duripan. These horizons occur mostly in soils of arid and semiarid regions and indicate the depth of water movement. In soils rich in carbonates, the calcic horizon tends in time to become plugged with carbonates and cemented into a hard, massive, continuous horizon that is called petrocalcic. In engineering behavior this horizon simulates hard country rock.

The diagnostic horizons may not have a direct bearing on soil behavior, but they are important building blocks of the system. They are used to group together soils that have something in common that is eventually expressed in the unique behavior of the soil. For example, argillic horizons indicate an accumulation of transported clay; they do not reflect kind and amount of clay, which strongly influence engineering behavior. Kind and amount of clay are reflected in the lower categories of the system, namely, family and series. Thus, there are many kinds of soils that have different engineering properties but that all have argillic horizons.

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Publication of this paper sponsored by Committee on Exploration and Classification of Earth Materials.

Soil Moisture and Temperature Regimes in Soil Taxonomy

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Soil moisture and temperature regimes have been used as criteria for the classification of soils in the United States since the National Cooperative Soil Survey adopted Soil Taxonomy in 1965. The quantitative criteria used to define soil moisture regimes are based on the depth, probable duration, and seasonality of soil saturation and vegetation-restricting soil dryness. Soils with morphological evidence of frequent surface flooding are identified. Soils with extremely low bearing strength because of the interaction of their mineral and organic components with ambient high moisture contents are also taxonomically identified. Criteria for soil temperature regimes encompass the mean annual soil temperature and the amplitude of the change in soil temperature from summer to winter. Permafrost conditions are identified. Limited ranges for each of these soil temperature and moisture properties are defined and readily identified by connotative formative elements in the formal taxonomic name of each soil classified in modern soil surveys.

Historically, the study of temperature and moisture conditions affecting plant growth has been ascribed to the science of climatology or meteorology. Earlier, and some current, attempts to classify soils did not deal directly with soil temperature or moisture content except as they related to the chemical or mineralogical properties of soil. Soil scientists have recognized since the late 1800s that temperature and moisture regimes are closely related to soil properties. In 1965, the U.S. National Cooperative Soil Survey officially began to use direct criteria of soil moisture and temperature in its taxonomic criteria. Although this was a break with the long-standing tradition of not using soil moisture and temperature data for classification, it could be logically argued that a given soil, or given site, had distinct temperature and moisture regimes. Even though these factors were closely related to climatic conditions, the relation was no more indirect than, for example, the association of sandy soils to sandy parent materials, i.e., sandstones and sandy alluvial sediments. Furthermore, soil temperature and moisture could be measured. It was well known that these parameters of a soil varied with time of day and from day to day, season to season, and year to year. It was thus apparent that the use of soil temperature and moisture data in a soil taxonomic system would require criteria based on absolute ranges and probability (3).

One of the roles of the National Cooperative Soil Survey is to provide an inventory of the possible uses of land in the United States. Because much of our land is used for the growth of food and fiber, the soil moisture and temperature criteria used to classify the soil must have some direct interpretation for the growth of plants. Much of our land is also used for buildings and roads, and moisture and temperature conditions at any given site are an integral part of the planning for such condition (1). Flooding, bearing strength, and permafrost are some of the features of direct concern.

SOIL TEMPERATURE CRITERIA

Temperatures near the surface of the soil fluctuate diurnally, seasonally, with the amount and type of plant cover and the amount of water present in the soil. The magnitude of the fluctuations decreases with depth. However, at a given site, the mean annual temperatures at all soil depths, and even below the soil profile, differ only slightly (6). The mean annual soil temperature (MAST) is related most directly to the mean annual air temperature. Daily temperature variations are detectable to a depth of about 50 cm (20 in). To avoid time-of-day variations, measurements of soil temperature are taken at this depth. Because short-term weather events may influence soil temperatures at 50 cm (20 in), antecedent weather is considered for individual measurements.

One major distinction is made with respect to soil temperature: Those soils for which the mean soil temperature of the three warmest months differs from the mean soil temperature of the three coldest months by less than 5°C (9°F) are referred to as iso and are separated from those soils for which the temperature difference is greater than 5°C (9°F). Except for small areas where the climate is greatly modified by the oceans, these iso areas are confined to the intertropical zone. In the United States iso-temperature soils are found in Puerto Rico, Hawaii, and some coastal areas of California.

Soil temperature regimes in noniso areas and their limits are given in the tables below. The following table gives the characteristics of regimes for which mean winter and summer soil temperatures vary by more than 5°C (9°F).

Regime	MAST
Hyperthermic	>22°C (>72°F)
Thermic	15 to 22°C (59 to 72°F)
Mesic	8 to 15°C (47 to 59°F)
Frigid	<8°C (<47°F) but not cryic or pergelic
Cryic	0 to 8°C (32 to 47°F)
Pergelic	<0°C (<32°F) and permafrost present

Mean annual soil temperatures cited above for soils of the cryic regime depend on the following conditions: (a) not water-saturated [with leaf cover mean summer temperature <8°C (<47°F)]; (b) not water-saturated [without leaf cover mean summer temperature <15°C (<59°F)]; (c) water-saturated in summer [without leaf cover mean summer temperature <13°C (<55°F)]; (d) water-saturated in summer [with leaf cover mean summer temperature <6°C (<43°F)]; (e) organic soils frozen at some depth 2 months after summer solstice or influenced by ocean water.

Characteristics of regimes for which mean winter and summer soil temperatures vary by less than 5°C (9°F) are as follows:

Regime	MAST
Isohyperthermic	>22°C (>72°F)
Isothermic	15 to 22°C (59 to 72°F)
Isomesic	8 to 15°C (47 to 59°F)
Iso Frigid	<8°C (<47°F)

The limits placed on the soil temperature groups were selected to correspond in a general way with the geographic range of major crop plants in the United States. Hyperthermic soils are essentially those in which it is possible to grow citrus successfully. Thermic soils encompass the cotton-growing areas. There is little hazard of frost heaving in construction in these soils. Mesic soils in the United States extend north to the approximate colder limit of corn-growing areas. Frigid soils occur in the still colder areas. Cryic soils are a special condition in the frigid areas that have extremely cold summer temperatures that essentially preclude crop production, while certain crops having a short growing season are possible in frigid soils. Frost heaving is a very real problem in construction in mesic, frigid, and cryic soils. Pergelic soils have permafrost.

SOIL MOISTURE CRITERIA

Water alternating with air occupies the void areas formed by the imperfect fit of the solid particles in the soil. Void volume composes about 50 percent of most soils but ranges drastically depending on particle-size distribution and natural aggregation of the solid particles. The tension with which water is retained in the soil voids is the basis for classifying the various states of soil water.

In Soil Taxonomy three states of soil water are considered. At the dryer end of the range is unavailable water, when soil moisture tension is greater than 1.5 MPa (15 bars) and water is largely not available for plant growth. This soil moisture state is considered dry. The saturated state occurs when there is no tension on the water and all the void space is filled with water. Available water is that water held in the soil at water tensions between 0 and 1.5 MPa (0 and 15 bars) (Table 1). Part of this water [about 0 to 0.03 MPa (0 to 0.3 bars)] drains under the force of gravity and is sometimes referred to as gravitational water. The duration and depth at which each of these soil water states occurs in a given soil are then used to define the various moisture regimes in Soil Taxonomy.

Moisture Control Section

The depths in the soil at which soil moisture criteria are established are defined by the concept of the moisture control section. The upper boundary of the moisture control section is the depth to which a dry soil will be moistened in 24 h after a 2.5-cm (1-in) rain. The lower boundary of the moisture control section is the depth to which 7.5 cm (3 in) of water, introduced through the soil surface, will moisten a dry soil in 48 h or the depth to a root-restricting layer such as hard rock, whichever is shallower. Because of the general relation of void size to particle-size distribution, rough estimates of the control-section depths are (a) between 10 and 30 cm (4 and 12 in) in soil material with either more than 18 percent clay or more then 50 percent silt and less than 15 percent sand, or both; (b) between 20 and 60-cm (8 and 24-in) depths in textures coarser than those given above but less than 70 percent sand if there is no clay or less than 15 percent clay and no silt; (c) between 30 and 90-cm (12 and 35-in) depths if the soil material has more than 70 percent sand and no clay or less than 15 percent clay and no silt. Although cumbersome at first glance, this definition permits rapid computer modeling of soil moisture regimes from soil properties and long-term weather records, which then permits probability predictions of the moisture regime of all soils. In the computer models it is assumed that some part of the moisture control section will be dry after evapotranspiration exceeds rainfall by 7.5 cm (3 in) and all of the control section will be dry after evapotranspiration exceeds precipitation by 17.5 cm (7 in). [A program in COBOL can be obtained on tape or printout from the Soil Conservation Service of the U.S. Department of Agriculture.] Specific soils have to be evaluated to account for runoff and runon.

Criteria for Soil Moisture Regimes

The following soil moisture regimes are identified for use in Soil Taxonomy.

1. Aridic or torric moisture regimes include those soils that have moisture control sections completely dry more than one-half of the time and never moist in any part for as long as 90 consecutive days when the soil temperature at 50 cm (20 in) averages more than 8°C (47°F). In the United States these areas are mainly in the desert Southwest.
2. Ustic moisture regime soils have moisture control sections that are dry in some parts more than 90 cumulative days in 6 out of 10 years. If the mean annual soil temperature is less than 22°C (72°F) and mean summer

Table 1. Soil moisture relations.

Atmospheres (approximate)	Tension (MPa/g)	Soil Moisture Constant	State of Soil Water
10 000	980	Oven dry at 105° C (223°F)	Unavailable water; most plants cannot extract water (dry); pore diameters less than 0.2 µm
15	1.5	Wilting point of many plants	Available water; most plants can take up water held by soil pores larger than 0.2 µm in diameter
0.1 to 0.3	0.08	Field capacity gravitational drainage almost imperceptible	Gravitational water; water moves in response to gravity; plants can use water but pores larger than about 10 µm in diameter drain rapidly under gravitational force
0	0	Saturation, all voids full	Saturated flow, either anaerobic or aerobic, depending on biological activity and duration of saturation

Note: 1 Pa = 1 x 10^{-5} bar; 1°C = (1°F - 32)/1.8; 1 µm = 4 x 10^{-5} in.

Table 2. Use of soil temperature and moisture regimes in soil names.

Regime	Order	Suborder	Great Group	Subgroup	Family
Aridic	Id	Torr	Torr (torri)	Torric[a], torr, aridic	
Ustic		Ust	Usti	Usti[b] (ust)	
Xeric[c]		Xer	Xer (xero)	Xeric[d] (xer)	
Udic		Ud	Ud (udi)	Udic, ud	
Aquic	Ist[e]	Aqu[f]	Sal[g]	Aquic[h] (aqu)	
Flooding		Fluv	Fluv	Fluvic (fluv)	
Low bearing			Hydra		
Pergelic				Pergelic	
Cryic			Cry (cryo)		
Frigid			Bor (boro)	Boric, bor	Frigid[i]
Mesic	Ult[j], ert[j]		Medi[k], medo		Mesic
Thermic			Medi[k], medo[k]		Thermic
Hyperthermic			Medi[k], medo		Hyperthermic
Iso		Trop[l]	Trop[l]	(Tropic)[l]	Iso

[a] Some part of moisture control section dry more than 60 percent of the time in most years.
[b] Ust (ustic) in Aridisols means part of control section moist 25 to 50 percent of the time.
[c] Also < 22°C (< 72°F) MAST if mean summer soil temperature differs more than 5°C (9°F) from mean winter soil temperature.
[d] Xer (xeric) in an Aridisol order may have control section moist 25 to 50 percent of the time.
[e] Ist means Histosol (organic soil) that is saturated, unless artificially drained or in a constantly humid environment recognized as folist.
[f] With aeric in subgroup these soils have deeper saturated zone than in typic subgroup.
[g] Saturated with high-salt-content (saline) water.
[h] Saturation and reduction at greater depth in the soil than when used at suborder level.
[i] Not in families where bor, cry, or pergelic appear at higher level.
[j] Ultisols and Vertisols are mesic, thermic, or hyperthermic, or iso equivalent.
[k] In Histosols (organic soils) med formative element covers everything with MAST > 8°C (> 47°F) and not iso.
[l] Presence of trop means iso, but its absence does not mean not iso.

and winter temperatures differ by more than 5°C (9°F), they are not dry in all parts for more than 45 d in the 4 months following the summer solstice in as much as 6 out of 10 years. These areas of the United States are in the western part of the Great Plains.

3. Xeric moisture regime soils have completely dry moisture control sections more than 45 consecutive days in the 4 months following the summer solstice in at least 6 out of 10 years and are not aridic. Most of these areas are in California, Oregon, and Washington.

4. Udic moisture regime soils have moisture control sections that are not dry, in any part, as long as 90 cumulative days in most years and not dry throughout for as much as 45 consecutive days within 4 months after the summer solstice in more than 6 of 10 years when the soil temperature is above 5°C (41°F). In the United States these areas are generally east of 95° longitude.

5. Aquic moisture regime soils have control sections saturated with water for a sufficient period of time during the year when soil temperatures are above 5°C (41°F) so that reducing conditions will develop that will cause iron to reduce to the ferrous form. These soils can occur in any part of the world where there is a seasonally high water table. Where these soils are subject to freezing, they are susceptible to severe frost heaving (7). In such soils every effort should be made to lower the water table in relation to the grade of a road.

6. Peraquic moisture regime soils are saturated near the surface all year, as in tidal marsh.

Special Moisture Regime Categories

Some soils that are normally saturated with water have very low bearing strength. When this condition becomes severe enough it precludes the grazing of livestock. Such a condition severely limits the use of conventional vehicles. In addition to field observation, the following formula is used to identify these soils:

$$n = (A - 0.2R) + (L + 3H) \quad (1)$$

where

A = percentage of water on an oven-dry-weight basis in the natural state of the soil,
R = percentage of solid material between 0.002 and 2 mm (0.07×10^{-3} and 0.07 in),
L = percentage of solids <0.002 mm (<0.07×10^{-3} in), and
H = percentage of organic matter.

Where the n value exceeds 0.7 the soil behaves as a liquid, squeezes from one's grip when examined in the field, and will not normally support animal or normal vehicular traffic. Such soils are classified in hydric subgroups.

Flooding is a characteristic of many soils. Flooding can of course be observed during the actual event. However, flooding events are often infrequent and may not occur for several consecutive years. However, flooding leaves distinct features in the soil profile that can be observed by careful morphological observation. Thus, it is possible to detect, from observation and analysis of the soil profile, if that soil has been subject to flooding and is therefore subject to future flooding (2, 4). In the normal processes of soil formation organic matter is deposited on the soil surface. When flooding occurs this surface is rapidly buried by mineral material not enriched with organic matter. Thus, while most soils show a regular decrease in organic matter content with depth, soils subject to flooding show an irregular decrease. This irregular decrease in organic matter content with depth, along with associated color and often textural stratification, identifies these soils. Such flood-prone soils are named fluv or fluvic, a shortened form of fluvial in Soil Taxonomy.

USE OF SOIL MOISTURE AND TEMPERATURE REGIMES IN SOIL TAXONOMY

Soil moisture and temperature are only two of the many soil characteristics used to classify soils in Soil Taxonomy. The relative significance of each soil characteristic in combination with the other ambient characteristics determines at what level in Soil Taxonomy that particular characteristic is assigned in the nomenclature (see the paper by Johnson and McClelland in this Record). Strict quantitative rules and keys are used to determine the soil name. Thus, depending on the other soil characteristics, the same characteristic may appear at a different position in the soil name.

Table 2 attempts to give all the ways in which soil moisture and temperature parameters are used in the nomenclature. Most of the moisture regimes are rather uniformly used at suborder, great group, or subgroup levels. Soils that have aridic moisture regimes and certain other profile characteristics are in the Aridisol (id) order. However, a floodplain soil in an aridic area would be recognized for its flooding Fluvent at the suborder level and later for its aridic moisture regime as a Torrifluvent at the great group level.

Most of the soil temperature regimes are identified at the family level, but there are some notable departures from this procedure. Where specific features of the frigid regime, cryic and pergelic, are used to identify the soil at a great group or subgroup level, frigid is omitted in the family name. Also, if boric (boro or bor) is used at a higher level, frigid is omitted in the family name. A soil not having any of these features may still be frigid, in which case frigid appears as a family name.

Two soil orders, Vertisols and Ultisols, are confined to mean annual soil temperatures warmer than 8°C (47°F). Also Histosols, organic soils with a mean soil temperature regime warmer than 8°C (47°F), carry the great group formative element medi (medo) if mean summer and mean winter temperatures differ by more than 5°C (9°F) or tropo if they differ by less than 5°C.

The element iso is used to modify any family temperature names where the difference between mean summer and mean winter temperatures is less than 5°C (9°F). Some soils with iso temperature regimes are also identified by the formative element tropo (trop) in either the suborder or great group position or tropic in the subgroup position. Iso is still used in the family name of such soils because many soils with iso temperature regimes do not carry the formative element tropo.

Using the nomenclature of Soil Taxonomy to identify soil moisture and temperature requires some familiarity with the connotative formative elements. Once a user has a working knowledge of these elements he or she can quickly see the taxonomic name of the soils in a given soil survey area and identify these characteristics. For example, a Typic Hapludult is clayey, kaolinitic, and thermic, with a udic moisture regime (suborder ud), a mean annual soil temperature between 15 and 22°C (59 and 72°F), and mean summer and mean winter temperatures that differ by more than 5°C (9°F) (thermic family). A Typic Ochraquult is clayey, kaolinitic, and thermic and has an aquic moisture regime (suborder aqu). Soil temperatures are in the same range in both soils. A Typic Torrifluvent, a fine-loamy, mixed, thermic soil, (a) is subject to flooding (fluv), (b) is usually dry (torric indicating aridic moisture regime), and (c) has a mean annual soil temperature between 15 and 22°C (59 and 72° F) (thermic).

SUMMARY

Categories of soil moisture and soil temperature are recognized and used to classify soils in Soil Taxonomy. All of these categories are identified in the proper name of a given soil. Some of these parameters are readily seen but, because they occur at different levels in the system, a user needs to have some familiarity with the system of nomenclature.

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Publication of this paper sponsored by Committee on Exploration and Classification of Earth Materials.