Wet vs Dry Basis Moisture Content Relationships

Preamble

This is a stand-alone version of Appendix B published in Measuring Biomass, Nutrient Utilization, and Yield in a Maize Crop Part II. The purpose was to describe, in general, different expressions wet and dry basis moisture content in relation to agricultural commodities. Reading Maize Part II isn't a prerequisite but we recommend it as a worked example using grain and stover is provided therein (link).

Moisture Content Determination: Why and How?

Moisture is a major constituent of many agricultural materials and food products. Moisture content is a critical factor in food quality, marketing, preservation, and exposure to deterioration. Determination of moisture content is necessary to quantify the amount of other constituents, commonly referred to as "dry solids", on a standard basis. Dry solids include things like crop stover (mostly structural carbohydrates and some mineral matter), and grain (mostly starch, lipids, some protein and minerals), two constituents commonly referenced in commodity marketing channels.

Moisture content can be defined as the quantity of water present in a moist material. The terms "moisture" and "water" are generally used interchangeably. Here, we reserve the term "water" for the substance H_2O, and "moisture" as H_2O that is absorbed by, or diffused in, a moist substance. That substance could be anything: food, soil, wood, fertilizer, etc.

Moisture content can be expressed two ways:

- Wet basis (*wb*)
- Dry basis (*db*)

Wet basis moisture content is the amount of water per unit mass of a moist substance, defined as:

$$MC_{wb} = \frac{mass\ of\ water}{mass\ of\ moist\ substance} \qquad [B1]$$

where MC stands for moisture content, and the subscript wb designates "wet basis".

Dry basis moisture content is the amount of water per unit mass of dry solids:

$$MC_{db} = \frac{mass\ of\ water}{mass\ of\ dry\ solids} \qquad [B2]$$

where subscript db designates "dry basis". Mass of dry solids means moisture-free, as in oven dry or "bone dry". Note that in Equations [B1] and [B2], the numerators are the same, but the denominators are different. In practice, terms MC_{db} and MC_{wb} may be unspecified, appearing simply as "% MC" or equivalent. Right side of Equations [B1] and [B2] tell the difference.

In the case of moisture content dry basis (MC_{db}), the denominator *mass of dry solids* represents a single, undifferentiated, variate, "dry solids". Whereas, the denominator in moisture content wet basis (MC_{wb}) has two variates, *mass of water* (H_2O), plus *mass of dry solids*.

$$MC_{wb} = \frac{mass\ of\ water}{mass\ of\ water + mass\ of\ dry\ solids} \qquad [B3]$$

Mathematically, this can be denoted as:

$$MC_{wb} = \frac{m_w}{m_w + m_d} \qquad [B4]$$

Where m_w and m_d symbolize the mass of water and mass of dry solids, respectively.

Wet and dry basis moisture content are different, but related, quantities. The relationship can be deduced mathematically by dividing the numerator and denominator in Equation [B4] by m_d, the *mass of dry solids*:

$$MC_{wb} = \frac{\frac{m_w}{m_d}\{MC_{db}}{MC_{db}\}\frac{m_w}{m_d} + \frac{m_d}{m_d}} \qquad [B5]$$

This creates a new expression with MC_{db} present in both numerator and denominator, because $MC_{db} = m_w/m_d$ by Equation [2]. The term m_d/m_d in the denominator cancels out, which is unity, symbolized by 1:

$$MC_{wb} = \frac{MC_{db}}{MC_{db} + 1}$$

This can be re-written as:

$$MC_{wb} = \frac{MC_{db}}{1 + MC_{db}} \qquad [B6]$$

Equation [B6] expresses wet basis moisture content in terms of dry basis.

Similarly, we can express dry basis moisture content in terms of wet basis:

$$MC_{db} = \frac{MC_{wb}}{1 - MC_{wb}} \qquad [B7]$$

This inversion can be obtained by dividing the numerator and denominator as in Equation [B5] using m_{ms}:

$$MC_{db} = \frac{m_w}{m_d} = \frac{m_w}{m_{ms} - m_w} = \frac{m_w}{m_w + m_d - m_w}$$

$$MC_{db} = \frac{\frac{m_w}{m_w+m_d}}{\frac{m_w+m_d}{m_w+m_d} - \frac{m_w}{m_w+m_d}} = \frac{MC_{wb}}{1 - MC_{wb}}$$

where m_{ms} represents the mass of two variates $m_w + m_d$ from Equation [B4].

The denominator for moisture content wet basis, $1+MC_{db}$ returns a value *greater than* the numerator. Whereas, the denominator for moisture content dry basis, $1-MC_{wb}$ returns a value *less than* the numerator. This means that moisture content wet basis always has fractional values from 0-1 (0-100%)

whereas dry basis moisture content can have values >1 (>100%). For the same set of values, moisture content dry basis is always greater than moisture content wet basis. Let's illustrate the interconversion of wet and dry basis moisture content by example.

Example 1. The moisture content of a sample was determined to be 80% wet basis. What is the dry basis moisture content?

Solution. Dry basis moisture content is given by:

$$MC_{db} = \frac{MC_{wb}}{1 - MC_{wb}}$$

First, convert mass percentage to a decimal fraction before substituting in the equation.

$$MC_{db} = \frac{0.8}{1 - 0.8}$$

$$MC_{db} = \frac{0.8}{0.2}$$

$$MC_{db} = 4 \times 100 = 400\%$$

This means the mass of water present in the sample is 4× the mass of dry solids, i.e. MC_{db} is a percentage equivalent of a ratio.

Example 2. Convert 60% dry basis moisture content to wet basis.

Solution. Wet basis moisture content is given by:

$$MC_{wb} = \frac{MC_{db}}{1 + MC_{db}}$$

Again, convert mass percentage to a decimal fraction before substituting in the equation.

$$MC_{wb} = \frac{0.6}{1 + 0.6}$$

$$MC_{wb} = \frac{0.6}{1.6}$$

$$MC_{wb} = 0.375 \times 100 = 37.5\%$$

This shows that 60% dry basis moisture content equals 37.5% wet basis, which is the fractional water content of the moist sample.

How does the interconversion of wet and dry basis moisture content relate to agricultural materials?

In Maize Part II we defined a bushel of maize grain as weighing 56 lbs., with a wet basis moisture content of 15.5%. What is the mass weight of dry grain?

Solution. If 56 lbs. equals 100% of the mass weight of a bushel, the percentage of dry solids is 100 -15.5 = 84.5%. The amount of dry grain in a bushel is therefore:

$$56\,lbs\,grain \times .845 = 47.32\,lbs\,dry\,grain$$

Thus, each bushel of maize grain contains exactly 47.32 lbs. "bone dry" solids, and 56 - 47.32 = 8.68 lbs. water (H_2O).

What is the % moisture content of a bushel of maize grain expressed on a dry basis?

Solution. We know that, by definition, a bushel of maize grain has a wet basis moisture content of 15.5%. The conversion to dry basis is given by:

$$MC_{db} = \frac{MC_{wb}}{1 - MC_{wb}}$$

$$MC_{db} = \frac{0.155}{1 - 0.155}$$

$$MC_{db} = \frac{0.155}{0.845}$$

$$MC_{db} = 0.183 \times 100 = 18.3\%$$

Note that moisture content dry basis is greater than moisture content wet basis, so it's a reasonable solution in accordance with Equations [B6] and [B7]. This means that each pound of dry grain contains 0.183 lb. water. If a bushel of grain contains 47.32 lbs. dry grain, how much water would have to be added back to obtain 15.5% wet basis moisture content?

Solution.

$$47.32 \times .183 = 8.68\,lbs\,of\,water$$

$$47.32 + 8.68 = \frac{56\,lbs\,grain}{bushel}$$

This aligns perfectly with Equation [B3]:

$$MC_{wb} = \frac{mass\ \ of\ water}{mass\,of\,dry\,solids + mass\,of\,water}$$

$$MC_{wb} = \frac{8.68\,lbs\,water}{47.32\,lbs\,dry\,solids + 8.68\,lbs\,water}$$

$$MC_{wb} = \frac{8.68\,lbs\,water}{56\,lbs\,moist\,solids}$$

$$MC_{wb} = 0.155 \times 100 = 15.5\%$$

In conclusion, the following points are emphasized:

- Moisture content can be expressed two ways, wet basis and dry basis.
- Wet and dry basis moisture content are interconvertible, but are not the same thing.
- Moisture content dry basis can be greater than 100%.
- If wet or dry basis moisture content is not specified, ask. Every discipline has its preferred usage.
- Generally, wet basis moisture is used to describe the water content of agricultural materials and food products.

We hope the foregoing account will enable the reader to distinguish wet and dry basis moisture content and better understand their relationship. The symbology of variates in Equations [B1] and [B2] may differ, depending on usage, but this shouldn't alienate their unique properties.

Hmm...What Did You Say?

The agronomic literature brims with technical jargon, sometimes redundant, often arcane. Take heart. Here's a list of common terms for agricultural mass- and moisture-determining processes including their definition and principle usage.

Air-dry: The mass of a substance in equilibrium with a well ventilated, indoor atmosphere. Most agricultural materials are *hygroscopic*, tending to exchange moisture with the atmosphere depending on factors like chemistry, water vapor pressure, seed coatings, among others. Mainly this procedure is utilized to deactivate microorganisms to prevent decomposition of fresh material before further processing. Not to be confused with sun-drying, which occurs outdoors.

Biomass: In agriculture, the organic materials built up by plants through photosynthesis, and by livestock through feeding activity. Crop biomass can be separated into different fractions, e.g. leaves, stems, roots, fruit, or simply referenced in aggregate.

Bushel: In the US, agronomic yields of grain crops are measured in bushels (bu), which are units of mass that vary among crops (Table B1). Originally, the bushel was a unit of volume measurement created by the Celtic peoples to ensure fair trade. Today, the bushel is identified on a standard weight and moisture basis to facilitate trading of grains. Globally, units of tons and metric tons are referenced and traded. These units do not vary among crops, nor are they tied to any standard moisture content. The bushel is not a scientific unit of mass. As such, it must be converted to other units (lbs., kg., tons) before using in scientific calculations.

Table B1. Bushel weight and moisture specifications for different crops.

Crop	Bushel weight, lbs.	Specified moisture, %	Lbs. at 0% moisture
Corn	56	15.5	47.32
Soybean	60	13	52.2
Wheat	60	13.5	51.9
Barley	48	14.5	41.04
Oat	32	14	27.52
Rye	56	14	48.16

Source: Reese and Carlson, 2017.

Dry matter: The solid mass of a substance when completely dried, abbreviated DM or D.M. It is calculated as:

$$100\% - \%\, Moisture = \%\, Dry\, Matter$$

Dry matter basis: The proportion of total dry matter in a substance. Dry matter basis of 100% means 0% water is present (impossible to achieve in most cases). There are different usages for dry matter basis. Typically, it is used to compare the nutritional value of animal foods, particularly those tending to have high moisture content like forages. Alternatively, it is used to specify relative dry matter content assuming some water is present. For example, if a document states that mass weight is expressed on a 84.5% dry matter basis, it means the moisture content is 15.5%.

Dry weight: The mass of a substance with all water removed. Sometimes used interchangeably with dry matter (DM), dry solids (DS), total solids (TS).

Grain: The harvested seed of grasses such as maize, wheat, oats, barley. Globally, these are known a cereals. The seed, or fruiting body, of grasses is referred to botanically as a *caryopsis*, a single-seeded fruit in which the ovary wall (pericarp) is attached to seed coat (integument). Grain seeds are capable of storing carbohydrates (mainly starch), lipids, protein, and minerals.

Mass: A fundamental measurement of how much matter a body contains. All three states of matter: solid, liquid, and gas, have mass that is independent of location. Mass is reported in units of grams or kilograms in the metric system.

Moisture content: Used to describe the quantity of water in a moist material. Wet basis describes the water content per unit moist or "fresh" material. Dry basis describes the water content per unit dry solids. Water is a major constituent of many agricultural materials and food products. As such, moisture content is determined at each point in the marketing channel, especially where ownership changes. Grain buyers are unwilling to pay extra $$ for water, sellers don't want to pay for pre-sale grain drying beyond what's needed to preserve food quality, and shippers are limited by weight restrictions.

Oven-dry: The mass of a substance after drying at standard temperature for a prescribed period of time or until a constant weight is achieved. The residual moisture content of 'oven-dry' material is solely dependent on the procedure specified for that material. Normally it is not possible to achieve 0% moisture without some degree of thermal mass decomposition (See ASABE 1988).

Solid: State of matter having definite shape and volume. Solids capable of dissolving in liquid water to form a solution (solutes) are called soluble or dissolved solids (sugar, salt). Those solids incapable of mixing with liquid water are called insoluble solids. Dry solids are solids with 0% moisture. Solids content may comprise a mixture of soluble and insoluble solids.

Stover: Stalks, leaves, cobs, husks left in the field after maize grain harvest (applies similarly to other crops). It is composed of structural carbohydrates like cellulose, hemicellulose, and lignin, and a small quantity of mineral matter. The percentage of stover left in the field may be large or small, depending on whether it is harvested for use as feed or bedding for livestock or feedstock for biofuels.

Water content: The proportion of the substance H_2O present in a material. Can be expressed on a gravimetric (mass per unit mass: m/m or w/w), or volumetric (mass per unit volume : m/v) basis.

Weight: Measurement of the gravitational force on a body. Weight depends on mass and location. For example, your body mass is the same no matter where you travel in the universe. Your weight, in contrast, changes from place to place depending on the force of gravitational acceleration. Sometimes we talk, imprecisely, about weight in grams or kilograms. Strictly speaking, weight should be measured in Newtons, the units of force.

Wet weight: The mass of a moist substance in its natural state without reference to moisture content. Also called fresh, moist, field moist, or 'as-is" weight.

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Prepared and written by:

Mr. Robert Walters, Engineering and Technology Applications Specialist | CPF Global Agronomics cpf-global@agrosphere-international.net

Published online April 12, 2023