



Agronomy Series

COLOR AND MOTTLING

IN

PENNSYLVANIA SOILS

by

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and

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Color and Mottling in Pennsylvania Soils

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Introduction

The color of a soil is a definitive and significant feature of the soil. The importance of color lies in what it tells you about a particular soil and its history. In this paper a very brief discussion will be presented on the color of Pennsylvania soils with particular reference to soil mottling.

Description of Soil Color

Though the efforts of the USDA Soil Survey (Pendleton and Nickerson, 1951) a portion of the Munsell color system has been adopted in the form of a book with color chips (Munsell Color, 1975) for the description of soil color (Soil Survey Staff; 1951, 1990). The color of a soil sample is determined by a visual best match to a chip in the color book. The Munsell system is composed of three variables (hue, value, and chroma). Hue is the dominant spectral color (wavelength) of light reflected from the soil and received by the eye. Value is the relative lightness or darkness of the color and is a function of the total amount of light reflected from the soil surface. Chroma is the relative purity (amount) of the dominant spectral color in relation to other spectral colors (hues) reflected from the soil. Value and chroma scales are linear to the eye. The scale of hue is also approximately linear. Soils exhibit only a limited number of hues, thus the red, yellowish red (brown), and yellow hues (10R to 5Y, Figure 1) are the only ones used in the color book. The scale of value in the Munsell system ranges from 0 for absolute black to 10 for absolute white (Figure 2). Soil colors do not span the entire range, consequently the color book utilizes only values from 2 to 8. The scale of chroma goes from 0 (no hue) to a maximum of 20 (Figure 2). Soils seldom range beyond 8 chroma, thus 8 is the maximum used in the color book.

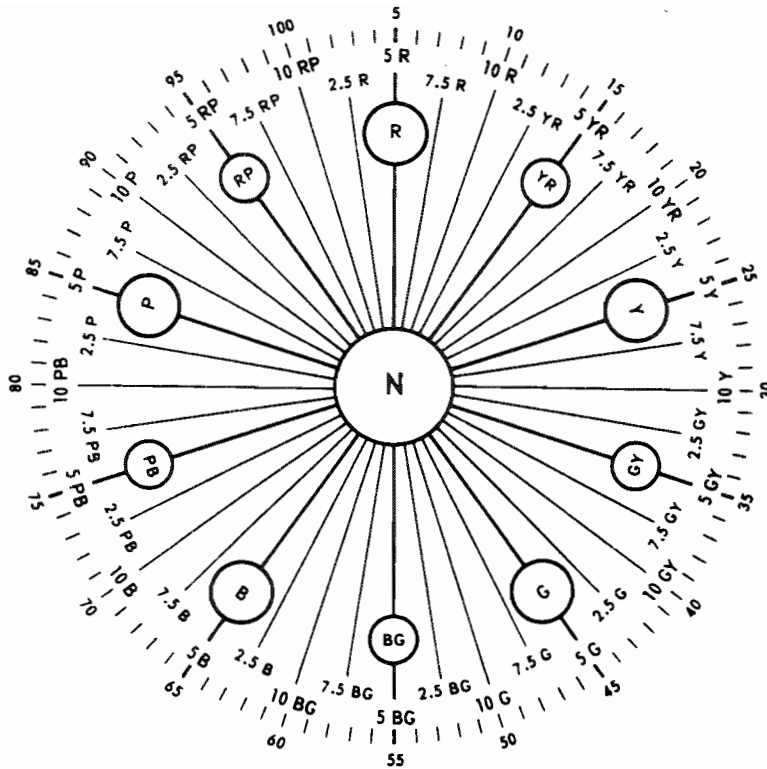


Figure 1. Arrangement of hues in the Munsell Color System. Symbols are as follows: R-red, Y-yellow, G-green, B-blue, P-purple. Additional symbols are combinations of these symbols plus number subdivisions, e.g., 2.5YR, 7.5YR, 10YR, etc.

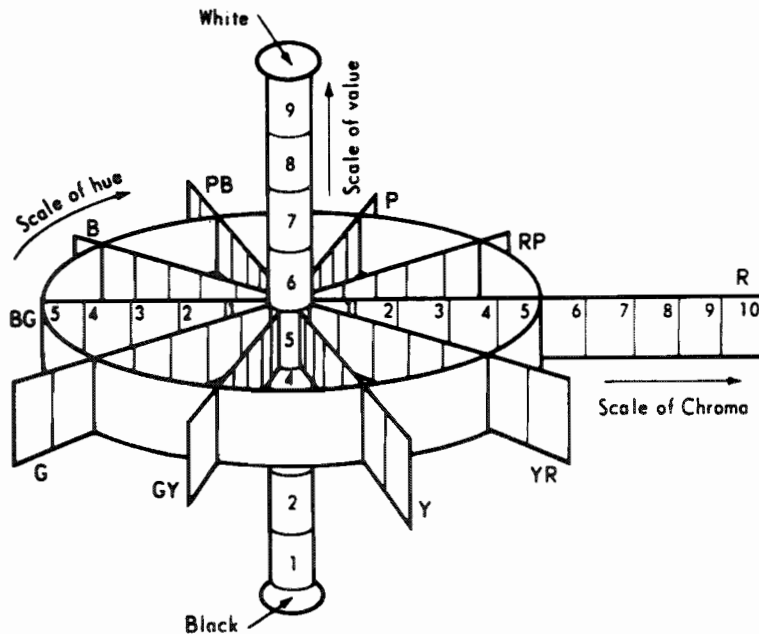


Figure 2. Munsell hue, value, and chroma scales and their interrelationships.

Soil samples reflect a wide array of wavelengths of light from their surfaces. The light (electromagnetic radiation) can be visualized as individual packets (photons) of specific wavelengths. The human brain mixes and integrates the effects of the various photons received by the eye and interprets the aggregate effect as color. Figure 3 gives a spectral reflectance curve for three soils which reflect equally across all visible wavelengths. The black soil (N 2/0) reflects a low total number of photons, the white soil (N 8/0), a large total number of photons and the gray (N 5/0), an intermediate number. Figure 4 gives spectral reflectance curves for two soils with the same hue (dominant wavelengths of light), the same value (total amount of light, all wavelengths reflected), but different chroma (relative amount of the dominant wavelengths). Because soil 1 reflects a greater relative amount of light in the 10YR hue area than soil 2, it will appear a more vivid or brighter yellowish brown than soil sample 2.

Materials that Color Soil

In Pennsylvania, humus and iron oxides are the main soil coloring agents. Humus is generally black and gives the A horizon its dark color. Little work has been done on the effect of humus on A horizon color other than some relationships have been developed for certain kinds of soils between color and organic matter (humus) content (Noel and Hole, 1958; Steinhardt and Franzmeier, 1979). This work has been done mainly in the midwestern United States. This work cannot be extended too far because soil humus from different types of vegetation and environments have not followed the same genetic pathway. Thus, their colors frequently are different. The main type of subsoil soil humus accumulation is found in the spodic horizon (Bhs and Bs) of Spodosols. This

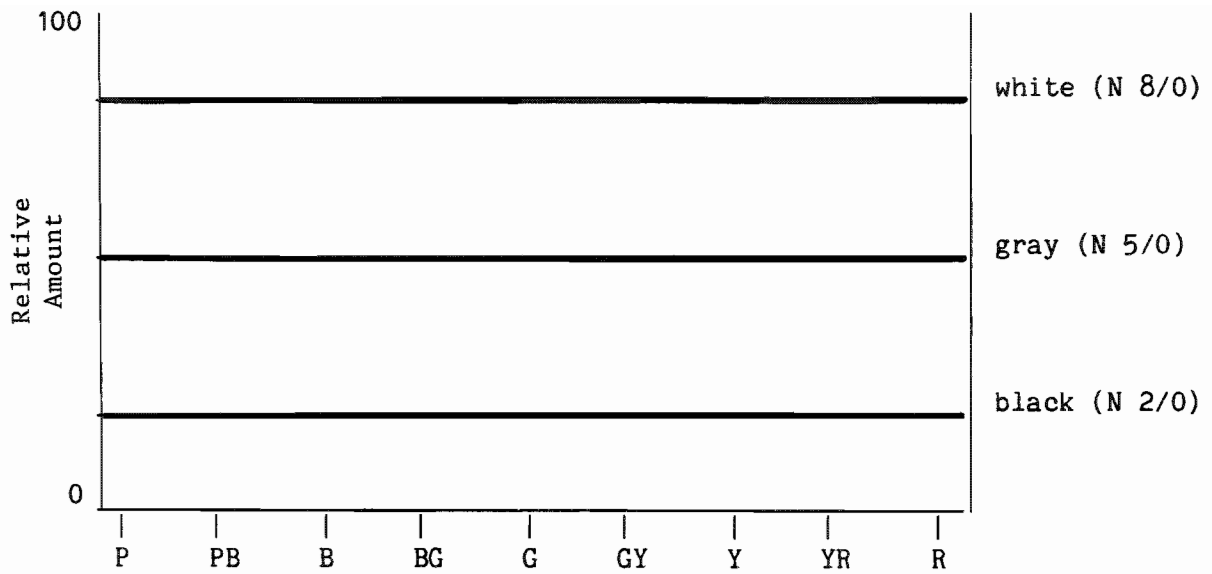


Figure 3. Visual spectral distribution of soil material with black (N 2/0), gray (N 5/0), and white (N 8/0) colors.

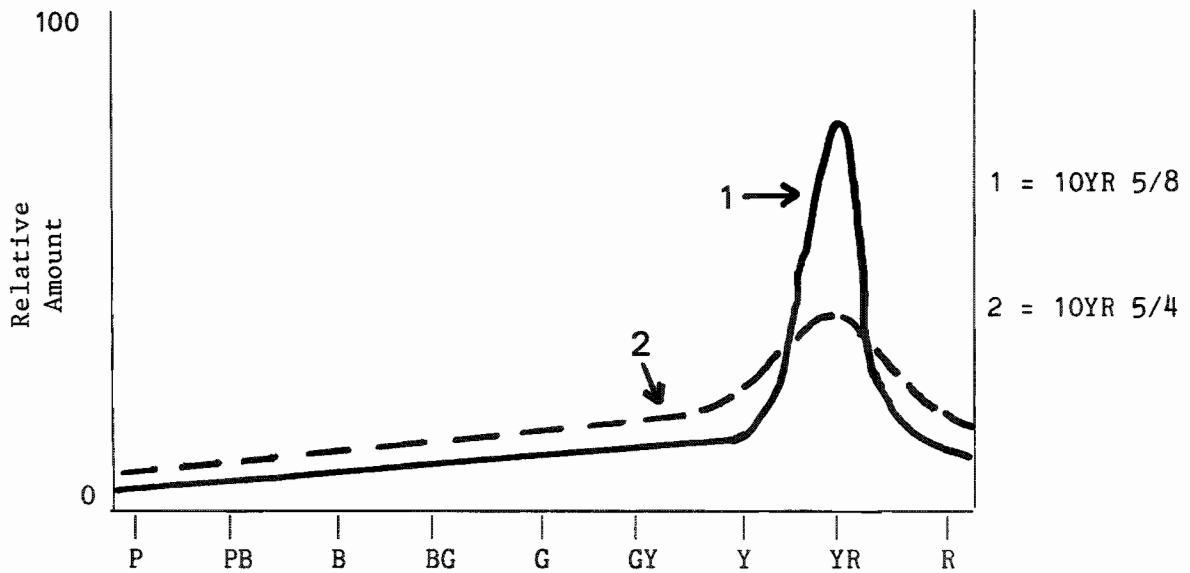


Figure 4. Generalized visual spectral distribution of a yellowish brown 10YR 5/4 and yellowish brown 10YR 5/8 soil sample.

illuvial accumulation gives these B horizons a dark reddish brown 5YR 3/2 (Bh) to strong brown 7.5YR 5/8 (Bs) color.

The subsurface horizons of Pennsylvania soils shows a much wider range of colors than surface horizons. Their colors vary in hue mainly from yellowish brown (10YR) to red (2.5YR) and in chroma from 2 to 8. Free iron oxides are the main coloring agents although Al and Mn oxides may also be important in some soils. This conclusion is supported by observations that when free iron oxides are removed from subsoil samples by the citrate-bicarbonate-dithionite (CBD) method of Mehra and Jackson (1960), the samples turn gray which is the color of the clay and other mineral surfaces of the soil. It has been assumed for many years that the free iron oxides in soils are amorphous coating on mineral grains. Recent work by Jaynes and Bigham (1986), however, indicates that the free iron oxides are primarily discrete crystalline particles. This leads to the question, what affect does the size and mineralogy of the free iron oxide particles have on the color of the soil material. According to Schwertmann and Taylor (1989) red colors are due to hematite (Fe_2O_3) and yellowish brown colors are due to goethite (αFeOOH). They also indicate relatively small amounts of added hematite can significantly redden a soil material. Hematite's strong pigmenting (reddening) capacity compared to goethite has been explained by Pazar (1983) as a result of very strong hematite absorption bands in the yellowish brown reflective area of goethite. The result of this interaction is both hematite and goethite reflect red light and goethite reflects yellowish brown light but hematite absorbs yellowish brown light. Thus, as hematite content increases there is a greater amount of yellowish brown light absorbed and more red light reflected from a soil resulting in a much redder color. Although this is the case with the exception

of Schwertmann's (1988) statement that hematite crystals of the size 0.020-0.100 μm are bright red and crystals $> 1 \mu\text{m}$ are often purple, little attempt has been made to determine the size of iron oxide particles, in relation to soil color, particularly in relation to its effect on hue and chroma. This is of significance because soil hue is a measure of the dominant spectral color reflected from a surface, and chroma is a measure of the purity of the spectral color. Thus, the smaller the particle size (keeping concentration constant) the greater the surface area to interact and reflect light. This is of importance because the soil surface produces a mosaic of reflected light which is analyzed by the eye. Thus, we may have high and low chroma yellowish brown and red colored soils depending on the amount, type, size, and distribution of the free iron oxides in the soil. Presently we do not know what affect these combination of variables has on soil color. Thus, research is needed to resolve these problems.

Mottling

Definition

Mottled is defined in the American College Dictionary (Barnhart, 1953) as "spotted or blotched in coloring." This definition is used in the Soil Survey Manual (Soil Survey Staff, 1951) as well as in the newly revised manual (Soil Survey Staff, 1990). This definition leads to the awkward necessity of constantly defining what kind of mottles are being discussed. Because mottling in soils is primarily associated with soil wetness, a better approach is to restrict the term mottling to a spotty soil color pattern due to wetness and describe all other spotty color patterns as variegations. This convention is not widely used but will be followed in this presentation.

Colors and Patterns

The mottling pattern in soils is usually composed of three colors; the matrix, the high chroma mottle, and the low chroma mottle. The common case in poorly structured (weak grade to structureless) soils is that the high and low chroma mottles are dispersed through the matrix. In structured soils, commonly the faces of the structural units (peds) show a greater effect of the mottling process than the ped interiors. This process is the reduction of iron in one area, its movement in solution and its oxidation and precipitation in another area. The iron in solution may also be completely removed from the soil. Thus, the low chroma mottle is the place where the iron was removed and the high chroma mottle is the place where the iron was deposited. The color of the low chroma mottle is that of the clay and other mineral surfaces that the iron oxides were obscuring, and the color of the high chroma mottle is that of the deposited and residual iron oxides. Limited data (Ranney et al., 1975) indicate that low chroma mottled material in Pennsylvania soils has about 0.5% free iron oxides while high chroma mottled material has 5 to 15 times more free iron oxides. The matrix material is intermediate in iron oxide content and has 50 to 70% of that in the high chroma mottles. In addition Schwertmann (1988) indicates that the iron oxides of high chroma mottles (usually 10YR or 7.5YR 5/6 to 5/8) are primarily the mineral Lepidocrocite (γ FeOOH). In addition to Lepidocrocite, Van Breeman (1988b) indicates that high chroma mottles may also contain some ferrihydrite and goethite.

As the mottling process increases in intensity, the low chroma color becomes more extensive and may become the matrix color. When this occurs, the term gleyed is frequently used to describe the soil. In very intensively gleyed soils, some blue and greenish colors are frequently observed. The

origin of these colors is not well documented, although vinianite (blue) and a poorly defined material called green rust (Van Breeman, 1988a) have been cited as the origin of the colors. These materials are very unstable and are only found in permanently reduced soil environments (Van Breeman, 1988a; Schwertmann and Taylor, 1989). Most Pennsylvania soils that are affected by the mottling process do not show blue and greenish colors because they are not permanently reduced. These soils undergo alternating, periodic (usually seasonal) oxidizing and reducing conditions. The late fall, winter, and spring are usually the reducing season and the summer and early fall are the oxidizing season. These seasons are related to the high stand (saturated soil conditions) of water within Pennsylvania soils (Latshaw and Thompson, 1972; Palkovics et al., 1975).

Factors and Processes of Formation

The factors that have been cited which affect mottle formation are: (1) a microorganism population, (2) an organic carbon energy source, (3) lack of oxygen, (4) time, and (5) temperature (Dobos et al., 1990). In addition, pH, although not often cited, is implicated because of its affect on microorganism growth and the solubility of Fe^{++} and Fe^{+++} (Dobos, 1986).

The mottle-forming process is in part a microbiological function. In order to move iron from one area to another in soils it must either be complexed or reduced. Reduction is believed to be the main mobilizing mechanism in mottle formation (Rowell, 1981; Blume, 1988; Van Breeman, 1988b). The details of the process are not well documented but are believed to be as follows:

1. Microorganisms transfer electrons, which are byproducts of their metabolic oxidation of soil organic material, to elements that will undergo oxidation-reduction (redox) changes. In soils, if O_2 is available, the transfer of electrons is to oxygen. If O_2 is lacking, then NO_3^- , SO_4^{2-} , Fe^{+++} , Mn^{++++} , etc., can accept the electrons, and be reduced. The main mechanism that restricts the flow of O_2 from the atmosphere into the soil is the saturation of the soil pores with water. Regardless of whether the soil is aerated or saturated with water microorganisms continue to oxidize organic matter. However, when the soil is saturated, the oxidation is slower, less efficient and different end products are produced (Merkel, 1955; Rowell, 1981).
2. If Fe^{+++} (in iron oxide minerals) accepts the electron and is reduced to Fe^{++} , it becomes more soluble than Fe^{+++} and can move by diffusion or mass flow. Thus, to produce a low chroma mottle in an area, the area must have; (a) microorganisms, (b) organic material, and (c) lack O_2 . The organisms are ubiquitously present in the soil. The organic material in the subsoil is in the form of roots or soluble material that has been leached into the subsoil. Thus, the low chroma mottles should form in the coarser pores or ped face areas where roots can penetrate or where soluble organic material can accumulate. In addition an adequate amount of time and a high enough temperature are also needed. A temperature of $5^{\circ}C$ is frequently cited as biological zero for low chroma mottle formation (Soil Survey Staff, 1975), and mottles will not form or form very slowly below this temperature.
3. Once the iron is in solution, it can move to a place where it can be oxidized and precipitated as an Fe^{+++} oxide. This could be a place

with a higher pH or a higher O₂ content. Varying pH domains in soils may be due to mineral hydrolysis (increases pH), to inherent pH heterogeneity of the soil parent material or the reduction reaction itself. During reduction H⁺ are consumed (Rowell, 1981) therefore their concentration is lowered in the area the reduction is taking place and the pH increases. As the reduced Fe⁺⁺ moves away from these centers of reduction, it may encounter higher pH domains and may be oxidized and precipitate. Higher O₂ content areas could also be encountered due to air trapped in the soil during cyclic water saturation periods. This may be a very important mechanism because Collis-George and Yates (1990) indicate that saturated soils may have 5 to 25% of its pore space filled with trapped air. The time required to form either low or high chroma mottles in natural soil environments is not known. Although unknown, it must take many oxidizing and reducing cycles (years). Logically if an energy source remains in a domain for a number of years, reduction will occur there producing a low chroma mottle. The production of high chroma mottles also must take a number of years. Why a high chroma mottle continues to develop is more difficult to explain particularly if the first precipitation was associated with an air trapped in pores. The most reasonable explanation is that the previously precipitated iron oxide crystals act as nucleating centers for continued crystal growth in the high chroma mottle. The effect of temperature on the mottling process is not known. Although unknown it is logical that increased temperature above biological zero should increase the rate of low chroma mottle formation. The effect of temperature on high chroma mottles is less

clear. The crystallization of iron oxides is an exothermic reaction; therefore, higher temperatures will increase the rate of precipitation, but decrease the amount of iron precipitated. Complicating the picture even greater is the effect of removal of water via evapotranspiration which would tend to concentrate the iron in solution and increase the precipitation of iron oxides in high chroma mottles.

Conclusions

In Pennsylvania as well as other areas, soil mottling has been associated with soil saturation (Loughry, 1960; Latshaw and Thompson, 1972; Franzmeier et al., 1983; Coombs et al., 1985). Although the association is well accepted, the relationship between the variables that cause soil mottling and the composition, abundance, size, and contrast of mottling has not been established. This is particularly true for red (2.5YR 4/4) glacial or residual parent materials derived from the Juniata, Bloomsburg, Catskill, and other similar geologic formations. These materials are believed to be more resistant to mottle formation than yellowish brown materials. Our lack of knowledge of the details of the soil mottling process greatly reduces the usefulness of mottling as an indication of saturation in Pennsylvania soils, and points out the need for research to establish a sound scientific understanding of this process.

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- No. 25 Cunningham et al. 1972. Laboratory Characterization Data and Field Descriptions of Selected Pennsylvania Soils. (This publication gives all the Pennsylvania soil characterization data up to 1972. Following 1972, data was published in the PA Ag Expt. Station Progress report series Characteristics, Interpretations, and Uses of Pennsylvania Soils: Number 290, Dauphin Co.; 295, Northampton Co.; 300, Huntingdon Co.; 306, Warren Co.; 316, Armstrong Co.; 320, Bradford Co.; 323, Bedford Co.; 324 Bucks Co.; 326, Butler Co.; 341, Soils Developed from Cherty Limestone Material; 344, Soils Developed from Colluvium; 355, Soils Developed from Redbeds and Calcareous Material; 362, Soils Developed from Acid Shale; 381, Minesoils. All of the data listed above plus subsequent data obtained is now in the following computer database: Ciolkosz, E. J. and N. C. Thurman. 1993. Pennsylvania State University Soil Characterization Laboratory Database, Agronomy Dept., Pennsylvania State University, University Park, PA.)
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