

# STRATEGIES FOR PREVENTING HAY FIRES

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## INTRODUCTION

Historically, when hay was stacked loosely (without binding), it may have dried more extensively than modern stacks because of the time required for hand labor. When small bales became the most common method for harvesting hay from 1950-1975, the bales were hand-stacked, weighed 40 to 80 lbs per 2-string bale and the density was 8 to 11 lbs/ft<sup>3</sup>. As machine stacking became commonplace, larger and denser bales were desired, and they could weigh 80 to 120 lbs per 2-string bale. Three-string bales became more popular for transporting because they were more dense and stable than 2-string bales. During the same time, commercial dairies wanted premium hay with high leaf attachment. The 3x3, 3x4, and 4x4 (ft) large rectangular-ended bales with 8-ft length have densities of 14 to 16 lbs/ft<sup>3</sup>, which is nearly double the density of the old 2-string bales. In the last 25 years, there may be more hay fires than in the past because high moisture is retained longer in the more dense and massive types of bales.

**Keywords: bale density, hay production, moisture, heating, fire, spontaneous heating**

What is the annual cost of hay fires in the West? It is not as easy to determine as you may think. If you search the National Fire Incident Reporting System (NFIRS) database you will find that the categories do not directly report hay fires as they are included in crop fires. Some small rural fire districts do not report fires regularly and many hay fires are located in the rural fire districts. If we assume that agricultural crops that burned were not fruits and vegetables, then it is likely that the majority of fires were hay, silage, or grain crop fires. If the content loss was \$169,400, the amount of hay at \$200 per ton would be 847 tons in Idaho during 2012. I suspect that hay fires cause much more damage than what is reported. Adjacent hay that doesn't burn is often rejected by livestock but it is difficult to quantify the economic loss.

This publication has the following objectives:

1. Describe forage moisture properties
2. Describe the process of plant and microbial respiration
3. Review how to sample and estimate forage moisture in the windrow, bale, and stack
4. Suggest 11 steps to prevent hay fires
5. Reduce everyone's risk of hay fires

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## Types of Moisture

Free water, often called “dew moisture”, can be readily evaporated from the forage. Physically trapped water is contained inside plant cells. A fraction of the water is bound water that cannot be removed without destroying the forage. Free and physically trapped water can eventually be evaporated from the forage given sufficient solar radiation, relative humidity, and time. The term “stem moisture” is used to describe the moisture that remains in the plant stem after leaves have dried during the curing process. Windrowed hay, given ample time to field-dry, will eventually dissipate stem moisture to a level safe for baling. Dew moisture on the outer surface of the stem and leaf is the result of relative humidity and temperature forming condensation. Dew moisture is rapidly removed by sunlight or a light breeze and usually remains on the hay for only a few hours each day.

## The Process of Plant and Microbial Respiration

Heat is generated in hay bales when microbial growth uses carbohydrates as an energy source. Plant and microbial respiration convert carbohydrates and oxygen into carbon dioxide, water and heat. This results in a loss of weight (dry matter yield) and increased bale temperature. This rise in bale temperature can have a detrimental effect on forage quality by binding proteins to fiber and rendering these proteins and nonstructural carbohydrates unavailable to the animal. There is a strong correlation between bale size or density and heating.

Large square-ended bales are susceptible to greater storage losses and risk of spontaneous heating than small square-ended bales formed at the same moisture. This is primarily due to reduced surface area per unit of forage dry matter, or greater density in the bale. Large square balers have a pre-compression chamber and hydraulically loaded panels on three sides of the bale chamber which can produce a high-density bale. Shinnars et al. (1996) determined that 3x3x8 ft bale density was 54% greater than small bale density. Bale characteristics and recommended maximum moisture levels are given in Table 1.

**Table 1.** Physical characteristics and moisture percentages required for good storage of various bale types, sizes, and densities of alfalfa hay. These values are general averages for several models and manufacturers.

Characteristic	Small	3-string	Mid-size	Large	Round
End size (in)	14 x 18	15 x 22	32 x 32	48 x 48	72
Length (in)	38	44	96	96	60
Volume (ft <sup>3</sup> )	5.5	8.4	56	112	141
Weight (lb)	60	130	900	1800	1900
Density (lb/ft <sup>3</sup> )	8-11	15	14-16	14-16	10-13
Maximum moisture (%)	20	18	16	15	18

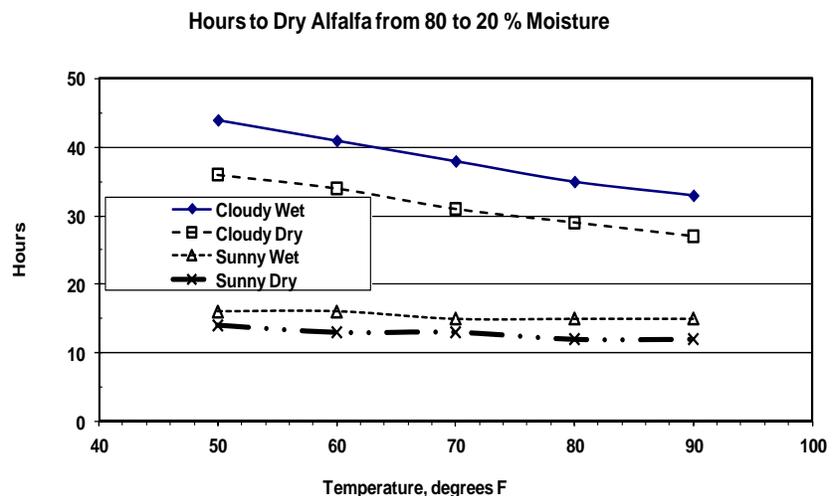
Shinners et al. (1996) found that 3x3 ft square-ended bales exhibited greater heating, had greater DM loss and had lower quality when removed from storage than small square bales at similar moistures (16 to 21%). Chemical preservatives can be used to reduce storage losses. Propionic acid, the most commonly used preservative, suppresses microbial growth and reduces heating from respiration. Typical application rates are 0.5 to 2% by weight. However, the preservative treatment works best within a short period of time because hay quality declines if stored too long. Rotz et al. (1991) found propionic acid treated hay at high moisture (22 to 26%) had greater dry matter and nutrient loss after six months in storage compared to a typical low moisture system (11 to 15%). Rotz et al. (1991) speculated that the hygroscopic nature of propionic acid caused acid treated hay to be consistently higher in moisture than untreated high moisture hay, even after six months in storage.

Whether there is economic justification to treating high moisture hay (20 to 28%) with propionic acid depends on the price of hay, the input costs, storage time, and the intended market. Another question to be answered is: what is the value of preventing a hay fire? There has been little research concerning large bale storage characteristics in the range of 15 to 22% moisture because of the costs of doing the research.

### Monitoring Moisture in the Windrow

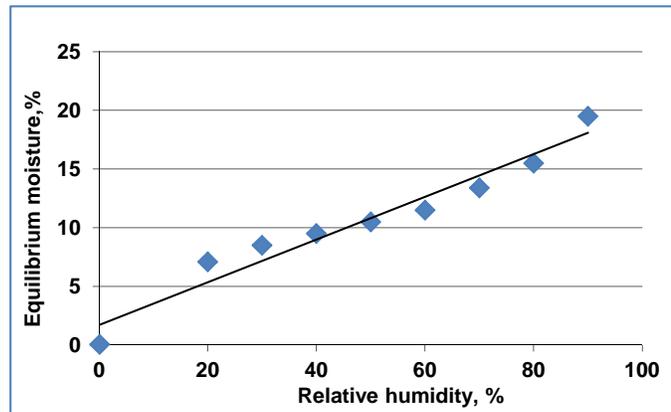
Weather and soil conditions affect drying rates of hay, so producers should monitor these conditions to help them make management decisions. The most important factors affecting hay curing are: 1) solar radiation, which provides the energy to evaporate water from the forage; 2) air temperature; 3) relative humidity; 4) wind speed; and 5) soil moisture. The moisture difference between the air and the forage is the driving force for water evaporation. For example, when the moisture content of fresh-cut forage is 75% and the moisture content of air is about 20%, the difference is large and so is the potential to dry the forage. Figure 1 demonstrates the hours to dry alfalfa from a fresh-cut sample to 20% moisture under four environmental conditions. A sunny day is most important to dry the hay.

**Figure 1.** Number of hours to dry alfalfa from a fresh-cut sample to 20% moisture under four environmental conditions: 1) cloudy and wet soil, 2) cloudy and dry soil, 3) sunny and wet soil, and 4) sunny and dry soil. Source: Rotz and Chen (1985).



Environmental conditions drive the equilibrium moisture content of hay in the windrow, and to a lesser extent the bale and stack. Relative humidity is a limiting factor for reduction of hay moisture (Figure 2).

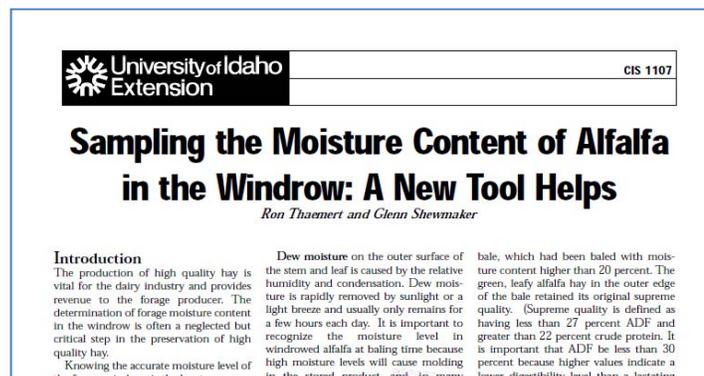
**Figure 2.** Equilibrium moisture content of hay as a function of percent relative humidity within an ambient air temperature range of 60-90°F (Adapted from: Stowell, D.E. 1988).



Thaemert and Shewmaker (2003) recommended alfalfa producers sample windrow moisture by using an electronic bale moisture probe and a windrow-sampling tool. The windrow-sampling tool is designed to simulate the compaction of hay in the bale, and allow samples to be oven dried to check probe accuracy.

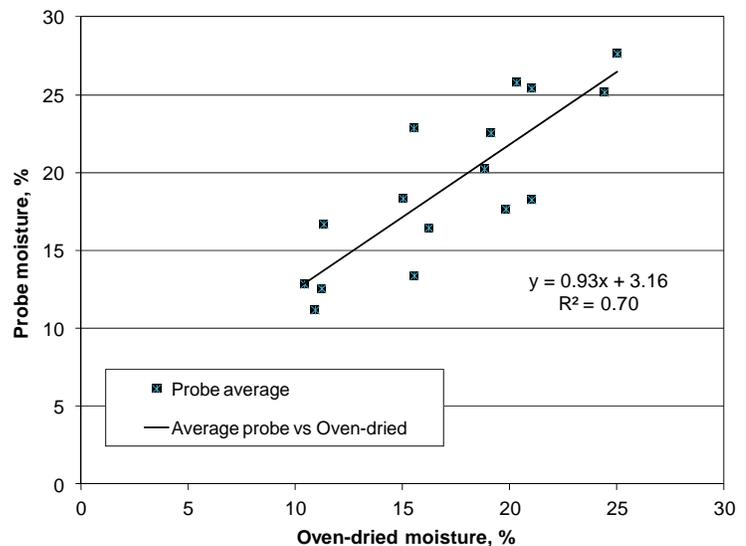
**Figure 3.** More information about use and construction of the windrow-sampling tool is available in “Sampling the Moisture Content of Alfalfa in the Windrow: A New Tool Helps.”

<http://www.cals.uidaho.edu/edComm/>



However, windrow moisture is variable and the electronic probe numbers have a natural error associated with their use. Figure 4 shows the relationship of probe estimates to oven-dried moisture.

**Figure 4.** The relationship of predicted windrow moisture concentration from the average of 4 measurements per probe to the actual oven-dried moisture concentration determined by mass (fresh moisture basis) (Thaemert and Shewmaker, 2003). Windrow moisture



concentration was determined by electronic moisture probe; each point is the average of readings taken at 4, 8, 16, and 20 inches into the Windrow Sampling Tool as compared to the oven-dried sample.

### **Moisture and Temperature Changes in a Bale or Stack**

Water is one of the end products of respiration, so the higher the moisture content of hay, the higher the microbial respiration and subsequent moisture production in hay after baling. At the upper end of the moisture content for safe baling, a typical amount of respiration in hay might add a couple of percentage units to the initial moisture content. This process is why farmers commonly report that hay “sweats” or feels wetter after they get it into the stack than it did when baled. Any water vaporized by the heating will be in airspace within the stack as it moves out, increasing humidity levels. Within a tight windrow or a bale with moisture above 20%, the relative humidity can be 90 to 100%, which favors mold growth.

With moisture levels considered to be "safe" for the specific forage and bale type, the bales will sweat and heat gradually from several degrees above ambient air temperature initially, to temperatures of about 140°F after 3 to 7 days of storage. This level of heating is typical and does not seem to impact forage quality significantly, as measured by acid detergent insoluble nitrogen (ADIN). Hay will then gradually cool back to ambient air temperature within 21 to 28 days after baling. Higher moisture hay may reach peak temperatures that are higher, which occurs somewhat later and results in an extended period of higher temperatures. Equilibrium moisture in alfalfa is around 15% for humid regions or seasons, and about 10 to 12 % in arid regions. The final moisture content of hay should not be over 12% to avoid mold.

### **Spontaneous Heating and Combustion**

Hay fires from spontaneous heating usually occur within six weeks of baling, but they may also occur in cured hay when external moisture is added, or more oxygen is allowed inside the stack. The moisture content of a bale shouldn't be higher than 18 to 22% for small rectangular bales, 14 to 18% for large round bales, or 14 to 16% for large rectangular bales. However, these are not absolute numbers because other factors affect spontaneous heating.

Higher moisture levels allow microbial activity to increase, which causes hay to heat and to mold resulting in loss of dry matter and usable protein. Temperature will peak from 3 to 7 days after baling. Temperature should decline in the period from 15 to 60 days to non-damaging levels, depending on relative humidity, the density of the bales, and the amount of rainfall the bales soak up. The longer it takes for temperature to decline, the more damage is done to hay, and more likely a fire may result.

Spontaneous heating is a continuous process with overlapping causes:

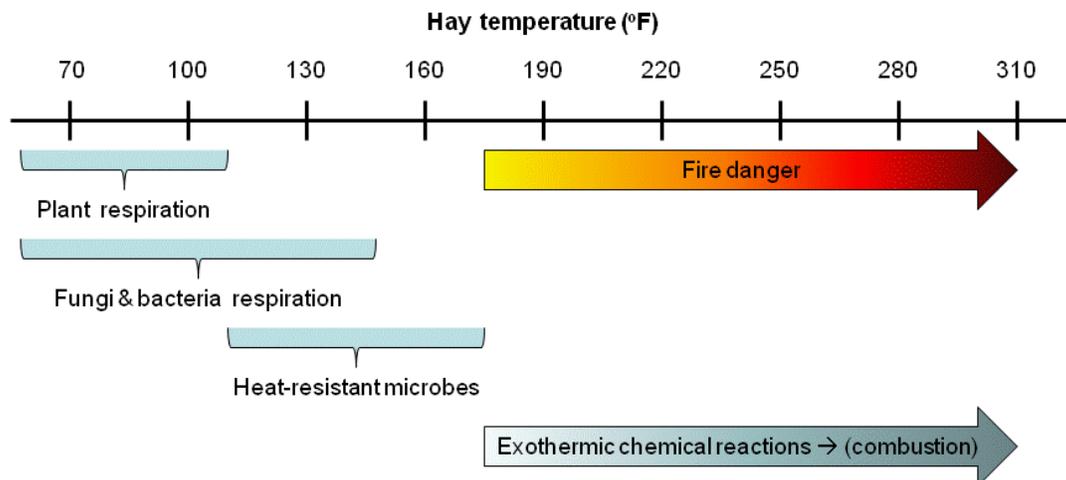
#### **1. Normal heating in baled hay**

- Sugars are respired to yield carbon dioxide, water, and heat.
  - Temperature may reach 100 degrees F or higher.
- 2. Secondary Storage Heating**
- Microorganisms continue to respire and heat accumulates faster than it dissipates from forage stored in a dense bale or stack.
  - Temperature may reach 160-170 degrees F.
- 3. Exothermic Heating**
- Oxygen combines with highly oxidizable material produced during secondary heating.
  - Process starts at about 130°F and may reach 190°F when the situation becomes critical.
  - Temperature will rise to the kindling point if enough oxygen and crop moisture are present to generate heat faster than it can escape.

### Monitoring Moisture and Temperature in Bales and Stacks

If the moisture level of hay at baling is greater than recommended for storage, check the moisture and temperature at least twice daily for abnormal heating. If the hay temperature reaches 130°F, you could be on the way to a hay fire, so close attention needs to occur. The best option is to arrange for someone to feed the bales as soon as possible. The bales could be placed to allow increased air circulation and cooling. If hay is stacked tightly or in a barn and temperature climbs to 150°F or greater, call the fire department and be prepared to inject water to cool any hot spots before moving the hay. Don't move the hay without fire suppression equipment if the hay is smoking, you can see charred centers within bales, or if you can smell a strong odor. If additional oxygen reaches areas near high-temperature hay, the hay can burst into flame.

**Figure 5.** The process, causative agents, and temperature ranges during spontaneous heating of forages. Adapted from Collins and Owens (2003).



If you don't have an electronic probe, or it doesn't extend past 12 inches, insert a 3/8 to 1/2 inch diameter metal rod into the bale center. After 10 minutes, extract the rod, and feel it with your hand. If you can hold it in your bare hand comfortably, the temperature is < 130°F. If you can hold the rod, but it's uncomfortable, the temperature is likely between 130 and 160°F. But if it's just too hot to hold, the temperature is > 160 °F, and a fire may be imminent.

Moisture levels and temperatures in bales and stacks may be more variable than you think. After baling a uniform field of alfalfa, the moisture concentration of 7 bales was monitored in the morning and afternoon of each day for 2 weeks (Figure 6). Notice the sweating of the bales from the 1<sup>st</sup> reading to the 4<sup>th</sup> reading taken 48 hours later. The stack of hay also was more variable than expected (Figure 7) with 11 readings from 12 to 15% and 31 readings over 23% moisture. The average (mean) of 21% has a standard deviation of +/- 6%, so 68% of the readings would be expected to be in the range of 15 to 27%.

### **Heat Damaged Hay**

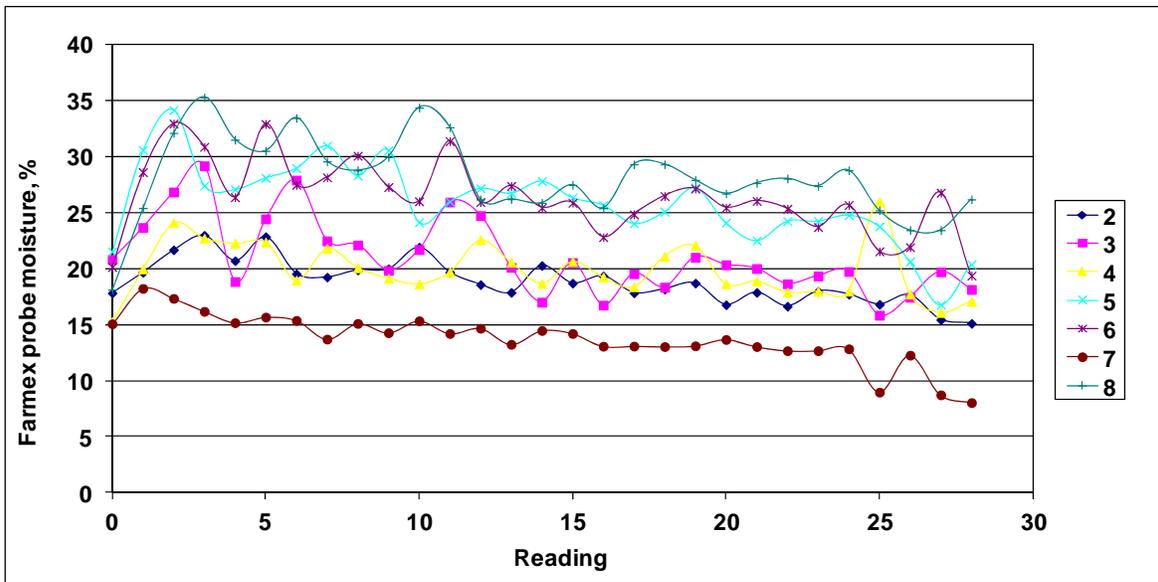
Heating of moist hay causes a chemical reaction that fuses plant sugar and amino acids into an indigestible product called the Maillard product. Protein bound up in this process is called heat-damaged protein and is unavailable for animals. When hay heats sufficiently to cause a very dark brown to black color, its protein may be nearly indigestible. The green colored bales in Figure 8 had 28% acid detergent fiber (ADF) compared to 46% ADF in the brown areas. Although this hay did not ignite, probably because it was treated with a preservative, the nutritional and market value of this hay was severely decreased.

### **Electronic Moisture Testers**

Most probe-type meters operate on the principle of electrical resistance. Moisture is an effective conductor of electricity and hay acts as an effective insulator. The "reading" is made between the two metal contacts at the tip of the probe. The wetter the hay, the more electricity flows through. However, other factors can affect electrical conductivity of the hay. Accuracy of moisture prediction depends on:

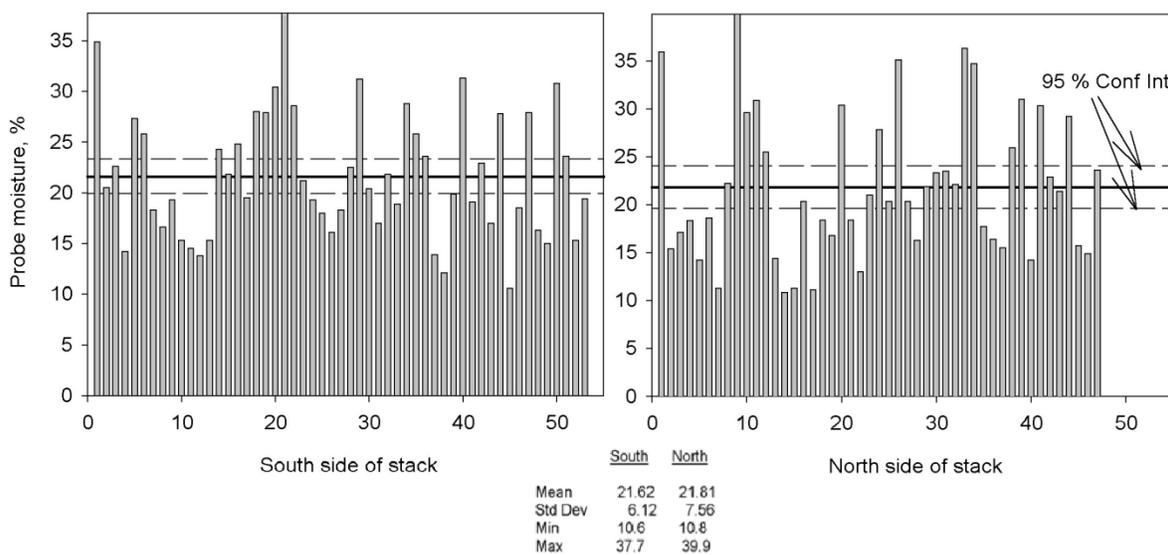
- Bale density
- Type of forage
- Stem moisture or dew moisture
- Whether acid preservative has been applied

**Figure 6.** Sequential moisture by electronic probe inserted in alfalfa bales (2 through 8) treated with preservative in morning and afternoon for 14 days after stacking near Declo, ID in August 2000. Source:



Thaemert and Shewmaker, unpublished.

**Figure 7.** The variability of moisture by electronic probe in a fairly uniform stack of hay near Declo, ID in August 2000. Source: Thaemert and Shewmaker, unpublished. Each bar represents a bale of hay.



**Figure 8.** Brown-black oxidized hay from high moisture hay and the resulting secondary heating. Photo by Glenn Shewmaker in August 2000.



Moisture testers should be used as a tool to supplement personal experience when checked with other methods. Don't let digital readings give you a false sense of security or accuracy. Some electronic probes list an operating range of 8 to 40% moisture. Read the specifications for your moisture meter and follow recommendations from the manufacturer. Instruments should be calibrated to the conditions and type of forage you are testing, and how a person operates the probe. The probe should be well maintained, have a well-charged battery, and clean contact points.

### **New Technology to Detect Moisture in Forage**

Portable near infrared reflectance (NIR) spectrometers are now available to predict real-time moisture in forage as it leaves a harvester. The NIR instruments predict moisture in the near surface of the forage. Microwave technology has been adapted to mount on bale chambers and these systems are calibrated to measure moisture throughout the bale. In addition, they can mark spots or strips of high moisture on the bale with paint so the stacker can readily identify high moisture bales and handle them with proper caution. Another company has installed electronic moisture probes on bale forks of the loader which alert the operator if the moisture is over a limit.

## Accuracy of Moisture Testing Methods

Some error is inherent in all methods of moisture measurement or estimation (Table 2). Some methods are more practical and less expensive than others.

**Table 2.** A comparison of moisture measuring method, operating principle, moisture range, sample size, testing time, and typical error expected.

<b>Method</b>	<b>Operating principle</b>	<b>Moisture range (%)</b>	<b>Sample size (grams)</b>	<b>Testing time</b>	<b>Typical error (%)</b>
Convection oven	Drying	0-100	10-1,000	5 hours – 3days	±1
Microwave oven	Drying	15-100	50-200	5-15 minutes	-2 to +1
Electronic probe	Electrical conductance	8-40%	Bale or windrow	1 minute	±5
Lab NIRS instrument	Electromagnetic properties	0-40	1-40	1 hour	±3
Portable NIRS instrument	Electromagnetic properties	0-40	near surface	Immediate	±4 *
Microwave detector	Electromagnetic properties	0-30	Through bale or windrow	Immediate	±0.5 *

\* estimate of error by manufacturers

## Steps to Reduce Hay Fires

Hay producers, brokers, and buyers need to avoid situations that increase the risk of hay fires and take necessary precautions. The following “Steps to Reduce Hay Fires” are some guidelines to minimize potential of heat-damaged hay and spontaneous heating:

1. Record day of cutting and drying conditions in a journal.
2. Monitor hay moisture prior to raking, tedding, and baling:
  - a. Use a tactile (feel) method to evaluate hay moisture.
  - b. If a single probe electronic meter is being used, use a windrow sampling tool (as described in Figure 3) appropriate to simulate the bale density that electronic moisture probes are designed to operate.
3. Record the day of raking, tedding, and inversion, as well as baling and drying conditions.
4. Test the first 3 bales from a field with a hand-held electronic moisture probe in 2 places on each side or ends of the bale (total 12 readings) and note the low, high, and average.

If the average moisture is below the maximum for the type of bale and forage, continue baling.

5. Observe the baler moisture meter if available, and/or the bale pressure indicator. When anything changes, get out and re-test more bales as in #4.
6. Record date, time, weather conditions, and moisture average and range in your journal.
7. Mark any bales with higher moisture than desired, and notify the person stacking the hay to place those bales separate from the dry bales with space between bales to facilitate air movement and drying. Try to feed these bales as soon as possible. Do not store any bales with moisture over the recommended level for that bale type in a large stack or hay shed!
8. Review and comply with your insurance carrier's requirements for fire insurance coverage.
9. If moisture is marginal, stack large bales in a single column with no more than 500 tons per stack. Under these circumstances, allow at least 100 feet of separation to the nearest adjacent stack. Lay out the stack so it can be quickly broken apart with a loader. Avoid mixing different lots of hay because of marketing and hay fire issues. If bale moisture is marginal, monitor the moisture and temperature in the stack at about 20 random or systematic locations.
10. Obtain a bale core sample, double sack the core sample in 2 zip-lock plastic bags, and submit it to a NFTA certified lab for moisture and forage quality analysis.
11. Protect the stored hay from external weather and water flow by elevating the base and having adequate rain gutters to direct flow of water away from the stack.

## **SUMMARY**

Moisture is not usually uniform throughout the field, windrow, bale, or stack. The electronic probe and portable NIR or microwave instruments have the advantage of testing many samples or locations quickly. A basic protocol should be followed, but in the end, each farmer should use his experience obtained from conserving hay in various weather conditions, monitor moisture with a tactile method, as well as a moisture tester to produce quality hay with the management and equipment available.

Everyone from the baler operator, stacker, trucker/broker, to the hay buyer needs to be aware of the dangers of high moisture, spontaneous heating, and hay fires. Everyone loses in a hay fire! Even if a producer is compensated for a loss of hay or buildings, the insurance company loses and must recover the costs in higher premiums. A hay pile which smolders for a week--even with fire fighters pouring water on the pile--is not a pleasant sight, smell, or environmental situation.

## REFERENCES

- National Fire Incident Reporting System (NFIRS) database.
- Collins, M. and V. Owens. 2002. Hay and silage preservation. P: 443-469 In R.F. Barnes, C.J. Nelson, M. Collins, and K. Moore (eds.), *Forages: The Science of Grassland Agriculture*, vol. 2. Ames, Iowa: Iowa State Univ. Press.
- Rotz, C.A., and Y. Chen. 1985. Alfalfa drying model for the field environment. *Transactions of the American Society of Agricultural Engineers*, 28, 1686–1691.
- Rotz, C. A., R. J. Davis, D. R. Buckmaster, and M. S. Allen. 1991. Preservation of alfalfa hay with propionic acid. *Applied Engineering in Agriculture* 7(1): 33-40.
- Shinners, K. J., R. J. Straub, R. L. Huhnke, and D. J. Undersander. 1996. Harvest and storage losses associated with mid-size rectangular bales. *Applied Engineering in Agriculture* 12(2):167-173.
- Stowell, D.E. 1988. On-the-go moisture testing in the bale chamber. Pg. 124-130 In Proc. California Alfalfa Symposium.
- Thaemert, R. and G.E. Shewmaker. 2003. Sampling the moisture content of alfalfa in the windrow: A new tool helps. CIS 1107, University of Idaho.  
<http://www.cals.uidaho.edu/edComm/pdf/CIS/CIS1178.pdf>