3-1-1993

Forage Moisture Determination NRAES-59

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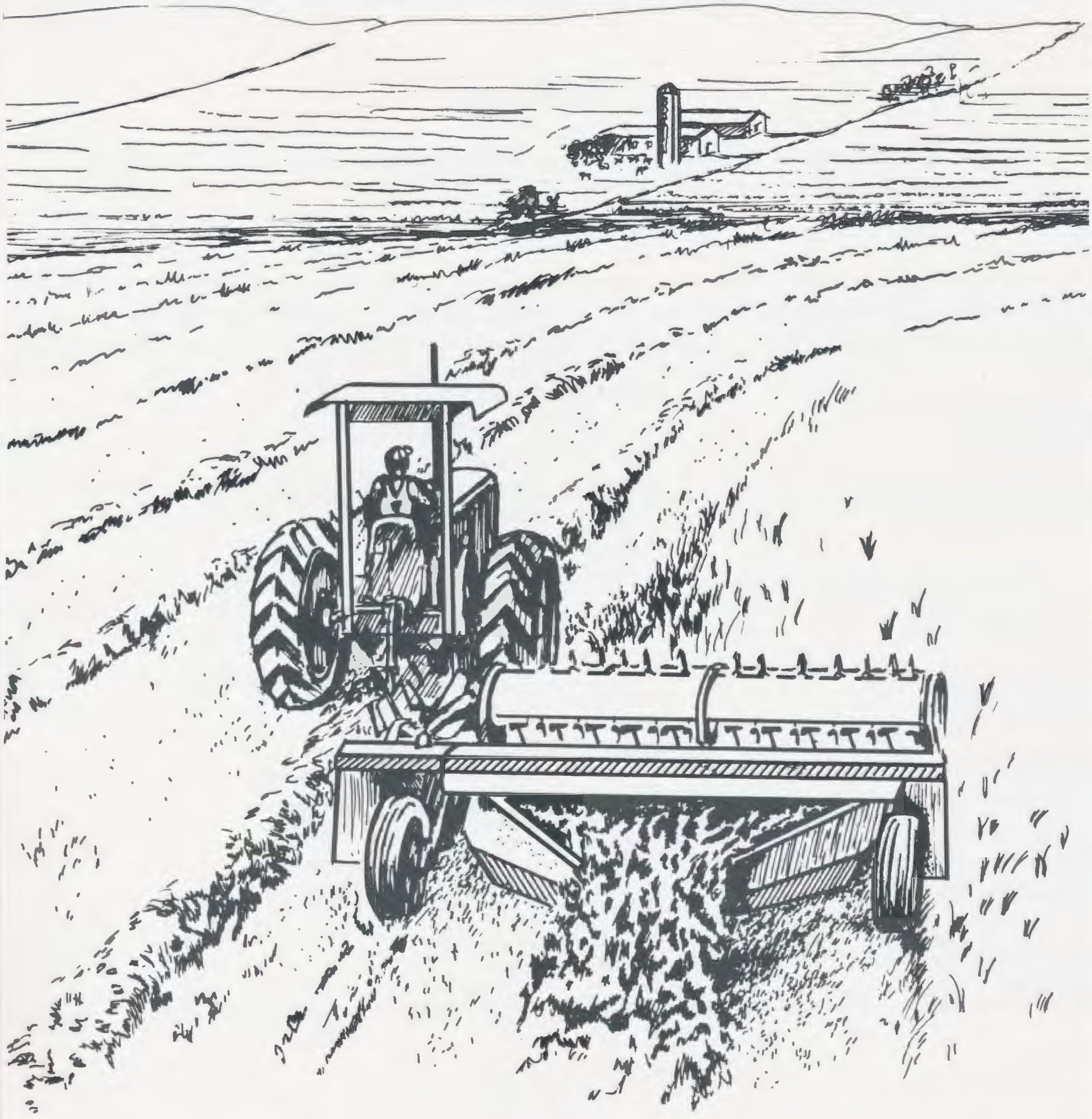

Northeast Regional Agricultural Engineering Service

COOPERATIVE EXTENSION

Acknowledgments

The authors wish to thank the following people who reviewed this bulletin:

Daniel Aneshansley, Cornell University
Dennis Buckmaster, The Pennsylvania State University
Jerry Cherney, Cornell University
John Conway, Cornell Cooperative Extension, PRO-DAIRY
Paul Sirois, Northeast Dairy Herd Improvement Association
Lester Vough, University of Maryland

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NRAES–59
March 1993

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Table of Contents

List of Figures

Introduction

Successful preservation of forage crops as either silage or hay depends on the accurate measurement of one forage property: its moisture content.

In silage making, moisture is required for growth of lactic acid bacteria that reduce pH and preserve the forage. The optimum moisture content for silage making is 50–70%. If the forage is above 65% moisture in a tower silo or above 70% moisture in a bunker silo, seepage of plant juices occurs, causing a loss of valuable nutrients and a possible environmental impact. Above 70% moisture, undesirable bacteria called clostridia may outgrow the lactic acid bacteria, causing a spoilage that may result in unpalatable or toxic feed. Below 50% moisture, the silage may undergo heating and browning that cause a loss of energy and a decrease in available protein.

In hay making, the moisture content must be low enough so that no chemical or biological activity takes place during storage. Forage should be raked, inverted, or tedded at 40–50% moisture and baled at 15–20% moisture. Baling hay at moisture levels below 15% results in excessive leaf loss and a reduction in nutrient content. Baling hay at moisture levels above 20% (without the use of an effective preservative) results in heating and may lead to barn fires.

Use of hay or silage additives requires an accurate assessment of moisture content, so that the proper amount of additive can be applied. If additive application rate is too low, excessive degradation of silage or heating of hay may result. If the application rate is too high, the cost-effectiveness of the additive may be reduced, and problems of handling and application of the additive may increase.

Estimating moisture content of forages by appearance, smell, and feel is popular but not sufficiently accurate for ensuring good preservation, for setting additive application rates, or for feeding. Silage is assumed to have an appropriate moisture content if a handful slowly falls apart. Falling apart too quickly means it is too dry; staying together means it is too wet. Hay is assumed to have an appropriate moisture content if a twisted handful of hay springs open and fluffs out. Brittle hay is too dry; hay that stays twisted or slowly untwists is too wet. Using these methods usually results in underestimates of silage moisture content and overestimates of hay moisture content.

This publication is intended for forage producers, extension specialists, consultants, and researchers. Part I is an overview of forage moisture determination and describes proper procedures for collecting samples. Part II covers on-farm methods: microwave oven drying, the Koster crop tester, electronic moisture meters for silage, and the Delmhorst hay moisture meter. Part III covers laboratory methods: vacuum or forced-air oven drying, toluene distillation, and near-infrared spectroscopy.

Part I
Overview

What is moisture content? Forages contain many compounds, but for the purpose of measuring moisture content, all compounds are divided into two categories: water and nonwater (dry matter). Moisture content is the part of forage mass which is water.

Calculating Moisture Content

Moisture content is determined by dividing the weight of water in a sample by the sample's total weight. This number multiplied by 100 is the percent moisture.

$$\text{Moisture content (\%)} = \frac{\text{weight of water}}{\text{total weight}} \times 100$$

The principle of moisture measurement by drying is to remove the water in a representative sample of forage. Moisture content is calculated from the following equation:

$$\text{Moisture content (\%)} = \frac{\text{wet weight} - \text{dry weight}}{\text{wet weight}} \times 100$$

Example: An 8-pound sample contains 2 pounds water and 6 pounds dry matter.

$$\begin{aligned}\text{Moisture content} &= (2 \div 8) \times 100 \\ &= 25\%\end{aligned}$$

Example: A 20-pound sample contains 14 pounds water and 6 pounds dry matter.

$$\begin{aligned}\text{Moisture content} &= (14 \div 20) \times 100 \\ &= 70\%\end{aligned}$$

Moisture measurement of feed ingredients and total mixed rations is integral to feeding programs. Most feeding programs are based on dry-matter content. The amount of "as-fed" forage that needs to be weighed out depends on moisture content.

$$\text{Weight as-fed} = \frac{\text{weight of dry matter}}{100 - \text{moisture content}} \times 100$$

Example: A ration is formulated using corn silage, 12 pounds dry matter and 65% moisture.

$$\begin{aligned}\text{Weight as-fed} &= (12 \times 100) \div (100 - 65) \\ &= 34.3 \text{ pounds}\end{aligned}$$

If the moisture content of the sample were 60%, then 30 pounds of corn silage would be needed to provide the same 12 pounds of dry matter.

If the moisture content of the forage was 65% but was thought to be 60%, the cow would be underfed by 4.3 pounds of wet silage or 1.7 pounds of dry matter.

Goals in Drying Samples

Several methods of moisture determination depend on drying a forage sample to remove the water. Water is present in forage in three states: free water, mechanically or physically trapped water, and bound water.

Free water, the "wetness" of the sample, is most easily evaporated and is usually removed completely in drying. Trapped water is held inside cells or tissues. The amount of trapped water removed during drying depends on drying time and temperature. Bound water is chemically attached to other molecules. Most bound water is not removed in drying, but is likely to be less than 1% of the remaining sample weight.

There are two goals in drying samples. One is to remove all the water in the sample. When insufficient drying occurs, the measured moisture content is lower than actual moisture content, which would cause underfeeding of the animal.

The second goal in drying forage samples for moisture determination is to remove only water and no dry matter. Some of the dry matter in forage evaporates easily, including ammonia, ethanol, and organic acids such as acetic and propionic acids. These compounds are more prevalent in fermented feeds such as silage and high-moisture corn. If the sample is burned or charred, substantial dry matter is lost. Because any loss of dry matter counts as moisture, estimated moisture contents in this case will be higher than actual. Thus, drying time and temperature are selected to remove as much water but as little dry matter as possible.

Sampling Procedures

Forage moisture is always measured in small samples. Proper sampling is the first step in determining forage moisture content. Moisture content results are meaningful only if forage samples are representative of the lots from which they were taken. Inadequate sampling procedures may result in inaccurate moisture values. Additionally, if these samples are used for quality analysis, the results will not be representative of the feed being fed.

Moisture content varies considerably from bale to bale or bucket load to bucket load. In one test, 20 different hay bales from a single lot were sampled and moisture tested. The moisture contents varied from 10.1–15.3%, with an average of 13.1%. The only way to obtain an accurate measurement of average moisture content is to take many samples.

General Sampling Procedure

The keys to proper sampling are to take enough samples and to sample randomly and thoroughly. In general, when and how frequently you sample will depend upon the forage that you want to test. While there are no set rules, you should sample every time a major change occurs in the forage—for example, when there is a change in the crop maturity, legume percentage, or handling practice. Frequent moisture testing is crucial to obtaining accurate measurements while the forage is drying.

Proper sampling is especially critical when the moisture tester holds only a small amount of forage. Only a handful of forage fits into most test devices, and this handful must represent the entire lot. A lot is usually defined as that forage from a single day's cutting, or a single species (or known mixture) harvested from a specific field. Between 6 and 12 subsamples are taken from each lot and mixed together thoroughly in a clean container, such as a pail. From the container comes the composite sample, which is used for moisture testing.

Sampling Windrows

Moisture content of hay varies considerably across a field and through the depth of a windrow. A representative sample is critical for accurately assessing moisture in the windrow.

1. Test each cutting and field separately. If parts of a field were cut at different times of the day (morning and afternoon), test each part separately. If necessary, make a separate test of the field borders, small wet areas, or areas where the stand is unrepresentative.

2. Collect subsamples from at least 5 locations. More sampling locations result in a more accurate moisture measurement.

3. At each location, take a subsample from the entire depth of the windrow. Sampling from only the top layer results in a low moisture estimate. Take at least 6 inches of windrow length. Use a pair of rugged scissors or hedge shears to slice the windrow, attempting to avoid leaf shatter, which is the loss of leaves from the stems.

4. Cut subsamples into pieces 1–1.5 inches long.

5. Place the subsamples in a pail and mix them together gently, avoiding leaf shatter as much as possible. Then take a composite sample for moisture determination.

Sampling during Silo Filling

The advantage of sampling during silo filling is that moisture content is available for feed programming before the silo is opened. The process of chopping also helps to mix the forage. It may be advisable to mark the location of the different lots of forage in upright silos. Cut up colored plastic strips or egg cartons and run them through the blower at the start of a new layer. When the markers are visible, a new lot is being fed. Moisture content should be retested when the silage is fed out to ensure appropriate dry-matter consumption.

1. Take grab samples of each load of forage from a single field and put each in a plastic bag.

2. Mix the subsamples from a single field and take a composite sample for moisture determination.

Sampling Hay

Always store hay so that you can distinguish between different lots later. You can choose from two techniques for sampling hay: grab sampling and coring.

Grab sampling is the less desirable of the two techniques for two reasons: you cannot grab a true cross section of the bale, and the leaves shatter and fall from the sample. However, if you must use this method, break open the bales before grabbing a sample. This reduces leaf shatter losses. Use scissors to chop the stems into 1-inch pieces for mixing. Take several subsamples before mixing and taking a composite sample.

Core sampling is the better technique for packaged hay because it gives a more representative sample. Core samplers can be purchased at agricultural supply houses. The Penn State forage sampler is widely available; it is driven with a hand brace or electric drill. The tip of the coring device must be sharp enough to cut through the bale and obtain a good cross section of material. A dull tip will not sample the bale adequately.

When using a core sampler always sample at right angles to the way that the bale is formed. Follow the guidelines below.

Rectangular bales

Sample the bales 4–6 weeks after packaging; the moisture level and other qualities may change throughout that period.

1. Randomly select 10–12 bales from each lot.

2. Bore into the end of each bale to collect subsamples; mix thoroughly.

3. Collect a composite sample and measure its moisture content.

Round bales

The quality of a lot of round bales stored outside is always changing because the bales are exposed to the weather. Therefore, sample these bales 2–4 weeks before feeding.

1. Randomly select 10–12 bales from each lot.

2. Bore across the layers of hay at a right angle to the wrap to collect subsamples; mix thoroughly.

3. Collect a composite sample and measure its moisture content.

Loose machine-made stacks

Like round bales, stacks should be sampled 2–4 weeks before feeding.

1. Randomly select 6–8 stacks from a lot.

2. Collect 3 core samples from each stack. Bore into the hay at right angles to the layers. If you sample straight into the side of the stack, you will not obtain a representative sample of leaves and stems. Mix subsamples thoroughly.

3. Collect a composite sample and measure its moisture content.

Sampling from a Silo

After fermentation, moisture content may be slightly different due to effluent loss, evaporation, or spoilage. Do not sample the top 2–3 feet of silage from an upright silo or from the edges of a horizontal silo, where the silage may have lost moisture or spoiled.

Upright silo

1. For a few seconds, collect silage falling from the blower in a pile or in a clean container. Repeat to obtain 6–12 samples. Do not grab samples from the unloader discharge chute because it separates heavy and light particles, giving a nonrepresentative sample.
2. Mix all subsamples together and take a composite sample.

Horizontal silo

How you sample from a horizontal silo depends upon how it was filled (figure 1.1). Silos filled in horizontal layers (silo A) can be sampled with a top-to-bottom slice of the face. In this case you would grab more samples from lot 3, which is the largest.

Silos filled in angled layers (silo B) should be sampled more often. When more than 4 lots of silage are placed unevenly in one silo, it is more difficult to know how much of each is being fed and how much mixing of lots has occurred.

To sample silo A: Rake working face with a front-end loader. Select 12 grab samples from unspoiled areas of the face, 3–6 inches in. Do not sample from the fallen material or from the slope at the end of the silo. Mix subsamples and collect a composite sample.

To sample silo B: Take 3–6 grab subsamples from each front-end loader bucket after it has been dumped into the bunk.

If using mixer wagons, sample after mixing the silage but before adding other feed. Make sure that the tractor engine and PTO are off!

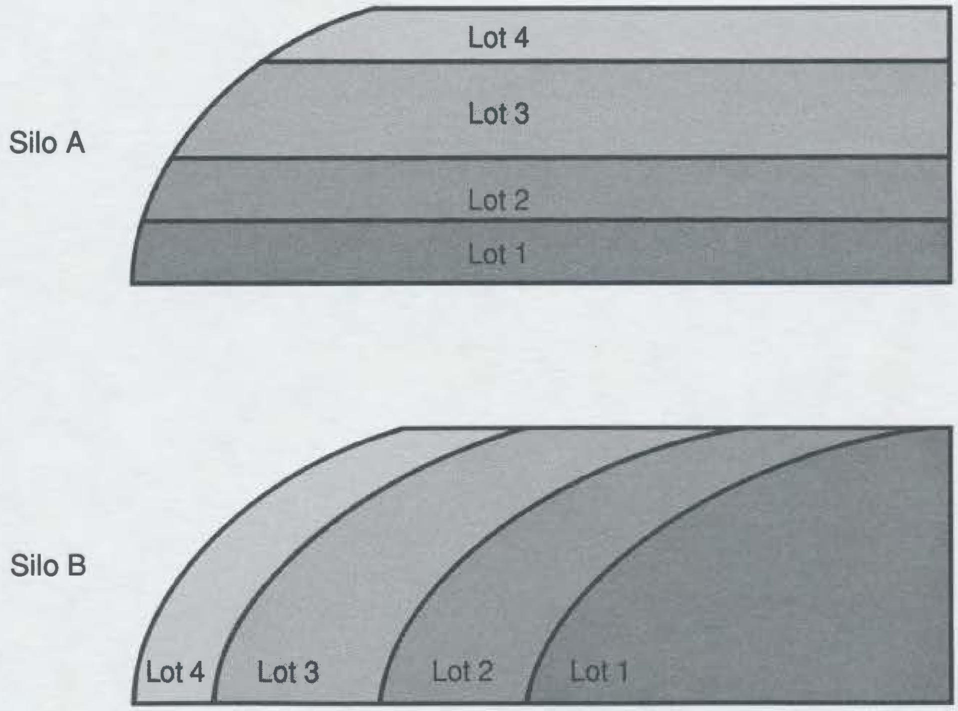

Figure 1.1. Two ways to fill a horizontal silo.

Sampling from a Feed Bunk

Feed bunk conveyers, especially augers, tend to separate heavy and light particles, so sampling from the bunk requires more care.

1. Select 4 or more 1- to 2-foot sections within the bunk.
2. Remove all of the silage from each of the sections and reblend the particles by hand in separate, clean containers.
3. Take a subsample from each remixed section and mix them in a separate pail. Then take a composite sample.

Sampling Pellets or Cubes

Pellets are easily sampled, but they are not packaged or stored to represent a single lot. To obtain a representative sample, select 10–12 random grab samples from each pile or one grab from each of 10–12 bags. Mix subsamples and take a composite sample.

Sampling Pastures

Sampling pastures for moisture testing is difficult because what you sample is not likely to be what the animals graze. Gathering a representative sample from a pasture is difficult. Sample using the "plucking method": walk through the pasture and periodically cut off a handful of forage 2–3 inches from the ground. Cut the subsamples into 1-inch pieces, mix thoroughly, and take a composite sample.

Summary

- Collecting a representative sample is the most important part of the testing process.
- Take a large number of subsamples from a lot of forage and mix them together. Then take a composite sample.
- Sample frequently. Moisture content changes rapidly during drying and fluctuates between different lots of forage.

Part II
On-Farm Methods

Testing moisture content on the farm is faster than having the test done in a laboratory, and with practice, the results can be quite accurate. This section will discuss on-farm methods for determining forage moisture content: microwave oven drying, the Koster crop tester, electronic moisture meters for silage, and the Delmhorst moisture meter for hay. Refer to the table inside the back cover to choose the appropriate method for your needs.

Microwave Oven

Oven methods to determine the moisture in a forage sample are simple, direct, and accurate. Their main disadvantage is the long time required to dry the sample. Drying samples in conventional heated-air ovens requires the sample to be heated for 24–72 hours, a time so long that the information is not very useful in making harvesting decisions on farms. In the microwave oven method, drying time is reduced to minutes, providing moisture information in time to help make decisions about cutting, chopping, raking, or baling.

Now that microwave ovens are in most homes, the microwave oven method of moisture determination has gained wide acceptance (figure 2.1). Microwave ovens use a fraction of the energy to dry a single sample as do conventional ovens (750 watts for a few minutes compared to 5,000–15,000 watts for several hours). However, using a microwave oven for moisture determination, as for cooking foods, requires an understanding of microwave heating with its unique features, limitations, and precautions to obtain consistent, accurate results. Microwave heating can be used for samples with at least 20% moisture content.

Principle

Microwave heating results not from the slow transfer of heat through the surface of a sample, as in a conventional oven, but from the coupling of electrical energy in an electromagnetic field in a microwave oven to material placed in the oven. Microwaves are generated by a magnetron which converts electrical energy alternating at 60 cycles per second (60 Hertz) to a faster rate or frequency (2,450 million Hertz). This creates an electromagnetic field with centers of positive and negative charge that vibrate billions of times per second. Molecules having both negative and positive charges (dipoles) attempt to align themselves within the electromagnetic field. Water is one such compound. Because the electrical field is reversing so fast (vibrating at such a high frequency), rotation, movement, and collision of the molecules cause internal friction and heating. Compared to heating in a conventional oven, microwave heating is almost instantaneous.

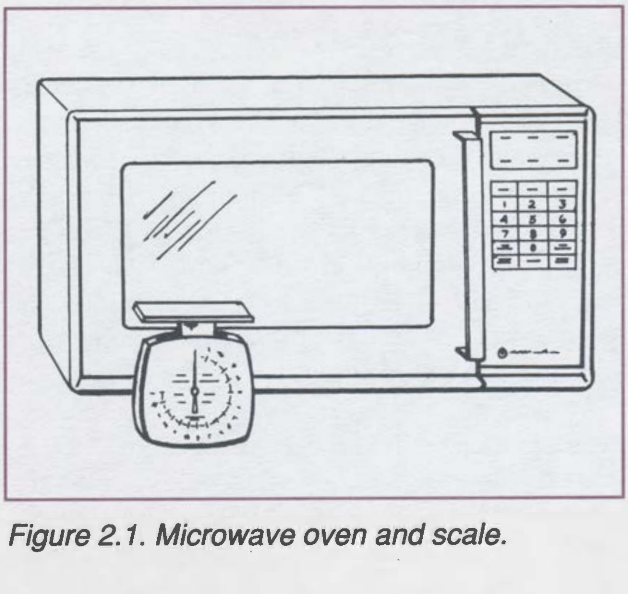

Figure 2.1. Microwave oven and scale.

Materials having no electrical charge, such as metals, paper, glass, and air, do not absorb microwave energy. Microwave energy is reflected by metals but passes freely through paper, glass, and air. Most plastics transmit microwaves but some absorb to a limited degree. Some plastic films (susceptors) contain a thin metal layer and thus reflect microwaves.

The most common absorber of microwaves in plant material is water. In a microwave oven, products containing water are heated because the water first absorbs the microwave energy and then conducts the heat to the rest of the sample. The primary reason for a microwave oven's speed in moisture determination is that energy is directly used to heat the moisture to evaporation.

Unlike that of a conventional oven, the output of a microwave oven depends on both input power and the characteristics of the sample in the oven. Energy transfer is most rapid for high-moisture products that are thin. Thick products that are low in moisture will be nonuniformly heated in a microwave oven. The temperature of a sample placed in a microwave oven is affected not only by the oven setting but also by the sample size, shape, moisture content, and time of heating. To obtain an accurate moisture content, the temperature of the forage sample must be controlled to prevent burning.

Method

Testing the moisture content of forage with a microwave oven requires a small but accurate scale, as the quality of the results depends on the accuracy of the weight readings before and after drying. A scale marked in grams that reads to within 0.1 gram, such as a home food diet scale, is acceptable for samples of 100 grams. A scale that reads to within 1.0 gram can be used, but will be less accurate; in this case, use a sample larger than 100 grams to reduce the error.

A forage sample should go directly from a collection container to the scale. Place the sample on a preweighed microwave-safe plate or paper plate. For a more accurate reading, preheat the empty paper plate for 20 seconds to remove any residual dampness. Use a large plate and spread the sample out. The forage pieces can be long, short, bent, or straight, as long as they fit into the oven. Place the plate with sample into the center of the oven. Set the oven to full power.

The goal is to heat the sample of forage just long enough to remove all the water without burning. Before running the actual test, experiment to find the right time for a certain size sample in a particular oven. The first time, try 6 minutes for 100 grams of high-moisture forage in an oven having at least 600 watts at full power. Larger samples or lower-power ovens require longer heating times. Forage samples of 50–80% moisture may take 8 minutes, while samples of less than 25% moisture may require only 4 minutes. At the end of the heating period, take the sample from the oven, weigh it, and place it back in the oven, rotated 90 degrees from the first position. Do not let the sample cool during this weighing; keep the time the sample is out of the oven to a minimum. Heat for 2 minutes and weigh again. Repeat for 1-minute heating intervals until the change in weight is less than 0.5 gram (or about 0.5% of the initial weight).

Watch the sample to ensure that it does not begin to char or burn, indicating that some dry matter has been removed. A charred sample should be discarded and a new sample started. The heating process must stop before charring occurs. Practice with a particular microwave oven, sample weight, and moisture range can reduce the number of heating and weighing cycles to one long heating period followed by a 1-minute heating to check that all water has been removed.

To compute moisture loss, subtract the final oven-dried weight from the initial wet weight. This difference is assumed to be the moisture lost from the sample. Divide moisture loss by initial wet weight of the forage sample, excluding the weight of the plate. Multiply by 100 to obtain percent moisture (see page 2). Using an initial sample of 100.0 grams eliminates the last two steps; for a 100-gram sample, moisture loss in grams equals percent moisture content.

Accuracy

Moisture content determination using a microwave oven can be almost as accurate as the conventional oven, although nonuniform heating of samples can limit its accuracy. High accuracy is attainable under certain conditions. Scales reading to 0.1 gram will give more accuracy than those reading to 1.0 gram. Results for high-moisture forage samples are more accurate than for low-moisture samples, in which weight changes are small during oven drying. In forages with less than 20% moisture, microwave drying will indicate a lower than true moisture content. Heating for too short a time will also underestimate the true moisture content. Heating for too long will overestimate moisture due to loss of dry matter.

With smaller microwave ovens it is especially important to use the full power setting and a smaller sample to ensure sufficient heating to remove all the moisture. The size of the sample may have to be a compromise—small enough to fit in a low-power oven and large enough to give an accurate reading. To ensure uniform heating, the forage should be spread as thinly as possible. A hand-wound carousel is recommended in lower-cost ovens to produce more uniform heating; newer ovens may not require the carousel. Temperature probes available with some ovens should not be used for porous products like forage.

Safety

The foremost safety precaution is not to leave the oven unattended during heating. If the forage sample develops hot spots near a combustible material such as a paper plate, it may burn. Metal should not be used in the oven because it reflects microwave energy. The inside walls of older ovens tend to heat after continued use; place a cup of water in the corner to absorb energy when the sample's moisture is nearly evaporated. Newer microwave ovens can be used safely without the cup of water. If the inner walls of the microwave oven become too hot to the touch, they should be allowed to cool for a few minutes before the oven is used again.

Microwave ovens pose little or no danger from radiation leaks provided the manufacturer's precautions are followed. The safety switch on the door should never be tampered with. Any uncertainty about possible leakage from around the door should be checked by authorized microwave-oven repair personnel.

Koster Forage Moisture Tester

Principle

The Koster forage moisture tester works on a principle similar to that of an oven. A forage sample is dried and the moisture content is determined from the weight change. The tester consists of a drying unit containing an electrical heating element and a fan, a sample container, and a scale (figure 2.2). Heated air is forced upward through the sample, evaporating the water in the sample. The system is easy to use and fairly rapid, requiring about 30 minutes of drying for most samples. The tester can operate well in protected areas outdoors, but must be used near a 110-volt electrical outlet. The Koster tester can be used for samples with 20–90% moisture content.

Method

Read the instruction card included with the tester.

1. Set the weigh scale on a flat surface and level it by adjusting the screws, using the level indicator on the side of the scale. Select a location with very little wind but enough ventilation to carry away the heat generated by the drying unit.

2. Place the empty sample container on the scale. Adjust the scale pointer to read 100% on the black scale. A thumbscrew underneath the scale platform is used to adjust the scale pointer.

3. Add the sample to be tested to the sample container until the pointer reads 0% on the black scale. Use about 2 pounds of chopped forage. Unchopped forage should be hand chopped with a paper cutter, scissors, or hedge trimmers.

4. Place the sample container on the drying unit. Run the drying unit for 20–25 minutes.

5. Remove the sample container and place it on the scale. The percent moisture content can be read directly on the black scale. The percent dry matter (100 minus percent moisture) can be read directly on the red scale.

6. Place the sample container back on the drying unit and run for 5 minutes. Again, weigh the container as described above. Repeat this sequence until there is no further change in the scale reading.

Accuracy

The accuracy and repeatability of the Koster tester were evaluated by the Prairie Agricultural Machinery Institute in 1981. Samples used in that test were chopped alfalfa and chopped corn. Moisture content of these samples ranged from 20–76%. Results from the Koster tester were compared with those from conventional oven-drying. For alfalfa, moisture readings were accurate at about 40% moisture, and were slightly low at higher moisture. A similar trend was found for corn, but with greatest accuracy at 50% moisture. Overall, moisture readings were within ±3 percentage points when compared to conventional oven drying. When four samples of each forage were tested and the results averaged, the average moisture readings were within ±2 percentage points of the oven values. For this

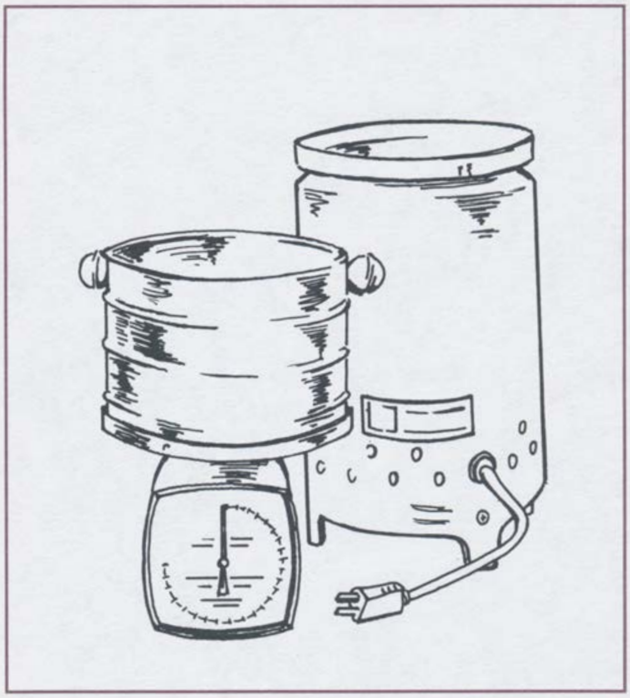

Figure 2.2. Koster forage moisture tester.

reason, the test engineers recommended that several samples of the same forage be tested for greatest accuracy.

The variation in readings from the Koster tester, after correcting for actual variations in moisture content (as determined by oven drying), was 1.0% for corn and 1.1% for alfalfa. These low figures indicate excellent repeatability, yielding moisture content readings within about 1% of each other for the same forage.

Safety

The Koster tester is an electrical device which operates on 110–120 volts alternating current. Follow normal precautions for using electrical appliances. The sides of the Koster tester become very hot during drying and could cause severe burns. The tester should be set away from flammable materials and should not be left unattended while it is on. Overdrying can burn or char the sample, resulting in inaccurate (high) moisture readings.

Electronic Moisture Meters for Silage

Electronic moisture meters are portable, hand-held devices that determine forage moisture content in about 4 minutes (figure 2.3). They measure an electrical property of the forage that changes as moisture content changes. The operator reads a meter on the instrument, then looks up the moisture content in a table provided by the manufacturer. Electronic meters can be used for samples with 25–80% moisture content. Only unfermented forage should be used in the instrument.

There are two basic types of electronic meters: those that measure conductance, and those that measure capacitance. Conductance meters measure the ability of the forage to conduct electricity. Conductance increases as moisture content increases. Capacitance meters measure the ability of the forage to alter the electric field between two charged plates. Capacitance also increases with moisture content.

Manufacturers of electronic meters generally consider them to be accurate to within ±5 percentage points of moisture content. However, some tests have shown that the error is more than 5 percentage points. Readings from electronic meters are useful as a rough guide to forage moisture content, but they may not be precise enough for making harvest decisions or formulating rations.

Figure 2.3. Two electronic moisture meters.

Principle

Conductance meters: When a voltage, or electromotive force, is applied between two sides of a material such as forage, electricity (or electrical charges) will flow through the material. This flow of electricity is current, and its unit of measure is the ampere. For a given voltage, more current flows through a more conductive material.

Conductance is a property of a material. Conductance is the flow of electricity through the material per unit of voltage applied to it. Its unit of measure is amperes per volt.

$$\text{conductance} = \frac{\text{current in amperes}}{\text{voltage}}$$

Example: 12 volts are applied across a material at a current of 0.5 amperes.

$$\begin{aligned}\text{Conductance} &= 0.5 \div 12 \\ &= 0.0625 \text{ amperes/volt}\end{aligned}$$

Forages conduct electricity. The conductance of forages increases as forage moisture content increases, because water conducts electricity more readily than forage dry matter or than air mixed in with the forage. In conductance moisture meters, the forage is placed between two contacts, a voltage V is applied across the contacts, and the current I which flows through the forage is measured. The instrument then calculates conductance as $I \div V$. With this reading, the operator looks up forage moisture content in a table provided by the manufacturer.

Capacitance meters: A capacitor is a device consisting of two parallel metal plates separated by a material called a dielectric. When a voltage is applied across the plates, opposite electric charges build up on each plate of the capacitor. Capacitance is the amount of charge that builds up per unit of voltage applied. Capacitance is proportional to the dielectric constant (D) of the material between the plates, increases with the surface area (A) of the plates, and decreases as the distance between the plates (L) increases.

$$\text{capacitance} = \frac{D \times A}{L}$$

When forage is placed in the electric field between plates, molecules that have a positive and negative charge on different ends (such as water) orient themselves with the electric field, and this alters the electric field. The dielectric constant of forages increases as moisture content increases because the dielectric constants for water, forage dry matter, and air are different. For water, D is 78; for dry matter, D is about 4; for air, D is about 1.

Method

Manufacturers specify the forage moisture range for their instrument. This is generally 25–78% for alfalfa, and 35–80% for corn.

1. Obtain a representative sample of the forage in which particle lengths are about 0.75 inch on average. If sampling from a windrow, chop the forage with shears before testing.

2. Isolate a properly sized sample that is suitable for the instrument. This varies from about 0.5 pound to 2 pounds, depending on the meter.

3. Mix the sample well before loading it into the instrument. The moisture content of the sample should be uniform throughout the sample.

4. For some conductance meters, the sample should be sealed in a polyethylene bag and put in the instrument. Make sure the bag is about 1 inch thick when filled, is carefully sealed, and is not wet on the outside.

5. Compress the forage in the meter until the pressure indicator is activated. This is meant to pack the forage to a standard density. In some instruments, the pressure indicator is mechanical; in others it is electrical. Check that electrical density indicators are functioning by manually pushing the switch that senses density in the forage chamber.

6. After compressing the forage, allow the meter about 20 seconds to stabilize.

7. Press the temperature compensation switch (if present) and record the meter reading. If required, measure the temperature of the sample with the probe of the instrument.

8. Consult the manufacturer's conversion chart to obtain the moisture content. There are usually different charts for corn and haycrops. Some charts require the temperature of the sample and the number of turns in the compression device when the sample was loaded.

9. Repeat the process for 4 samples of the same forage, and average the 4 moisture readings.

Accuracy

Tests of electronic moisture meters have shown them to be fairly inaccurate. There is no apparent pattern for predicting when the meter will be high, low, or accurate.

A test of a capacitance device was conducted by the Prairie Agricultural Machinery Institute in 1981. For alfalfa, the meter was accurate at 20% moisture but read 45% moisture when the actual moisture was 70%. For corn the meter read 35% when actual moisture was 40%, and read 66% when actual moisture was 72%. Thus, the results were better with corn than alfalfa, and better at low moisture than at high moisture. If the meter reading is low in forage being ensiled, seepage losses and clostridial spoilage could result.

A test of a conductance device found that for alfalfa, the meter read 33% when actual moisture was 30%, but read 62% when actual moisture was 70%. The meter was accurate at 40% moisture. For corn, the meter was accurate at 70% moisture but read 28% when actual moisture was 34%. Thus, the

Factors Affecting Electrical Properties of Forages

The conductance and dielectric constant of forages are not only affected by moisture content. Other factors affecting these properties include:

- Temperature
- Packing density of the forage in the instrument
- Type of forage
- Fineness of chop
- Stage of maturity
- Cutting number for haycrops
- Nonuniformity in moisture content through a sample
- Surface moisture on the sample
- Acidity (pH)
- Forage preservatives and feed additives

To estimate moisture content, measurements from electronic meters have to be corrected for these factors. Most meters have automatic temperature compensation, which is internally controlled by the meter. Packing density of the forage in the meter is controlled by a turnscrew. There are usually different moisture content tables for different crops. Chop length must be controlled by the operator.

Only unfermented forage should be used in the instrument. The operator has to make sure the samples are uniform in moisture content. Because maturity and cutting number affect electrical properties, it is difficult to obtain precise moisture contents with these instruments across the entire harvest season.

most accurate moisture range was different for corn and alfalfa.

For individual samples of the same forage, electronic meters in these tests gave readings that varied by 10–15 percentage points. Averaging the readings of 4 samples reduces the variation but does not correct for inaccuracies they may have.

Safety

Electronic moisture meters operate at a very low voltage and are as safe to touch as the battery of an automobile.

Delmhorst Moisture Meter for Hay

The Delmhorst meter is an electronic device designed to measure moisture content of windrowed or baled hay, or hay in the bale chamber. The meter consists of a probe and a readout (figure 2.4). Its attachments include a handle, a short pin prod for windrow samples, a long probe for hay bales, and a contact sensor for bale chambers. The readout has a digital or dial indicator and "read" and "adjust" buttons. The probe, prod, or sensor has 2 electrodes for conducting electricity. The Delmhorst meter can be used for samples of hay only, not silage, with 5–50% moisture content.

Principle

The Delmhorst meter operates based on the relationship between hay moisture content and electrical conductance. Conductance increases as hay moisture increases (see Electronic Moisture Meters for Silage, page 12). When a voltage is applied across the electrodes, the meter detects the amount of current that flow from one electrode, through the forage, and into the other electrode.

Method

Earlier models of the Delmhorst meter (F-4, for example) require a calibration and battery check just before use; this is done by pressing the adjust button and moving the needle over the adjust mark on the screen. Battery power is low when the needle cannot be moved to the adjust mark. Newer models complete this process internally and thus do not require manual adjustment. After adjustment, the following procedures are recommended.

For testing windrows

1. Select a representative sample of hay from a windrow. Collect small quantities from several different locations in a 5- to 10-gallon pail. Use the short pin prod to probe the hay. To exert the

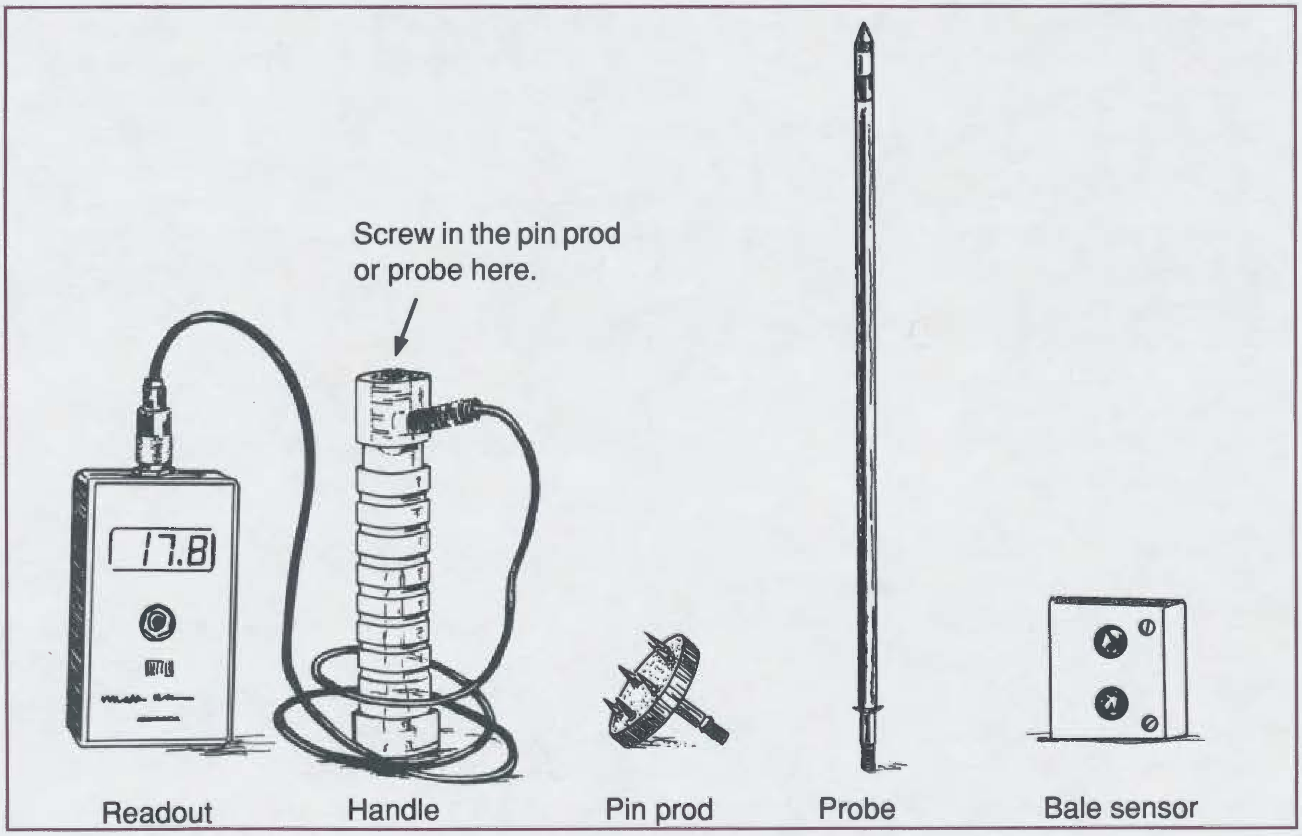

Figure 2.4. Delmhorst moisture meter with attachments.

Factors Affecting Delmhorst Moisture Readings

Delmhorst moisture readings are affected by forage density, temperature, and hay preservatives. Readings are also affected by field variation in hay moisture.

Bale density affects the degree of contact between the sensor and the hay. Lower densities produce lower readings, and higher densities produce higher readings by 1–2% moisture. Stacked hay may be lower in density than baled hay and usually yields readings 2–3 percentage points lower than average-density baled hay, for the same moisture content.

Density is also an important factor in determining moisture of windrowed hay placed in a bucket. The spring located in the handle of the meter provides a relatively uniform density, which helps assure more consistent and accurate readings. A minimum of 27–30 pounds of force must be applied to press the spring far enough to cause the retaining screw located in the handle to contact the palm of the hand.

Temperature also influences the meter readings. The meter is calibrated at 80°F and reads 1 percentage point low in moisture for each 20°F decrease in temperature and 1 percentage point high for each 20°F increase in temperature. These temperature effects on meter readings are small compared with the variation in hay moisture at different locations in a field.

Hay preservatives are usually in liquid form and may be mixed with water before application at the time of baling. Their presence tends to increase meter readings. To avoid this problem, sample hay from the windrow, or prepare bales for moisture determination without the additive.

Field variation in moisture content affects the accuracy of the readings from windrowed hay. A 1987 study performed at the University of Kentucky found that alfalfa bales from a single field averaged 31.3% moisture but ranged from 19.7–42.3%. This was due mainly to variations in drying rate in areas of different swath density, resulting from variations in growth across the field. Field variation in moisture can be especially large when moisture content is 20–30%. Awareness of high moisture pockets in baled hay is important when hay preservatives are in use because most products must be applied at a rate that increases with moisture content. If the average moisture reading was used in this situation, additive application rate could be too low, resulting in heating of hay to dangerous levels in storage.

correct amount of compressive force, press the handle so that a retaining screw in the handle contacts the palm of the hand.

2. Press the read button to display the moisture reading on the needle scale or digital readout.

3. Mix the hay in the container and repeat the process at least twice.

4. Repeat the procedure several times at different spots in the field to ensure adequate sampling of the variation in hay moisture, which can be large due to differences in initial moisture, drying rate, and other factors.

For testing baled hay

1. Insert the probe into the bale perpendicular to the stems, if possible, rather than between the slices. This helps ensure good contact between the sensor and the hay.

2. Press the read button and note the reading.

3. Collect readings at several locations within the same bale.

4. Test bales from several spots within the field and average the moisture readings.

For testing in bale chambers

1. The bale-chamber sensor has two metal electrodes that contact the hay as it passes through the bale chamber. The sensor must be installed so that the electrodes are aligned in a certain direction relative to the flow of hay.

2. Power is supplied by connection to the 12-volt tractor battery with an auxiliary 9-volt battery for portable operation.

3. Moisture readings are continuously displayed on the digital readout. With enough cable, the readout can be placed near the tractor operator.

Accuracy

Studies were conducted at the University of Kentucky in 1987 to assess the accuracy of the model F-4 Delmhorst meter against oven drying at 150°F for 48 hours (figure 2.5). Delmhorst readings coincided with oven moisture at 17%. Above 17% moisture, the Delmhorst readings were below oven values. Below 17% moisture, Delmhorst readings were above oven moistures. For example, hay at 23% moisture would have a Delmhorst reading of 20%, and hay at 33% moisture would have a Delmhorst reading of 25%. This would result in hay going into storage too wet, and heating and browning would be likely to occur.

Although Delmhorst readings were related to actual hay moisture content (meter readings explained 85% of the variation in hay oven moisture), there was still some inaccuracy. Averaging 12 separate readings on a particular bale resulted in moisture content readings within ±2.0 percentage points of the actual moisture content. Accuracy can be improved by using a set of your own samples to calibrate the Delmhorst meter to microwave oven readings made on the farm. However, the variations in moisture readings may be due more to field variation than to instrument inaccuracy.

Safety

The pin prod provided for windrow moisture measurement is made of sharpened metal. Care should be taken when handling this unit to avoid injury. The voltages at the end of the prod are too small to administer an electrical shock to humans.

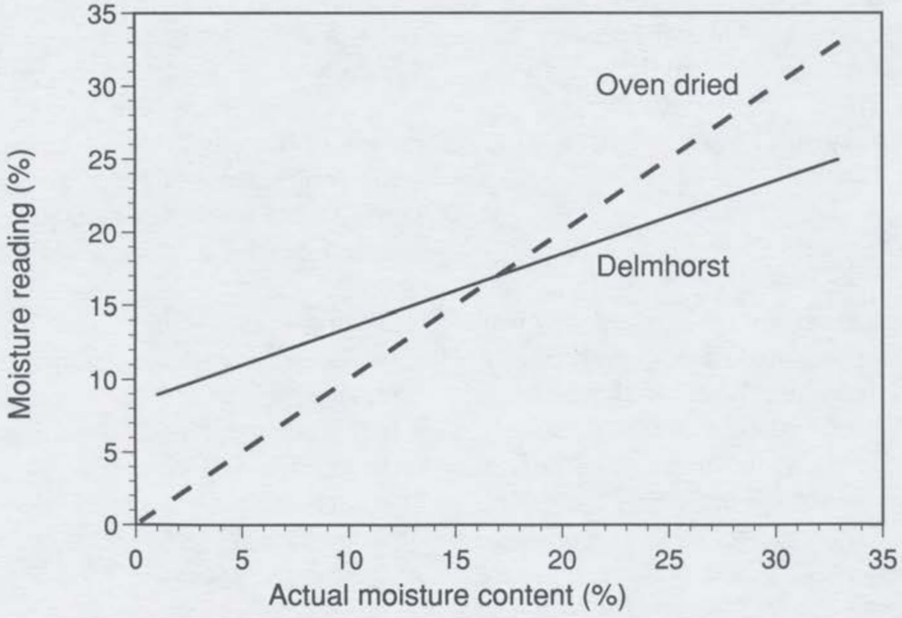

Figure 2.5. Relationship between Delmhorst meter readings and actual alfalfa hay moisture content.

Part III
Laboratory Methods

Laboratory tests of forage moisture content are more accurate than on-farm methods, but take more time and require expensive equipment and trained technicians. This section will discuss three laboratory methods: vacuum or forced-air oven drying, toluene distillation, and near infrared spectroscopy. Refer to the table inside the back cover to compare the different methods.

Vacuum or Forced-Air Oven Drying

Drying with a vacuum or forced-air oven is the most common method of moisture determination used by commercial laboratories. It is considered one of the most accurate moisture measurements available. However, oven temperatures, sample sizes, and drying times may vary considerably among laboratories. Because of the slowness and complexity of procedures involved, vacuum or forced-air oven drying is not suitable for on-farm use. Oven drying can be used for samples of any moisture content.

Principle

Water is evaporated from a forage sample by placing the sample in an oven at high temperature. The sample is left in the oven until it reaches a constant weight. The difference in the weight of the sample before and after drying is assumed to be water weight.

Method

According to the Association of Official Analytical Chemists (AOAC), there are two accepted procedures for plant or feed samples. In both methods, the samples are frozen and then ground through a 0.04-inch screen to obtain a fine mixture. In the first method, a subsample containing about 2 grams of dry matter (about 10 grams wet weight) is dried in a covered aluminum dish at 203–212°F under a vacuum of less than 4 inches mercury, or 1.9 pounds per square inch. Drying time is approximately 5 hours. For feeds high in molasses, the temperature is reduced to 158°F and the vacuum lowered to 2 inches mercury to prevent loss of volatile compounds with the water. The lower temperature increases drying time.

The second method is similar except the samples are dried in a forced-air oven at a temperature of 275°F without covers on the aluminum dishes. Drying time is reduced to about 2 hours.

Other common procedures (not AOAC methods) are drying in conventional forced-air ovens at 219°F for 24 hours or at 140°F for 72 hours. Typically these procedures are used with larger samples (more than 10 grams of dry matter) that may not be ground or may be used for chemical analysis after drying. If the sample is not ground, sample sizes of at least 100 grams are recommended.

A common practice in commercial laboratories is a two-step procedure. An unground sample is dried overnight at 140°F for a preliminary moisture value. Then the dried sample is ground and a subsample is analyzed for remaining moisture. This final moisture is determined either by oven drying at 275°F for 2 hours or by near infrared spectroscopy (see page 22).

Accuracy

Oven procedures vary widely because each has its limitations. First is the problem of evaporating all the water from the sample. Although free water is completely removed, the amount of mechanically trapped water varies with oven temperature. At 140°F, the sample may contain 2–5% moisture, most of which is mechanically trapped. At 212°F, much of the mechanically trapped water will be evaporated, but bound water remains. At 275°F, all of the mechanically trapped water will be evaporated, and significant amounts of the bound water will be removed.

Although higher temperatures remove more water, they also cause a greater loss of volatile nonwater compounds including ammonia, ethanol, and organic acids such as acetic and propionic acids. Even at 140°F some of these compounds will be lost during drying. If the dried sample will be used for further chemical analysis, drying above 140°F may affect the measurement of sugar and nitrogen contents because of chemical reactions occurring during drying.

For most samples, drying at around 212°F gives reasonably accurate results (±1 percentage point). The water not evaporated is approximately matched by the nonwater compounds that are lost from the sample. However, for feeds high in molasses or for silages, the loss of volatile organic compounds results in measured moisture contents that are higher than actual values. In these cases, oven temperatures of 140–160°F and drying times of up to 3 days are necessary to approximately balance the moisture retained with the nonwater compounds lost by drying.

Given these inaccuracies, it may be surprising that oven drying is the usual method for moisture determination in commercial and research laboratories. However, the method is relatively inexpensive and repeatable, and it requires no toxic chemicals or hazardous procedures. Furthermore, the accuracy is acceptable for all but a few research studies. For the foreseeable future, vacuum or forced-air oven drying will probably remain the method of choice for most laboratory determinations of forage moisture content.

Toluene Distillation

Moisture content of silage as determined by oven drying may be too high because volatile compounds, such as acetic acid, propionic acid, butyric acid, ethanol, ammonia, and to some extent lactic acid, can be lost during drying. A more accurate method of moisture measurement in silage is toluene distillation. It can be used for samples of up to 90% moisture content.

Principle

In this method, the sample is covered with toluene (methyl benzene, $C_6H_5CH_3$) and heated to boiling (231°F) on a hot plate. (Toluene will not mix with the sample but will rest above the sample like oil on water.) Both water and toluene evaporate and rise into a condenser, where both gases are cooled, condense to the liquid state, and fall into a receiving tube (figure 3.1). In the receiving tube, the toluene floats on top of the water. After all the water is removed from the forage sample, the water volume in the receiving tube is read.

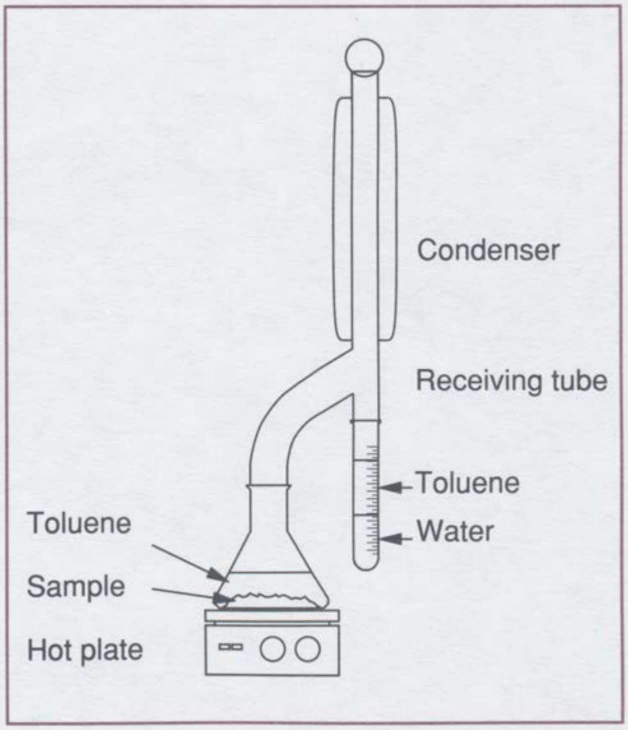

Figure 3.1. Toluene distillation apparatus.

Method

The AOAC method for toluene distillation calls for a sample size that will contain 0.07–0.17 fluid ounce of water (0.1–0.7 ounce wet weight). The sample is covered by 2.5 fluid ounces of toluene. The mixture is brought to a boil, and the hot plate is adjusted so that approximately 2 drops of condensed liquid per second fall into the receiving tube. When most of the water has been transferred to the receiving tube, the heating is increased to double the evaporation rate. After about an hour, distillation is complete. The condenser is rinsed with toluene to flush any remaining droplets of water into the receiving tube. After cooling, the water volume in the receiving tube is read.

Accuracy

The amount of water remaining in the sample with this technique is very small and constitutes an insignificant error. The largest error in this method comes from volatile compounds such as acetic acid, other volatile acids, ethanol, or ammonia leaving the sample and ending up in the condensed water, resulting in moisture values that are too high. The error for silages is typically 0.5–1.5 percentage points of moisture. The AOAC method offers no correction for the error, but the condensed liquid can be titrated with acid to estimate the error. A portion of the condensed water is added to 4 parts ethanol and titrated to pH 8.3 with 0.1 Normal sodium hydroxide. The volume of sodium hydroxide required to titrate all of the condensed water is multiplied by a correction factor (0.0055) and subtracted from the water volume to correct for the presence of volatile compounds. This correction usually provides an accurate measurement of moisture in silages. Only in rare cases, where silages have abnormally high ammonia or ethanol contents, will the measurement along with the correction for volatiles be substantially in error.

In most cases, toluene distillation can provide accurate measurements of moisture content (±1 percentage point) in silages provided a correction is made for volatile compounds in the condensed water. Without this correction, accuracies of moisture determination are similar to those from vacuum or forced-air oven drying. Because of cost and safety, this procedure is not warranted for other types of forage and feed samples, which are best measured through oven-drying techniques.

Safety

The major problem with this method is working with and disposing of the toluene. The vapor is irritating to eyes and lungs. The liquid is easily absorbed through skin and has various toxic effects on humans, although it is not a known carcinogen. Toluene is highly flammable; normal disposal is through incineration. Precautions in handling toluene are necessary.

Near Infrared Spectroscopy

The use of near infrared (NIR) spectroscopy for quality analysis of forages has gained wide acceptance in the past 10 years. The advantages of NIR analysis include rapid measurement, high accuracy, minimal sample preparation, and simplicity of operation and analysis. In some commercial laboratories, silage moisture content is determined by drying in a forced-air or vacuum oven at 140°F overnight to about 30% moisture, followed by NIR spectroscopy to determine the remaining moisture. This combined procedure reduces drying time and minimizes loss of volatile compounds such as ammonia which may be of interest in subsequent analysis. NIR spectroscopy can be used for samples of up to 40% moisture content.

Principle

NIR spectroscopy is based on the fact that different compounds absorb electromagnetic radiation at different wavelengths. Visible light has wavelengths in the range of approximately 400–750 nanometers (1 nanometer is a billionth of a meter). Light at 400 nanometers is violet, and at 750 nanometers is red. Just beyond the red wavelength is NIR radiation, whose wavelength ranges from 750 to 2,600 nanometers. Within the NIR region are two "water absorption" bands, 1,400–1,450 and 1,900–1,950 nanometers, in which the absorption of radiation by a sample is highly dependent on its moisture content. Radiation at these wavelengths causes the chemical bonds within water molecules to vibrate, which therefore absorb the energy in the radiation. With more water present, more energy is absorbed.

NIR spectroscopy does not measure moisture content directly. Rather, it measures NIR absorption which can be related to moisture content as determined by forced-air or vacuum oven drying. The development of a relation between NIR absorption and moisture content is called calibration. In calibration, a set of about 100 samples of known moisture content are scanned by NIR radiation, and then a mathematical equation is developed that describes the data for moisture content versus NIR absorption. With this equation, the NIR absorption of a new sample can be used to estimate its moisture content.

There are two crucial requirements in developing a calibration equation. First, the error in the reference technique (oven drying) must be low. Second, the set of samples used in calibration must be representative of the population of samples in which moisture content will be determined. For example, different calibration equations are needed for corn and alfalfa.

Central to the NIR system is the spectrometer. It uses optical filters or prisms or gratings to disperse light from a tungsten illumination source into light of a narrow wavelength. By changing the filter or moving the prism or grating, a different wavelength is obtained. The result is that a narrow band of wavelengths, almost monochromatic (single-wavelength) light, is emitted from the spectrometer. This light interacts with the sample and is then collected by a sensing detector, which is usually made of lead sulfide or silicon (figure 3.2). A computer controls the wavelength mechanism, records the data from the detector, and analyzes the data to determine moisture content.

Method

Just before irradiation, the forage samples are ground in a Udy cyclone mill or a Wiley mill with a 1-millimeter opening screen, and a subsample of 1–5 grams is placed in a cylindrical container about 1.5 inches in diameter and 0.38 inch high. The container (or "cell") is capped on one end with a quartz window which transmits NIR radiation, the other end with a rubber or paper stopper. The sample is then placed under the spectrometer, which emits NIR radiation.

Upon striking the sample surface, the radiation either is reflected back at random directions or penetrates the surface and interacts with the material (figure 3.3). It is the penetrating radiation which can be absorbed by water molecules. This

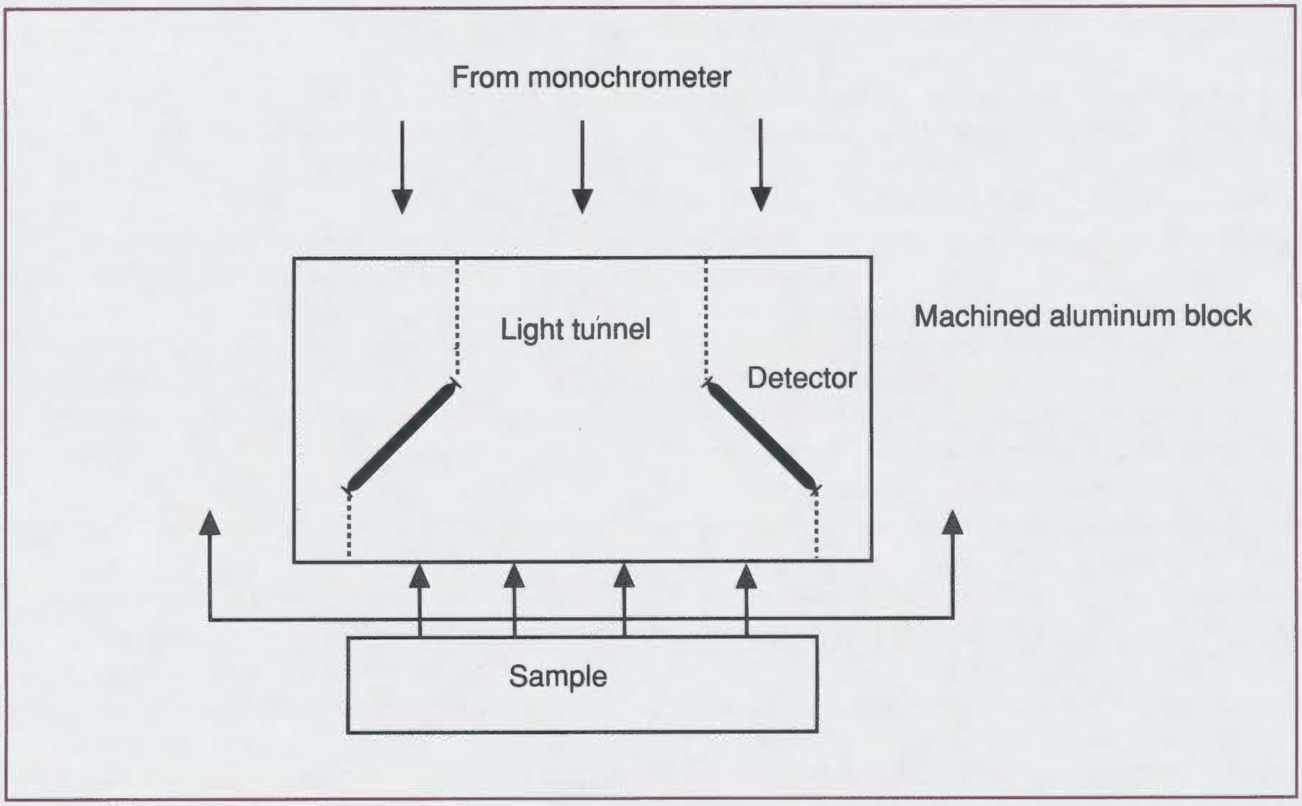

Figure 3.2. Typical layout for diffuse reflectance measurement assembly.

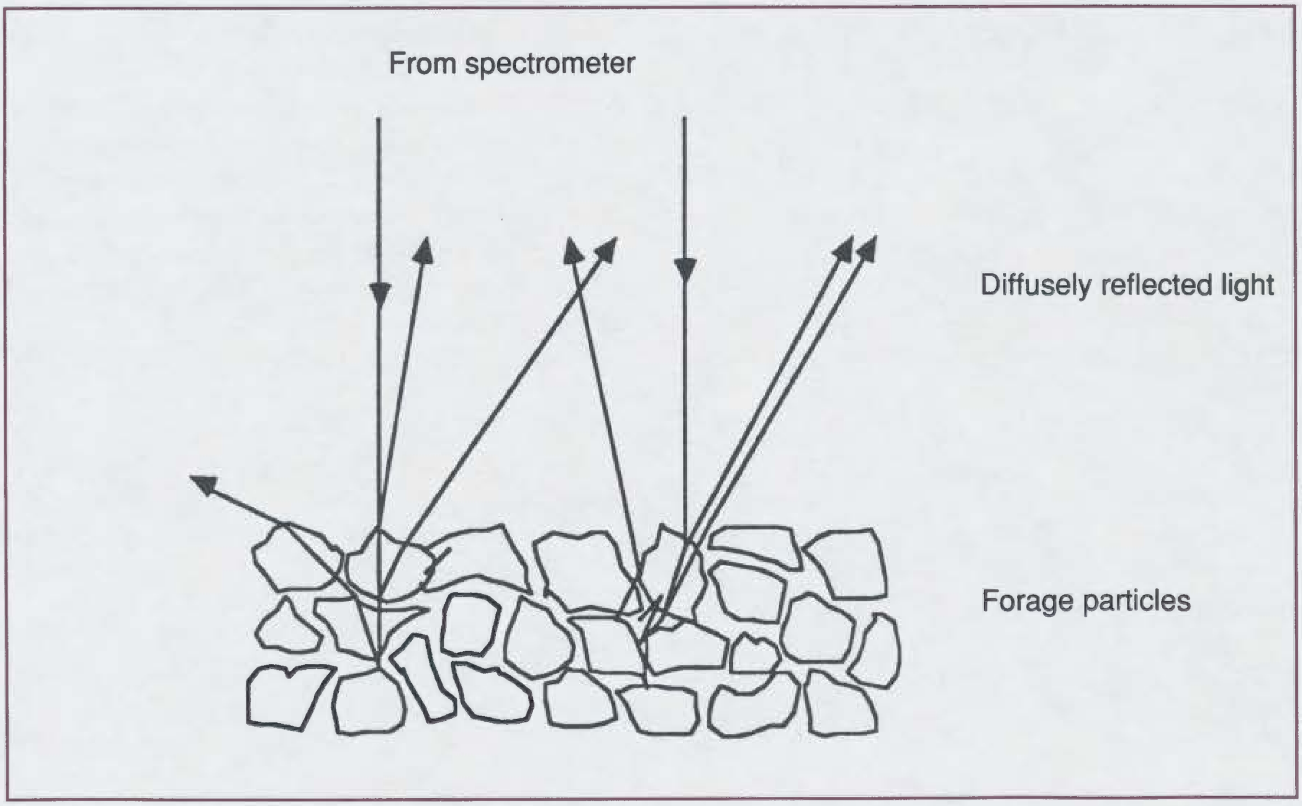

Figure 3.3. Representation of the light-particle interaction.

radiation is bent, leaves the particle, enters the pores between particles, encounters other particles, and eventually may escape the sample and be picked up by a detector near the sample.

The detector measures the energy of the radiation that is reflected from the sample. Sample reflectance is the energy measured by the detector relative to that for a ceramic reference disk. Then, in order to make the sample readings proportional to the level of moisture, the absorbance of the sample is calculated from the reflectance (absorbance equals the negative of the logarithm of the reflectance). Figure 3.4 shows an example curve for the absorbance of a forage sample scanned over a range of wavelengths. Sample A is at 4% moisture content, sample B at 10% moisture. The two curves are nearly identical except in the water absorption regions (1,400–1,450 nanometers, 1,900–1,950 nanometers). To accentuate the differences between the two curves, the data are further processed by calculating their curvature, or rate of change of slope (figure 3.5). The curvature graphs are commonly used to calibrate and predict moisture content.

Accuracy

Moisture content determinations and other forage measurements from NIR spectroscopy can be very accurate if the following conditions are met:

1. A large enough number of forage samples, representative of the samples to be tested, must be used in calibration.
2. The oven-drying method used in determining the moisture content of the calibration samples must be highly accurate.
3. All samples must be ground in the same way.
4. All samples must be packed at the same density.
5. Stray light from sources other than the spectrometer must be eliminated.
6. The spectrometer must be periodically monitored to ensure the same wavelengths are being emitted.
7. The sample cells must be clean and the samples uncontaminated by foreign matter.

NIR spectroscopy is an accurate and rapid method of determining forage constituents, including moisture content. Although currently too expensive for individual use, costing tens of thousands of dollars, recent developments in optically tuned diodes could lead to a portable NIR-based instrument selling for less than $5,000.

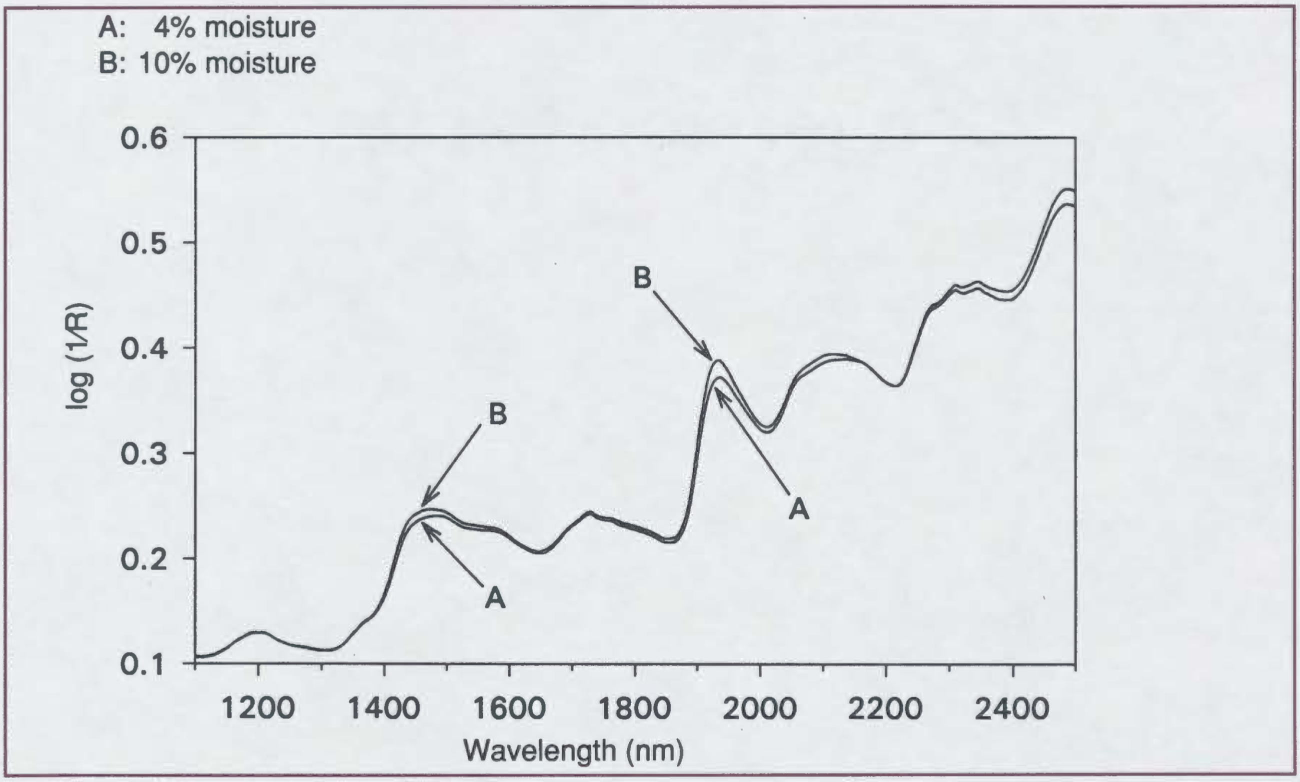

Figure 3.4. NIR spectra of ground alfalfa at two moisture contents.

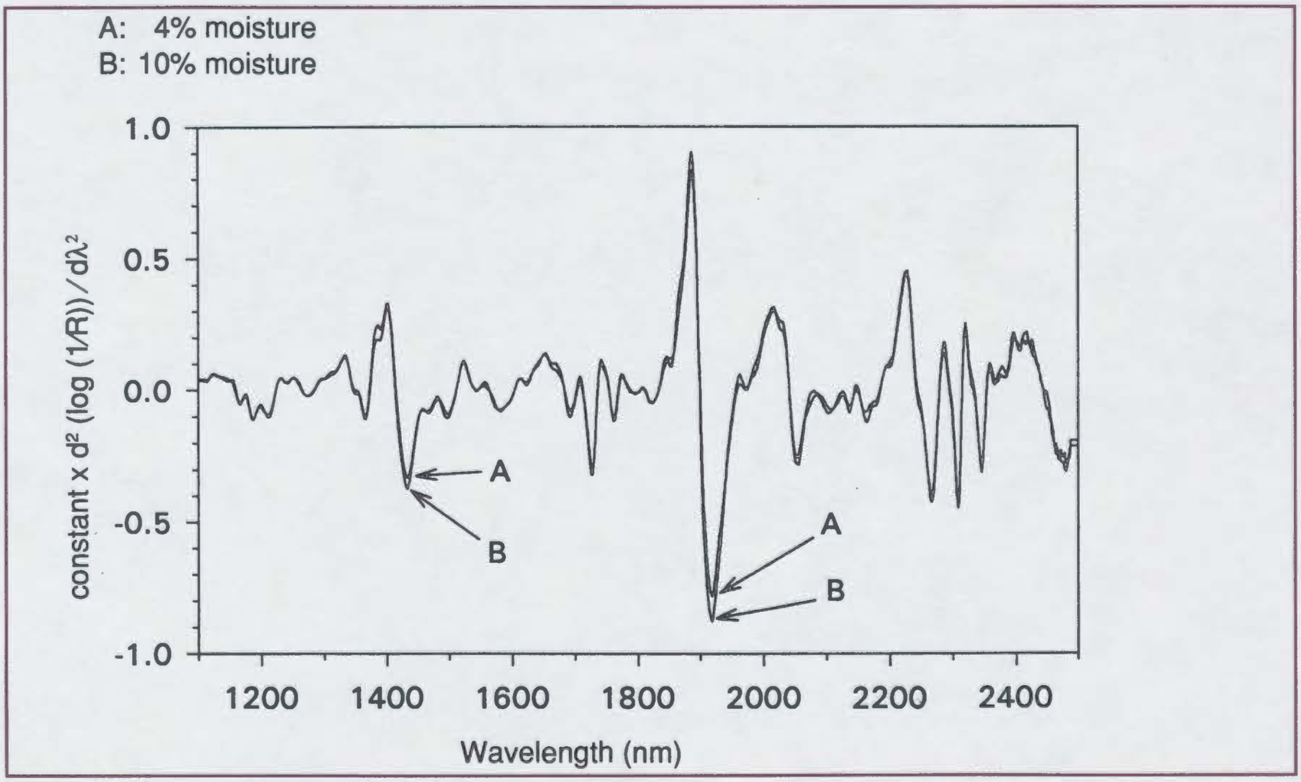

Figure 3.5. Curvature of the NIR spectra of ground alfalfa at two moisture contents.

Conversion Factors

	U.S. Customary Units		SI/Metric Units	Multiply by
Length	inches	to	centimeters	2.54
	feet	to	meters	0.305
	yards	to	meters	0.914
Weight	ounces	to	grams	28.3
	pounds	to	kilograms	0.454
	tons	to	kilograms	907
Volume	pints	to	liters	0.473
	quarts	to	liters	0.946
	gallons	to	liters	3.79
Pressure	pounds per square inch	to	pascals	6,895
Temperature	degrees Fahrenheit	to	degrees Celsius	$\frac{5}{9}$ (°F – 32)

Glossary

Absorbance. Logarithm of 1 divided by the reflectance of a sample.

Accuracy. The closeness of a measured value to the true value.

Average. The sum of a set of data points divided by the number of data points.

Calibration. Establishment of the relation between an electrical measurement and a physical quantity such as moisture content.

Capacitance. The electrical charge needed to develop a given voltage across two parallel plates.

Composite sample. A sample of forage taken from a group of subsamples mixed together.

Conductance. The ease with which a material conducts electricity.

Dielectric. A material that changes capacitance when it is inserted between two electrically charged plates.

Fermented feed. Forage and high-moisture corn preserved by lactic acid bacterial action in a silo.

Hertz. The frequency with which electrical current alternates. One Hertz = one cycle per second.

Lot. 1. All the forage from a single day's cutting. 2. A single species or known mixture harvested from a specific field.

Mean. Average.

Microwave radiation. Electromagnetic radiation with wavelengths of 0.001 to 0.1 meters.

Nanometer. One billionth of a meter.
25.4 million nanometers = 1 inch.

Near infrared (NIR) radiation. Electromagnetic radiation with wavelengths in the range of 750–2,600 nanometers.

Pascal. A unit of pressure.
6,895 pascals = 1 pound per square inch.

Population. The collection of all members of a group; for example, all forage samples to be tested.

Reflectance. The near infrared energy diffusely reflected from a sample, divided by the energy reflected from a ceramic disk.

Repeatability. The tendency to obtain similar results when a test is repeated several times with the same sample.

Representative sample. A sample whose composition is truly typical of the population from which it is taken.

Sample. A subgroup or member selected from a population.

Standard deviation. A measure of variability in test data. Normally 68% of observation values fall within ±1 standard deviation from the mean.

Subsample. A small amount of forage taken from a lot of forage to be moisture tested.

Toluene. A chemical used to boil water from a forage sample.

Watt. A unit of power output or input.
746 watts = 1 horsepower.

Comparison of Methods for Determining Forage Moisture Content

Method	Operating Principle	Moisture Range	Sample Size	Testing Time	Typical Error
On-Farm Methods					
Microwave oven	Drying	20–100%	50–200 grams	5–15 minutes	-2 to +1%
Koster tester	Drying	20–90%	2 pounds	30 minutes	±3%
Electronic moisture meters for silage	Electrical conductance or capacitance	alfalfa: 25–78% corn: 35–80%	0.5–2 pounds	4 minutes	±8%
Delmhorst moisture meter for hay	Electrical conductance	5–50%	Bale or swath	1 minute	±5%
Laboratory Methods					
Conventional oven	Drying	0–100%	10–1,000 grams	5 hours–3 days	±1%
Toluene distillation	Boiling	0–90%	0.1–0.7 ounce	2 hours	±1%
Near infrared spectroscopy	Electromagnetic properties	0–40%	1–5 grams	1 hour	±3%

References

Dewar, W. A., and McDonald, P. "Determination of Dry Matter in Silage by Distillation with Toluene." *Journal of the Science of Food and Agriculture* 12 (1961): 790-795.

Farmer, G. S., and G. H. Brusewitz. "Use of Home Microwave Oven for Rapid Determination of Moisture in Wet Forages." *Transactions of the American Society of Agricultural Engineers* 23:170-172. St. Joseph, Michigan: American Society of Agricultural Engineers. 1980.

Henson, W. H., Jr., G. M. Turner, M. Collins, and O. J. Yeoman. *Electrical Measurement of the Moisture Content of Baled Alfalfa Hay.* ASAE Paper 87-1073. St. Joseph, Michigan: American Society of Agricultural Engineers. 1987.

Holland, C., and W. Kezar, eds. *Pioneer Forage Manual—A Nutritional Guide.* Des Moines, Iowa: Pioneer Hi-Bred International. 1990.

Hunt, W. H., and S. W. Pixton. "Moisture—Its Significance, Behavior and Measurement." In: Christensen, C.M., ed. *Storage of Cereal Grains and Their Products.* 2nd edition. St. Paul: American Association of Cereal Chemists. 1974.

Jones, C. E. "Animal Feed." In: Williams, S., ed. *Official Methods of Analysis of the Association of Official Analytical Chemists.* 14th ed. Arlington, Virginia: Association of Official Analytical Chemists. 1984.

Marten, G. C., J. S. Shenk, and F. E. Barton, eds. *Near Infrared Reflectance Spectroscopy (NIRS): Analysis of Forage Quality.* Agriculture Handbook No. 643. Washington, DC: U.S. Department of Agriculture. 1985.

Norris, K. H., R. F. Barnes, J. E. Moore, and J. S. Shenk. "Predicting Forage Quality by Infrared Reflectance Spectroscopy." *Journal of Animal Science* 43 (1976): 889-897.

Pitt, R. E. *Silage and Hay Preservation.* NRAES-5. Ithaca, New York: Northeast Regional Agricultural Engineering Service. 1990.

Prairie Agricultural Machinery Institute (PAMI). *Delmhorst F-4 Forage Moisture Tester.* Report No. E0678C. Portage la Prairie, Manitoba: PAMI. 1981.

———. *Dickey-John Forage Moisture Tester.* Report No. E0678D. Portage la Prairie, Manitoba: PAMI. 1981.

———. *Froment NJF 1210 Forage Moisture Tester.* Report No. E0678A. Portage la Prairie, Manitoba: PAMI. 1981.

———. *Koster Forage Moisture Tester.* Report No. E0678B. Portage la Prairie, Manitoba: PAMI. 1981.

Wetzel, D. L. *Near-Infrared Reflectance Analysis—Sleeper among Spectroscopic Techniques.* Analytical Chemistry 55 (1983): 1165A-1176A.

Williams, P. C. and K. H. Norris, eds. *Near-Infrared Technology in the Agricultural and Food Industries.* St. Paul: American Association of Cereal Chemists. 1987.

Windham, W. R., F. E. Barton, and J. A. Robertson. "Moisture Analysis of Forage by Near Infrared Reflectance Spectroscopy: Preliminary Collaborative Study and Comparison between Karl Fischer and Oven Drying Reference Methods." *Journal of the Association of Official Analytical Chemists* 71(2): 256-262. 1987.

Windham, W. R., J. A. Robertson, and R. G. Leffler. "A Comparison of Methods for Moisture Determination of Forages for Near Infrared Spectroscopy Calibration and Validation." *Crop Science* 27 (1987): 777-783.

NRAES–59

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