Chapter 7. Numbers, Mathematical Equations, and Units of Measure

NUMBERS

- The decimal separator in ASA, CSSA, and SSSA publications is a comma, used for five-digit numbers and higher (e.g., 10,000).
- As an exception to usage for other numbers, monetary values are always written with commas, e.g., $1,000.
- Dates, page numbers, percentages, time, numbers preceded by capitalized nouns, and numbers followed by units of measure are expressed as numerals (e.g., Table 1, Chapter 1, 2%, Journal Article no. 1, Treatment 3, 1 g, 5 s).
- A numeral is used for a single number of 10 or more, except when the number is the first word of the sentence. Numerals are used to designate the numbers nine and below when two or more numbers are used and any of them are greater than nine: ". . . 2, 5, and 20 pots were planted," but "a group of 12 plants was incubated at three temperatures."
- Use the abbreviation or symbol for units only with numeric values. Use the same form for both singular or plural (e.g., 1 kg; 14 g; 2 h).
- At the beginning of a sentence, spell out the numeric value and the unit of measurement that follows (e.g., "Fifteen liters . . . was added"). Within a sentence, use the usual numerals and symbols ("15 L . . . was added"). Note the use of singular verb.
- Ordinal numbers are treated like cardinal numbers: third, fourth, 33rd, 100th, except in references, where digits are used (e.g., 5th ed., 7th Congress).
- For large numbers ending in zeros, good practice is to use a word or prefix for part of the number (e.g., 1.6 million, not 1,600,000; 23 μg, not 0.000023 g).
- Rounding treatment means to one-tenth of their estimated standard error is often acceptable. For example, if the estimated standard error is 1.43, the means should be rounded to the nearest 0.1, and if the standard error is 18.4, the means should be rounded to the nearest 1.0.
- A zero is used before the decimal point with numbers that are less than 1 when the unit can exceed 1, such as 0.23 cm, Cohen's $d = 0.70$, 0.48 s.
- A zero does not need to be used before a decimal fraction when the statistic cannot be greater than 1 (e.g., correlations, proportions, and levels of statistical significance: *p*, beta, alpha), such as $r(24) = -.43$, $p = .028$.
- 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). It is generally advisable to include the country prefix at first use and at every use if more than one country currency is used where the dollar is the unit of currency (e.g., US$500, Can$350, NZ$300).
- For complete dates, give the month, day (one or two digits), and year (four digits), e.g., August 1, 2023.
- Use the abbreviations a.m. and p.m. to distinguish between the halves of the day, e.g., 12:02 a.m. 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 a.m. 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 if needed to avoid ambiguity. In this system, the day begins at midnight, 0000 h, and the last minute is 2359 h. Thus, 2400 h on December 31, 2022, is the same as 0000 h on January 1, 2023.

MATHEMATICAL EXPRESSIONS

Mathematical equations and symbols often must be retyped and reformatted during composition. Therefore, to help prevent the introduction of errors, preparation of the manuscript copy and identification of letters and symbols must be clear.

Use keyboard formatting where possible (i.e., bold, super-/subscripts, simple variables, Greek font, etc.), and use MathType (preferred) or Microsoft Word Equation Editor (only if MathType is not available) for display equations. If your equations are drawn from calculations in a computer language, translate the equation syntax of the computer language into standard mathematical syntax. Likewise, translate variables into standard mathematical format. If you need to present computer code, do that in an appendix.

Position and Spacing

The position and spacing of all elements of an equation must be exactly as they are to appear in printed form.

Place superscript and subscript letters and symbols in the correct positions.

Put a space before and after most mathematical operators (main exception is the solidus sign for division). For example, plus and minus signs have a space on both sides when indicating a mathematical operation but no space between the sign and the number when indicating positive or negative position on the number line (e.g., $5 - 2 = 3$; a range from -15 to 25 kg).

No space is left between variables and their quantities or between multiplied quantities when the multiplication sign is not explicitly shown. No space is left between an expression and its power (or any superscripted or subscripted modifier). No space is left after trigonometric functions.

Special Characters

Letters, including Greek letters, that denote mathematical constants, variables, and unknown quantities in text and in equations are set in italic. Vectors and matrices are set in boldface roman type.

Special characters should be treated the same in the text, equations, tables, and figures.

Call attention to unusual symbols and modification of symbols that may be lost or distorted during file conversion or exchange. Carefully distinguish between primes and apostrophes; the uppercase letter O and the numeral zero; the lowercase letter l, uppercase letter I, and the numeral 1; the degree symbol and a superscripted zero or letter o; and rho (ρ) and the letter p.

Simplifying Equations

Use in-line fractions (i.e., with a solidus rule, as in x/y) as much as possible, especially in the text. Show the necessary aggregation by using fences (i.e., parentheses, brackets, and braces). Use the sequence {[( )]}.

In display fractions, align the rules with the main signs of the equation or formula. In complex equations, use horizontal rules for the main fractions and slant rules in numerators, denominators, and exponents. Some display equations can be reformatted as in-line equations. Thus, $a/(bcd)$ and $a/(b - c)$ and $(a/b) - (c/d)$ can easily substitute for

$$\frac{a}{bcd} \text{ and } \frac{a}{b-c} \text{ and } \left(\frac{a}{b}\right)-\left(\frac{c}{d}\right)$$

Use the same techniques to simplify a complex display equation.

For large numbers in text, tables, or figures, standard scientific notation is preferred instead of computer exponentials (e.g., 7.0×10^{-3} instead of 7.0 E-03). Computer exponentials may be used for presentation of software-generated data in tables and figures. SI prefixes are usually preferable to scientific notation when expressing units.

Integrals, Summations, and Limits

With single integral signs, the upper and lower limits should always be placed to the right of the integral sign, never above and below. In text, this can be accomplished by stacking supers and subs ($\int_{\infty}^{0}$). For summations, the limits above and below are customary in display equations; in text, however, and in the numerator and/or denominator of display equations, the right-side position is required.

Roots

As practical, use negative exponents or the solidus instead of display fractions and fractional powers instead of the radical sign. For example,

$$\frac{\cos\frac{1}{x}}{\sqrt{a+\frac{b}{x}}}$$

is better written as

$$\frac{\cos(1/x)}{[a+(b/x)]^{1/2}}$$

However, considerations of space should not override clarity. The previous equation can be further condensed to fit within the text line as $[\cos(1/x)]/\{[a + (b/x)]^{1/2}\}$, but this is not necessarily the best presentation. Consider your readers.

Numbering Equations

It is not necessary to number all displayed equations, but they are usually numbered in articles that have a substantial number of equations or if more than one is referred to within the text. If equations are numbered, place the numbers in parentheses at the right margin. Cite equations in text in the form Equation (1), Equations (4) and (5), and Equations (7–19), but (Equation 1).

Exponential Functions

For lengthy or complex exponents, the symbol exp is preferred, particularly if such exponentials appear in the body of the text. Thus, $\exp(a^2 + b^2)^{1/2}$ is preferable to $e^{(a^2+b^2)^{1/2}}$. The larger size of symbols permitted by this usage also makes reading easier.

UNITS OF MEASURE

The SI system (Système International d'Unités) of reporting measurements is required in the majority of 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 & 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

ASA, CSSA, and SSSA publications impose less-stringent requirements in style than the full formal SI system as published by the National Institute of Standards and Technology (Thompson & Taylor, 2008; Taylor & 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 & 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 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 two zeros are assumed to be significant; otherwise, the value of l would have been written $l = 1.2$ km.

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 [a]	lux	lx	cd sr	cd sr
Inductance	henry	H	$Wb\ A^{-1}$	$m^2\ kg\ s^{-2}\ A^{-2}$
Luminous flux [a]				
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 [b]	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 [b]	steradian	sr		$m^2\ m^{-2} = 1$

[a] Photometric units are not allowed in ASA–CSSA–SSSA publications. [b] The class of supplemental units was eliminated and the radian and steradian were reclassified as derived units in 1995 (Thompson & Taylor, 2008).

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 preferred to the otherwise acceptable center dot (•) and solidus (/). Thus, $m\ s^{-1}$ is preferred to m/s, but be consistent. Only one solidus may be used in combinations of units, unless parentheses are used to avoid ambiguity. Thus, $\mu mol\ m^{-2}\ s^{-1}$ is preferred, and $\mu mol/(m^2\ s)$ is acceptable, but $\mu mol/m^2/s$ 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 &

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

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. Abbreviate SI units in numeric expressions; SI unit symbols do not end in a period.

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 is usually used to express temperature. The degree sign is used with Celsius temperature (°C) but not with the kelvin scale.

The base unit second (s) is the preferred unit of time. Other units (e.g., minute, min; hour, h; week; month; year) are acceptable. Spell out week, month, and year. Periods of time shorter than 182 days (26 weeks) should not be expressed in months without a qualifying word such as "about" or "approximately." The unit "month" may be used for periods of 6 months 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 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 & 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.

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

$1\ \mathrm{mol\ L^{-1}} = 1\ \mathrm{M} = 1\ \mathrm{mmol\ mL^{-1}}$
$1\ \mathrm{mmol\ L^{-1}} = 1\ \mathrm{mM} = 10^{-3}\ \mathrm{M} = 1\ \mu\mathrm{mol\ mL^{-1}}$
$1\ \mu\mathrm{mol\ L^{-1}} = 1\ \mu\mathrm{M} = 10^{-6}\ \mathrm{M} = 1\ \mathrm{nmol\ mL^{-1}}$

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)	$\mu L\ L^{-1}$
		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	$\mu mol\ m^{-2}\ s^{-1}$
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

$$1\ nmol\ L^{-1} = 1\ nM = 10^{-9}\ M = 1\ pmol\ mL^{-1}$$

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}. Milliequivalents (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 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 400–700 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 $\mu L\ L^{-1}$, $mg\ L^{-1}$, or $mg\ kg^{-1}$ in place of parts per million. The 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).

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 [a]	salt tolerance	siemen per meter	$S\ m^{-1}$
Elongation rate	plant	millimeter per second (P)	$mm\ s^{-1}$
		millimeter per day (A)	$mm\ day^{-1}$
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	$g\ m^{-2}\ day^{-1}$
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)	$g\ kg^{-1}$
Photosynthetic rate	CO_2 amount of substance flux density (P)	micromole per square meter per second (P)	$\mu mol\ m^{-2}\ s^{-1}$
	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

TABLE 7–5 Continued

Quantity or rate	Application	Unit	Abbreviation
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 $kernel^{-1}$)

[a] 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.