

Relating Soil Color to Soil Water Table Levels¹

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ABSTRACT. According to Soil Taxonomy, soil horizons with mottles that have a Munsell color chroma of 2 or less, with a moist Munsell value of 4 or more, are saturated for some period of the year during which the temperature of the horizon is above 5°C, if the soil is not drained. Although soil scientists have been predicting depth to the water table for many years using depth to colors with 2 chroma or less, sufficient data have not been gathered to verify this relationship. As a result, the reliability of soil interpretations has suffered. This project was conducted on a glacial till plain toposequence containing three soils representative of those common throughout northwestern Ohio. Depth to the water table was measured for two years using piezometers. During part of the year, a water table was observed within 110 cm of the soil surface for the well drained Morley soil. The moderately well drained Glynwood soil had a water table that rose to within 60 cm of the soil surface. The Blount soil, somewhat poorly drained, had a water table within 15 cm of the soil surface. The data gathered suggests that the presence of colors with 2 chroma or less, reliably predicts the depth to the water table.

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INTRODUCTION

Seasonal incidence of water tables in soils is one of the most important characteristics influencing their use and management. The occurrence of high water tables has an important bearing on the suitability of soils for crop production, homesites, septic system installations, parks and recreational facilities, and transportation systems (Boersma et al. 1972). The frequency, duration, and depth of saturation are all important parameters for defining soil water tables (Soil Survey Staff 1981). Soil morphology (mainly the color pattern) is commonly used to estimate water table levels in a soil.

Color is one of the most obvious soil properties and it is easily, but somewhat subjectively, determined. Soil color is generally attributable to two materials, organic matter and iron. The dark color of temperate region soils is usually caused by humified organic matter which accumulates at the mineral surface, whereas red to yellow colors in the subsurface are attributed to iron oxides. Schwertmann and Taylor (1977) note that even at low concentrations in a soil, iron oxides have a high pigmenting power and determine the color of many soils. Organic matter tends to control soil color in the surface horizons. However, since organic matter content decreases with depth, iron oxides frequently control color in the lower horizons.

During the weathering of a primary mineral, iron, mainly bound in silicates in the reduced state, will be released through a combination of hydrolytic and oxidative reactions (Schwertmann and Taylor 1977). As a result of the extremely low solubility of Fe⁺³ oxides in the normal pH range of soils, the iron that is released is precipitated as an oxide or hydroxide. This precipitated oxide or hydroxide may be distributed uniformly throughout the soil matrix or segregated to form mottles and concretions.

Another process that usually contributes to mottle formation is reduction. Alexander (1977) suggested that organic matter can be biologically oxidized if O₂, NO₃, Mn, Fe, or S are available to accept electrons. When a soil is aerobic, reduction of O₂ is favored. If the soil system becomes saturated with water resulting in greatly reduced oxygen exchange with the atmosphere, the soil becomes depleted of oxygen; and, if organic matter is present, facultative anaerobic and true anaerobic organisms may use oxidized inorganic compounds for metabolic processes. This reduction process may be indirect as a result of chemical reactions with fermentation products, or direct as a result of electron transport with the inorganic compound functioning as an electron acceptor. The usual order of reduction of inorganic compounds is O₂, NO₃, Mn oxides, Fe oxides, and sulfates (Alexander 1977), with oxidation occurring in reverse order.

According to Bouma (1983), there are three conditions that must occur simultaneously in order for Fe⁺³ to be reduced to Fe⁺²: (1) sufficient period of saturation for free oxygen to be depleted; (2) source of organic matter; (3) temperature greater than 5° C (biological zero).

When a zone is saturated with water, free oxygen is absent because atmospheric exchange is greatly reduced and aerobic microbes deplete the remaining dissolved oxygen. This causes anaerobic organisms to dehydrogenate (oxidize) organic matter and donate electrons to reduce Fe⁺³ (Alexander 1977). Because these processes require a microbial population, which generally only functions when the temperature is above 5° C, temperature becomes a very important factor. All three conditions, as defined by Bouma (1983), must occur at the same time in order for Fe⁺³ to be reduced to Fe⁺².

If iron acts as an electron acceptor, ferric compounds are reduced to more soluble ferrous forms (Gotoh and Patrick 1974). Migration of the more soluble ferrous iron to zones of oxidation induces re-oxidation and subsequent reprecipitation of ferric iron as mottles. The removal and/or segregation of these oxides under reducing conditions will result in spots, patches, and/or zones of that soil appearing gray or bluish gray. These spots and

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patches of bluish gray and gray color are the low chroma mottles. These mottles are indicative then of saturation in that part of the soil at some time during the year when the soil temperature was 5° C or greater.

The Soil Survey Manual (Soil Survey Staff 1981) traditionally describes soil wetness in terms of soil drainage classes. Soil drainage is defined as the rapidity and completeness of removal of natural water added to the soil and, also, to the frequency and duration of periods when the soil is free of saturation or partial saturation (Soil Survey Staff 1981). External drainage is controlled largely by the slope of the land surface. Internal drainage, in addition to being influenced by landscape position, is a function of soil permeability and the influence of the water table. Soil drainage classes are useful for summarizing water conditions that are important to major crop and farming systems as well as urban land use in a given area. Drainage classes have been widely used on a local scale in soil surveys to estimate duration and fluctuations of water table during the year.

Seven drainage classes are recognized. The first two classes, excessively drained and somewhat excessively drained soils, describe soils that are dry longer than is typical for the dominant soils of an area because of either excessive runoff or porosity. The third class, well drained soils, does not exhibit excessive water retention because of either high permeability or depth to water table levels. Increasing degrees of wetness characterize moderately well drained, somewhat poorly drained, poorly drained, and very poorly drained soils (Soil Survey Staff 1981). The definitions of drainage classes are intentionally vague in order to allow flexibility from region to region when developing specific local definitions and interpretations.

Field estimates of soil water table levels and soil drainage classes are based on soil color and on water table measurements made in selected study areas. Long term water table measurements provide the most reliable information concerning seasonal water table fluctuations; however, such measurements are rare because they are time consuming and costly. Monitoring should cover periods of at least two years to compensate for annual variations (Nelson et al. 1973). Because Soil Taxonomy (Soil Survey Staff 1975) and the Soil Survey Manual (Soil Survey Staff 1981) both suggest the use of low chroma colors as indicators of wetness, soil scientists generally use soil color patterns (mottles) to infer depth and duration of saturation.

According to Soil Taxonomy (Soil Survey Staff 1975), horizons with colors having a chroma of 2 or less with moist value of 4 or more (Munsell color notations), are saturated for some period of the year that the temperature of the horizon is above 5° C, if the soil is not drained. If either the minor or major part of a horizon has chroma of 1 or 2 and value, moist, of 4 or more and there are spots of higher chroma, the part that has the lower chroma is included in the meaning of "mottles that have chroma of 2 or less." This phrase means that the horizon with such mottles is saturated with water at some time during the year. Observations of soils in Ohio (Ransom 1984, Zobeck and Ritchie 1984a, and Zobeck and Ritchie 1984b) and at other sites across the United States (Boersma et al. 1972,

Franzmeier et al. 1983, Harlan and Franzmeier 1974, Vepraskas and Wilding 1983) suggest that soil colors with 2 chroma or less predict the general water table levels. Daniels et al. (1987) and Vepraskas and Wilding (1983) found that the 2 chroma mottles may underestimate the height of the periodic high water levels and thus may not be as conservative as necessary for land use decisions.

The primary objective of the present study was to determine the relationship between soil color and color patterns and water table levels in selected Ohio soils. A second objective was to compare the measured water table levels to predictions based on the occurrence of low chroma (≤ 2) colors and to evaluate the appropriateness of soil drainage classes for characterizing these soils.

MATERIALS AND METHODS

Site Location

A toposequence represented by the Morley (fine, mixed, mesic Mollic Hapludalf), Glynwood (fine-loamy, mixed, mesic Aquollic Hapludalf), and Blount (fine, mixed, mesic Udollic Ochraqualf) soils was chosen in Hardin County, OH, to study the relationship between soil color and depth to water table. Specific soil characterization information for these soils may be found elsewhere (Guertal 1987). Hardin County, OH, is located within the Wisconsin till-plain section of the Central Lowlands Province of Thornbury (1965). The topography in this region ranges from gently rolling glacial end moraines to nearly level ground moraines. This particular toposequence was selected because it contains soil typically found in the Wisconsin high lime glacial till region and represents one of the most extensive soil associations in Ohio.

The toposequence is located in the southern portion of the county on gently undulating topography along the northern edge of the Broadway moraine (Div. of Geological Survey 1966). The monitoring sites were located approximately 11 km south of Kenton, OH.

Soils

The well drained Morley soils are found on narrow summits and shoulder areas along the crests of moraines and in more sloping areas (Fig. 1). The moderately well drained Glynwood soils are located on the shoulder and backslope positions and at the head of drainageways on ground moraines. The somewhat poorly drained Blount soils usually occur in nearly level and concave positions on the till plain. The poorly drained Pewamo usually found in association with these soils did not occur at the monitoring site.

Three profiles, representing the three soil series, were described and the morphology of each profile was recorded in detail using the format and horizon nomenclature of Chapter 4 of the Soil Survey Manual (Soil Survey Staff 1981).

Climate and Vegetation

The climate of Hardin County is humid-temperate continental (Thornbury 1965). Soil water balance was computed for this soil association using 50-year averages compiled at the Kenton weather station and represents

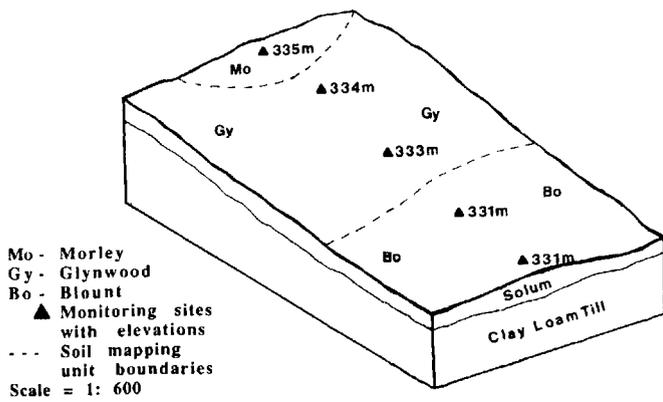


FIGURE 1. Block diagram of the soil association in the Hardin County toposequence showing location of ground water monitoring sites.

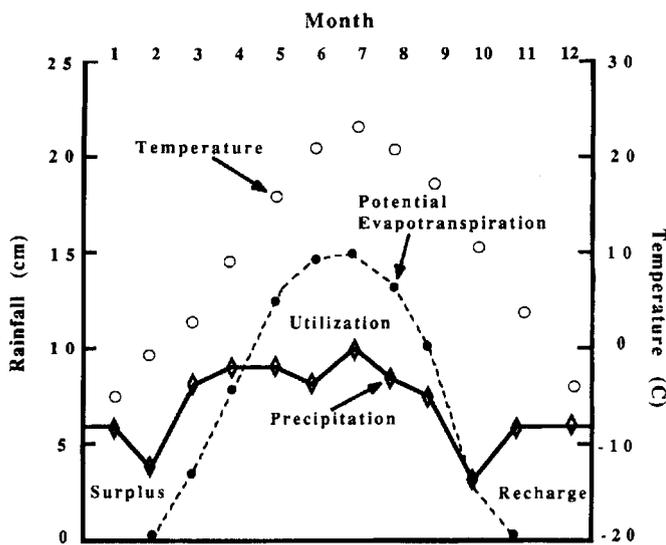


FIGURE 2. Climatic data and soil water balance for the Morely-Glynwood-Blount soil association located in Hardin County, OH. Information was adapted from U.S. Weather Bureau Records, Kenton, OH (1985).

rainfall, temperature, and evapotranspiration for a normal year (Fig. 2). Potential evapotranspiration was calculated using the Thornthwaite method (Thornthwaite 1948).

The native vegetation of the study area was hardwood forest. The dominant trees are black walnut, cherry, silver and red maple, oak, and other hardwoods. Throughout most of this region, the vegetation has been altered by the clearing of forests and the hydrology has been changed by changes in vegetation, installation of agricultural drainage systems, highway drains, dams, and other structures. The monitoring site was not tile drained and the vegetation was similar to the original forest vegetation. Many of the trees at the monitoring site are between 80 and 100 years old. Some of the larger trees are approximately 100 cm in diameter. This site was chosen because it was important to study these soils in hydrologic conditions similar to those under which they developed.

Water Table Measurement

Depth to the water table was determined by the use of

piezometers. An effort was made to place most piezometers at depths corresponding to major horizon boundaries so soil water table levels and saturation could be related to soil morphology. At each site, piezometers were installed at four depths; base of the A horizon, base of the B horizon, 140 cm, and 180 cm. The piezometers were placed at these depths to determine if the water table uniformly saturated the soil or if saturated zones occurred above unsaturated zones. A saturated zone above an unsaturated zone would be considered a perched water table.

The piezometers were made from 3.2 cm inside-diameter (3.8 cm outside-diameter) PVC pipe that had been perforated in the bottom 20 cm. The pipes were driven into boreholes that had been drilled using a 3.8 cm diameter auger (Ransom 1984). After placement, the inside of the pipe was cleaned using a 3.1 cm auger. Care was taken to make sure that the cleaning auger did not remove soil from a depth greater than the bottom of the pipe. After cleaning, approximately 100 g of pea size gravel was dropped into the pipe to help keep the bottom of the hole free of soil. After installation, the contact area between the soil surface and the tube was packed with bentonite to prevent water seepage down the sides of the piezometer. The opening at the soil surface was plugged with a rubber stopper to exclude rainwater from the pipe between readings. A hole was drilled 5 cm below the top of the tube so that the air pressure inside did not differ from the outside air pressure.

Measurement of the water table was made once a week by a county soil scientist using Tygon tubing which had been attached to a meter stick. The Tygon tubing was scaled in 2.5 cm increments. Air was blown through one end of the tubing as it was lowered into the hole. When bubbling was heard, the depth was recorded (Robson and Thompson 1977).

Thermocouples were used to measure soil temperature (Guertal 1987). At each monitoring site, thermocouples were placed at depths of 30, 60, and 90 cm. The soil temperatures were measured once a week when the outside air temperature was above 0° C.

RESULTS AND DISCUSSION

Water Table Depths

Rainfall and depth to the water table were measured at the site during the period May 1985 through April 1987. Weather data were also collected at the Kenton weather station. The difference was determined between the actual precipitation for the period of the study and the long term average annual precipitation for the weather station during the last 50 years (Table 1). Whereas annual precipitation was fairly close to the long term average, there was some fluctuation between monthly precipitation and long term monthly averages. Notable deviations include November and December 1985, which were wetter than normal, September 1986, which was wetter than normal, and the spring of 1987, which was drier than normal.

In most cases, where readings were made, water levels for each monitoring site occurred at approximately the same depth in all piezometers. At times during the study

TABLE 1

Actual precipitation and deviation in precipitation at Kenton, Hardin County, OH.

DATE	**AVERAGE PRECIPITATION	*ACTUAL PRECIPITATION	DEVIATION FROM NORMAL
1985	cm	cm	cm
May	9.8	12.4	+2.6
June	12.2	6.4	-5.8
July	9.3	8.6	-0.7
August	9.6	14.5	+4.9
September	6.9	1.3	-5.6
October	5.4	4.3	-1.1
November	6.3	19.3	+13.0
December	5.6	10.7	+5.1
Total	65.1	77.5	+12.4
1986			
January	6.5	2.1	-4.4
February	4.9	11.4	+6.5
March	8.3	7.1	-1.2
April	9.0	8.6	-0.4
May	9.8	8.9	-0.9
June	12.2	7.9	-4.3
July	9.3	14.7	+5.4
August	9.6	5.8	-3.8
September	6.9	18.1	+11.2
October	5.4	9.7	+4.3
November	6.3	8.4	+2.1
December	5.6	5.8	+0.2
Total	93.8	108.5	+14.7
1987			
January	6.5	4.3	-2.2
February	4.9	0.1	-4.8
March	8.3	6.2	-2.1
April	9.0	5.1	-3.9
Total	28.7	15.7	-13.0

* Precipitation compiled at the Kenton weather station.

** Averages are for 50 years of data, 1937-1986

period, water table levels in the deepest piezometers lagged behind the water levels in the shallower piezometers. When the water table was rising, the water level in the 180 cm piezometer was lower than that of the shallower piezometer. However, when the water table was falling the water level in the 180 cm piezometer was higher than that in the shallower piezometer. This lag in the piezometer response was not believed to be indicative of a perched water table; however, perched water tables may have occurred between measurements.

The Morley profile remained unsaturated from May to December 1985, reflecting the dry summer that occurred that year (Fig. 3). The water table began to rise in January 1986 and reached its maximum height, 110 to 115 cm

below the soil surface, in late March and early April 1986. During the second week of April, the water table dropped rapidly to 150 cm and fell below the deepest piezometer in July 1986. The sudden drop of the water table in early April corresponded to leaf-out of the forest vegetation. Ransom (1984) reported that leaf-out induces a substantial rise in potential evapotranspiration which causes a rapid depletion of soil water. The water table rose higher than 160 cm in the middle of December 1986, in response to recharge, and was above that depth through April 1987 (Fig. 3).

The water table in the Glynwood pedon did not drop below the depth of the deepest piezometer until the first week of July 1985 (Fig. 3). As with the Morley soil, the

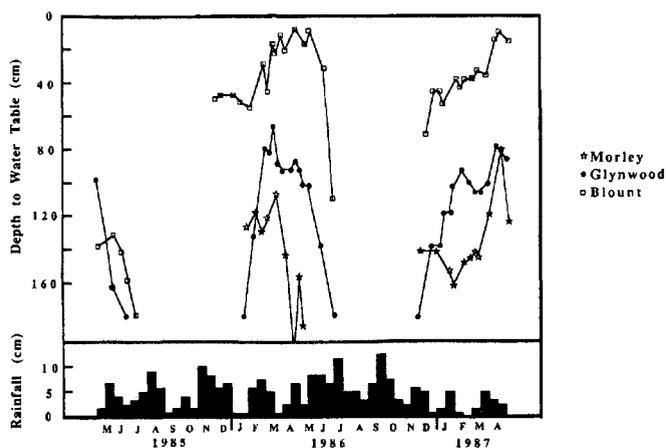


FIGURE 3. Precipitation and water table levels for the Morley, Glynwood, and Blount monitoring sites.

deepest piezometer until July 1985 and rose rapidly during the last part of November 1985 in response to higher than normal rainfall for that month. Much of this rapid increase may be related to subsurface and surface lateral flow of water from higher landscape positions. Since these sites were the lowest in the toposequence, water tended to collect in this location. The area was not a closed depression, but there was a very low gradient surface drainage away from the site. The accumulation of water from lateral movement coupled with low evapotranspiration rate at this time of year resulted in a rapid rise in the water table. This soil had a water table within 50 cm of the soil surface between November 1985 and May 1986. Following the summer depletion period, the water table again rose to 40 cm below the soil surface during the last week of November 1986. From November through April 1987, the water table fluctuated between 15 and 80 cm below the soil surface.

water table began to rise again during January 1986. The water table reached its maximum height in early March 1986 at a depth of 75 cm below the soil surface. During the second week of April 1986 the water table dropped in response to leaf-out. Compared to the Morley soil, the water table remained at a higher level for a longer period of time following this date. This effect could in part be caused by lateral subsurface recharge of the water table from higher positions in the landscape (Franzmeier et al. 1983). The water table rose to within 89 cm of the soil surface the first week of December 1986. Between this time and 29 April 1987 the water table fluctuated between 60 and 90 cm below the soil surface.

Depth to the water table is a function of both precipitation and potential evapotranspiration. During the active growing season (May through September), the potential evapotranspiration exceeded precipitation and the free water surface dropped even though this may be a period of high rainfall. The water table rise during late fall and winter is the result of moderate precipitation and minimal potential evapotranspiration (Fig. 2). Any nonseasonal changes in the depth to free water generally follow abnormal rainfall patterns such as during November 1985 and September 1986.

The Blount soil exhibited water table patterns similar to those observed at the Glynwood sites; however, the water table remained at higher levels for longer periods of time (Fig. 3). The water table did not drop below the

Relationship of Soil Morphology to Soil Drainage Classes

Soil Conservation Service's Soil Interpretation Record (Form SCS-SOI-5) gives specific information about a soil's physical and chemical characteristics plus land-use interpretation information. Information from these records was compared to observed and measured features of each soil in the toposequence.

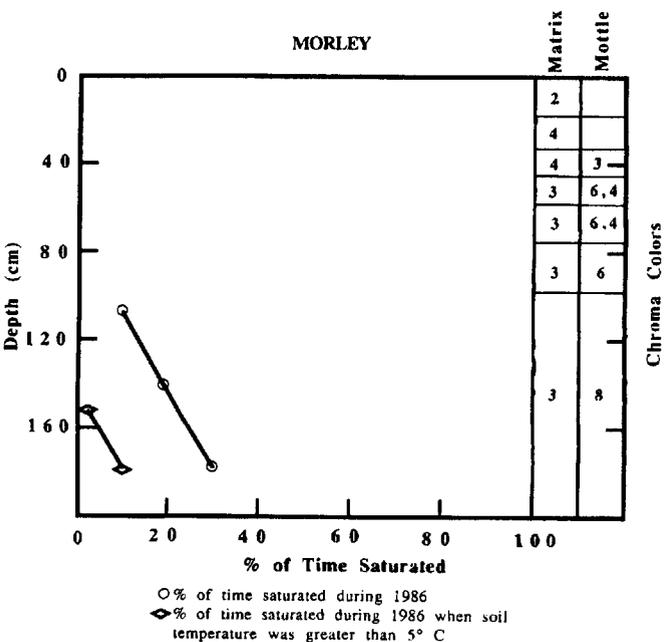


FIGURE 4. Depth and percent time Morley profile was saturated during 1986. Munsell chroma colors are given for the soil matrix and mottles (if present).

The Soil Conservation Service's Soil Interpretation Record for the well drained Morley soil reports a perched water table that fluctuates between 90-180 cm during the months of March to May. The water table in the Morley soil examined in this study was above 180 cm for 30% of the time in 1986 (Fig. 4). The water table was between 110 and 180 cm from January through April 1986, and between 80 and 160 cm from November to April 1987. The duration of wetness therefore appears to be similar to that indicated by the Soil Interpretation Record. Also, the water table appears to be continuous rather than perched.

Three chroma matrix colors are found in the subsoil of the Morley soil (Fig. 4). These 3 chroma colors may indicate long-term zones of water table fluctuations that occur when the soil temperature is below 5° C. The pedon was saturated at a depth of 150 cm for 23% of the time during 1986 but was saturated only 1% of the time when the soil temperature was greater than 5° C. The low chroma matrix in the surface horizons of this and the other soils in the toposequence were attributable to organic matter rather than reduction. Three chroma colors are also found in higher parts of the profile which never appeared to be saturated. These 3 chroma colors may result from the

extension of the capillary fringe into these horizons or from the saturation of these horizons for short periods during some years, but water was not observed during the study period.

Soil Conservation Service's Soil Interpretation Record indicates that the Glynwood soil should be moderately well drained with a perched water table that fluctuates between 60-107 cm during the months of January through April and between 60 and 180 cm from December through June. Thus the Soil Interpretation Records match the actual water table levels and duration very well. This pedon was not as well drained as the Morley soil (Fig. 5), and morphological features (i.e. 2 chroma mottles) accurately define the upper limit of the seasonal water table. Once again, the water table appears to be apparent rather than perched.

The total percentage of time that the Glynwood soil was saturated and the time saturated when the soil temperature was greater than or equal to 5° C during 1986 was determined (Fig. 5). The 2 chroma colors seen in the upper horizons are probably the result of the capillary fringe saturating portions of the horizon. The low chroma mottles in the lower horizons correctly predicted periods of saturation in those horizons; however, no low chroma mottles were seen in the lowest horizon. This horizon was saturated for extended periods of time but probably did not develop low chroma colors because the organic matter content was insufficient to cause reduction. Similar effects were observed by Vepraskas and Wilding (1983).

The Blount pedon is the most poorly drained soil in the toposequence. The water table or the capillary fringe may saturate the whole soil at some time during the year (Fig. 6). Soil Conservation Service's Soil Interpretation Record for this soil suggests that the water table fluctuates between 30-90 cm during the months of January to May. Data gathered in the present study showed that these

interpretations are basically correct.

The Blount profile is gleyed and has 2 chroma mottles throughout. Long periods of saturation occurred when the soil temperature was above 5° C, which explains why somewhat poorly drained soils are grayer than their better drained counterparts. The soil is saturated approximately 20% of the year (Fig. 6), at a depth of 100 cm, when the temperature is above 5° C. This should allow ample time for reduction to occur providing there is an organic matter source. The morphological indicators accurately predict that Blount is more poorly drained than the associated Morley and Glynwood soils.

A similar study was conducted on a toposequence of soils which was located in Scioto County, OH. That toposequence was of interest because it contained soils with fragipans or pan-like materials that formed in old alluvium from river terraces, in this case located along the Ohio River. Results from the Scioto County study were similar to those presented in this paper (Guertal 1987).

SUMMARY

As the soil drainage class changed from well drained to moderately well drained to somewhat poorly drained, the depth to low chroma colors decreased. The Morley soil had no low chroma (≤ 2) colors except in the surface, where they were the result of organic matter accumulation. The Glynwood soil had low chroma colors beginning 37 cm below the soil surface, and the Blount soil had low chroma colors 28 cm below the soil surface. Low chroma mottles were the most abundant and wide spread in the Blount soil profile.

Decreasing depth to low chroma colors can be related to changes in the soil water table levels. The results suggest that gray colors (chroma of ≤ 2) in mottles indicate that the horizon is near or just above the water table level. If the horizon is dominated by gray colors (gleyed) in the

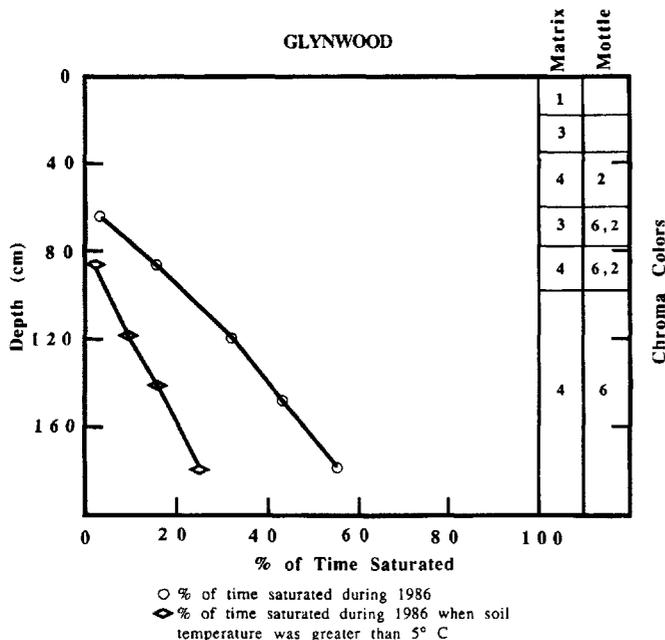


FIGURE 5. Depth and percent time Glynwood profile was saturated during 1986. Munsell chroma colors are given for the soil matrix and mottles (if present).

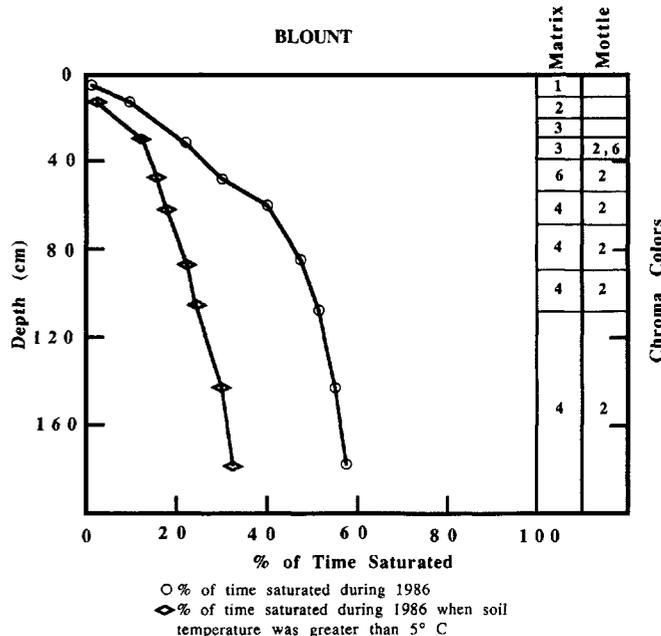


FIGURE 6. Depth and percent time Blount profile was saturated during 1986. Munsell chroma colors are given for the soil matrix and mottles (if present).

soil matrix, then that horizon is saturated much of the time. It can be concluded that the presence of colors of 2 chroma or less reliably predicts the depth to the water table.

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LITERATURE CITED

- Alexander, M. 1977 Introduction to soil microbiology, 2nd ed. John Wiley and Sons. New York, NY. p. 368-379.
- Boersma, L., G. H. Simonson, and D. G. Watts. 1972 Soil morphology and water table relations: I. Annual water table fluctuations. *Soil Sci. Soc. Am. Proc.* 32: 211-215.
- Bouma, J. 1983 Hydrology and soil genesis of soils with aquic moisture regimes. *In* L. P. Wilding, N. E. Smeck, and G. F. Hall (eds.). Pedogenesis and soil taxonomy, 1. Concepts and interactions. Elsevier Science Publishing Co., NY.
- Daniels, R. B., E. E. Gamble, L. A. Nelson, and A. Weaver 1987 Water-table levels in some North Carolina soils. *Soil Survey Investigations* No. 40. SCS-USDA.
- Division of Geological Survey. 1966 Map of glacial deposits of Ohio. Department of Natural Resources, State of Ohio, Columbus, OH.
- Franzmeier, D. P., J. E. Yahner, G. C. Steinhardt, and H. R. Sinclair, Jr. 1983 Color patterns and water table levels in some Indiana soils. *Soil Sci. Soc. Am. J.* 47: 1196-1202.
- Gotoh, S. and W. H. Patrick, Jr. 1974 Transformation of iron in a water-logged soil as influenced by redox potential and pH. *Soil Sci. Soc. Am. Proc.* 38: 66-71.
- Guertal, W. R. 1987 Relating soil color to soil water table levels. M. S. Thesis. The Ohio State University, Columbus, OH.
- Harlan, P. W. and D. P. Franzmeier. 1974 Soil-water regimes in Brookston and Crosby soils. *Soil Sci. Soc. Am. Proc.* 38: 638-643.
- Nelson, L. A., R. B. Daniels and E. E. Gamble. 1973 Generalizing water table data. *Soil Sci. Soc. Am. Proc.* 37: 74-78.
- Ransom, M. D. 1984 Genetic processes in seasonally wet soils on the Illinoian till plain in southwestern Ohio. Ph. D. Thesis. The Ohio State University, Columbus, OH.
- Robson, J. D. and A. J. Thompson. 1977 Soil water regimes, a study of seasonal water logging in English lowland soil. *Soil Survey Technical Monograph* No. 11. Harpenden, England.
- Schwertmann, U. and R. M. Taylor. 1977 Iron oxides. *In* J. B. Dixon and S. B. Weed (ed.). Minerals in soil environments. *Soil Sci. Soc. Am.*, Madison, WI. p. 145-180.
- Soil Survey Staff. 1975 Soil taxonomy: A basic system for making and interpreting soil surveys. *Agric. Handbook* No. 436, USDA-SCS. U.S. Government Printing Office. Washington, D.C.
- 1981 Examination and description of soils in the field. Chapter 4, Soil survey manual (in revision), Issue 1, Directive 430-V-SSM, May 1981, USDA-SCS. Washington, D.C.
- Thornbury, W. D. 1965 Regional geomorphology of the United States. John Wiley and Sons. NY.
- Thornthwaite, C. W. 1948 An approach toward a rational classification of climate. *Geograph. Rev.* 38: 55-94.
- U.S. Weather Bureau Records. 1985 Climatological Summary, Kenton, OH.
- Vepraskas, M. J. and L. P. Wilding. 1983 Aquic moisture regimes in soils with and without low chroma colors. *Soil Sci. Soc. Am. J.* 47: 280-285.
- Zobeck, T. M. and A. Ritchie, Jr. 1984a Analysis of long-term water table depth records from a hydrosequence of soils in central Ohio. *Soil Sci. Soc. Am. J.* 48: 119-125.
- 1984b Relation of water table depth and soil morphology in two clay-rich soils of northwestern Ohio. *Ohio J. Sci.* 84: 228-236.