

Equivalence Between Metric and U.S. Units for the Grain Industry

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Effective trading requires general agreement about units for weights and measures, whether for grain, processed foods, or any other commodity. Although this necessary agreement may be established within regions, uniformity is still lacking internationally, specifically between nations using imperial units (U.S. or British versions) and those who have adopted the International System of Units (*Systeme Internationale d'Unites*) (SI). This article answers some questions about the strange diversity of units. It also provides tables for conversion between metric and U.S. units (Tables I and II).

Examples in the grain industry include questions such as the difference between a “ton” and a “tonne.” Is a bushel a measure of volume or mass (weight)? Why and how does the size of the U.S. bushel differ between grain species? How large is a “section” in the United States? Why are there 100 pounds in the American hundredweight, but 112 pounds in the British hundredweight? The unit known as an “ounce” differs in quantity depending on whether it is a measure of mass or of volume; if volume, whether it is a dry or liquid measure; if weight, whether it is an ounce Troy, an Apothecaries’ ounce, or an ounce Avoirdupois! Finally, a unit that should interest grain scientists: What unit is a barleycorn?

The Metric System

Prior to the French Revolution of 1789, the familiar units of length in France were the *pied-de-roi* (king’s foot), *pouce*, and *perche*. These corresponded respectively to the British foot, inch, and perch, but the lengths were different for the corresponding French and British units. Even within France, the *pied-de-roi* varied in length. The Paris *pied* was 11% longer than the Strasbourg *pied* and 10% shorter than the Bordeaux *pied*. In 1790, the French *Academie des Sciences* set about producing a unified system of weights and measures (1). A pendulum system was initially proposed as the basis of the unit of length, as previously considered in collaboration with the Royal Society of Britain, whereby the *pendule* would be the length of a pendulum with a swing period of one second, leading to secondary units of *kilopendules*, *millipendules*, and *cubic pendules* (1).

Nevertheless, the *Academie des Sciences* decided upon the *metre* as one-ten millionth part of one-quarter of the earth’s meridian. The original package of units also included a 10-hour clock, a circle divided into 400 *grades* (still in limited use), and a republican calendar. The republican year started on September 22 (the equinox) with 12 renamed months (e.g., *Pluviose* for January, *Floreal* for April, *Thermidor* for July), each month being divided into three 10-day *decades*, plus a five-day annual

holiday (*fête*) (six days’ holiday in a leap year) (1). The package of changes met public resistance, plus some confusion, and in 1812, the government of the day proclaimed that the traditional system may be used in parallel with the new one. Nevertheless, many aspects of the new metric system survived and have gone on to acceptance in many countries, but not all.

Table I. Conversion from metric to U.S. units^a

Metric Units	U.S. Units
Mass	
1 gram (g)	= 0.0353 ounce (oz)
1 kilogram (kg)	= 2.205 pounds (lb)
1 tonne (t) (metric ton)	= 1.102 U.S. short tons (2,000 lb)
1 tonne	= 0.9843 U.S. long ton (2,205 lb)
22.68 kg	= 1 U.S. bag of grain (50 lb)
1 quintal (q) (100 kg)	= 220.5 pounds
Volume	
1 cubic centimeter (cc)	= 0.0610 cubic inch
1 milliliter (mL)	= 0.3382 fluid ounce
1 liter (L)	= 0.2642 U.S. liquid gallon
1 hectoliter (hL)	= 26.42 U.S. liquid gallons
1 hectoliter	= 2.838 U.S. bushels
1 liter	= 0.02838 U.S. bushel
Bulk Density	
1 kilogramme/hectolitre	= 0.7770 pound/U.S. bushel
Grain Yield	
1 quintal/hectare	= 0.79 U.S. cwt/acre
0.1235 tonne/hectare	= 1 bag/acre
6.73 tonnes/hectare	= 100 bushels/acre for wheat
1 tonne/hectare (t/ha)	= 7.92 bushels/acre for oats
1 tonne/hectare	= 11.89 bushels/acre for barley
1 tonne/hectare	= 13.87 bushels/acre for maize
1 tonne/hectare	= 13.87 bushels/acre for rye
1 tonne/hectare	= 14.86 bushels/acre for wheat
Temperature	
0°C (Celsius)	= 32°F (Fahrenheit)
20°C	= 68°F
100°C	= 212°F
Length	
1 centimeter (cm)	= 0.3937 inch (in)
1 meter (m)	= 3.2808 feet (ft)
1 meter	= 1.094 yards (yd)
1 kilometer (km)	= 0.6213 mile
Area	
1 square centimeter (cm ²)	= 0.1550 square inch (in ²)
1 square meter (m ²)	= 10.76 square feet
1 square meter	= 1.196 square yards
1 square meter	= 0.0002471 acre (ac)
1 hectare	= 2.471 acres
1 hectare	= 0.00386 square mile
Power	
1 kilowatt (kW)	= 1.341 horsepower (hp)
Energy	
1 joule (J)	= 0.239 calorie (cal)
1 kilojoule (kJ)	= 0.945 British thermal unit (BTU)

^a Adapted from Wrigley (3).

The 1790 initiative of the French *Academie des Sciences* included an approach to the king of England for British collaboration in this process, even though France and England were officially at war at the time. Perhaps this offer was not relayed to the English or perhaps it was rebutted at a high level. It was, however, a natural continuation of apparently cordial cooperation previously. The *Philosophical Transactions of the Royal Society* of 1742 record (as quoted by Freeman and unedited) (1):

“Some curious Gentlemen both of the ROYAL SOCIETY of London and of the ROYAL ACADEMY of SCIENCES at Paris, thinking it might be of good Use, for better comparing together the Success of Experiments made in England and in France, proposed some time since, that accurate Standards of the Measures and Weights of both Nations, carefully examined, and made to agree with each other, might be laid up and presented in the Archives both of the ROYAL SOCIETY here, and of the ROYAL ACADEMY of SCIENCES at Paris. Which proposal having been received with the general Approbation of both those Bodies, they were therefore

Table II. Conversion from U.S. to metric units^a

U.S. Units	Metric Units
Mass	
1 ounce	= 28.35 grams
1 pound (lb)	= 0.4536 kilogram (kg)
1 U.S. hundredweight (cwt) (100 lb)	= 45.36 kg
1 U.S. short ton	= 0.9072 tonne
1 U.S. long ton	= 1.016 tonnes
1 bag of grain (50 lb)	= 22.68 kg
Volume	
1 cubic inch	= 16.38 cubic centimeters
1 fluid ounce	= 29.57 milliliters
1 U.S. liquid gallon	= 3.785 liters
1 U.S. bushel	= 35.24 liters
1 quart (liquid)	= 0.9463 liter
Bulk Density	
1 pound/bushel	= 1.287 kg/hL
Grain Yield	
1 U.S. cwt/acre	= 1.265 quintals/hectares
1 bushel/acre for wheat	= 6.73 kg/ha
1 bushel/acre for maize	= 7.21 kg/ha
1 bushel/acre for rye	= 7.21 kg/ha
1 bushel/acre for barley	= 8.41 kg/ha
1 bushel/acre for oats	= 12.62 kg/ha
Temperature	
32°F (Fahrenheit)	= 0°C (Celsius)
68°F	= 20°C
212°F	= 100°C
Length	
1 inch (in)	= 25.4 millimeters (mm)
1 foot (ft)	= 0.3048 meter
1 yard	= 0.9144 meter
1 mile	= 1.6093 kilometers
Area	
1 square inch	= 645.2 square millimeters
1 acre	= 0.4047 hectare
1 square mile (1 “section”)	= 259.0 hectares
Power	
1 horsepower	= 0.7457 kilowatt
Energy	
1 calorie	= 4.187 joules
1 British thermal unit (BTU)	= 1.055 kilojoules

^a Adapted from Wrigley (3).

pleased to give the necessary Directions for the bringing the same into Effect.”

The International System of Units

The SI system of metric units (*Système Internationale d’Unités*) has developed as a result of successive General Conferences on Weights and Measures, starting in 1889, and continuing about every four years to the present, with worldwide representation. At the tenth such conference (in 1954), seven base units were adopted: the meter, the kilogram, the second, the ampere, the Kelvin (for temperature), the mole, and the candela (for luminous intensity). All other metric units are derived from these. At the eleventh such conference in 1960, the official symbol “SI” was allocated

Table III. SI prefixes to indicate the sizes of SI units, based on powers of ten

Factor	Prefix	Symbol
10 ²⁴	yotta	Y
10 ²¹	zetta	Z
10 ¹⁸	exa	E
10 ¹⁵	peta	P
10 ¹²	tera	T
10 ⁹	giga	G
10 ⁶	mega	M
10 ³	kilo	k
10 ²	hecto	h
10 ¹	deca	da
10 ⁻¹	deci	d
10 ⁻²	centi	c
10 ⁻³	milli	m
10 ⁻⁶	micro	μ
10 ⁻⁹	nano	n
10 ⁻¹²	pico	p
10 ⁻¹⁵	femto	f
10 ⁻¹⁸	atto	a
10 ⁻²¹	zepto	z
10 ⁻²⁴	yocto	y

for the *Système International d’Unités* as the “modernized metric system,” providing a practical system of units for unifying techniques for measurement used in industry, commerce research, and education (reviewed by Lentner) (2). The eleventh conference also confirmed prefixes (*pico-*, *nano-*, *micro-*, *mega-*, *giga-*, and *tera-*) to indicate powers of 10 as prefixes to the SI units. The expanded list of these is provided (Table III).

Imperial Units in Two Versions

If the Anglo-French cooperation of the eighteenth century had been successful a few centuries ago, it could have led to a more unified world today. The lack of uniformity of units was compounded by the spread of the earlier British imperial system to North America where it remained in its original form, despite a subsequent British revision of imperial units defined by the “British Weights and Measures Act” of 1824 (the “foot-pound-second” system). Continued use of the pre-1824 British system in the United States created the following differences between the British imperial system of 1824 and the U.S. customary system, adapted from Wrigley (3):

- One U.S. liquid gallon is 3.785 liters, smaller than the British gallon, dry or liquid (4.546 liters), the volume of 10 pounds (avoirdupois) of water at 62°F. British units of liquid capacity are thus about 20% larger than the corresponding American units.
- One U.S. dry gallon is 4.405 liters, one-eighth of a U.S. Winchester bushel.
- One U.S. “short ton” is 2,000 pounds (20 U.S. hundredweight [cwt], 907.2 kilograms), a “shorter” measure than the British “long ton” of 2,240 pounds (1,016 kilograms), made up of 20 British hundredweight of 112 pounds each.
- The U.S. hundredweight (45.36 kilograms) is 100 pounds (as the name suggests), significantly less than the British hundredweight of 112 pounds (50.80 kilograms). This anomaly has been explained by the changes incurred during the shipping of wool from Australia to Britain in the nineteenth century. Although bales of wool started as 100 pounds on the dry Australian sheep station, they gained moisture

during the long ocean voyage in the wool clippers to become 112 pounds on arrival in Britain. Evidently, the British mill owners preferred to change the definition of the hundredweight, rather than to pay for 12 pounds of water!

The word “ton” (pronounced “tun”) used in the British and U.S. systems is similar to the metric “tonne” (pronounced “ton” to rhyme with “Don”), also known as a “metric ton.” However, the ton (in its various forms) and the tonne are slightly different quantitatively (Tables I and II). One U.S. long ton is 1.016 tonnes (metric ton) and one U.S. short ton is 0.9072 tonne.

A barrel (dry) is 105 U.S. dry quarts (26.25 dry U.S. gallons) or 36 British gallons (liquid and dry are the same). A barrel of flour, sometimes in U.S. use, is 196 pounds. Otherwise, the mass of the U.S. barrel obviously depends on the commodity being measured. One U.S. liquid barrel is 31.5 U.S. gallons.

The U.S. bushel (35.24 liters), a dry measure of volume, is 2,150 cubic inches, 8 U.S. dry gallons, 4 pecks, or 32 dry quarts. The U.S. bushel differs from the British bushel (8 British gallons), which is 36.37 litres. The British bushel is thus about 3% larger than the U.S. bushel. The term “Winchester bushel” originated in Britain as a result of the choice of the city of Winchester by King Alfred the Great as the capital of his kingdom of Wessex in the ninth century; the term “Winchester measure” did not appear in British law until the seventeenth century. The “Winchester bushel” crossed the Atlantic and stayed on after the term was abandoned by the British in 1824.

The U.S. Bushel—Both Dry Volume and Mass

The U.S. bushel is primarily a measure of volume, but it has also become a measure of mass (weight); however, its weight differs for each of several grain species (Tables I and II). In the metric system, grain yield is measured in tonnes per hectare; that is, units of mass per unit of area. However, the U.S. tradition has been to measure yield in bushels per acre; that is, units of volume (originally not mass) per unit of area. The use of volume measurement units for grain in the United States makes it difficult to provide direct conversion between metric and U.S. units for grain yield. To overcome this problem, the U.S. government has defined the bushel for the following grains in terms of mass, irrespective of the true test weight:

- 1 bushel of wheat = 60 pounds
- 1 bushel of maize = 56 pounds
- 1 bushel of oats = 32 pounds
- 1 bushel of barley = 48 pounds
- 1 bushel of rye = 56 pounds

As a result, conversion factors for grain yields depend on the grain being considered. For wheat, 100 bushels/acre becomes 6,000 pounds per acre, equal to 2,723 kilograms per 0.4047 hectare, or 6.73 tonnes per hectare (Tables I and II). A rough “rule of thumb” for wheat is to take the yield in pound/acre and increase it by 10% to obtain an approximation of kilogram/hectare. Correspondingly, 1 tonne/hectare equates to 14.86 bushels/acre for wheat, 13.87 bushels/acre for maize, 7.92 bushels/acre for oats, 11.89 bushels/acre for barley, and 13.87 bushels/acre for rye.

Farmers use yet another measure of grain yield, namely “bags to the acre.” However, this colloquial and informal estimate of grain yield is difficult to define. The British bag measures three British bushels (0.1091 cubic meter), so a grain yield of 1 tonne per hectare is about 15 British bushels per acre and about 5 bags per acre. The U.S. bag is 50 pounds.

Temperature Units

Conversion is also needed for temperature—between Fahrenheit and Celsius (Centigrade). The two scales equate at about 40 degrees below the freezing point of water, but not at any other

temperature. Conversion from Celsius to Fahrenheit involves multiplying the temperature in degrees Celsius by nine, dividing the result by five, and adding 32. To convert from Fahrenheit to Celsius, deduct 32 from the temperature, multiply by five, and divide by nine.

The United States is actually officially on the metric system. All U.S. units are defined in terms of SI units. The use of U.S. customary units continues to be permitted in trade, but they are not mandated. In many cases, including consumer foods, such as canned foods and packaged baking mixes, they are dual-labelled in U.S. customary units, as well as in their metric equivalent.

Until there is worldwide agreement on units and universal adoption of one system of weights and measures, we need to rely on conversion tables to permit reliable “translation” from one system to another. Tables I and II provide for conversion between the two systems in most general use, namely, the SI metric system and U.S. units.

Finally, to answer the trivia question in the introduction, a barleycorn is an old British unit of length, equal to one-third inch or 0.84667 centimeter.

Translation Still Needed from One System to Another

Despite the lack of general adoption of the metric system in the United States and its limited use, there has also involved spelling changes that further confound the possibility of international standardization. Specifically, the tonne, litre, metre, and gramme of the SI metric system have become the metric ton, liter, meter, and gram, respectively, in U.S. spelling and terminology.

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References

1. Freeman, J. H. The metre and the pendulum. *Nature* 348:105, 1990.
2. Lentner, C., ed. *Geigy Scientific Tables, Volume 1*. CIBA-GEIGY Ltd., Basle, Switzerland, 1981.
3. Wrigley, C. W. Units of grain science: Conversion tables between metric and U.S. units. Pages 475–482 in the *Encyclopedia of Grain Science, Vol. 3*. Wrigley C, Walker C., and Corke, H., eds. Elsevier Ltd, Oxford, United Kingdom, 2004.



Colin W. Wrigley's 48 years in cereal chemistry research have earned him international recognition, in the form of several Australian and international research awards, including the Osborne Medal and being made a member of the Order of Australia in the Queen's Birthday Honours. His work is described in nearly 600 publications, including several patents, many edited books, and a series of eight books on Australian cereal varieties. He was editor-in-chief of the *Encyclopedia of Grain Science*, published in 2004 by Elsevier Science (Oxford, United Kingdom) in three volumes (1,700 pages). He can be reached at ColinWrigley@inet.net.au.

CORRECTION: This perspective was revised on March 8, 2010. Tables I and II previously cited that a U.S. bag of grain is equivalent to 50 kilograms. The amount should be 22.68 kilograms. This article contains the corrected tables.