Soil Moisture-Temperature Correlation and Classification Model

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Abstract

Traditionally, soils that do not display evidence of wetness (i.e. redoximorphic features) are regionally defined regarding soil moisture classification. Likewise, soil temperature classification has been closely tied to mean annual air temperature recorded at nearby weather stations. Early models to aid soil scientists determine soil moisture classification regarded soil as a reservoir with a fixed capacity (Newhall 1980). Water was added through precipitation with the excess being lost to deep leaching or runoff. Stored water was removed through evapotranspiration. Later models included a formulation to account for rainfall intensity and the amount of energy required to remove moisture from layers of soil (Newhall and Berdanier 1996). Site specific variables or factors which affect soil moisture and temperature, including the interrelationship of percent slope, aspect, albedo, changes in elevation or latitude, and soil moisture handling characteristics, are quite complex and have not been consistently evaluated or used in determining these classifications.

The soil moisture-temperature model goes beyond regional determinations for moisture and temperature. It predicts site specific effects that elevation, latitude, slope, aspect, vegetation, soil depth, water holding capacity, and albedo have on soil moisture and temperature at both horizontal and vertical distances from the weather station.

Key Words

MCS, perudic, udic, ustic, xeric, aridic (torric).

Introduction

Soil moisture and temperature classification is a foundation for many modern international soil classification systems. It is recognized at virtually all levels of Soil Taxonomy (Soil Survey Staff 1999). Soil moisture and soil temperature properties influence soil-plant relationships and serve as a determinant of the chemical, mechanical, and biological processes that occur in the soil.

It has been conventional to recognize three soil moisture states or classes: saturated (wet), moist, and dry (Soil Survey Staff 1999; Soil Survey Division Staff 1993). Saturated occurs when water is not held by the soil and flows freely through soil pores, usually associated with a water table; moist occurs when water is held by the soil at tensions greater than 0 to less than 1500 kPa, where water moves down to a saturated substratum and can cause leaching of clay, carbonates, etc.; and dry occurs when water is held at tensions greater than or equal to 1500 kPa. In a dry state, water in soil is not available to keep most mesophytic plants alive (Greulach 1973; Soil Survey Division Staff 1993). With the possible exception of those saturated soils which have a permanent water table, soil will become alternately moist and dry during the growing season as rainfall enters the soil at the surface and moves downward. Eventually the water will be extracted by evaporation, evapotranspiration (plants), or passed through as deep percolation. It is these periods of saturated versus moist versus dry, and the amount of time during the growing season each of these conditions are present, that influences the type of native vegetation grown in the soil (Smith *et al.* 1964). Realizing this, soil scientists have identified and characterized six soil moisture regimes that occur world-wide: aquic, aridic (torric), ustic, xeric, udic, and perudic (Soil Survey Staff 1999).

The aquic moisture regime indicates that a soil is or has been saturated for extended periods of time. The saturated zone is virtually free of dissolved oxygen. In this state, iron in the soil undergoes reduction causing the soil to become gray and mottled in color. Since this moisture regime is readily identifiable in the field through visual or simple chemical testing, it is not the focus of this paper.

To aid in the classification of soil moisture regimes other than aquic, the concept of a soil moisture control section (MCS) was developed (Smith *et al.* 1964; Soil Survey Staff 1999). For standardization the top of the moisture control section was defined as being the depth to where 25 mm of water will moisten in 24 hours after being added to a soil surface with soil-water tension being at 1500 kPa. The bottom of the soil-moisture control section is determined by the depth 75 mm of water will moisten in 48 hours after being added to the soil surface with soil-water tension being 1500 kPa. The depths of the MCS from one soil to the next can vary widely depending on soil texture and water holding capacity. For instance, a clayey soil may have a MCS from 15 to 35 cm and a sandy soil may have a MCS that extends from 45 to 125 cm. If the soil contains a root limiting layer above the point where 75mm of water moistens, that point becomes the bottom of the MCS (Soil Survey Staff 1999).

Classification of the aridic (torric), ustic, xeric, udic, and perudic soil moisture regimes is determined by a statistical function of how many days the soil MCS is moist or dry when the soil is above critical soil temperatures that affect germination and active plant growth. Also factored in are when these periods of time occur during the year.

Nine soil temperature regimes are recognized: cryic, frigid, mesic, thermic, hyperthermic, isofrigid, isomesic, isothermic, and isohyperthermic (Soil Survey Staff 2006). The depth chosen to sample soil temperature is 50 cm or at a densic, lithic, or paralithic contact, whichever is shallower. That depth was chosen because it is deep enough to not be susceptible to daily temperature fluctuations, yet is shallow enough to excavate and collect a temperature reading without a lot of expense or effort (Smith *et al.* 1964). The average annual temperature at this depth is used for classification purposes. In the U. S., soil scientists have typically added 1 degree C. to the mean annual air temperature to approximate the soil temperature. U. S. soil scientists will quickly acknowledge that this method does not take into account temperature differences caused by slope and aspect, soil drainage, elevation and latitude changes over short distances, and shade or lack thereof from vegetation (Soil Survey Staff 1999).

Presently, soil classification and mapping throughout most of the U.S. is conducted by individual soil scientists with varying degrees of training, skill, ability, and experience. Soil moisture classification of soil containing redoximorphic features is usually straightforward (Soil Survey Division Staff 1993; Soil Survey Staff 1999); however, in the absence of these features, soil moisture classification tends to become more subjective. This is especially the case in areas that are intermediate or intergrade to perudic, udic, ustic, xeric, or aridic (torric). Ordinarily, soil moisture and temperature estimates are based on local meteorological data. Field soil scientists project these estimates by various means to the site by incorporating elevation or some regional or vegetative boundary as a guide in assessing the soil's moisture and temperature classification. The position of the soil on the landscape, or the soil's moisture handling characteristics, is typically not part of this process. In general, calculating soil moisture and temperature over large areas, (based on the interrelationships of soil, climate, physiography, and vegetation) is too complex for a consistent prediction by field soil scientists.

Factors influencing soil moisture and temperature at any given point on the landscape are: percent slope, aspect, albedo, vegetative cover (type and amount), relative humidity, runoff, soil depth, soil texture, soil mineralogy, soil bulk density, elevation, latitude, percent possible sunshine, daylength, wind speed, temperature, and precipitation. These interrelationships are commonly not considered when assessing soil temperature and moisture. Since current soil climate models are regional in nature, this has often resulted in erroneous soil moisture and temperature classifications, especially in areas of the country with high relief (Newhall and Berdanier 1996). In addition, soil scientists typically are unable to quantify or predict with a consistent degree of confidence how soil moisture or temperature would be affected if the landscape were altered. Consider the following situations and the effects each could have on soil moisture and temperature: forest fire, revegetating a barren area, overgrazing, severe erosion, desertification, and global climate change.

Gathering site or soil specific data with regard to moisture and temperature would be costly and time consuming since the data required is both seasonal and long-term. Although there is a very large body of common knowledge about soil moisture and temperature variation over time, there are very few long-term records and fewer still relating to the energy concept of soil moisture and temperature. Meteorological records, most of which are long-term, are available over many parts of the country and the world. A number of methods have been devised to relate meteorological records to soil moisture and temperature. These methods are typically based on average values of precipitation, temperature, and potential evapotranspiration. They tended to give an oversimplified picture of soil moisture and temperature and did not address the soil's chemical and physical properties, the soil's relative position to a weather station, or the position of the soil on the landscape (Soil Survey Staff 1999).

Modeling moisture accretion/depletion and soil temperature to regions or areas of the country using climatological data has been done by Thornthwaite (1948); Thorthwaite and Mather (1955); Palmer and Havens (1958); Smith *et al*. (1964); Newhall (1980); and Newhall and Berdanier (1996), to assist soil scientists in classifying soil. Predicted results were projected over large areas and often a rather wide range in latitude and elevation. Newhall and Berdanier (1996) improved on earlier models by accounting for a reduction in potential evapotranspiration as the soil dried. Even with these improvements, none of these earlier models accounted for variations in climatic conditions that occur as elevation and latitude changes, even over short distances. In addition, none of these earlier models considered the relational effects that physiography, vegetation, or soil properties have on soil moisture and temperature (Soil Survey Staff 1990).

Methods and Discussion

A five-part relational model was developed to help soil scientists calculate soil moisture, temperature, and taxonomic classification virtually anywhere on the earth's surface with readily available data. The five-part model includes: (1) Climate data: nine climatic variables, including elevation and location of the weather station, are user-entered (Sellers and Hill 1974). (2) Soil data: due to the complexity of the model, seventy-seven critical soil variables, including the soil's elevation and location, are required to run the model. An additional fourteen optional variables are used in certain instances to refine classification. A complete soil description usually suffices for the information necessary. (3) Soil moisture calculator: a model that calculates the limits of the soil moisture control section (Baumer 1983). (4) Water balance calculator: a set of calculations which incorporates Thornthwaite and Mather's (1955) premises and equations along with other physiographic and vegetative computations and serves as the primary calculation engine for the model (Anderson 1976; Greulach 1973; and Palmer and Havens 1958). (5) Classification: an output which displays soil moisture, temperature, and taxonomic classification along with graphs depicting calculated monthly soil moisture, precipitation, and runoff at the sample site. Typically, climate data is entered only once for a survey area unless the area is large enough to have more than one weather station within or near the survey area.

Meteorological variables such as percent possible sunshine, relative humidity, precipitation, temperature, wind speed, and the number of storm events are entered into the (1) climate data section. Data from nearby weather stations is extrapolated in the model to sites being correlated. This provides consistency and standardization to estimated local climate. Soil property variables from pedon descriptions such as soil horizons or layers, depth, texture, consistence, chemical properties, color, clay activity, density, and hydrologic group are entered into the (2) soil data section along with vegetation variables and physiographical property variables such as aspect and percent slope. The (3) soil moisture calculator uses data from the (2) soil data section including layer depth, texture, bulk density, clay activity, and percent organic matter to calculate wilting point and MCS limits. The (4) water balance calculator uses data and calculations from (1), (2), and (3) to estimate soil moisture and temperature conditions. The (5) classification output displays results of the calculations made in the (4) water balance calculator to predict the soil taxonomic classification to the "Great Group" and, in some instances, the "Sub Group" level of Soil Taxonomy (Anderson 1976; Soil Survey Staff 1999). Where soil surveys are available, this data could be provided in a GIS format in order to classify or reclassify large areas.

The model was tested by comparing calculated output with data from soil moisture/temperature monitoring sites that are part of the USDA Soil Climate Analysis Network (SCAN). Ten sites representing five temperature and four moisture regimes located around the United States were evaluated. Calculated vs. measured classifications were in agreement at eight of the sites. Of the two sites that differed, one had a measured frigid soil temperature regime vs. a predicted cryic regime the other had a measured ustic soil moisture regime vs. a predicted ustic aridic regime. Soil temperature at the first site averaged 2.8 degrees C warmer than air temperature compared with the model's 1 degree C pre-adjusted default which was discussed above. The moisture discrepancy on the second site can be attributed to the way the model uses a water holding capacity average for each soil texture. A large deviation from this average can cause the model to overstate or understate the number of days the MCS is moist which may affect classification of the soil moisture regime.

Conclusion

The Soil Moisture-Temperature Correlation and Classification Model correlates site specific soil, vegetative, and physiographical variables with extrapolated climatological data. The relational aspects of the model can demonstrate how a change in any single variable can affect all the other factors of soil moisture, temperature, runoff, classification, etc. "What If ?" scenarios can be quantitatively assessed. Predictions of soil moisture, temperature, and classification are documented for testing, evaluation, or validation for every point on the landscape.

The model will never replace the need for good field descriptions of soil and vegetative characteristics; these descriptions fuel the model. In addition, the model does not replace the need for monitoring soil moisture and temperature in diverse areas. This data is crucial for validation and improvement of the model.

Further study of the model is needed including: a statistical evaluation of soil moisture and temperature calculations in various regions of the country, testing the runoff formula in various rainfall regions, developing a user manual, and scripting for GIS inputs and outputs.

Acknowledgments

I wish to thank R. Ahrens, N. McCaleb, and H. Mount, Soil Scientists, S. Barker and D. Robinett, Range Conservationists, J. Elder, Engineer (all USDA·NRCS), and T. Keefer, Hydrologist (USDA-ARS) for providing advice, data, support, review, and encouragement for the development of this model.

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