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USE OF SI UNITS IN SOIL PHYSICS

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Use of SI units in soil physics

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ABSTRACT

Descriptions of the state and movement of heat and mass within soil using units conforming to the International System of Units (SI) are discussed. We propose that gas and water flux densities should be expressed in terms of kg m^{-2} s^{-1} and heat flux densities in terms of W m^{-2}. The joule per kilogram (J/kg) is suggested as the preferred unit for describing water potential, and hydraulic conductivity then has units of kg s m^{-3}. Alternative systems are also given.

Additional index words: **Measurement of soil quantities, Flux densities.**

SOIL physicists are generally concerned with heat and mass transport in soil. Subjects they consider most frequently include soil aeration, soil temperature, and soil water. These are described in both static and dynamic terms. When considering adoption of the International System of Units (SI), for teaching or research, one should choose units which (a) are consistent throughout the discipline, (b) give numbers that are easy to manipulate and remember, (c) have physical significance, and (d) where possible, are numerically equal to or are easily obtained from units used in previous systems. These ideas have been discussed by Rose (1979).

STATIC PARAMETERS

Many of the static parameters used in soil physics are dimensionless, and therefore, do not change with adoption of SI. Examples are total and air-filled porosity, degree of saturation, and void ratio. Mass and volume wetness (water content) are also dimensionless, but are normally reported as kg/kg or m^3/m^3 to indicate mass or volume of water per unit mass or volume of soil. These values would not change numerically in SI, but standard SI units would be used.

Densities of solid particles, water, bulk soil, or soil gases all have dimensions M L^{-3} and thus the basic unit is kg m^{-3}. Bulk and particle density, and density of water can be expressed in Mg m^{-3}; this gives numbers which are conveniently remembered and are numerically equal to those in familiar centimeter-gram second (cgs) units. Soil gas concentrations also can be expressed in terms of mass per unit volume of soil air. Here, since mass per unit volume is lower than for solids and liquids, convenient units are g m^{-3}.

The potential energy of water in soil can be expressed on a mass or volume basis. Energy per unit mass has dimensions of L^2T^{-2}. Units are joules per kilogram (J/kg) in SI. Energy per unit volume is dimensionally equivalent to pressure, and the SI pressure unit, the Pascal (Pa), is used. One J/kg is 1 kPa if the density of water is 1 Mg/m^3; and since 1 bar = 100 kPa, 1 J/kg is equal to 0.01 bar at this same density. The volume basis potential has several disadvantages, the most important of which is that its use in flow equations requires the assumption that the density of water is a constant (Hubbert, 1956).

Adoption of either J/kg or Pascal as the standard water potential unit would require some relearning for most soil physicists since neither is numerically equal to the more familiar units in common use. The mass basis potential has fewer assumptions associated with its use and is more clearly related to the concept of energy status of water in soil. It is preferred, therefore, over the pressure unit.

It also is possible to use the height of a water column in the earth's gravitational field as an index of water potential. Use of this index has some advantages in flow equations, as will be discussed later. The potential in J/kg is just the gravitational constant multiplied by the height of the water column. Since the gravitational constant is close to 10 (9.81 m s^{-2}), hydraulic head in meters of water is approximately 10 times water potential in J/kg or kPa.

Variables related to soil thermal status are temperature and specific heat. Temperature is expressed in Kelvin or Celsius, which is conventional. The SI unit for specific heat is joule per kilogram kelvin (J kg^{-1} K^{-1}).

DYNAMIC PARAMETERS

Mass and energy transport in soil are described using the Darcy law for water, the Fourier law for heat, and the Fick law for gas diffusion. Each of these laws states that a flux density of heat or substance is proportional to a driving force. The driving force for water flow is a water potential gradient (J kg^{-1} m^{-1} or m s^{-2}, since J = N m = kg m^2 s^{-2}). The driving force for heat flow is a temperature gradient (K m^{-1}), and the driving force for gas diffusion is a concentration gradient (kg m^{-4}). The SI unit for heat flux density is watts per square meter (W m^{-2}), which requires that thermal conductivity be in units of W m^{-1} K^{-1}. Flux density for gas is kg m^{-2} s^{-1}, which results in units for diffusivity in the Fick equation of m^2 s^{-1}.

Water flux density can be expressed either as mass of water per unit area per unit time (kg m^{-2} s^{-1}) or volume of water per unit area per unit time (m^3 m^{-2} s^{-1} or m s^{-1}). The latter has the disadvantage of varying with water density, but results in the familiar depth/time units which are in current use. When the flux density and driving force are expressed on a volume basis, the hydraulic conductivity has units of m^3 s kg^{-1}, while for mass-based flux density and driving force the units are kg s m^{-3}. There are advantages to using mass fluxes for water as well as gases, and the (approximate) conversion from mass flux density to depth per unit time is simple (1 kg/m^2 = 1 mm). Consistency is the main advantage to be gained by SI, and this is best accomplished by using mass flux density.

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Table 1. SI units for use in soil physics

Quantity	Application	Unit†	Symbol
Density	Particle density Bulk density	megagram per cubic meter	Mg/m^3
Concentration	Gas concentration	gram per cuic meter (P)	g/m^3
		mole per cubic meter (A)	mol/m^3
	Water content	kilogram water per kilogram soil	kg/kg
		cubic meter water per cubic meter soil	m^3/m^3
Potential energy of soil water	Driving force for flow	joule per kilogram (P)	J/kg
		kilopascal (A)	kPa
		meter of water in a gravitational field (A)	m
Specific heat	Heat storage	joule per kilogram kelvin	J kg^{-1} K^{-1}
Flux density	Heat flow	watts per square meter	W/m^2
Flux density	Gas diffusion	gram per square meter second (P)	g m^{-2} s^{-1}
		mole per square meter second (A)	mol m^{-2} s^{-1}
	Water flow	kilogram per square meter second (P)	kg m^{-2} s^{-1}
		cubic meter per square meter second (A)	m^3 m^{-2} s^{-1} or m/s
Thermal conductivity	Heat flow	watt per meter kelvin	W m^{-1} K^{-1}
Gas diffusivity	Gas diffusion	square meter per second	m^2/s
Hydraulic conductivity	Water flow	kilogram second per cubic meter (P)	kg s m^{-3}
		cubic meter second per kilogram (A)	m^3 s kg^{-1}
		meter per second (A)	m/s

† (P) = preferred, (A) = alternate.

As we previously mentioned, it is common for soil physicists to use depth of water in a gravitational field as an index of water potential. This practice parallels that of [illegible] who, with Darcy, express the basic flow equation in terms of hydraulic head and hydraulic gradient. It also is formally comparable to the foregoing expression for potential by expressing it in terms of energy per unit of weight of water in a gravitational field. The advantage of this approach is that the driving force in Darcy's law becomes dimensionless and that the flux density and hydraulic conductivity have the same dimensions, namely depth of water per unit time. Furthermore, it relates directly to laboratory and field measurements. A disadvantage is that it represents a departure from the consistent set of units presented above. When the use of potential is expanded to include, for example, osmotic potential, the expression in terms of the height of a column of water is a bit forced.

Table 2. Unit systems for water flow applied to Darcy's law

Flux density	Hydraulic conductivity	Potential gradient
Potential in energy per unit mass kg m^{-2} s^{-1}	kg s m^{-3}	J kg^{-1} m^{-1}
Potential in energy per unit volume m s^{-1}	m^3 s kg^{-1}	Pa m^{-1}
Potential in energy per unit weight m s^{-1}	m s^{-1}	m m^{-1}

The overriding consideration in adoption of SI is consistency, and in light of this, it seems reasonable to favor reporting potentials in J kg^{-1} and conductivities in kg s m^{-3} so that flux densities are in kg m^{-2} s^{-1}. If the units for conductivity seem unwieldy, perhaps a name could be attached to them such as with other combinations of units. It is not inconsistent with the SI rules, however, to express flux densities and driving forces in volume units, or to express the driving force in terms of a hydraulic gradient. Depending on the intended audience and/or use, these deviations from a rigorously consistent system seem acceptable.

Hydraulic conductivities in m/s are multiplied by water density and divided by the gravitational constant to convert to kg s m^{-3}. For an approximate conversion, multiply m/s by 100 to get kg s m^{-3}. Conductivity in kg s m^{-3} is converted to m^3 s kg^{-1} by dividing by the square of the water density. Thus kg s m^{-3} are approximately 10^6 larger than m^3 s kg^{-1}.

Table 1 lists our proposed units for soil physics along with acceptable alternatives. Table 2 is intended to clarify the interrelationships among the three sets of conventions for the Darcy equation.

LITERATURE CITED

1. Hubbert, M. K. 1956. Darcy's law and the field equations of the flow of underground fluids. J. Petrol. Technol. 8(10):222-239.
2. Rose, D. A. 1979. Soil water: quantities, units and symbols. J. Soil Sci. 30:1-15.

Soil Science Terminology

The Glossary of Soil Science Terms (revised SSSA, 1983), contains definitions of nearly 1200 terms, plus appendices covering obsolete terms, procedural guide for tillage terminology, and new designations for soil horizons and layers.

Measurements, SI System

The SI system (Le Systeme International d'Unites) of reporting measurements is being adopted on a woldwide basis and is requied in all society publications except Crops and Soils Magazine.

Basic references on the use of SI units were published by the National Bureau of Standards and the American Society for Testing Materials. The Journal of Agrnomic Education contains three articles on use of SI units and conversions from other units which are particularly useful to agronomists, crop scientists, and soil scientists.

Base, supplementary, and derived units

The seven base and two supplementary units, with their names and symbols, on which SI is based, are listed in Table 1. Precise definitions are given elsewhere.

Some of the units can pose problems in the agronomic sciences.

Table 1. Base and Supplementary SI Units

Quantity	Unit	Symbol
Amount of substance	Mole	mol
Electric current	Ampere	A
Length	Meter	m
Luminous intensity	Candela	cd
Mass	Kilogram	kg
Thermodynamic temperature	Kelvin	K
Plane angle	Radian	rad
Solid angle	Steradian	sr

Table 2. Derived SI Units With Special Names

Quantity	Name	Symbol	Expression in terms of other units	Expression in terms of SI base units
Absorbed dose, specific energy imparted, kerma, absorbed dose index	Gray	Gy	J/kg	$m^2 s^{-2}$
Activity (of a radionuclide)	Becquerel	Bq		s^{-1}
Capacitance	Farad	F	C/V	$m^{-2} kg^{-1} s^4 A^2$
Celsius temperature	Degree Celsius	°C		K
Conductance	Siemens	S	A/V	$m^{-2} kg^{-1} s^3 A^2$
Electric potential, potential difference, electromotive force	Volt	V	W/A	$m^2 kg s^{-3} A^{-1}$
Electric resistance	Ohm	Ω	V/A	$m^2 kg s^{-3} A^{-2}$
Energy, work, quantity of heat	Joule	J	N·m	$m^2 kg s^{-2}$
Force	Newton	N		$m kg s^{-2}$
Frequency	Hertz		s^{-1}	
Power, radiant flux	Watt	W	J/s	$m^2 kg s^{-3}$
Pressure, stress	Pascal	Pa	N/m^2	$m^{-1} kg s^{-2}$
Quantity of electricity, electric charge	Coulomb	C	A s	s A

Since the quantification of light in visual terms (candela) does not correspond to the photosynthetically active portions of the electromagnetic spectrum (400 to 700 nm), plant scientists cannot use the candela to report photosynthetically active radiation, but must quantify light in terms of photon count, i.e. the number (moles) of photons incident per unit area over time, or in terms of energy (watts per square meter). The definition of the mole, adopted by the 14th General Conference on Weights and Measures in 1971(1) is the amount of substance of a system which contains as many elementary elements as there re atoms in 0.012 kg of carbon-12. When the unit mole is used, the entities must be specified. See Light below.

Derived units (Table 2) are expressed algebraically in terms of base units. Some of these units 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 meter kilogram per second squared. Another unit with a special name is the pascal (Pa), which is a newton per square meter.

Using SI units

Base, supplementary and derived units, and combinations thereof, should be used as follows:

Prefixes and symbols listed in Table 3 are used to indicate orders of magnitude in SI units. They reduce the use of insignificant digits and decimals and provide a convenient substitute for writing powers of 10 as generally preferred in computations. A prefix preferably should be chosen so tht the numerical value lies between 0.1 and 1000. The same unit, multiple or submultiple should be used throughout the text, tables, and graphs. Prefixes should be used in the numerator, not the denominator of compound units; kilogram is an exception since it is a base unit of SI. An exponent attached to a symbol containing a prefix indicates that the unit with its prefix is raised to the pwoer expressed by the exponent. For example:

1 cm3 = (10-2 m)3 = 10-6 m3

Punctuation is used sparingly with SI units. The center dot, generally used to indicate the product of two or more units, is dispensed with when there is no risk of confusion with another unit symbol (use N m not N.m). A solidus (oblique stroke,/), horizontal line, or negative powers may be used to express a derived unit formed by two others by division. For example:

m/s or or m s -1

Only one solidus may be used in combinations of units, unless parentheses are used to avoid ambiguity. For example:

g m-2 s-1 or g/(m2s) but not g/m2/s

Table 3. SI Prefixes

Order of magnitude	Prefix	Symbol
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

Table 4. Preferred (P) and Acceptable (A) Units for Several Quantities

Quantity	Application	Unit	Symbol
Concentration	Known molar mass (liquid and solid material)	Mole per cubic meter (P)	mol m^{-3}
		Mole per liter (A)	mol L^{-1}
	Unknown molar mass (liquid and solid material)	Gram per cubic meter (P)	g m^{3}
		Gram per liter (A)	g L^{-1}
	Known ionic charge	Mole charge per cubic meter	mol (p^+) m^{-3} or mol (e^-) m^{-3}
		Mole charge per liter(A)	mol (p^+) L^{-1} or mol (e^-) L^{-1}
	Gas	Gram per cubic meter (P)	g m^{-3}
		Mole per cubic meter (A)	mol m^{-3}
		Gram per liter (A)	g L^{-1}
		Mole per liter (A)	mol m^{-3}
		Mole per mole (A)	mol mol^{-1}
Exchange parameters	Exchange capacity	Mole charge of saturating ion, i, per kilogram (P)	mol (i) kg^{-1}
		Centimole charge of saturating ion, i, per kilogram (A)	cmol (i) kg^{-1}
	Exchangeable ion composition	Mole charge of specified ion, i, per kilogram	mol (i) kg^{-1}
Light	Irradiance	Watts per square meter	W m^{-2}
	Photo flux density (400–700 nm)	Micromole per square meter second	μmole m^{-2} s^{-1}
Water potential	Driving force for flow	Joule per kilogram (P)	J kg^{-1}
		Megapascal (A)	mPa
		Meter of water in a gravitational field (A)	m

Periods are used after any SI unit symbol, except at the end of a sentence. When writing numbers less than one, a zero should be written before the decimal marker.

Use of non-SI units

Some units not in SI can be used--including use in the denominator--in the societies' publications, but these units have been limited to those that are convenient for crop and soil scientists. The quantity of area can be expressed as hectare (1 ha = 10 4 m2). Use of liter in the deonimnator of derived units is permitted in the societies' publications, but m3 is encouraged.

The base unit, second(s), is the preferred unit of time. Other units--minutes (60 s), hour (3600 s), day (86 400 s), etc.--are acceptable although their use introduces difficulties in rapid conversion from one time scale to another. Units of time that vary in length, such as month or growing season, should be avoided.

The term "ton" can be confusing. In SI, a ton, t, equals 10 3 kg or 1 Mg, and is understood to be metric ton. Do not use the term metric ton. Although it is obvious that, when SI units are used, the ton cannot refer to the English long or short ton, potential confusion can be avoided by using the unit 1 Mg. In verbal communications, the preferred unit is the megagram.

While radians is the base unit for measurement of plane angles, degrees are also acceptable.

Specific applications

Special attention is required for reporting concentration, exchange composition and capacity, energy of soil water (or water potential), and light. Table 4 summarizes the appropriate units for society publications.

Concentration: Examples for correctly expressing concentration, c, include:

$c(HCl)$ = 0.1 mol L-1 (=0.1 M HCl) and

$c(H_2PO_4^-)$ = 2.1 mol m-3)=2.1 mmol L-1)

The concentration 0.1 mol L-1 can also be reported as a 0.1 M (molar) solution. Molality (mol kg-1) is an acceptable term and unit: it is the preferred unit for precise, nonisothermal conditions.

Normality, N, the amount of substance concentration based on the concept of equivalent concentration is preferably expressed on a molar basis (5, 7). For example, c (H_3PO_4) = 0.1 M (1/2 H_3PO_4) = 0.1 N (1/2 H_3PO_4). The species 1/2 H_3PO_4 can represent that entity which in a specified reaction would combine with or be in any other appropriate way equivalent in an acid-base reaction to one entity of titratable hydrogen ions, H^+.

Gas concentration can be expressed as g -3 , mol m-3, partial pressure, as mole fraction. The first unit is useful for particulate concentration in gases. The term mol m-3 is directly proportional to the partial pressure of an ideal gas; it is acceptable within SI to express gas concentration in units of pressure. At less than 500 kPa pressure, gases behave virtually ideally so moles and volumes are equivalent; at a fixed pressure, a mole of a given gas occupies the same volume as any other gas. The denominator of the mole fraction needs no summation sign because SI defines a mole 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 x 10-2 mol mol-1 or 0.21 mole fractions.

Exchange Composition and Capacity: Historically, the soil scientist has expressed exchange capacity in equivalents (eq) per 100 g. Neither unit in the numerator or denominator conforms to SI. Exchange capacity and exchangeable ion composition should be expressed as moles of charge -- either positive (p+) or negative)(e-) -- per unit mass (6). For example, the exchangeable ion composition and cation exchange capacity for a soil which contains 4 cmol of exchangeable K^+ and 2 cmol of exchangeble Ca^{2+} (4 cmol of 1/2 Ca^{2+} or 4 cmol of p+) per kilogram should be reported in tabular form as follows:

Exchangeable ion		Cation exchange capacity
K^+	Ca^{2+}	
cmol(p+)kg-1		
4	4	8

Formerly, the method of expressing exchange composition and capacity would indicate the soil contained 4 meq per 100 g of exchangeable K^+ and of Ca^{2+} with cation exchange capacity of 8 meq per 100 g.

If the cation exchange capacity is determined by the single ion saturation technique, then the ion used should be specified since it can affect the cation exchange capacity measured. If Mg^{2+} were used for the soil in the example above, and specific ion effects were insignificant, the cation exchange capacity would be expressed as 8 cmol (1/2 Mg^{2+}) kg^{-1}.

Energy of soil water or water potential: The soil water potential refers to its equivalent potential energy; it can be expressed on either a mass or a volume basis (39). Energy per unit mss 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 J kg^{-1} is 1 kPa if the density of water is 1 Mg m^{-3}; and since 1 bar = 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 over the pressure unit (Pa).

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 J kg^{-1} is the gravitational constant multiplied by the height of the water column. Since the gravitational constant is close to 10 (9.81 m s^{-2}), hydraulic head in meters of water is approximately 10 times the water potential expressed in J kg^{-1} of kPa.

Light: Accepted SI notation for total radiant energy per unit area is joule per square meter. Energy per unit time,, or irradiance, is expressed as joule per square meter second or watt per square meter. Alternative units, based on calories or ergs for energy and square centimeter for area, are not acceptable.

As mentioned earlier, plant scientists concerned with the photochemical photosynthetic reaction must qualify light (400 to 77 nm in the electromagnetic spectrum) in terms of photon content, rather than total energy. To this end, photon flux density is expressed in moles of photons incident per unit area over time. One mole of photons has been equated directly with one einstein (E) in the calibration of certain commercially available sensors. Thus, a common expression of photon flux density is microeinsteins per square meter second (E m^{-2} s^{-1}). When reporting electromagnetic spectrum measurements, however, specify the light source and the name of the measuring instrument and use SI units.

Use of Percent in the SI System

Use of percent to express quantitative relationships may or may not meet usage requirements of the SI system. The following guidelines are presented to assist authors and editors in determining correct usage of the percentage expression.

1. Conditions where the use of percent (%) is inappropriate and should be replaced by suitable SI units.

Whenever the composition of some mixture is being described and it is possible to express entities of the mixture in SI base or derived units, then use of percent is unacceptable and should be replaced by appropriate SI units.

2. Conditions where the use of percent (%) is acceptable and may be suitably used in conjunction with SI units.

Wherever an event is being described whose elements cannot be described in SI base or derived units then percent is acceptable for describing the frequency, rate, difference, distribution, share, etc., of that event. Essentially then percent is reserved for use with observations not quantifiable in SI units. Use of percent in this manner is very commonplace and frequently enhances the understanding of comparable events. Users, however, must accept responsibility for removing any ambiguity surrounding its interpretation. Examples of conditions where SI cannot be used and use of % is permissible when ambiguity is removed are: botanical composition, stand and cover estimates, % leaves (or plants) infected, or % applied nitrogen recovered by plants.

Tables of recommended units (Table 5) and conversion factors (Table 6) are included to aid in the use of SI units. (Linda is setting tables).

Table 5. Examples of Preferred (P) and Alternate (A) Units for General Use

Quantity	Application	Unit	Symbol
Area	Land area	Hectare	ha
	Leaf area	Square meter	m^2
	Pot area	Square centimeter	cm^2
	Specific surface area of soil	Square meter per kilogram	$m^2\ kg^{-1}$
Density	Soil bulk density	Megagram per cubic meter	$Mg\ m^{-3}$
Electrical conductivity	Salt tolerance	Decisiemens per meter	$dS\ m^{-1}$
Elongation rate	Plant	Meter per second	$m\ s^{-1}$
		Millimeter per second	$mm\ s^{-1}$
		Meter per day	$m\ d^{-1}$
Evapotranspiration rate	Plant	Cubic meter per square meter second	$m^3\ m^{-2}\ s^{-1}$ or $m\ s^{-1}$
Flux density	Heat flow	Watts per square meter	$W\ m^{-2}$
	Gas diffusion	Gram per square meter second (P)	$g\ m^{-2}\ s^{-1}$
		Mole per square meter second (A)	$mol\ m^{-2}\ s^{-1}$
	Water flow	Kilogram per square meter second (P)	$kg\ m^{2}\ s^{-1}$
		Cubic meter per square meter second (A)	$m^3\ m^{-2}\ s^{-1}$ or $m\ s^{-1}$
Gas diffusivity	Gas diffusion	Square meter per second	$m^2\ s^{-1}$
Hydraulic conductivity	Water flow	Kilogram second per cubic meter (P)	$kg\ s\ m^{-3}$
		Cubic meter second per kilogram (A)	$m^3\ s\ kg^{-1}$
		Meter per second (A)	$m\ s^{-1}$
Ion transport	Ion uptake	Mole per kilogram (of dry plant tissue) second	$mol\ kg^{-1}\ s^{-1}$
		Mole of charge per kilogram (of dry plant tissue) second	$mol\ (p^+)\ kg^{-1}\ s^{-1}$ or $mol\ (e^-)\ kg^{-1}\ s^{-1}$
Leaf area ratio	Plant	Square meter per kilogram	$m^2\ kg^{-1}$
Length	Soil depth	Meter	m
Photosynthetic rate	CO_2 mass flux density	Milligram per square meter second	$mg\ m^{2}\ s^{-1}$
	CO_2 amount of substance flux density	Micromole per square meter second	$\mu mol\ m^{-2}\ s^{-1}$
Resistance	Stomatal	Second per meter	$s\ m^{-1}$
Specific heat	Heat storage	Joule per kilogram Kelvin	$J\ kg^{-1}\ K$
Thermal conductivity	Heat flow	Watt per meter Kelvin	$W\ m^{-1}\ K$
Transpiration rate	H_2O mass flux density	Milligram per square meter second	$mg\ m^{-2}\ s^{-1}$
Volume	Field	Cubic meter	m^3
	Laboratory	Liter	L
Water content	Soil	Kilogram water per kilogram dry soil	$kg\ kg^{-1}$
		Cubic meter water per cubic meter dry soil	$m^3\ m^{-3}$
Yield	Grain or forage yield	Megagram per hectare	$Mg\ ha^{-1}$
		Gram per square meter	$g\ m^{-2}$
	Mass of plant or plant part	Gram (gram per plant or plant part)	g (g $plant^{-1}$ or g $kernel^{-1}$)

Table 6. Factors for Converting Non-SI Units to Acceptable SI Units

Non-SI Units Multiply	By	SI Units To obtain
acre	4.05×10^{3}	square meter, m^2
acre	0.405	hectare, ha (10^4 m^2)
acre	4.05×10^{-3}	square kilometer, km^2 (10^6 m^2)
Angstrom unit	0.1	nanometer, nm (10^{-9} m)
atmosphere	0.101	megapascal, MPa (10^6 Pa)
bar	10^{-1}	megapascal, MPa (10^6 Pa)
British thermal unit	1.05×10^{3}	joule, J
calorie	4.19	joule, J
calorie per square centimeter minute (irradiance)	698	watt per square meter, W m^{-2}
calorie per square centimeter (langley)	4.19×10^{4}	joules per square meter, J m^{-2}
centimeters per day (elongation rate)	0.116	micrometers per second, $\mu m\ s^{-1}$ (10^{-6} m s^{-1})
cubic feet	0.028	cubic meter, m^3
cubic feet	28.3	liter, L (10^{-3} m^3)
cubic inch	1.64×10^{-5}	cubic meter, m^3
cubic inch	16.4	cubic centimeter, cm^3 (10^{-6} m^3)
curie	3.7×10^{10}	becquerel, Bq
degrees (angle)	1.75×10^{-2}	radian, rad
dyne	10^{-5}	newton, N
erg	10^{-7}	joule, J
foot	0.305	meter, m
foot-pound	1.36	joule, J
gallon	3.78	liter, L (10^{-3} m^3)
gallon per acre	9.35	liter per hectare, L ha^{-1}
gram per cubic centimeter	1.00	megagram per cubic meter, Mg m^{-3}
gram per square decimeter hour (transpiration)	27.8	milligram per square meter second, mg m^{-2} s^{-1} (10^{-3} g m^{-2} s^{-1})
inch	25.4	millimeter, mm (10^{-3} m)
micromole (H_2O) per square centimeter second (transpiration)	180	milligram (H_2O) per square meter second, mg m^{-2} s^{-1} (10^{-3} g m^{-2} s^{-1})
micron	1.00	micrometer, μm (10^{-6} m)
mile	1.61	kilometer, km (10^3 m)
miles per hour	0.477	meter per second, m s^{-1}
milligram per square decimeter per hour (apparent photosynthesis)	0.0278	milligram per square meter second, mg m^{-2} s^{-1} (10^{-3} g m^{-2} s^{-1})
milligram per square centimeter second (transpiration)	10 000	milligram per square meter second, mg m^{-2} s^{-1} (10^{-3} g m^{-2} s^{-1})
millimhos per centimeter	1.00	decisiemens per meter, dS m^{-1}
ounce	28.4	gram, g (10^{-3} kg)
ounce (fluid)	2.96×10^{-2}	liter, L (10^{-3} m^3)
pint (liquid)	0.473	liter, L (10^{-3} m^3)
pound	454	gram, g (10^{-3} kg)
pound per acre	1.12	kilogram per hectare, kg ha^{-1}
pound per acre	1.12×10^{-3}	megagram per hectare, Mg ha^{-1}
pound per cubic foot	16.02	kilogram per cubic meter, kg m^{-3}
pound per cubic inch	2.77×10^{4}	kilogram per cubic meter, kg m^{-3}
pound per square foot	47.9	pascal, Pa
pound per square inch	6.90×10^{3}	pascal, Pa
quart (liquid)	0.946	liter, L (10^{-3} m^3)
quintal (metric)	10^{2}	kilogram, kg
square centimeter per gram	0.1	square meter per kilogram, m^2 kg^{-1}
square feet	9.29×10^{-2}	square meter, m^2
square inch	645	square millimeter, mm^2 (10^{-6} m^2)
square mile	2.59	square kilometer, km^2
square millimeter per gram	10^{-3}	square meter per kilogram, m^2 kg^{-1}
temperature (°F − 32)	0.556	temperature, °C
temperature (°C + 273)	1	temperature, K
ton (metric)	10^{3}	kilogram, kg
ton (2000 lb)	907	kilogram, kg
ton (2000 lb) per acre	2.24	megagram per hectare, Mg ha^{-1}