conditioning, which gained acceptance during the 1950's is probably still the greatest single change in hay harvesting and storage technology during this century. However, a number of other noteworthy changes and innovations have occurred in recent years which have helped to reduce the extent of losses during hay harvesting and storage.

Developments in hay harvesting technology in recent years include chemical desiccants such as potassium carbonate, chemical and biological additives at the time of baling, and swath and windrow management equipment such as tedders and windrow inverters.

The general relationship between forage moisture concentration at harvest and losses during the field and storage phases is shown in Figure 1. Harvest losses are greatest for very dry forage and are low for very wet material like

![Figure 1. Relationship between forage moisture concentration and field and storage losses.](image-url)
direct cut silage. However, the latter is subject to excessive storage losses due to seepage and to quality deterioration. Storage losses are generally minimized by harvesting at low moisture levels.

High moisture hay, baled between 20 and about 30% moisture has lower harvesting losses than dry hay but can suffer high storage losses and quality loss if not adequately preserved or dried. Many options are available in haying equipment and in new products marketed for use in hay curing and preservation is such that making informed choices can be very difficult. Research information is not available on all of these new products, however, representatives of most of the categories have been studied.

Under high humidity, relatively cool conditions, hay does not dry as rapidly as under low humidity high temperature conditions. A good corollary is found in the way in which tobacco leaves become moist and pliable under high humidity conditions. Likewise, under high humidity conditions hay may not by able to reach the 20% moisture level recommended for baling dry hay regardless of the time spent in the field. **Figure 2** shows equilibrium moisture concentrations measured for alfalfa hay over a range of humidity conditions at a temperature of 77°F. At a relative humidity of 80%, this graph indicates that alfalfa would not dry below 25 to 27% moisture. It is because of this problem and in order to reduce the likelihood of rain damage that alfalfa hay is sometimes baled at moisture levels above 20%. Our data comparing alfalfa hay storage in round and rectangular bales indicates that for storage without heat damage, alfalfa in round bales should be slightly drier (18% moisture) than similar alfalfa in rectangular bales.

![Equilibrium moisture concentrations of alfalfa hay at different temperatures and humidity levels (Adapted from Hill et al., 1977).](image)
Baling hay at elevated moisture levels can reduce losses by reducing leaf loss and by helping to avoid rain damage. However, when hay is baled above 20% moisture steps should be taken to prevent the microbial growth that is responsible for heat damage and dustiness.

**Respiration and Microbial Growth**

Respiration and microbial growth, and some elevation in temperature during hay storage are normal and do not necessarily harm feeding value. Hay with more than 20% moisture may undergo excessive mold growth and heating that reduces both yield and digestibility compared with dry hay. Populations of fungi in stored hay peak after about 1 week of storage and this corresponds to the peak temperatures reached in the stack.

**Health Effects**

Mold spores contribute to colic in horses and are responsible for significant losses for this economically important industry. Breathing spores of the fungus *Aspergillus fumigatus* during the handling of moldy hay can cause farmer's lung, a sometimes debilitating disease in which the fungus grows in lung tissue. Hay with a significant amount of mold and mold spores can be utilized in cattle rations because these livestock are less sensitive.

**Heat Damage**

Heat damage may occur in moist hay as a result of plant and microbial respiration and chemical reactions. The moisture range in which the maximum amount of heating occurs is in the 20-40% moisture range for hay. This is close to the range in moisture for dry haylage at which excessive heating is observed. Dry hay does not heat excessively because it lacks the necessary moisture to support microbial growth. Plant enzymatic activity and microbial growth can elevate temperatures to 160°F within a few days. When the temperature goes above this level, it becomes too hot for continued microbial growth and further heating results from chemical reactions. These reactions are responsible for raising the temperature to levels at which spontaneous combustion may occur.

Heating during hay storage reduces forage quality. The extent of the heat damage is related to the color change during storage is related to the amount of heat damage in composition during heating of hay or silage are detrimental to forage quality. When hay heats sufficiently to cause a very dark brown to black color, its protein may be nearly indigestible.

**Moisture Loss During Storage**

The evaporation of water dissipates the heat generated in moist hay. The thermal conductivity of dry hay is actually less than that of moist hay. Thus, as
hay moisture declines due to heating, the transfer of heat to the outside air becomes less effective. Hay temperature may not rise sharply until most of the moisture has been evaporated. This heat generation in a mass of hay is caused by the growth of microbes that require oxygen. Because of the distance, the centers of large hay stacks tend to be low in oxygen supply and spontaneous combustion occurs outside this zone.

The data in Figure 3 indicate the importance of proper preservation of moist alfalfa hay in order to maintain quality. As moisture concentration increased in alfalfa baled in large round bales without any preservative or drying treatment, the digestibility of the hay after storage decreased sharply. All of this hay was very similar in digestibility at the time of baling. This decrease in digestibility is directly related to the heating that occurs when hay is baled at elevated moisture levels. Microorganisms are responsible for this heating and the resulting increase in heat-damaged protein and molding can be very detrimental to quality. Thermophilic bacteria, the actinomycetes, grow well at high temperatures and contribute to the attainment of very high temperatures that result in hay fires in some instances. The hay temperature information below shows temperatures at which fire danger becomes important. Temperatures well below that level can still reduce quality significantly. This moist hay can be preserved by the addition of organic acids at the time of baling. Propionic acid has been widely tested as a hay preservative and has proven effective.

Figure 3. Relationship between moisture level at baling of alfalfa hay and hay digestibility after storage (From Collins et al, 1987).
to be very effective when it is well distributed and applied at the proper rates. The most common rate recommendations for applying organic preservatives to hay are shown below. These rates are calculated on an active ingredient basis. In products containing some water, this must be considered in determining the product application rate. The rate applied must be increased for wetter hay because of the importance of maintaining the level of preservative in the water contained in the hay.

### Hay Additives

Additives are sometimes used to aid in the preservation of hay above 20% by preventing microbial growth during storage. Materials shown to be effective in the preservation of moist hay include sodium diacetate, propionic acid, ammonium propionate, urea, anhydrous ammonia and others. In addition to control of microbial growth, some materials, such as ammonia and urea, may also enhance forage quality by increasing crude protein concentration and increasing fiber digestibility.

The amount of propionic acid that needs to be applied to ensure acceptable control of microbial growth is greater for hay that is higher in moisture. Apparently, the critical factor is to maintain the necessary concentration of propionic acid in the water contained in the hay. Thus, hay with more moisture requires more organic acid for preservation. Hay heating and molding can be controlled by the application of rates as low as 6 lb/ton for 25% moisture hay under controlled conditions but under field conditions about twice that rate is needed to ensure preservation.

Ammonium propionate is a buffered propionic acid material that is less volatile than propionic acid and is also less corrosive. The low pH of acid preservatives is involved in their effectiveness but it is not the only factor since ammonium propionate is effective even though it is less acidic. Formic acid, sodium diacetate, propionic acid and ammonium propionate were tested and all were found to be effective in the inhibition of fungi and actinomycetes when each organism was grown separately in culture.

### Moisture Variation Within The Field

Research has shown that it is important to achieve good distribution of the material in the bale. Buffered products have the benefits of being less volatile than acid products, however with that advantage comes the problem that these materials do not move around to equalize within the bale. Some very volatile...
products like ammonia move so well that the anhydrous ammonia can simply be released within a stack of hay and will diffuse throughout the mass with a short time. Even the acid forms of organic acids do not move that readily but the buffered forms remain where they are placed during the application process.

Wet spots that have more moisture than the application rate is adequate for can still result in moldy areas within an otherwise well preserved bale. In a field study using alfalfa from a small field (5 acres), moisture at the time of baling varied widely depending upon the density of the swath at a particular location. Variation above and below that average will mean that some hay will receive more material than needed and other hay will receive less. Moisture levels ranged from 58 to 80% and averaged 69%. A propionic acid application rate of 19 lb/ton would be sufficient to obtain a rate of 3% of the average water content. However many of the bales were above 69% moisture and would require more material. It would be necessary to apply 28 lb/ton to insure adequate preservation of 99% of the bales from this field. These results point up the importance of wide swaths and tedding to help improve the uniformity of the moisture concentration.

Measuring Moisture In Hay

It is critical that we have dependable information on the moisture concentration in the hay in order to be sure of adequate storage if it is dry hay or that the preservative rate is adequate if preservatives are being used. A typical home microwave oven is an excellent method for determining hay moisture. Later in this article, a microwave method that can be used for either hay or silage is described.

Electronic probe testers are also available for field use in moisture determination. Of the units tested, the "Delmhorst" moisture unit did the best job of predicting actual oven moisture determinations. Based on the variation we found between measurements on the same bale, it would be necessary to take 12 readings to estimate moisture concentration within +2%. Also, although the correlation with actual oven moistures was very good, the probe reading was not identical to the actual moisture concentration. At about 17% moisture, the two would give identical readings but above that moisture level, probe readings underestimated the actual moisture concentration. A rule-of-thumb system for estimation of hay moisture when a tester is unavailable is shown below.

The same unit discussed above has been modified to automatically probe the bale inside the bale chamber between plunger strokes. These readings can be averaged and accessed continuously to allow moisture monitoring. We have the possibility of using moisture measurements of the bale either inside the bale chamber or just after tying to adjust preservative application rate continuously. If this could be accomplished it would insure adequate rates of preservative for every bale whether they needed more or less than the average.
In the absence of testing equipment, hay moisture can be estimated using changes in texture visual characteristics during drying. The table below illustrates how this system works.

<table>
<thead>
<tr>
<th>Moisture Range</th>
<th>Hay Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-40%</td>
<td>Leaves begin to rustle and do not give up moisture unless rubbed hard. Juice easily extruded from stems using thumbnail or knife or with difficulty by twisting.</td>
</tr>
<tr>
<td>25-30%</td>
<td>Hay rustles-a bundle twisted in the hands will snap with difficulty, but should extrude no surface moisture. Thick stems extrude moisture if scraped with thumbnail.</td>
</tr>
<tr>
<td>20-25%</td>
<td>Hay rustles readily-a bundle will snap easily if twisted - leaves may shatter-a few juicy stems may remain</td>
</tr>
<tr>
<td>15-20%</td>
<td>Swath-made hay fractures easily-snaps easily when twisted-juice difficult to extrude</td>
</tr>
</tbody>
</table>


**SILAGE**

Preservation as silage rather than hay reduces total harvesting losses by reducing physical losses, which impact primarily the leaf component. At high moisture levels the leaves are not brittle and losses during raking are low. As moisture declines, the leaf component dries faster than the stem and can be susceptible to shatter even when average crop moisture is well above a safe level for baling hay. Our previous research showed that shattered leaf collected from alfalfa baled at moistures between 20 and 30% in mid-afternoon was extremely dry, near 10% moisture.

**Silage Fermentation**

Silage preservation depends upon the development and maintenance of anaerobic conditions. The ensiling process has predictable phases which are will understood. Aerobic respiration by plant enzymes and by microbes on the crop continues after the forage is ensiled. Plant enzymes oxidize carbohydrates and produce carbon dioxide, water, and heat. Plant proteases can cause proteolysis and form peptides, free amino acids, and amides. Respiration is inhibited as anaerobic conditions develop. Some of the management practices recommended for conventional silage production, such as fine chopping, rapid silo filling, adequate compaction, and tight sealing are recommended in order to minimize this aerobic phase. With respect to rapid exclusion of oxygen and tight
sealing, these same factors hold for the production of silage in round bales.

By greatly shortening the field exposure time required for curing, silage offers the opportunity to greatly reduce losses in alfalfa yield and quality during harvest. Compared with outside-stored round bales of hay, silage also reduces yield and quality loss during the storage process.

Good silage preservation depends upon the development and maintenance of anaerobic conditions. The ensiling process has predictable phases that have been described. For example, the respiration that is normal in the cut crop during curing continues after the forage is ensiled. Plant enzymes oxidize carbohydrates and produce carbon dioxide, water, and heat. Plant proteases can cause proteolysis and form peptides, free amino acids, and amides. Respiration is inhibited as anaerobic conditions develop. Some of the management practices recommended for conventional silage production, such as fine chopping, rapid silo filling, adequate compaction, and tight sealing are recommended in order to minimize this aerobic phase. With respect to rapid exclusion of oxygen and tight sealing, these same factors hold for the production of silage in round bales.

Once oxygen levels are reduced by aerobic organisms and plant enzymes, the second phase of the ensiling process involves the production of acids that reduce silage pH and which account for the preservation of the silage. Lactic acid bacteria should become the predominant bacteria, and lactic acid is often the predominant acid, although acetic and propionic acids may predominate in legume silages. Lactic acid bacteria are of two types, homofermentative that convert carbohydrates to lactic acid; and heterofermentative, which also produce acetic acid, ethanol, and mannitol in addition to lactic acid.

Fermentation can reduce silage pH to values as low as 3.5, however, wilted silages such as those that would ordinarily be used in baled silage may only reach pH's in the range of 4.8 to 5.2. Such silages are not as stable as more acidic silage but usually have lower fermentation losses. The extent of the pH decline depends somewhat on the amount of fermentable carbohydrates present. Fermentation is limited in haylage because of its low moisture levels and preservation depends on the maintenance of anaerobic conditions during the entire storage period.

Sugars and other readily fermentable carbohydrates are present in high concentrations in some silage crops, such as corn, making their preservation relatively simple. Perennial forages, especially legumes, however, may not have sufficient concentrations of fermentable carbohydrates to lead to final silage pH levels low enough to preserve the material as effectively as corn silage. Legumes such as alfalfa also have greater buffering capacities, meaning that more acidity is needed to reduce silage pH by a given amount. Even with these limitations, our research has shown that alfalfa can be preserved very effectively as round bale silage. However, grass silages are generally easier to preserve
than legume silages because grasses have a lower buffering capacity and sugar concentrations of 10 to 20%. Because of these differences, legume stands with a grass component would be most suitable for silage production.

**Baled Silage**

Most Kentucky producers do not have the choppers, wagons and silos necessary to move to a chopped-silage system. The round bale silage system offers an opportunity to gain the forage quality and yield retention of silage at a lower initial cost compared with a chopped silage system. All of the major forage crops grown in Kentucky can be harvested effectively as balage. In general, harvesting forage crops in the transition stage between vegetative (leafy, immature) and reproductive or flowering stage will produce the best compromise between yield and quality. Round baled silage has several advantages compared with hay or chopped silage but there are also concerns or disadvantages to consider.

**Producing Baled Silage**

Silage bales are frequently about twice the weight of similar-sized bales of dry hay. With variable chamber balers, bale diameter can be reduced to 42 to 48 inches if necessary to reduce bale weight. Bales should be formed as tightly as practical. Slower ground speeds during baling increases bale density. A dry-matter density of 10-12 lb per cubic foot is considered ideal. A typical silage bale (4 feet in diameter by 5 feet in length) should weigh 1300 to 1550 pounds and contain 600 to 650 pounds of dry matter. Bales can be handled using bale spikes prior to the wrapping process but avoid making holes in the plastic after wrapping because this will allow greater entry of air during the storage process.

**Wrappers**

Three main types of wrappers are available for use in producing round bale silage. Some are also capable of wrapping mid-sized or large rectangular bales as well as round bales. Wrappers vary widely in cost depending on the basic design and on options, such as the bale-loading arm, selected. Labor availability and the number of bales to be wrapped are major factors in selecting the best wrapper for a given operation. Based on UK research and experience of producers, it appears that the three-point hitch wrapper is suitable for smaller operations, wrapping 100 to 200 bales per season; the individual wrappers are suitable for producers wrapping 200 to 400 bales per season and the in-line wrappers are ideal for producers wrapping larger numbers of bales.

**Individual Bale Wrappers:**

*Platform Wrappers.* The most common type of wrapper is the individual bale wrapper that use a single roll of UV-treated stretch film. These wrappers vary widely in cost from about $5,000 to $12,000 or more depending on features.
The recommended method for wrapping using these units is to overlap the plastic one-half of the previous layer. With this system two complete layers of plastic are applied with each complete revolution of the bale. We recommend 4 layers for the individual wrap machines unless the bales are very dry or intended for long-term storage, where 6 layers are preferred.

**Swinging-Arm Wrappers.** With this type of wrapper, the bale rests on powered rollers that turn it as an arm, with the film roll attached, swings around the bale. Hydraulic cylinders open the rollers to pick the bale up from the ground. Some have rollers underneath the frame to help support the weight of heavy bales.

**Row Bale Wrappers**

**In-Line Wrappers.** These wrappers consist of a large hoop on which two or three rolls of plastic film move around the bale as it is pushed through. Since no plastic is applied to the ends of the bales except for the beginning and end of the line, these types of machines use much less plastic than the individual wrap design. Because of this, we have recommended that 6 layers of film be applied during in-line wrapping. These wrappers generally cost slightly more than the upper-end of the individual wrap units.

**Three-Point Hitch Bale Wrapper.** With this unit, individual bales are wrapped from a single roll of film moved back and forth by the operator as the bale is turned. Film should overlap the end of the bale several inches to ensure that film contact is made with adjacent bales in the row. The continuous row is formed by jamming individually wrapped baled end-to-end. The first and last bales in the row should be wrapped completely by hand or a plastic barrier inserted and dry hay bales applied in order to avoid deterioration during storage.
MICROWAVE MOISTURE TEST

Step 1 - Weigh a paper plate to hold the sample during drying. Alternatively, “tare” or “zero” the scale with the empty plate to remove this weight from the calculation. A paper sack will also work for holding the forage sample during drying.

Step 2 - Mix your sample and weigh exactly 100 grams onto the paper plate.

Step 3 - Place the plate and sample into an oven, ideally one with a turntable to help avoid hot-spots in the sample, and set it at full power for 3 to 5 minutes. Check and mix the sample before repeating the drying process for an additional time of 1 to 2 minutes depending on how dry it was after the initial drying period. Repeat as needed to dry the sample without charring. Reduce the time to 30 seconds toward the end of the process.

Step 4 - Drying is complete when no weight loss occurs after a 30 second drying period in the microwave.

Note: Older ovens needed a glass of water inside during drying to avoid damage to the oven magnetron but newer ovens do not.

Calculations:
CASE I (With a weighed paper plate or bag is used to hold the sample)
(Dry sample weight) Dry plate plus sample weight minus the empty plate weight
(Wet sample weight) Weight of plate plus 100-gram fresh sample

CASE 2 (With a tared paper plate or bag is used to hold the sample)
(Dry sample weight) Sample weight after drying is completed
(Wet sample weight) Sample fresh weight, normally 100.0 grams

\[
\text{MOISTURE \%} = \frac{(\text{Wet weight} - \text{Dry weight})}{\text{Wet weight}} \times 100
\]

Forage moisture greatly affects storage behavior of hay and silage. Accurate moisture information is important because excessively wet forage is prone to heating during storage with resulting loss in forage quality and in rare cases spontaneous combustion fires can occur. On the other hand, overly dry hay suffers excessive physical losses during raking and baling which are
especially detrimental to quality of forage legumes. Recent developments in silage production using the round bale silage system increase the need for measuring forage moistures between 35 and 75% moisture.

Two tests are described below, the twist test and the microwave test. The “twist test” gives a quick, but less accurate estimate of forage moisture concentration. The microwave test uses a postal scale readable to one-tenth gram along with any typical microwave oven the dry a small sample of forage completely before reweighing for quick calculation of the moisture concentration. Of the two methods, the microwave test takes more time but is also more accurate than the twist test.

**TWIST TEST FOR MOISTURE IN SILAGE**

>70% Moisture: Some moistening or moisture appears at the breaking point when a handful of forage is twisted multiple times. This forage is too wet for silage production. This forage will break when twisted hard.

50-60% Moisture: Surface moisture almost completely absent but some leaves are flaccid and some t juice can be expressed from stems or leaves if pressed hard using the thumbnail.

40-50% Moisture: Surface moisture is absent and some leaves are becoming brittle. Some juice may be expressed using the thumbnail. Stem may break near the cut end.

30-40% Moisture: Leaves begin to rustle and juice is difficult to express using the thumbnail. Stem breaks up 2 to 3 inches from the cut end.

**Other Considerations**

Recommended moisture levels for baled silage are generally between 45 and 65%, covering the range between wilted silage and haylage. The ideal moisture appears to be 50-60% because there is considerable fermentation in that range and less heat damage and mold are observed compared with low-moisture silage. As an alternative to rain damage on windrows, baling and wrapping at lower moisture levels around 30% may salvage the crop, however, our observations indicate that significant mold can occur on alfalfa bales wrapped below 40% moisture.

Damage to plastic during handling or storage can introduce oxygen into the bale and allow spoilage. Any holes made during bale transport and placement into storage should be repaired immediately by taping. Holes allow oxygen to enter and lead to the same problems that occur if bagging is delayed too long. To minimize storage losses due to spoilage, we suggest in Kentucky that bagged silage bales be fed during the winter following their production and
that baled hay be carried over if excess feed is available. The storage period for bagged or wrapped silage is also reduced by baling the fall cut of alfalfa or other forages that comes during October or November in this area when hay curing conditions are generally very poor.

**Cost**

With four layers of film and an individual wrap machine, plastic cost per bale is around $2.50. In line wrappers use much less plastic per bale even with 6 layers, probably no more than one-half the amount used by individual wrapping. The cost of the machine itself will vary depending on the unit itself and on the number of bales wrapped. Several counties have purchased wrappers that are made available to producers. As wrapping becomes more common, custom operators are also becoming available in some areas.

**Summary**

Baled silage offers a way for Kentucky farmers to conveniently and inexpensively produce silage with present hay making equipment (adapted to wet forage). Bale wrappers vary in cost from approximately $3,000 to over $18,000 depending on the level of automation and control desired. The benefits of making baled silage come from more timely harvest, lower dry matter losses during curing and storage, less chance for rain damage, and better retention of leaves in high quality forage crops like red clover and alfalfa. Disadvantages include handling heavy bales, maintaining plastic integrity, adapted baling equipment to handle wet forage, and plastic disposal.