Chapter 7. Units and Measurements

The SI system (Système International d'Unités) of reporting measurements is required in all ASA, CSSA, and SSSA publications. Other units may be reported parenthetically if this will clarify interpretation of the data.

The National Institute of Standards and Technology maintains online resources for SI (http://physics.nist.gov/cuu/) and has published a comprehensive guide (Thompson and Taylor, 2008) that includes a concise checklist of style requirements. Table 7–6 at the end of this chapter gives selected conversion factors.

BASE AND DERIVED UNITS

The SI system is based on seven base units (Table 7–1). Derived units (Table 7–2) are expressed algebraically in terms of the base units. Some of these have been given special names and symbols, which may be used to express still other derived units. An example of a derived unit with a special name is the newton (N) for force; the newton is expressed in basic units as m kg s^{-1}. Another unit with a special name is the pascal (Pa), which is one newton per square meter.

Using SI Units

Publications of ASA, CSSA, and SSSA impose less stringent requirements in style than the full formal SI system as published by the National Institute of Standards and Technology (Thompson and Taylor, 2008; Taylor and Thompson, 2008), and new developments in SI may take time to win adoption by the editorial boards. For example, this style manual allows molar concentration but disallows normal concentration, whereas strict SI usage declares both to be obsolete (Thompson and Taylor, 2008, 8.6.5). For certain papers or publications, traditional English counterparts may be used along with the SI units. (If in doubt, check with the editor to whom you are submitting your work.)

The prefixes and their symbols listed in Table 7–3 are used to indicate orders of magnitude in SI units. They reduce the use of nonsignificant digits and decimals and provide a convenient substitute for writing powers of 10. With some exceptions (notably tonne, liter, and hectare; see the discussion of non-SI units, below), for ease of understanding, base units (kg, m, s) should be used in the denominator of combinations of units, while appropriate prefixes for multiples (or submultiples) are selected for the numerator so that the numerical value of the term lies between 0.1 and 1000. Values outside this range may be used instead of changing the prefix to keep units consistent across a single presentation or discussion.

A digit is significant if it is required to express the numerical value of the quantity. In the expression $l = 1200$ m, it is not possible to tell if the last two zeros are significant or only indicate the magnitude of the numerical value of l. In the expression $l = 1.200$ km, the

Table 7–1. Base SI units.

Quantity	Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Table 7–2. Derived SI units with special names.

Derived quantity	Name	Symbol	Expression in terms of other SI units	Expression in terms of SI base units
Absorbed dose, specific energy imparted, kerma	gray	Gy	J kg^{-1}	m^2 s^{-1}
Activity (of a radionuclide)	becquerel	Bq		s^{-1}
Capacitance	farad	F	C V^{-1}	m^{-2} kg^{-1} s^4 A^2
Celsius temperature	degree Celsius	°C		K
Dose equivalent	sievert	Sv	J kg^{-1}	m^2 s^{-2}
Electric charge, quantity of electricity	coulomb	C		s A
Electric conductance	siemens	S	A V^{-1}	m^{-2} kg^{-1} s^3 A^2
Electric potential, potential difference, electromotive force	volt	V	W A^{-1}	m^2 kg s^{-3} A^{-1}
Electric resistance	ohm	Ω	V A^{-1}	m^2 kg s^{-3} A^{-2}
Energy, work, quantity of heat	joule	J	Nm	m^2 kg s^{-2}
Force	newton	N		m kg s^{-2}
Frequency	hertz	Hz		s^{-1}
Illuminance†	lux	lx	cd sr	cd sr
Inductance	henry	H	Wb A^{-1}	m^2 kg s^{-2} A^{-2}
Luminous flux†				
Magnetic flux	weber	Wb	V s	m^2 kg s^{-2} A^{-1}
Magnetic flux density	tesla	T	Wb m^{-2}	kg s^{-2} A^{-1}
Plane angle‡	radian	rad		m m^{-1} = 1
Power, radiant flux	watt	W	J s^{-1}	m^2 kg s^{-3}
Pressure, stress	pascal	Pa	N m^{-2}	kg s^{-2}
Solid angle	steradian	sr		m^2 m^{-2} = 1

† Photometric units are not allowed in ASA–CSSA–SSSA publications.

two zeros are assumed to be significant; otherwise, the value of l would have been written l = 1.2 km.

An exponent attached to a symbol containing a prefix indicates that the unit with its prefix is raised to the power expressed by the exponent. EXAMPLE: 1 mm^3 = $(10^{-3}\ m)^3$ = 10^{-9} m^3.

Use a space to show multiplication of units and a negative exponent to show division; these are strongly preferred to the otherwise acceptable center dot (•) and solidus (/). Thus, m s^{-1} is preferred to m/s. Only one solidus may be used in combinations of

Table 7–3. SI prefixes.

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

units, unless parentheses are used to avoid ambiguity. Thus, μmol m^{-2} s^{-1} is preferred, and μmol/(m^2 s) is acceptable, but μmol/m^2/s is not allowed. Where the denominator unit is modified by a quantity, the negative exponent goes after the unit, not the number. EXAMPLE: g 1000 $seed^{-1}$.

When reporting the value of a quantity, under strict SI usage, the information defining that quantity should be presented so that it is not associated with the unit (Thompson and Taylor, 2008, 7.5). EXAMPLE: "the water content is 20 mL kg^{-1}" not "20 mL H_2O kg^{-1}"; however, such expressions are acceptable in ASA, CSSA, SSSA publications.

Punctuation with SI units is only as required by the English context. In particular, SI unit symbols take a period only at the end of a sentence.

Non-SI Units

Some non-SI units may be used in ASA, CSSA, SSSA publications, but these units are limited to those that are convenient for crop and soil scientists. The quantity of area can be expressed as hectare (1 ha = 10^4 m^2). The use of liter (1 L = 10^{-3} m^3) in the denominator of derived units is permitted, but cubic meters is encouraged. Soil bulk density can be expressed as g cm^{-3}, but Mg m^{-3} is encouraged and t m^{-3} is allowed (see below). Angstroms are allowed for atomic spacing, and wave number can be reported as reciprocal centimeter (cm^{-1}).

The SI base unit for thermodynamic temperature is kelvin (K); however, the Celsius scale may be used to express temperature. The degree sign should be used with Celsius temperature (°C) but not with the kelvin scale.

The base unit second (s) is the preferred unit of time. Other units (i.e., minute, min; hour, h; day, d; week, wk; year, yr) are acceptable. Periods of time shorter than 182 d (26 wk) should not be expressed in months (mo) without a qualifying word such as "about" or "approximately." The unit "month" may be used for periods of 6 mo or greater in text, tables, or figures; the word "month" may be used to mean calendar month. Named units (e.g., July rainfall) are also acceptable.

In SI, a tonne (t) equals 10^3 kg, or 1 Mg, and is understood to mean metric ton. When expressing yields or application rates, the term Mg ha^{-1} is preferred; t ha^{-1}, widely used outside the United States, is acceptable. For a million tonnes, use Tg (not Mt).

Radian (rad) is the derived unit for measurement of plane angles, but degree is also acceptable. Other acceptable non-SI units are dalton (Da), electron volt (eV), poise (P), Svedberg units (S), degree (°), minute (′), and second (″). Use decimal values for minutes, degrees, and seconds (both are allowed for for geographic coordinates; see Chapter 2).

SPECIFIC APPLICATIONS

Special attention is required for reporting concentration, exchange composition and capacity, energy of soil water (or water potential), and light. Table 7–4 summarizes the appropriate units for society publications. Prefixes (Table 7–3) should be used to modify units in Table 7–4 so that numerical values fall between 0.1 and 1000.

Concentration

SI defines a mole (mol) as the amount of a substance of a system that contains as many elementary entities as there are atoms in 0.012 kg of ^{12}C (Taylor and Thompson, 2008, 2,1,1,6). With this definition, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles. The substance may be a mixture, such as air.

Table 7–4. Preferred (P) and acceptable (A) units for quantities most likely to be used in ASA–CSSA–SSSA publications (concentration, exchange parameters, light, and water potential).

Quantity	Application	Unit	Symbol
Concentration	known molar mass (liquid or solid)	mole per cubic meter (P)	mol m^{-3}
		mole per kilogram (P)	mol kg^{-1}
		mole per liter (A)	mol L^{-1}
		gram per liter (A)	g L^{-1}
	unknown molar mass (liquid or solid)	gram per cubic meter (P)	g m^{-3}
		gram per kilogram (P)	g kg^{-1}
		gram per liter (A)	g L^{-1}
	known ionic charge	mole charge per cubic meter (P)	mol_c m^{-3}
		mole charge per liter (A)	mol_c L^{-1}
	gas	mole per cubic meter (P)	mol m^{-3}
		gram per cubic meter (A)	g m^{-3}
		gram per liter (A)	g L^{-1}
		liter per liter (A)	L L^{-1}
		microliter per liter (A)	µL L^{-1}
		mole per liter (A)	mol L^{-1}
		mole fraction (A)	mol mol^{-1}
Exchange parameters	exchange capacity	mole charge of saturating ion per kilogram (P)	mol_c kg^{-1}
		centimole charge of saturating ion per kilogram (A)	$cmol_c$ kg^{-1}
	exchangeable ion composition	mole charge of specific ion per kilogram	mol_c kg^{-1}
	sum of exchangeable ions	mole charge of ion per kilogram	mol_c kg^{-1}
Light	irradiance	watt per square meter	W m^{-2}
	photosynthetic photon flux density (400–700 nm)	micromole per square meter per second	µmol m^{-2} s^{-1}
Water potential	driving force for flow	joule per kilogram (P)	J kg^{-1}
		kilopascal (A)	kPa
		meter of water in a gravitational field (A)	m

Express concentrations on a molar basis (mol L^{-1}). Using M is acceptable although not preferred. Equivalencies include

1 mol L^{-1} = 1 M = 1 mmol mL^{-1}
1 mmol L^{-1} = 1 mM = 10^{-3} M = 1 µmol mL^{-1}
1 µmol L^{-1} = 1 µM = 10^{-6} M = 1 nmol mL^{-1}
1 nmol L^{-1} = 1 nM = 10^{-9} M = 1 pmol mL^{-1}

Solutions containing ions of mixed valence should also be given on the molar basis of each ion. Molality (mol kg^{-1} of solvent) is an acceptable term and unit; it is the preferred unit for precise, nonisothermal conditions. Moles of charge per liter (mol_c L^{-1}) is also acceptable in some ionic situations. Do not use normality, N, the amount of substance concentration based on the concept of equivalent concentration. The relationship between normality and molarity is expressed by

$$N = nM$$

where n is the number of replaceable H^+ or OH^- per molecule (acids and bases) or the number of electrons lost or gained per molecule (oxidizing and reducing agents). A useful reference is Segel (1976).

In some instances, it is convenient to report concentrations in terms of their components—either weight to volume or volume to volume. Do not use percentage.

Gas concentration can be expressed as mol m^{-3}, g m^{-3} partial pressure, or mole fraction. The denominator of the mole fraction needs no summation sign, because the mole is defined as Avogadro's number of any defined substance, including a mixture such as air. An O_2 concentration of 210 mL L^{-1} is therefore 21×10^{-2} mol mol^{-1} or 0.21 mol fraction. A CO_2 concentration of 335 µmol mol^{-1} equals 335 µmol fraction.

Nutrient concentration in plants, soil, or fertilizer can be expressed on the basis of mass as well as the amount of substance. For example, plant P concentration could be reported as 180 mmol kg^{-1} P or 5.58 g kg^{-1} P. Extractable nutrients in soil should be expressed as mg kg^{-1} when soil is measured on a mass basis, or g m^{-3} when soil is measured on a volumetric basis. Exchangeable ions determined by the usual acetate procedure on weighed samples should be expressed as $mmol_c$ kg^{-1} or $cmol_c$ kg^{-1}.

Water content of plant tissue or plant parts can be expressed in terms of water mass per unit mass of plant material (e.g., g kg^{-1} H_2O). State whether reported plant mass is on a dry or wet basis.

Exchange Composition and Capacity

Exchange capacity and exchangeable ion composition should be expressed as moles of charge per kilogram (e.g., 5 $cmol_c$ kg^{-1}). Omit the sign of the charge (+ or –); it should be apparent from the text. If the cation exchange capacity is determined by the single-ion saturation technique, the ion used should be specified in the text as it can affect the cation exchange capacity measured. If Mg^{2+} were used for the soil, and specific ion effects were nonsignificant, the cation exchange capacity would be expressed as 8 $cmol_c$ (½-Mg^{2+}) kg^{-1}. Milliequivallents (meq) per 100 g is not an acceptable unit in the SI system and should not be used in ASA, CSSA, SSSA, publications.

Energy of Soil Water or Water Potential

Soil water potential refers to its equivalent potential energy; it can be expressed on either a mass or a volume basis. Energy per unit mass has units of joules per kilogram (J kg^{-1}) in SI. Energy per unit volume is dimensionally equivalent to pressure, and the SI pressure unit is the pascal (Pa). One joule per kilogram is 1 kPa if the density of water is 1 Mg m^{-1} and, since 1 bar is equal to 100 kPa, 1 J kg^{-1} is equal to 0.01 bar at this same density. Energy per unit mass (J kg^{-1}) is preferred to the pressure unit (Pa). The use of the non-SI unit bar is accepted for use with the SI, although it is not preferred.

The height of a water column in the earth's gravitational field, energy per unit of weight, can be used as an index of water potential or energy. The potential in joules per kilogram (J kg^{-1}) is the gravitational constant multiplied by the height of the water column. Since the gravitational constant (9.81 m s^{-1}) is essentially 10, hydraulic head in meters of water is approximately 10 times the water potential expressed in joules per kilogram or kilopascals.

Light

Accepted SI notation for total radiant energy per unit area is joule per square meter (J m^{-2}). Energy per unit time or irradiance is expressed in watts per square meter (W m^{-2}). Alternative units, based on calories or ergs for energy and square centimeter for area, are not acceptable. Also, photometric units, including lux, are not acceptable.

Plant scientists studying photochemically triggered responses (e.g., photosynthesis, photomorphogenesis, and phototropism) may quantify radiation in terms of number of photons rather than energy content. Express photon flux density per unit area in moles of photons per square meter per second (mol m^{-2} s^{-1}). The photosynthetic photon flux density (PPFD) is photon flux density in the waveband 400 to 700 nm. For studies involving other wavebands, the waveband should be specified. See Shibles (1976) and the summary under Light Measurements and Photosynthesis in Chapter 3 of this manual.

Use of Percentage in SI

Whenever the composition of some mixture is being described and it is possible to express elements of the mixture in SI base or derived units, the use of percentage is unacceptable. In such cases the percentage should be replaced by appropriate SI units. For example, plant nutrient concentration must be expressed in SI units based on either amount of substance or mass.

The use of percentage is acceptable when the elements of an event cannot be described in SI base or derived units, or when a well-known fractional comparison of an event is being described. The following are examples where use of percentage is acceptable.

- Coefficient of variation.
- Botanical composition, plant stand, and cover estimates.
- Percentage of leaves (or plants) infected.
- Percentage increase (or decrease) in yield.
- Percentage of applied element(s) that are recovered by plants, extractants, etc.
- Fertilizer grades.
- Relative humidity.
- As an alternative unit of soil texture. This is allowed because each component is well defined and is a fraction on a mass basis.
- As an alternative unit to express fractional base saturation. This is permissible because each component is a fraction on a chemical basis.
- Atom percent abundance of a stable isotope (e.g., ^{15}N, ^{18}O). This is determined on a mass basis.

Parts per Thousand

The term *parts per thousand*, used in some mineralogy and oceanography references, is acceptable. This term is widely accepted for reporting isotope ratios relative to a standard and is dimensionless. Its symbol is ‰.

Parts per Million

Parts per million (ppm) is an ambiguous term. To avoid ambiguity, authors are required to use preferred or acceptable SI units. Depending on the type of data, authors could use μL L^{-1}, mg L^{-1}, or mg kg^{-1} in place of parts per million. The only exception to the use of ppm is when associated with nuclear magnetic resonance (NMR) measurements. Parts per million is the official term used to express the relative shift of a NMR line of a given nucleus from the line associated with the standard for that nucleus. The term is dimensionless.

Cotton Fiber

Official standards for cotton staple length are given in terms of inches and fractions of an inch, generally in gradations of thirty-seconds of an inch. Stapling is done by a classer in comparison with staple standards. Measurement by instrument has shown unequal increments between consecutive staples in these standards. Because the classer is the authority on length, these unequal increments have been maintained. When staple length is determined by a classer, it may be reported as a code number, with the code being the number of thirty-seconds of an inch called by the classer.

Instrument measurements are preferable in experimental work because of equal incremental differences between successive fiber lengths. Report these values using appropriate SI units (Table 7–5). Fiber fineness determined by the micronaire instrument should be reported as *micronaire reading*.

Recommended Units and Conversion Factors

Tables of recommended units (Table 7–5) and conversion factors (Table 7–6) are included to aid in the use of SI units. See also Thompson and Taylor (2008, Appendix B).

TIME AND DATES

Clock Time

Use the abbreviations AM and PM, capital letters, to distinguish between the halves of the day, e.g., 12:02 AM. Time zones may be used if needed to avoid ambiguity. Do not capitalize the names of times zones when spelled out. Capitalize the abbrevations of time zones, without periods, when they directly following the time (e.g., 11:30 AM CST). The 24-h system, which is indicated by four digits—the first two for hours and the last two for minutes—may be used to avoid ambiguity. In this system, the day begins at midnight, 0000 h, and the last minute is 2359 h. Thus, 2400 h on 31 Dec. 2012 is the same as 0000 h on 1 Jan. 2013.

Dates

In running text, capitalize and spell out the names of days and months. For complete dates, give the day (one or two digits), month (abbreviated), and year (four digits), e.g., 1 Aug. 2013. Abbreviate names of months and days of the week in tables and references. Standard abbreviations for months are Jan., Feb., Mar., Apr., Aug., Sept., Oct., Nov., and Dec.; May, June, and July are never abbreviated.

Dates may also be identified as day of the year (i.e., in the year's sequence of 365 or 366 days), thus: Day of Year 235. Its typical abbreviation (DOY) should be defined at first use. Note that *Julian day* does not mean day of the year. A Julian day describes a date in terms of days elapsed since Greenwich noon on 1 Jan. 4713 BC. Julian dates are used primarily in astronomy, information science, and space science.

MONETARY UNITS

For monetary values, use the appropriate currency symbol. You may use the full numeric form (e.g., $1,500,000) or a combination of numbers and words ($1.5 million). Because many nations use the dollar as the unit of currency, it is generally advisable to include the country prefix (e.g., US$500, Can$350, NZ$300) at first use and at every use if more than one country currency is used.

Table 7–5. Preferred (P) and acceptable (A) units for other quantities.

Quantity or rate	Application	Unit	Abbreviation
Angle	x-ray diffraction pattern	radian (P)	θ
		degree (A)	°
Area	land area	square meter (P)	m^2
		hectare (A)	ha
	leaf area	square meter	m^2
	surface area of soil	square meter per kilogram	$m^2\ kg^{-1}$
Interatomic spacing	crystal structure	nanometer (P)	nm
		Angstrom (A)	Å
Bulk density	soil bulk density	megagram per cubic meter (P)	$Mg\ m^{-3}$
		gram per cubic centimeter (A)	$g\ cm^{-3}$
Electrical conductivity†	salt tolerance	siemen per meter	$S\ m^{-1}$
Elongation rate	plant	millimeter per second (P)	$mm\ s^{-1}$
		millimeter per day (A)	$mm\ d^{-1}$
Ethylene production	N_2–fixing activity	nanomole per plant per second	$nmol\ plant^{-1}\ s^{-1}$
Extractable ion	soil, mass basis	centimole per kilogram (P)	$cmol\ kg^{-1}$
		milligram per kilogram (A)	$mg\ kg^{-1}$
	soil, volume basis	mole per cubic meter (P)	$mol\ m^{-3}$
		gram per cubic meter (P)	$g\ m^{-3}$
		centimole per liter (A)	$cmol\ L^{-1}$
		milligram per liter (A)	$mg\ L^{-1}$
Fertilizer rate	soil	gram per square meter (P)	$g\ m^{-2}$
		kilogram per hectare (A)	$kg\ ha^{-1}$
Fiber strength	cotton fiber	kilonewton meter per kilogram	$kN\ m\ kg^{-1}$
Flux density	heat flow	watt per square meter	$W\ m^{-2}$
	gas diffusion	mole per square meter per second (P)	$mol\ m^{-2}\ s^{-1}$
		gram per square meter per second (A)	$g\ m^{-2}\ s^{-1}$
	water flow	kilogram per square meter per second (P)	$kg\ m^{-2}\ s^{-1}$
		cubic meter per square meter per second (A)	$m^3\ m^{-2}\ s^{-1}$
Gas diffusivity	gas diffusion	square meter per second	$m^2\ s^{-1}$
Grain test weight	grain	kilogram per cubic meter	$kg\ m^{-3}$
Growth rate	plant growth	gram per square meter per day	$g\ m^{-2}\ d^{-1}$
Hydraulic conductivity	water flow	kilogram second per cubic meter (P)	$kg\ s\ m^{-3}$
		cubic meter per second per kilogram (A)	$m^3\ s^{-1}\ kg^{-1}$
		meter per second (A)	$m\ s^{-1}$
Ion transport	ion uptake	mole per kilogram (of dry plant tissue) per second	$mol\ kg^{-1}\ s^{-1}$
		mole of charge per kilogram (of dry plant tissue) per second	$mol_c\ kg^{-1}\ s^{-1}$
Leaf area ratio	plant	square meter per kilogram	$m^2\ kg^{-1}$
Length	depth, width, and height	meter (P)	m
		centimeter (A)	cm
		millimeter (A)	mm
Magnetic flux density	electronic spin resonance (ESR)	tesla	T
Nutrient concentration	plant	millimole per kilogram (P)	$mmol\ kg^{-1}$
		gram per kilogram (A)	$g\ kg^{-1}$

(continued on next page)

Table 7–5. Continued.

Quantity or rate	Application	Unit	Abbreviation
Photosynthetic rate	CO_2 amount of substance flux density (P)	micromole per square meter per second (P)	μmol m^{-2} s^{-1}
	CO_2 mass flux density (A)	milligram per square meter per second (A)	mg m^{-2} s^{-1}
Precipitation	rainfall	millimeter	mm
Radioactivity	nuclear decay	becquerel (P)	Bq
		curie (A)	Ci
Resistance	stomatal	second per meter	s m^{-1}
Soil texture composition	soil	gram per kilogram (P)	g kg^{-1}
		percent (A)	%
Specific heat	heat storage	joule per kilogram per kelvin	J kg^{-1} K^{-1}
Thermal conductivity	heat flow	watt per meter per kelvin	W m^{-1} K^{-1}
Transpiration rate	H_2O flux density	gram per square meter per second (P)	g m^{-2} s^{-1}
		cubic meter per square meter per second (A)	m^3 m^{-2} s^{-1}
		meter per second (A)	m s^{-1}
Volume	field or laboratory	cubic meter (A)	m^3
		liter (A)	L
Water content	plant	gram water per kilogram wet or dry tissue (P)	g kg^{-1}
	soil (acceptable for plants)	kilogram water per kilogram dry soil [or plant matter] (P)	kg kg^{-1}
		cubic meter water per cubic meter soil [or plant matter] (A)	m^3 m^{-3}
Wave number	infrared (IR) spectroscopy	reciprocal centimeter	cm^{-1}
Yield	grain or forage yield	gram per square meter (P)	g m^{-2}
	mass of plant or plant part	kilogram per hectare (A)	kg ha^{-1}
		megagram per hectare (A)	Mg ha^{-1}
		tonne per hectare (A)	t ha^{-1}
		gram (gram per plant or plant part, such as kernel)	g (g $plant^{-1}$ or g $kernel^{-1}$)

† The term *electrolytic conductivity* has been substituted for electrical conductivity by the International Union of Pure and Applied Chemistry (IUPAC). Use of the SI term electrolytic conductivity is permissible but not mandatory in ASA, CSSA, SSSA publications.

Table 7–6. Conversion Factors for SI and non-SI Units.

To convert Column 1 into Column 2, multiply by	Column 1 SI Unit	Column 2 non-SI Units	To convert Column 2 into Column 1, multiply by
		Length	
0.621	kilometer, km (10^3 m)	mile, mi	1.609
1.094	meter, m	yard, yd	0.914
3.28	meter, m	foot, ft	0.304
1.0	micrometer, μm (10^{-6} m)	micron, μ	1.0
3.94×10^{-2}	millimeter, mm (10^{-3} m)	inch, in	25.4
10	nanometer, nm (10^{-9} m)	Angstrom, Å	0.1
		Area	
2.47	hectare, ha	acre	0.405
247	square kilometer, km^2 $(10^3\ m)^2$	acre	4.05×10^{-3}
0.386	square kilometer, km^2 $(10^3\ m)^2$	square mile, mi^2	2.590
2.47×10^{-4}	square meter, m^2	acre	4.05×10^3
10.76	square meter, m^2	square foot, ft^2	9.29×10^{-2}
1.55×10^{-3}	square millimeter, mm^2 $(10^{-3}\ m)^2$	square inch, in^2	645
		Volume	
9.73×10^{-3}	cubic meter, m^3	acre-inch	102.8
35.3	cubic meter, m^3	cubic foot, ft^3	2.83×10^{-2}
6.10×10^4	cubic meter, m^3	cubic inch, in^3	1.64×10^{-5}
2.84×10^{-2}	liter, L (10^{-3} m^3)	bushel, bu	35.24
1.057	liter, L (10^{-3} m^3)	quart (liquid), qt	0.946
3.53×10^{-2}	liter, L (10^{-3} m^3)	cubic foot, ft^3	28.3
0.265	liter, L (10^{-3} m^3)	gallon	3.78
33.78	liter, L (10^{-3} m^3)	ounce (fluid), oz	2.96×10^{-2}
2.11	liter, L (10^{-3} m^3)	pint (fluid), pt	0.473
		Mass	
2.20×10^{-3}	gram, g (10^{-3} kg)	pound, lb	454
3.52×10^{-2}	gram, g (10^{-3} kg)	ounce (avdp), oz	28.4
2.205	kilogram, kg	pound, lb	0.454
0.01	kilogram, kg	quintal (metric), q	100
1.10×10^{-3}	kilogram, kg	ton (2000 lb), ton	907
1.102	megagram, Mg (tonne)	ton (U.S.), ton	0.907
1.102	tonne, t	ton (U.S.), ton	0.907
		Yield and Rate	
0.893	kilogram per hectare, kg ha^{-1}	pound per acre, lb $acre^{-1}$	1.12
7.77×10^{-2}	kilogram per cubic meter, kg m^{-3}	pound per bushel, lb bu^{-1}	12.87
1.49×10^{-2}	kilogram per hectare, kg ha^{-1}	bushel per acre, 60 lb	67.19
1.59×10^{-2}	kilogram per hectare, kg ha^{-1}	bushel per acre, 56 lb	62.71
1.86×10^{-2}	kilogram per hectare, kg ha^{-1}	bushel per acre, 48 lb	53.75
0.107	liter per hectare, L ha^{-1}	gallon per acre	9.35
893	tonne per hectare, t ha^{-1}	pound per acre, lb $acre^{-1}$	1.12×10^{-3}
893	megagram per hectare, Mg ha^{-1}	pound per acre, lb $acre^{-1}$	1.12×10^{-3}
0.446	megagram per hectare, Mg ha^{-1}	ton (2000 lb) per acre, ton $acre^{-1}$	2.24
2.24	meter per second, m s^{-1}	mile per hour	0.447

(continued on next page)

Table 7–6. Continued.

To convert Column 1 into Column 2, multiply by	Column 1 SI Unit	Column 2 non-SI Units	To convert Column 2 into Column 1, multiply by
		Specific Surface	
10	square meter per kilogram, $m^2\ kg^{-1}$	square centimeter per gram, $cm^2\ g^{-1}$	0.1
1000	square meter per kilogram, $m^2\ kg^{-1}$	square millimeter per gram, $mm^2\ g^{-1}$	0.001
		Density	
1.00	megagram per cubic meter, $Mg\ m^{-3}$	gram per cubic centimeter, $g\ cm^{-3}$	1.00
		Pressure	
9.90	megapascal, MPa (10^6 Pa)	atmosphere	0.101
10	megapascal, MPa (10^6 Pa)	bar	0.1
2.09×10^{-2}	pascal, Pa	pound per square foot, $lb\ ft^{-2}$	47.9
1.45×10^{-4}	pascal, Pa	pound per square inch, $lb\ in^{-2}$	6.90×10^3
		Temperature	
1.00 (K – 273)	kelvin, K	Celsius, °C	1.00 (°C + 273)
(9/5 °C) + 32	Celsius, °C	Fahrenheit, °F	5/9 (°F – 32)
		Energy, Work, Quantity of Heat	
9.52×10^{-4}	joule, J	British thermal unit, Btu	1.05×10^3
0.239	joule, J	calorie, cal	4.19
10^7	joule, J	erg	10^{-7}
0.735	joule, J	foot-pound	1.36
2.387×10^{-5}	joule per square meter, $J\ m^{-2}$	calorie per square centimeter (langley)	4.19×10^4
10^5	newton, N	dyne	10^{-5}
1.43×10^{-3}	watt per square meter, $W\ m^{-2}$	calorie per square centimeter minute (irradiance), $cal\ cm^{-2}\ min^{-1}$	698
		Transpiration and Photosynthesis	
3.60×10^{-2}	milligram per square meter second, $mg\ m^{-2}\ s^{-1}$	gram per square decimeter hour, $g\ dm^{-2}\ h^{-1}$	27.8
5.56×10^{-3}	milligram (H_2O) per square meter second, $mg\ m^{-2}\ s^{-1}$	micromole (H_2O) per square centimeter second, $\mu mol\ cm^{-2}\ s^{-1}$	180
10^{-4}	milligram per square meter second, $mg\ m^{-2}\ s^{-1}$	milligram per square centimeter second, $mg\ cm^{-2}\ s^{-1}$	10^4
35.97	milligram per square meter second, $mg\ m^{-2}\ s^{-1}$	milligram per square decimeter hour, $mg\ dm^{-2}\ h^{-1}$	2.78×10^{-2}
		Plane Angle	
57.3	radian, rad	degrees (angle), °	1.75×10^{-2}

(continued on next page)

Table 7–6. Continued.

To convert Column 1 into Column 2, multiply by	Column 1 SI Unit	Column 2 non-SI Units	To convert Column 2 into Column 1, multiply by
	Electrical Conductivity, Electricity, and Magnetism		
10	siemen per meter, S m^{-1}	millimho per centimeter, mmho cm^{-1}	0.1
10^4	tesla, T	gauss, G	10^{-4}
	Water Measurement		
9.73×10^{-3}	cubic meter, m^3	acre-inch, acre-in	102.8
9.81×10^{-3}	cubic meter per hour, m^3 h^{-1}	cubic foot per second, ft^3 s^{-1}	101.9
4.40	cubic meter per hour, m^3 h–1	U.S. gallon per minute, gal min^{-1}	0.227
8.11	hectare meter, ha m	acre-foot, acre-ft	0.123
97.28	hectare meter, ha m	acre-inch, acre-in	1.03×10^{-2}
8.1×10^{-2}	hectare centimeter, ha cm	acre-foot, acre-ft	12.33
	Concentrations		
1	centimole per kilogram, $cmol_c$ kg^{-1}	milliequivalent per 100 grams, meq 100 g^{-1}	1
0.1	gram per kilogram, g kg^{-1}	percent, %	10
1	milligram per kilogram, mg kg^{-1}	parts per million, ppm	1
	Radioactivity		
2.7×10^{-11}	becquerel, Bq	curie, Ci	3.7×10^{10}
2.7×10^{-2}	becquerel per kilogram, Bq kg^{-1}	picocurie per gram, pCi g^{-1}	37
100	gray, Gy (absorbed dose)	rad, rd	0.01
100	sievert, Sv (equivalent dose)	rem (roentgen equivalent man)	0.01
	Plant Nutrient Conversion		
	Elemental	***Oxide***	
2.29	P	P_2O_5	0.437
1.20	K	K_2O	0.830
1.39	Ca	CaO	0.715
1.66	Mg	MgO	0.602