

## **How Straw Decomposes: Implications for Straw Bale Construction**

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### **1 Introduction**

Straw is a natural fiber that can last many thousands of years under certain conditions. Intact straw has been found in dry Egyptian tombs and buried in layers of frozen glacial ice. However, under typical conditions straw will slowly degrade as do all natural fiber materials like wood, paper, cotton fabric, etc. The rate at which this happens is highly dependent on the conditions under which the straw is stored, primarily moisture content and temperature. With proper attention to moisture control, a straw bale structure should be able to last as long as any conventional wood framed home.

Straw is the structural material that makes a plant stand up. This fiber structure is made up of cellulose strands bound in a matrix of hemicellulose and lignin. Some straws like rice have a significant amount (up to 20%) of inorganic compounds like silica ash that serve a structural or pest resistance role for the plant. After the plant is harvested and dries, the fiber structure remains intact unless it is decomposed by biological or chemical mechanisms. It is in the interest of all straw bale builders and homeowners to try to prevent such conditions.

Straw is a potential food source for microorganisms like fungi and bacteria. Under the right conditions this can be a primary way that the straw is decomposed in a process similar to composting. Although not necessarily the preferred meal, there are adequate amounts of energy and nutrients within the straw to provide for the growth and sustenance for these organisms. Spores of these microorganisms are baled with the straw as it is harvested from the field, and these are ready to produce and multiply given the right conditions. The four main conditions that affect the rate of growth of these microorganisms and, thus, the rate of straw decomposition are: nutrients contained in the straw, availability of oxygen in the straw, temperature of the straw, and free moisture on the straw. It follows from both logic and experience that bales that have been wetted (ie by rain) prior to placement in a building structure will have experienced some microbial growth, and thus have more spores available for future (ie in the wall) growth.

In terms of nutrients, straw is generally lower in nitrogen than what is considered optimum for compost mixes, which makes it slower to grow and sustain large populations of decomposing microbes. The optimum ratio for carbon to nitrogen in compost is 1:20 to 1:40 where straw has a ratio of 1:70 to 1:120. Generally hay and grass are higher in nitrogen than grain straws making them better food sources. Another general rule is that

the greener the straw, the more nitrogen level in it. Allowing a longer period of time for field drying can reduce the amount of nitrogen in the plant when it is baled. Other nutrients in straw are typically adequate for biological growth and are not limiting in the rate of microorganism growth.

The availability of oxygen is another key factor for active microbial growth. Just like animals do, most fungi and bacteria require oxygen to respire while utilizing the food and energy source contained in the straw. While a bale of straw is almost 90% air, the amount of oxygen within the bale will quickly be used up and replaced with carbon dioxide during active microorganism respiration. If the diffusion of new oxygen into the bale is inhibited, as it would be by wall plaster, this will limit the rate of decomposition. Although it has not been quantified, it is likely that the rate of decomposition in a completed straw bale wall will be lower than a bale that is open to the environment because of limits on the amount of available oxygen.

Temperature is an important parameter for microorganism growth. Below 32°F (0°C) these tiny life forms cannot exist because water is frozen. Many fungi and bacteria cannot survive at temperatures below 50°F (10°C) so growth is not very active at low temperatures. In the range of 68°F (20°C) to 150°F (65°C) the fungi and bacteria can thrive, each species having its own range and optimum temperature for growth. Above 150°F (65°C) most species cannot survive and biological growth ceases.

Moisture is the key ingredient that initiates decomposition in straw, and most people are familiar with the relationship between moisture and mold growth. One of the key questions for straw bale builders is “How much moisture is too much?”. This has been studied in detail by food researchers who have determined the relationships between water content and microorganism growth for prevention of spoilage in various types of foods. In general, foods with a water activity<sup>1</sup> less than 0.7 experience little microorganism growth. Molds generally do not initiate unless water activity is greater than 0.7, yeasts begin at 0.8, and bacteria generally require water activities greater than 0.9. Translated into straw terms, a water activity of 0.7 would correspond to a moisture content of 15%-18% dry basis (13%-15% wet basis)<sup>2</sup>.

To date, much of the knowledge on proper moisture content is based on “rules-of-thumb” from the haymaking industry or from straw bale builder’s experience. Some recent and

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<sup>1</sup> Water activity can be thought of as the relative humidity within the material (expressed as a fraction rather than a percentage). The air within the material is in equilibrium with the moisture content of the material. The concepts of equilibrium moisture and moisture transport are discussed in more detail in the EBNet report by John Straube.

<sup>2</sup> Dry basis moisture content is the weight of water over the weight of dry material. Wet basis moisture content is the weight of water over the weight of dry material+ water. The building industry typically uses dry basis moisture content but the food and agriculture industry often uses wet basis, and many moisture meters are wet basis. To convert: Wet Basis Moisture = (Dry Basis Moisture)/(1+Dry Basis Moisture) or Dry Basis Moisture = (Wet Basis Moisture)/(1-Wet Basis Moisture).

ongoing studies have looked more carefully at decomposition and moisture in straw and are discussed below. In general, it was observed that rice straw could have moisture content as high as 27% dry basis (21% wet basis) before initiation of significant microorganism growth and decomposition. In the studies, only straw with a moisture content above 40% moisture content on a dry basis (28% on a wet basis) supported significant growth. This corresponds to a water activity of 1.0, meaning the straw fiber is saturated and additional free moisture builds up on the straw surfaces. This suggests that straw should be able to withstand fairly high relative humidities without significant decomposition. Additionally, it appears that straw can tolerate higher moisture contents than 15% although, on a practical level, moisture can migrate and condense, and bulk moisture content is never uniform throughout a bale. Bulk moisture levels of greater than 25% dry basis (20% wet basis) should be avoided to give a margin of safety.

## 2 Moisture and Temperature Testing

The amount of nutrients and (except as discussed above) the availability of oxygen are not parameters that will change once a straw bale has been placed inside a wall. However, moisture content and temperature will fluctuate based on outdoor climate, indoor conditions or the accidental entry of liquid moisture. Of key interest to straw bale builders is what effect different moisture and temperature regimes will have on the degradation of straw contained within a wall. A study was initiated under the direction of Bryan Jenkins at University of California, Davis to investigate this in samples of rice straw<sup>3</sup> and more thorough tests are currently being performed on rice and wheat straw. [Wheat straw results expected in January 2004.]

In order to quantify rate of decomposition with a high degree of accuracy, samples of straw were placed in sealed containers and the rate of carbon dioxide evolution was monitored. As the carbon is broken down in the straw, oxygen is converted to carbon dioxide in the container. By monitoring the quantity of carbon dioxide produced from the straw, an accurate estimate of the rate of carbon loss in the straw sample can be measured. To put it in practical terms for straw bale builders, this rate of carbon loss can tell you the rate that organic matter is being degraded in the straw. Rapid rates of organic matter loss indicate significant degradation of straw and should be avoided. Other signs of decomposition are odorous compounds, locally elevated temperature, and discoloration that accompany the conversion of straw organic matter to carbon dioxide.

In the first experiment, rice straw was taken from the field, dried to less than 12% dry basis (10% wet basis) and stored for several months. It was remoistened to various different moisture contents between 12 to 150% dry basis (10-60% wet basis) and placed in the sealed containers. Containers were placed in environments of 50°F, 68°F and 95°F (10°C, 20°C, and 35°C) and carbon dioxide evolution was monitored for two weeks.

The basic results of the first study showed that rate of carbon dioxide evolution for each sample was fairly constant for the two weeks and generally increased with temperature and moisture

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<sup>3</sup> Summers, M.D. S.L. Blunk, B.M. Jenkins. 2002. Moisture and Thermal Conditions for Degradation of Rice Straw. ASAE Meeting Paper #026153. St. Joseph, Mich. ASAE [available on EBNet website.]

content. For all of the samples below a water activity of 1.0 or 39% dry basis moisture content (28% wet basis), the rates of organic matter decomposition were all below 0.009% per day (Figure 1) although more data is needed between dry basis moisture contents of 27% to 39% (21% to 28% wet basis). If the rate of 0.009% per day were to be maintained for an entire year, then 3% of the straw organic matter would be lost. In reality this rate would likely decrease to near zero with time as more highly degradable forms of organic matter are used up; a long-term experiment would be needed to verify this. It is likely that the structure of the straw would be maintained for many years (>50 years) in these conditions. This result suggests that humidity alone is not likely to initiate significant decomposition in a straw bale wall, although more data is needed at higher humidity levels. However, because high humidity can result in condensation within a strawbale wall, it is important to consider the possible effect of this condensed moisture on decomposition.

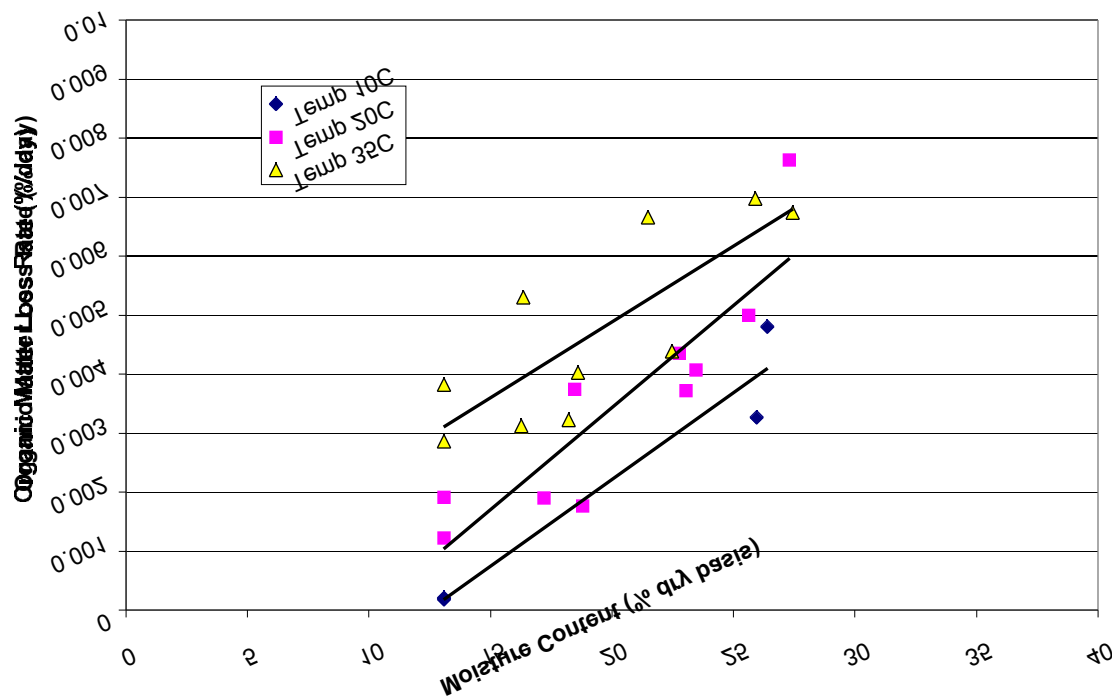


Figure 1. The rate of organic matter loss in samples of rice straw at moisture contents below the fiber saturation point. Data from Summers, Blunk et al. 2002.

At moisture contents above 39% dry basis (28% wet basis), the straw fiber is saturated and free moisture is available on the straw surfaces. In the experiments, the rate of decomposition ramped up significantly above this fiber saturation point (Figure 2). At moisture contents of between 40% and 150% dry basis (30 – 60% wet basis) the organic matter loss rates were in the range of 0.5 to 2% per day, over 50 to 200 times faster than the rates at the moisture contents below fiber saturation. At these levels significant amounts of the straw material will be decomposed over a short period of time. Straw will likely be discolored and lose structural properties if these moisture levels are maintained for a few weeks to months.

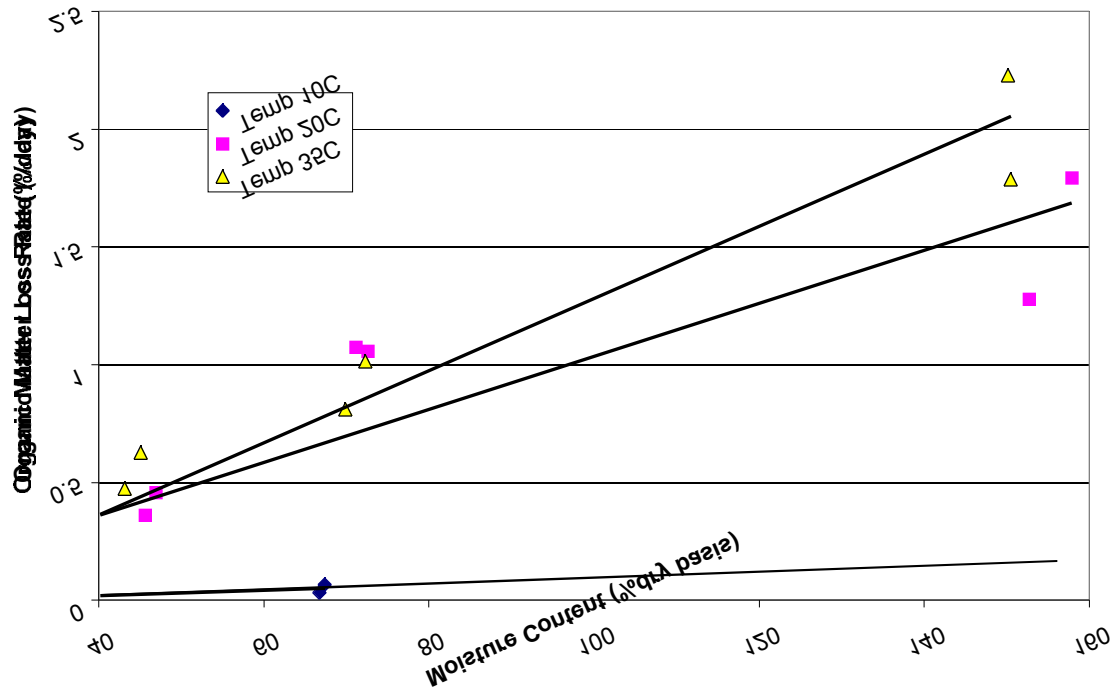


Figure 2. The rate of organic matter loss in samples of rice straw at moisture contents below the fiber saturation point. Data from Summers, Blunk et al. 2002.

More experiments on rice and wheat straw are continuing but the same basic result is expected, ie that high rates of decomposition only occur when free moisture is available in the straw. For now the following basic guidelines can be used by straw bale builders.

### 3 Moisture Management in Straw Bale Buildings

The key questions for straw bale builders are: what moisture levels should be of a concern, and what should be done when moisture is detected. Based on our studies and experience with straw, the following guidelines should be followed.

Only bales with bulk moisture content below 25% dry basis (20% wet basis) should be used in wall systems. This helps insure that there is no free moisture being added to the system and the moisture levels are below that required for microorganism growth. If bales become wet during transport or storage, it should be insured that they have dried out sufficiently before placing them in a wall. This requires using a moisture probe or testing core samples, as the bale surface can appear dry when significant moisture is still contained within. Once in the wall, drying will be inhibited by the wall treatments. Builders may want to avoid bales that have been exposed to liquid moisture during their collection and transport because they are likely to contain additional microorganism spores that are undesirable in the building envelope.

Moisture content indicates conditions conducive to degradation, but elevated temperature is a direct measure of decomposition activity within a bale; decomposition gives off carbon dioxide but also gives off heat. Since bales are good thermal insulators, this heating will lead to an increase in the bale temperature, similar to the way a compost pile heats up. In our experience, wet bales in the field reach a maximum center temperature of 140°F (60°C) about 7 days after becoming wet and slowly drop in temperature as the bale dries out. Upon re-wetting the same heating process takes place. It should be noted that this temperature rise occurs in a condition where oxygen transport is not inhibited. Within a wall it is likely that the temperature rise would not be as high.

As with hay, if the bale temperature rises above 155°F (68°C), bales should be handled with extreme caution because there may be increased risk for spontaneous combustion. We have never recorded temperatures this high in straw, and wet straw does not appear as likely to reach these conditions as wet hay (ie straw with the seed heads still attached). As discussed above, oxygen needs to be supplied to reach these higher temperatures and a static stack may not meet these conditions. Within a plastered wall, the supply of oxygen would not be suitable to support this temperature rise. However, as a precaution, if bales within a wet stack are found with these high temperatures they should be removed and dismantled to avert any risk.

Once a bale has been identified as “wet”, temperature is the primary indicator of the level of decomposition activity, and should be monitored until the bale dries out. This temperature should be measured at the bale center because the outside of the bale will appear normal. A compost thermometer can be used to monitor the center temperature. Alternatively a metal rod (like re-bar) can be inserted into a bale for a minute or two. If the rod comes out hot to the touch this indicates that the bale is self-heating. Never put a “hot” bale into a stack or wall as this could exacerbate that heating or prevent drying. Bales should be allowed to dry in the open air, or, if significantly wet, just not used. Contrary to a practice sometimes employed by bale builders, forced-air drying is not recommended as this may accelerate the decomposition by providing oxygen.

Situations where liquid water enters a straw wall or a significant amount of condensation is suspected should be investigated in a way similar to that described above. First the wall should be sampled to determine the depth and extent of the moisture entry. If high moisture straw is only on the bale surface below the stucco, then it is likely that it will dry out without much activity. If moisture content is elevated deep into the bale, then the temperature should be monitored until the bale dries out; this drying period could take weeks to months depending on outside conditions. Precaution should be taken not to increase the level of ventilation in the wall during this wet period as this will exacerbate decomposition. If sampling holes are made in the plaster and straw, they should be re-plugged to prevent oxygen entry. Under no conditions should forced air drying be used as this can result in accelerated heating and decomposition.

Although highly unlikely, a wall whose temperature rises above 140°F (60°C) should be dismantled for safety reasons. The proper way to dismantle a wall would be to cut out the hot section and remove it, with a water hose on hand to suppress flare-ups as may occur when the straw is exposed to oxygen.