EVALUATING DIFFERENCES IN SOIL APPEARANCE FROM FIELD TO PHOTOGRAPHS TO AID IN DEVELOPING SOIL PROFILE PHOTOGRAPHY GUIDELINES

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GUIDELINES

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NOMENCLATURE

Bandpass (also known as passband)-spectral bandpass-the width in nanometers at ½ energy of the band of wavelengths transmitted by the dispersive element. The bandpass should be equal to the wavelength measurement interval; the wavelength range over which the radiant power through the passband is at least half its maximum value within the passband; a narrow portion of a dispersed spectrum, selected by the exit slit of a monochromator or the equivalent, for the purpose of defining an emitted spectral power function (ASTM, E 308-96, 1998).

Black body-A temperature radiator of uniform temperature whose radiant exitance in all parts of the spectrum is the maximum obtainable from any temperature radiator at the same temperature (Kaufman and Christensen, 1972; Hunter, 1975).

Brightness-The attribute in accordance with which the source seems to emit more or less luminous flux per unit area (Kaufman and Christensen, 1972); The human sensation by which an area exhibits more or less light (Bourgin, 1999).

Candella-The unit of luminous intensity. One candella is defined as the luminous intensity of 1/600,000 m^2 of the projected area of a black body radiator operating at a temperature of solidification of platinum under a pressure of 101,325 newtons/ m^2 (Kaufman and Christensen, 1972).

Chroma-The colorfulness of an area relative to the brightness of a reference white (Bourgin, 1999); saturation; expressed on a scale from 0 for gray to a maximum of 20 (MacAdam, 1985).

Chromaticity-The color quality of a color stimulus defineable by chromaticity coordinates (ASTM, E 308-96, 1998). That part of a color specification that does not involve luminance. Chromaticity is 2 dimensional and is specified by pairs of numbers such as dominant wavelength and purity (Hunter, 1975).

CIE-The abbreviation for the French title of the International Commission on Illumination, Commission Internationale de l'Eclairage (ASTM, E 308-96, 1998); the main international organization concerned with problems of color and color measurement (Hunter, 1975).

CIELAB color scales-CIE 1976 LAB opponent-color scales, in which a* is positive in the red direction and negative in the green direction, and b* is positive in the yellow direction and negative in the blue direction (ASTM, E 308-96, 1998).

CIELUV color scales-CIE 1976 LUV opponent-color scales, in which u* is positive in the red direction and negative in the green direction, and v* is positive in the yellow direction and negative in the blue direction (ASTM, E 308-96, 1998).

CIE Standard Observer-absolute or derived standards; a psychophysical relation sufficiently characteristic of normal observers that it could be adopted internationally (Kaufman and Christensen, 1972); any two light stimuli that calculate to the same value by means of the standard observer function would have the same luminance; when the

two light stimuli are observed directly, in a 2° split field, they would match for brightness (Hunter, 1975); an ideal observer having visual response described by the CIE color-matching functions (ASTM, E 308-96, 1998).
CIE 1931 standard colorimetric system-A system for determining the tristimulus values of any spectral power distribution using the set of color reference stimuli, X, Y, Z and the three CIE color-matching functions x bar(λ), y bar, (λ), z bar (λ) adopted by CIE in 1931 (ASTM, E 308-96, 1998).
CIE 1931 standard observer-Ideal colorimetric observer with color-matching functions x bar (λ), y bar (λ), z bar (λ) corresponding to a field of view subtending a 2° angle on the retina; commonly called the 2° standard observer (ASTM, E 308-96, 1998).
CIE 1964 supplementary standard colorimetric system-A system for determining the tristimulus values of any spectral power distribution using the set of color stimuli, X_{10}, Y_{10}, Z_{10} and the three CIE color-matching functions x bar_{10} (λ), y bar_{10}, (λ), z bar_{10} (λ) adopted by CIE in 1964 (ASTM, E 308-96, 1998).
CIE 1964 supplementary standard observer-ideal colorimetric observer with color-matching functions x bar_{10} (λ), y bar_{10} (λ), z bar_{10} (λ) corresponding to a field of view subtending a 10° angle on the retina; commonly called the 10° standard observer (ASTM, E 308-96, 1998).
Clear sky-A sky that has < 30% cloud cover (Kaufman and Christensen, 1972).
Cloudy sky-A sky having > 70% cloud cover (Kaufman and Christensen, 1972).
Color-A characteristic of light by which a human observer may distinguish between two structure free patches of light of the same size and shape (Kaufman and Christensen, 1972).
Color matching functions-The amounts, in any trichromatic system, of three reference color stimuli needed to match, by additive mixing, monochromatic components of an equal-energy spectrum (ASTM, E 308-96, 1998).
Color of an object-Aspect of object appearance distinct from form, shape, size, position or gloss that depends upon the spectral composition of the incident light, the spectral reflectance, transmittance, or radiance of the object, and the spectral response of the observer, as well as the illuminating and viewing geometry (ASTM, E 308-96, 1998).
Color temperature (of a light source)-The absolute temperature at which a black body radiator must be operated to have a chromaticity equal to that of a light source. Color temperature designates the exact color of light produced by a specific source (Kaufman and Christensen, 1972).
Concentrations (redoximorphic)-Zones of iron and manganese oxides (Soil Survey Staff, 1994).
Depletions (redoximorphic)-Low chroma, ≤ 2, where iron and manganese oxides and clay have been stripped from the soil (Soil Survey Staff, 1994).
Diffuse reflectance-The ratio of the flux leaving a surface or medium by diffuse reflection to the incident flux (Kaufman and Christensen, 1972).
Diffuse reflection-The process by which incident flux is re-directed over a range of angles (Kaufman and Christensen, 1972).
Direct lighting-Lighting by luminaires distributing 90-100% of the emitted light in the general direction of the surface to be illuminated. The term usually refers to light emitted in the downward direction (Kaufman and Christensen, 1972).

Dominant wavelength of a light-The wavelength of a radiant energy of a single frequency that, when combined in suitable proportions with the radiant energy of a reference standard, matches the color of the light (Kaufman and Christensen, 1972).
Drainage classes-Excessively drained, immediate water infiltration; well drained, water table > 91.4 cm; moderately well drained, water table 45.7-91.4 cm; somewhat poorly drained, water table 22.9-45.7 cm; poorly drained, water table between 0-22.9 cm; very poorly drained, standing water (Soil Survey Staff, 1994).
Filter-A device for changing, by transmission, the magnitude, and or the spectral composition of the flux incident on it. Filters are colored, selective, or neutral, depending on whether they alter the spectral distribution of the incident flux (Kaufman and Christensen, 1972).
Flux (radiant)-The time rate flow of radiant energy (Kaufman and Christensen, 1972); radiant power (ASTM Designation: E 179-96, 1998).
Footcandle-A unit of length equating to the illumination on a surface one square foot in area on which there is a uniformly distributed flux of one lumen, or the illumination produced on a surface all points of which are at a distance of one foot from a directionally uniform point source of one candela (Kaufman and Christensen, 1972)
Goniophotometer-A photometer for measuring the directional light distribution characteristics of sources, luminaires, media and surfaces (Kaufman and Christensen, 1972).
Hue-The attribute of color perception by means of which an object is judged to be red, yellow, blue, green, or purple (MacAdam, 1985); the attribute that determines whether the color is red, yellow, green, blue, or the like (Kaufman and Christensen, 1972).
Illuminance-Luminous flux per unit area incident on a surface (Bourgin, 1999); the density of the luminous flux incident on a surface (Kaufman and Christensen, 1972).
Indirect lighting-Lighting by luminaires distributing 90-100% of the emitted light upward (Kaufman and Christensen, 1972).
Intensity-A shortening of the terms, luminous intensity and radiant intensity; often misused for level of illumination (Kaufman and Christensen, 1972).
Light-For the purpose of illuminating engineering, visually evaluated radiant energy. Light is psychophysical-neither purely physical nor purely psychological. Light is not synonymous with radiant energy, however restricted, nor is it merely a sensation. In a general, non-specialized sense, light is the aspect of radiant energy of which a human observer is aware via the stimulation of the retina of the eye (Kaufman and Christensen, 1972).
Lightness-The sensation of an area's brightness relative to a reference white in a scene (Bourgin, 1999).
Luminance-Luminous flux per unit solid angle and per unit projected area, in a given direction, at a point on a surface (Bourgin, 1999). The luminous intensity of any surface in a given direction per unit of projected area of the surface as viewed from that direction (Hunter, 1975).
Luminosity-Ability to appear luminous; Luminosity is the property of light by which we define how easily we can see it (Bourgin, 1999).
Lumen-The unit of luminous flux. Equal to the flux through a unit solid angle (steridian) from a uniform point source of 1 candella or to the flux on a unit surface all points of

which are at a unit distance from a uniform point of 1 candella (Kaufman and Christensen, 1972).

Luminous flux-The time-rate flow of light (Kaufman and Christensen, 1972).

Luminous intensity-The luminous flux per unit solid angle in a specific direction (Kaufman and Christensen, 1972).

Munsell chroma-The index of saturation of a perceived object color defined in terms of the Y value and chromaticity coordinates x,y of the color of light reflected or transmitted by the object (Kaufman and Christensen, 1972).

Munsell color system-A system of surface color specification based on perceptually uniform color scales for the three variables, hue, value, and chroma. For an observer of normal color vision adapted to daylight and viewing a speciman when illuminated by daylight and surrounded with a middle gray to white background, the Munsell hue, value, and chroma of the color coincides well with the hue, lightness, and saturation of the perceived colors (Kaufman and Christensen, 1972).

Munsell hue-The index of the hue of the perceived object color defined in terms of the Y value and chromaticity coordinates x,y of the color of the light reflected or transmitted by the object (Kaufman and Christensen, 1972).

Munsell value-The index of lightness of the perceived object color defined in terms of the Y value (Kaufman and Christensen, 1972).

Nanometer-nm-A unit of measurement, commonly used for the measurement of wavelength; 25,400,000 nm= 1 inch (MacAdam, 1985).

Opponent color scales-scales that denote one color by positive scale values, the neutral axis by zero value, and an approximately complementary color by negative scale values, common examples being scales that are positive in the red direction , and negative in the green direction, and those that are positive in the yellow direction and negative in the blue direction (ASTM, E 308-96, 1998).

Overcast sky-One that has 100% cloud cover; the sun is not visible (Kaufman and Christensen, 1972).

Partly cloudy sky-One that has 30-70% cloud cover (Kaufman and Christensen, 1972).

Photometer-An instrument for measuring photometric quantities such as luminance, (photometric brightness), luminous intensity, luminous flux, and illumination (Kaufman and Christensen, 1972).

Quantity of light-Luminous energy; The product of the luminous flux by the time it is maintained. It is the time integral of luminous flux (Kaufman and Christensen, 1972).

Quality of light-Pertains to the distribution of luminance in the visual environment. The term is used in a positive sense and implies all luminance contributes favorably to visual performance, visual comfort, ease of seeing, safety and aesthetics for the specific visual tasks involved (Kaufman and Christensen, 1972).

Radiant energy-Energy traveling in the form of electromagnetic waves. It is measured in units of energy such as joules or kilowatt hours (Kaufman and Christensen, 1972).

Radiant flux-The time rate flow of radiant energy, expressed in watts or joules per second (Kaufman and Christensen, 1972); the total power/energy of the incident radiation (Bourgin, 1999).

Radiator-An emitter of radiant energy (Kaufman and Christensen, 1972).

Redoximorphic features-Soil properties associated with wetness class that result from the reduction and oxidation of iron and manganese compounds in the soil after saturation with water and desaturation (Soil Survey Staff, 1994).
Reflectance-Ratio of the reflected flux to the incident flux (ASTM Designation: E 179-96, 1998).
Reflectance of the surface-The ratio of the amount reflected divided by the amount incident, a value between 0 and 1.
Reflected flux-Flux reflected from the specimen at a specified viewing angle and aperture angle (ASTM Designation: E 179-96, 1998).
Refraction-The process by which the direction of a ray of light changes as it passes obliquely from one medium to another in which it's speed is different (Kaufman and Christensen, 1972).
Saturation-The colorfulness of an area relative to its brightness (Bourgin, 1999).
Saturation of object color-The attribute used to describe the departure of a perceived light source color from gray of the same lightness (Kaufman and Christensen, 1972).
Soil depth class-Very deep, ≥ 150 cm; Deep, 100-150 cm; Moderately deep, 50-100 cm; Shallow, 25-50 cm; Very shallow, < 25 cm (Soil Survey Division Staff, 1993).
SPD (spectral power distribution)-Energy radiated per unit time; relative power (Melville and Atkinson, 1985).
Spectral radiant energy-radiant energy per unit wavelength interval at wavelength λ in units of joules or nanometers (Kaufman and Christensen, 1972).
Spectral radiant flux-radiant flux per unit wavelength interval at wavelength λ in units of watts or nanometers (Kaufman and Christensen, 1972).
Spectral tristimulus values-The tristimulus values per unit wavelength interval and unit spectral radiant flux (Kaufman and Christensen, 1972).
Spectrophotometer-An instrument for measuring the transmittance and reflectance of surfaces and media as a function of wavelength (Hunter, 1975).
Speed of light-The speed of all radiant energy (2.997925×10^8 m/sec in a vacuum) (186,000 miles/sec); changes with the index of refraction of the material (Kaufman and Christensen, 1972).
Standard Illuminant-A luminous flux, specified by its spectral distribution, meeting specifications adopted by a standardizing organization (ASTM, E 308-96, 1998).
Transmission-A general term for the process by which incident flux leaves a surface or medium on a side other than the incident side (Kaufman and Christensen, 1972).
Transmittance-Ratio of the transmitted flux to the incident flux (ASTM Designation: E 179-96, 1998).
Tristimulus values-The amounts of 3 reference or matching stimuli required to give a match with colored stimulus considered, in a given tristimulus system (MacAdam, 1985).
Tristimulus values of a light, XYZ-The amounts of each of the three primaries required to match the color of the light (Kaufman and Christensen, 1972).
Tristimulus weighting factors, Sx bar, Sy bar, Sz bar-Factors obtained from products of the spectral power S of an illuminant and the spectral color-matching functions x bar, y bar, z bar (or x bar_{10}, y bar_{10}, z bar_{10}) of an observer, usually tabulated at wavelength intervals of 10 or 20 nm, used to compute tristimulus values by multiplication by the spectral reflectance, transmittance, or radiance (or the corresponding factors) and summation (ASTM, E 308-96, 1998).

Value-lightness (versus darkness) pertaining to the color of an object (MacAdam, 1985).
Wavelength-the distance between two successive points of a periodic wave in the direction of propagation in which the oscillation has the same phase (Kaufman and Christensen, 1972).
Wetness class-Class 1, > 150 cm; Class 2, 100-150 cm; Class 3, 50-150 cm; Class 4, 25-50 cm; Class 5, < 25 cm (Soil Survey Staff, 1994).

CHAPTER I

INTRODUCTION

Soils are not well represented in photographs. Photographs are the most widely used medium for conveying static visual information. Photography of soil profiles has been limited to taking photographs which are mere likenesses of what was seen under field conditions. Photographs of soil profiles are often over or under-exposed, out of focus, taken at inconsistent distances, and lack detail. This approach is common and the photography involved is not difficult (Morgan and Lester, 1941). An alternate approach is to take the time and preparation necessary to obtain the most detailed representative photographic images possible.

ASTM (E 312-96, 1998) photography standards center around laboratory based photography of a specimen and do not encompass soil profile photography. Procedures mentioned in ASTM Designation: E 312-96 (1998) contain practical suggestions to be used for photographing specimen under controlled laboratory conditions. Soil profiles require special consideration as the subject photographed changes in appearance over time, is influenced by many factors and is usually viewed outside under daylight conditions.

Since the start of soil science, soil information has been difficult to exchange between professionals and non-professionals due, in part, to wide ranges in soil property values and technical terminology used. The population having understanding of the technical jargon and terminology is confined to individuals of similar scientific knowledge and background (Mieth, 1941). Properly composed photographs can supply visual evidence to explain or reinforce terms, clarify words, aid in making interpretations, create interest and hold attention (Zisman, 1941). Taking properly composed, clear, sharp and detailed photographs of soil profiles under standard conditions would aid in conveying key soil information of which individuals from different backgrounds can visually relate. One aim of photography is to produce a reasonably truthful record of a scene (Rockwell, 1941). For soil scientists, the goal should be to produce an accurate record of a scene, a soil profile. Photographs are a captured segment of time, where time is a method used to record events. Vocabulary, soil series names, soil property quantification methods and people all change, often resulting in many ways to interpret written soils descriptions. Soil color, structure, discontinuities, layers, and to some degree, texture, can be seen. Photography allows for the capture of the description, visually. Detailed photographs of soil profiles would introduce the soil subject to individuals who may not otherwise be exposed to this resource from the soil scientist's perspective. Information accompanying photographic prints of soil profiles often do not contain specific information such as the conditions present and equipment used at the time the photograph was produced. Neglecting to mention specific information detracts from the scientific tenet of reproducibility. Soil characteristics and features displayed can be manipulated using various techniques such as adjusting lighting conditions, changing the angle of the camera, or using filters. Use of these techniques without informing the audience (reader) results in photographs which may suggest properties which were not actually seen under field conditions (ASTM: E 312-96, 1998). Even when no techniques or enhancements are used to intentionally modify the appearance of a soil profile in photographs, there may be differences from what the photographer perceived to capture to what is actually displayed in a photograph due to other factors such as change in lighting and different sensitivities between film and the human eye.

Honestly portraying soil properties seen under field conditions to produce an accurate representation in the final product is imperative to facilitate correct soil interpretations. Chapter headings in *Soil Color* (Bigham and Ciolkosz, 1993) exemplify some of the broad categories (terms, field and lab measurements, iron oxides, organic matter, stratigraphic and hydraulic properties and red bed geology) which influence interpretations of apparent soil color. The importance placed on each category changes from one region to another where, for example, field identification of organic matter may be reduced in regions where the mineral soil color blends with the color of the soil organic matter. An individual photographing soil profiles should portray only what is actually present in the soil profile. Some of the conditions and factors suspected to affect soil appearance in photographs include the use of filters, the film chosen, the lens used, the time of day or night the photographs are taken, distance from camera lens to soil profile, the angles from camera lens to soil profile, camera settings of aperture and shutter speed, soil moisture conditions, preparation and surface relief of the soil profile, type of light and lighting conditions, camera assessories used, photographic papers and gloss, weather conditions, the ability and eyesight of the photographer, the film processing lab's equipment and abilities and what the photographer wants the viewer to see. Information should be recorded and presented so the viewer of the photograph is aware of all the photographic components utilized to produce the image. Traditionally, Munsell Soil Color Charts (GretagMacbeth, 1994) have been used as an aid to identify and label field measurement of soil color. The Munsell (GretagMacbeth, 1994) color system is the most widely accepted color system used for measurement of soil color in part due to the fact that the color notation employed was designed to indicate color as perceived by the observer (Judd, 1940). Obtaining numerical values derived from instrumental measurement is another method of identifying soil color. Instrumental measurement of color is often relied upon as a repeatable method of obtaining numerical values which eliminates variability in perceived colors between individuals and acceptably represents colors observed. Spectrophotometers measure reflectance as a function of wavelength (Hunter, 1975) and are the most direct method for obtaining color difference data (ASTM: E 1347-97; ASTM: E 1164-94, 1998).

Through out this paper, Munsell Soil Color Charts and Munsell soil color chips refer to the reference GretagMacbeth, 1994. Referrals to Munsell color sheets, Munsell color system, and Munsell notation refer to the company reference of Munsell Color, GretagMacbeth, New Windsor, NY.

Lighting conditions have the single greatest effect on object appearance under field conditions as well as what is captured in photographic media. Visibility distinguishes light waves from other electromagnetic waves. The visible spectrum measured by wavelength in units of nanometers (nm) consists of violet (400-450 nm), blue (450-490 nm), green (490-560 nm), yellow (560-590 nm), orange (590-630 nm), and red (630-700 nm) (MacAdam, 1985). The eye is most sensitive to light at about 550 nm and is insensitive to radiation outside the visible spectrum.

Physically, light waves are the same as xrays or radio waves, differing from them only in wavelength. All electromagnetic waves are radiant energy (Hunter, 1975).

Sixty-five hundred Kelvin (6500 K) is the color temperature received from the sun outside the earth's atmosphere. At an average rate of 0.135 W/cm^2, 75% reaches the earth's surface at sea level on a clear day. The illumination of the earth's surface by the sun is > 10,000 foot candles. Cloudy days produce < 1,000 foot candles. The moon shining is reflected sunlight with illumination of 0.01 foot candles. Light leaving an object surface is either reflected or transmitted by the object. Reflected light leaves the object from the same side as was illuminated whereas transmitted light exits the opposite side after penetration through the specimen (Hunter, 1975).

The International Commission on Illumination (Commission Internationale de l'Eclairage), commonly referred to as CIE, is a group of specialists who recommend and revise methods for measurement of light and color. The CIE system is the most applicable system with relation to color specification and measurement issues. The CIE specified the spectral power distributions of Standard Illuminants and Sources as well as the spectral response characteristics of an average, normal-visioned human observer (1931 CIE 2° Standard Observer and the 1964 CIE 10° Supplemental Standard Observer) in terms of three primary colors. The CIE standard illuminants are: Illuminant A, which represents a tungsten filament lamp (incandescant lamp light) with a correlated color temperature of 2856 K, Illuminant C, which represents average daylight with a correlated color temperature of 6770 K, Illuminant D_{50}, used by graphic artists for viewing color transparencies and prints; represents the noon sky with a correlated color temperature of 5000K, Illuminant D55, which represents noon sky daylight with a correlated color temperature of 5500K, Illuminant D_{65} used for general evaluation of color and represents north sky daylight with a correlated color temperature of 6500 K, and Illuminant D_{75}, used for general evaluation of color and represents north sky daylight with an average color temperature of 7500K (GretagMacbeth, 2000a). There are several other illuminants specific to location and use (such as the fluorescent illuminants of F2, DLF-7, and NBF-11) which are not discussed here. The 1931 CIE Standard 2° Observer was developed to represent an ideal observer with color matching functions x barλ, y bar λ, and z bar λ corresponding to a field of view subtending a 2° angle to the retina. In 1964, the CIE presented the 1964 CIE 10° Supplemental Standard Observer defined as an ideal colorimetric observer with color-matching functions x bar_{10} (λ), y bar_{10} (λ), z bar_{10} (λ) corresponding to a field of view subtending a 10° angle on the retina (ASTM: E 308-96, 1998).

The CIE system uses coordinates which classify color according to hue, value and saturation (HVS). The CIE system defines hue as the attribute of a visual sensation according to which an area appears to be similar to one, or two proportions of 2, of the perceived colors, red, yellow, green and blue (MacAdam, 1985). Brightness (value) is the attribute of a visual sensation according to which an area appears to exhibit more or less light (Bourgin, 1999). Saturation is the attribute of a visual sensation according to which an area appears to exhibit more or less of its hue (MacAdam, 1985; Bourgin, 1999). Spectrophotometers measure color as a function of wavelength and generate output of CIE system language (XYZ) that can be converted to Munsell notation or to numerous other existing color systems.

The concept of a color space embraces the idea that the three attributes used to describe a color are in three dimensional space. The colors we perceive can be represented by the CIE system and other color spaces are subsets of this perceptual space. There are many color spaces and many arrangements of attributes in color space, each suited to different applications and subject to limitations. People commonly define color in terms of its attributes of brightness, hue, and colorfulness. TV displays use RGB (red-green-blue phosphors, additive-computer graphics) color space, a cube with red, green and blue axis. This cube is a subset of our perceptual space because it is a subset of the range in colors we can actually see. CMY (cyan-magenta-yellow, subtractive-printing press and photography) space can be represented by a second cube, with a different orientation and a different position within the perceptual space. A color space is then a method by which we can specify, create, and visualize color, a mathematical representation of our perceptions. To represent colors in a uniform perceived color space better, CIE (1978) recommended two systems of describing uniform color space and appropriate color-difference equasions. These two systems are the CIE 1976 (L*u*v) system and the CIE 1976 (L*a*b) system abbreviated CIELUV and CIELAB respectively (CIE, 1978). These systems are opponent-type color spaces based upon non-linear transformation of the X, Y, Z tristimulus values where u* and a* are opponent red/green scales (+u* and +a* being reds, -u* and –a* being greens) and similarly, v* and b* are opponent yellow/blue scales. L* is the 'metric lightness function' and is common to both systems. With CIELUV, where L is luminancy, and U and V are chromanancy, chromaticity and saturation values can be obtained. CIELUV is usually used to distinguish small color differences, especially with additive colors. With CIELAB, where L is luminancy, and A and B refer to the red/green and yellow/blue chromanancies, hue and chroma but not saturation values can be obtained (Melville and Atkinson, 1985). CIELUV and CIELAB are common color scale options on spectrophotometers and are the two most relevant color scales for measurement of soil color.

The objectives of this research are to: 1) determine if the conditions and factors chosen for this study affect soil appearance in photographs especially with relation to observing key soil features and characteristics, 2) evaluate differences between visual and spectrophotometric measurements, and 3) use the results of 1) and 2) to develop soil profile photography guidelines.

CHAPTER II

VISUALLY EVALUATING DIFFERENCES IN SOIL APPEARANCE FROM FIELD TO PHOTOGRAPHS

Introduction

The apparent color of a soil profile can vary based on what was observed under field conditions versus what is portrayed in photographic images of the same soil. As a fundamental visual means of communication, photographic images are often used as a resource for interpretations based on the soil properties and features displayed. Photographic images of a soil profile often fail to accurately represent the actual soil, obscuring, distorting, or eliminating soil features and properties. Portraying the soil as seen under field conditions is important for making accurate interpretations based on soil properties and features observed, especially with regards to soil color, a soil property commonly used for interpretations.

Soils containing various colors absorb and reflect heat waves differently, affecting temperatures along with corresponding changes in soil moisture and structure. Temperature fluctuations affect soil warming, germination, and plant growth. Since individuals first began to recognize soil as a resource, soil color has been used for making interpretations with regards to mineralogy, soil drainage, the presence of organic matter, the translocation of silts and clays, horizonation, and classification (Buol et al, 1989; Bigham and Ciolkosz, 1993).

The parent material present in an area often indicates the types of minerals present in the landscape. Identification of soil mineral components are commonly carried out initially by color and use of a hand lens in the field (Buol et al, 1989; Bigham and Ciolkosz, 1993). The soil's color aids in determining whether the soil is actually formed from the parent material present. The mineralogical make-up of a soil, the reflectance and absorbance values of not only the type of material such as hematite versus quartz, but also the size of the soil particles (sand, silt, and clay) and concentration affect the apparent color of a soil (Buol et al, 1989; Bigham and Ciolkosz, 1993). Soil color can be an indication of the constituents of the soil. Rust colors may indicate mica, oxides or clays. Green colors may indicate hornblende. Black may indicate organic matter, oxides or magnetite. Clear particles may indicate quartz and feldspar. Purple colored mineral constituents may indicate fluorite. The form of a mineral can be indicative of past or present specific soil processes. Free iron oxides may aid in determining the extent of soil weathering. Fe^{3+} is ferric, the reduced form of iron. Fe^{2+} is ferrous iron, the form found commonly in hematite. When the oxygen supply is high in soils and microbial demand for oxygen is low, the oxidation of iron can occur where Fe^{2+} loses an electron to become Fe^{3+} (plus an electron). This process often results in orange and red colors in a soil profile. In minerals containing ferrous iron (Fe^{2+}) the mineral may disintegrate and facilitate soil weathering (Buol et al, 1989). Color has been used to assess the mineral content in soils. Iron oxides such as Fe_2O_3 with Munsell (GretagMacbeth, 1994) hues of 2.5-5YR often indicate goethite. Goethite is often formed under oxidizing conditions as a weathering product of iron-containing minerals (Klein and Hurlbut, 1977). Similarly, FeO(OH) with a Munsell (GretagMacbeth, 1994) hue of 7.5YR may indicate lepidocrosite, a polymorph of goethite. Torrent et al (1983) used a redness rating and the Munsell (GretagMacbeth, 1994) color system to assess hematite content of soils (Melville and Atkinson, 1985). However, high (versus low) concentrations of these minerals are often key to accurate identification. Reduced areas of the soil are commonly shades of blue, gray, or green where oxygen demand is high due to high microbial activity. Iron is reduced to a mobile form where it is then either lost through the movement of groundwater or it reacts to form other compounds (Buol et al, 1989). Oxidized and reduced (or depleted) zones of the soil are identified by soil color.

For many years, color in landscapes has been used to assess soil drainage, especially with regard to movement of the water table. Hydrologic factors, including precipitation, recharge, flow-through, and discharge influence leaching, oxidation and reduction, the accumulation of precipitates of iron and calcium, and the translocation of clays. Light gray areas may indicate a history of leaching of iron and other cations. Red colors may reveal an accumulation of iron, or the leaching of silica. Redoximorphic features (reduced and/or oxidized areas) may indicate a seasonal fluctuation of water (Pierzynski et al, 1994) in the soil. These processes affect observed soil color (Kohnke, 1986).

Soil organic matter is commonly very dark in hue colored primarily by the humic and fulvic constituents. Extractable organic matter is normally divided into two parts based on solubility characteristics: humic acid which usually appears in shades of brown to black, and fulvic acid, which usually appears as a yellowish-brown to reddish-brown substance (Kohnke, 1986; Buol et al, 1989; Bigham and Ciolkosz, 1993). Kondrat'yev and Fedchenko (1983) have established a relationship between the percent humus content of a soil and the sum of the tristimulus values (Melville and Atkinson, 1985). Prior to laboratory testing, soils are commonly visually assessed as to their organic matter content or organic carbon percentage based on color.

The process of translocation of silts and clays through the soil profile is often identified by a combination of color differences and coatings on soil particles usually producing clay films on ped faces and siltans (in sodic soils).

Distinguishing the layers of a soil profile is initially accomplished visually by differences in color and structure, and texturally. Identifying surface and subsurface characteristics such as an E horizon or albic material in horizons and ochric versus mollic epipedons is accomplished with the aid of soil color. Part of the criteria for an E horizon is the loss of silicate clay, iron or aluminum, leaving a concentration of sand and silt particles lighter in color (usually) than the underlying B horizon (Soil Survey Division Staff, 1993). Albic materials have Munsell value and chroma color criteria reflecting the color of the primary sand and silt particles rather than their coatings. These processes indicate that clay and/or free iron oxides have been removed (Soil Survey Staff, 1998). Mollic epipedons are distinguished by low Munsell values and chromas (3/3 or less moist), whereas ochric epipedons are distinguished by high values and chromas (>3 moist).

Soils in the United States are classified based on their features and attributes, one of which is soil color. Separation of soil orders such as Mollisols (which have a mollic epipedon) from Alfisols (which do not have a mollic epipedon) involves identifying Munsell (GretagMacbeth, 1994) notation soil color values and chromas of three or less moist (dark-colored soils) of the surface epipedon layers. Several orders of the soil classification system have color criteria named directly, or indirectly through the naming of other features or characteristics that have color criteria. The Spodosol order is an example where color is named indirectly. The color referral is in relation to the color of organic matter and iron accumulations. From the Order to the Series levels of the U.S. soil classification system (Soil Survey Staff, 1996), soil color is incorporated either directly by naming of specific Munsell color notations or indirectly through the identification of color identified characteristics or features such as redoximorphic features.

Included in the U.S. Soil Survey Reports (United States Department of Agriculture-Natural Resources Conservation Service; USDA, NRCS) for each county is a soil series description sheet of each soil series found in the county and the range of soil features and properties (including soil color) allowed for each soil series.

Hunter (1975) identifies six factors which need to be identified and controlled to make accurate visual determinations of appearance. The six factors are the spectral quality of the light source, the intensity of the light source, the angular size of the light source, the direction from which light strikes the object (angle of incidence), the direction from which the object is viewed (angle of viewing), and the background.

Many factors are suspected in contributing to poor photographic representations of soil appearance. Several factors, which are readily changeable are suspected to have a noticeable affect on photographic images of soil profiles and are within the scope of this paper.

The objective of this research was to determine (via photographs of soil profiles) if and how changing the factors and conditions chosen for this study (film, distance between the camera lens and soil profile, soil profile surface moisture, aperture and shutter speed settings, filters, camera angles, time of day the photographs are taken, night photography, and color matching to a standard) affect the appearance of soil characteristics and features in photographs. The justification is that soils need to be accurately portrayed in order to best display the characteristics that distinguish one soil from another. Visual soil characteristics often aid in making interpretations which then influence land use and management decisions, so accurate portrayal is important for correct interpretations. To increase public awareness of the value of the soil resource, soils need to be accurately portrayed to best display soil attributes. Lastly, for documentaion of the soil resource, accurate portrayal is mandatory.

Review of Literature

Soil Series

The land area of Oklahoma is comprised of 43,954,269 acres (177,877.4 sq. km or 68,678.5 sq. mi). Over 570 soil series are represented within this land area. The soil series is incorporated at the lowest and most detailed level of the soil classification system (Soil Survey Staff, 1996).

Soils of the Teller series (Fine-loamy, mixed, active, thermic Udic Argiustoll (Soil Survey Staff, 1996)) are moderately extensive in the Central Rolling Red Prairies of Oklahoma, Kansas and possibly Texas, and are classed as 4-V-W≤n-FL (Ponte and Carter, 1999) indicating a soil, as represented by the typical pedon, having 4 primary layers (4), being very deep (V) and well drained (W), with an A horizon less than 3/3 in value and chroma, respectively (≤), the 3/3 value and chroma not (n) extending to the lower layers, with a family particle size class of the control section being fine-loamy (FL). The type location for Teller is Payne County, Oklahoma; about 1 mile west and 1 mile north of Perkins; 2,100 feet north and 80 feet east of the southwest corner of sec. 36, T.18N., R.2E) (USDA-NRCS; Soil Survey Staff, 1996) (Appendix A).

Soils of the Grainola series (Fine, mixed, active, thermic, Udertic Haplustalf) (Soil Survey Staff, 1996)) are moderately extensive and found in the Central Rolling Red Prairies (MLRA 80A) of Oklahoma and possibly Kansas and are classed as 4-M-W≤n-F (Ponte and Carter, 1999) indicating a soil, as represented by the typical pedon, having 4 primary layers (4), being moderately deep (M), and well drained (W), with an A horizon less than or equal to 3/3 in value and chroma, respectively (≤), ≤3/3 value and chroma not extending below the A horizon (n), and a fine (F) control section family particle size class. The type location for Grainola is located in Osage County, Oklahoma; about 4 miles west and 3 miles north of Shidler; 1,060 feet east and 280 feet south of the northwest corner of sec. 14, T.27 N., R. 5 E (USDA-NRCS; Soil Survey Staff, 1996) (Appendix B).

Soil Color

The importance of soil color lies in the relative color difference between and within horizons and soil profiles (Melville and Atkinson, 1985). Traditionally, field measurement of soil color has been accomplished with the aid of Munsell Soil Color

Charts, where soil samples are held under the page and show through the opening located under each color chip (Bigham and Ciolkosz, 1993).

The color of a soil is commonly the most obvious soil morphological characteristic seen. Color is often one of the first properties recorded in written soil profile descriptions and may be one of the few features considered significant by individuals who are not soil scientists (Bigham and Ciolkosz, 1993). Soil color aids in distinguishing horizons, identifying soil properties, processes, and features (such as organic matter, the translocation of silts and clays, and redoximorphic (or wetness class) features) and also facilitates the classification of a soil. Soil color under field conditions is affected by many factors including the quality and intensity of the light, surface reflectance characteristics of the soil, moisture content of the soil sample, pigmented clay coatings on soil particles, the relief of the soil surface, degree of crushing of the soil sample, and the individual's eyesight and perceptions (Simonson, 1993; Melville and Atkinson, 1985; Bigham and Ciolkosz, 1993).

Munsell Color System

Determination of field soil color is usually accomplished by matching a soil sample to a standard color chart such as Munsell Soil Color Charts (Bigham and Ciolkosz, 1993). Although it is unlikely that the spectral reflectance characteristics of the soil will exactly match those of the Munsell soil color chips, under a particular set of illumination conditions, the human eye can achieve a close approximate match (Melville and Atkinson, 1985). Munsell Soil Color Charts have ten hues although the charts used by soil scientists normally contain nine pages (10R, 2.5YR, 5YR, 7.5YR, 10YR, 2.5Y, and

5Y and two gley pages). Two pages, (designated 5R and 7.5R), contain colors normally associated with tropical soils and are not sold as part of the standard Munsell Soil Color Chart, but are purchased separately. The Munsell color system consists of three components, Hue, Value, and Chroma. In the Munsell color system, Hue is the quality of the color or the attribute of color perception by means of which an object is judged to be red, yellow, blue, green or purple; the dominant spectral color as related to the wavelength of light (MacAdam, 1985). Value (where 0 is absolute black and 10 is absolute white) is the degree of lightness or darkness and is related to the total amount of light reflected (MacAdam, 1985). Munsell Chroma is the degree of saturation expressed on a scale of 0 for gray to a maximum of 20 (Munsell Soil Color Charts utilize 0-8) (MacAdam, 1985); the strength of the spectral color (Melville and Atkinson, 1985). The Munsell circle is comprised of 5 main hues and 5 intermediate hues. The circle has a range of 0-100 where 0 begins at the boundary between purple and red. Each intermediate hue has a range of 10 units and is noted by using notation such as 2.5 YR. Munsell Soil Color Charts have 10 hues although the charts used by soil scientists normally contain seven (10R, 2.5YR, 5YR, 7.5YR, 10YR, 2.5Y, and 5Y) hue pages and two gley pages, but can also contain 5R and 7.5R pages.

Matching Munsell color chips to soil under average daylight illumination is the standard to be adhered to as it results in more color matching precision than other viewing conditions (Melville and Atkinson, 1985). The Munsell system was designed by Albert H. Munsell (Nickerson, 1940) to designate color as seen by the human observer. Field descriptions of soils utilize only the observed soil color and features under field conditions (versus controlled laboratory conditions) which underscores the need to realistically portray soil color and features when obtaining photographic images of soil. There are other systems used to describe color, but Munsell is the most widely accepted and used for soil color (Kaufman and Kristensen, 1972).

Suspected Factors Contributing to Inconsistent Photographic Representations of Soil

Film Choice

Photographic films respond differently to light of different colors. Some films are designed to be more sensitive to blue or ultraviolet rays while others may have sensitivity in the red region of the spectrum (Hawken, 1976). Several types of films are available which have properties tailored to the type of photography work and the lighting used (Helpren et al, 1973; Stroebel, 1993). Photographic film is manufactured by several companies (Stroebel, 1993) that may result in films having a variety of color properties even when designed for the same purpose. Different films chosen may produce different soil colors that could affect subsequent interpretations.

Some of the most consistent representations of soil profiles in photographs has been the work completed by Dr. Andrew Aandahl in *Soils of the Great Plains* (Aandahl, 1982). In his photography work of the Great Plains, Dr. Aandahl used a Speed Graphic 4x5 large format camera. The same camera scaled down to eliminate non-essential features which add unnecessary bulk and weight, is the Graflex Crown Graphic. Both models are high quality view cameras that utilize 4" x 5" (10 x 13 cm) film, hence the coined phrase "4 x 5 large format cameras". This format size is also commonly found classified as a medium format camera.

Kodak's Pro 100 PRN (Eastman Kodak Co., 1998) film is a standard daylight color film. One hundred (100) is the film speed and "PRN" is an abbreviation for print. Portra 160 NC (Eastman Kodak Co., 1998) is a standard studio portrait film. One hundred and sixty (160) is the film speed and "NC" is an abbreviation for natural color. Vericolor (Eastman Kodak Co., 1998) is a portrait film with a film speed of 160. When taking light meter readings, film speed settings on the light meter must be changed to reflect the film currently in use.

The 35 mm single lens reflex cameras have dominated the field of professional photography for many years, due in part, to the main advantage of portability. The primary disadvantage to using 35 mm cameras is the small film size. Sharpness is lost as print size increases from the size of the original negative.

Although several size formats are available in traditional photography, large format (10 x 13 cm film size, hereby referred to as 4 x 5) is 13 ½ x sharper than the same photograph taken with 35 mm film. Although the choice of format size is one of personal preference, a primary consideration should be choosing a film size equal to or larger than the desired final product to ensure sharpness and no loss of detail (Burchfield et al, 1997) (McFarlane, 1941; Morgan and Lester, 1941; Stroebel, 1993). Photographers who strive to obtain the best quality, use film large enough to permit them to make contact prints rather than projection prints (Stroebel, 1993).

<u>Distance From Camera Lens to Soil Profile</u>

The distance between the camera lens and subject affects the photographic image produced. Photographing a soil profile at several distances utilizing the same camera lens affects the size of the soil area captured, the scale of the image (Stroebel, 1993), the detail seen, and the color observed due to more reflected light reaching the camera with longer distances than with shorter distances. The lens chosen affects the distance from the lens to soil profile and the area viewed as lenses have different optical qualities.

The distance in front of and behind the area focused upon (known as "depth of field") is affected by the distance between the lens and the subject (Burchfield et al, 1997). The greater the distance, the greater the depth of field. Distance from camera lens to soil profile affects the amount of haze, light, reflectance (Helpren et al, 1977) and overall interference reaching the camera lens. Assuming use of the same lens, the distance from lens to soil profile may affect whether or not key features that separate one soil from another will be seen in the photograph.

Soil Moisture

Soil moisture content is thought to affect field identification of soil color (Bigham and Ciolkosz, 1993). Generally, too little moisture and the soil appears lighter in color. With the addition of moisture, soils appear darker in color. Changes in moisture status affect the assessed Munsell value of a soil sample (Melville and Atkinson, 1985), since value indicates lightness or darkness of the hue. The ability of a given soil to hold or drain excess water is assessed by the presence or absence of redoximorphic (reduced and oxidized zones) (wetness class) features whose identity in a soil profile are color dependent. Extremes in soil color due to moisture differences may affect visibility of soil features and subsequent interpretations based on soil color.

Camera Settings-Aperture and Shutter Speed

The camera aperture controls the amount of light that passes through the lens and aids in determining the range of sharpness on either side of the point of focus (depth of field). The smaller the aperture, the greater the depth of field (Burchfield et al, 1997). The aperture opening on a camera is often used interchangeably with the term F-stop. The aperture is the lens opening that lets light into the camera. The term F-stop is often discussed in conjunction with the shutter speed setting of a camera. F-stop numbers express the ratio between the focal length of the lens and the diameter of the lens. The focal length is the optical distance from the lens, when focused at infinity, to the focal point. The focal point is where the light rays converge when the lens is focused at infinity. Film is placed at the focal point of a lens (Hawken, 1976; Burchfield et al, 1997). An aperture opening of ¼, for example, would allow the same amount of light to reach the film by selecting a fast shutter speed as a smaller aperture opening (1/22) used in conjunction with a slower shutter speed (to allow more time for exposure of the film). Using different combinations of aperture and shutter speeds to obtain the same amount of exposure is referred to as equivalent exposure (Burchfield et al, 1997). Most normal lenses (does not include specialty, wide angle, or zoom lenses) have an associated F-stop in which the focal point will be greatest for that particular lens. However, other aperture settings are often chosen to tailor a specific effect the photographer is trying to obtain. Soil profiles are a relatively flat, although textured, wall (surface). An aperture opening of 1/16 and 1/22 have been recommended (Eastman Kodak, 1998) as the desirable F-stops for the most accurate portrayal of soil profiles.

As light passes through small aperture openings, it is scattered or diffracted. Too small an aperture and the image is less sharp. To obtain a sharp image, the aperture must be large enough to reduce the effects of diffraction to a minimum. An aperture that will satisfy this condition is too large to form a sharp image from the standpoint of geometrical optics. It is only by bending the rays of light passing through the aperture so that they converge to form an image point that the requirements of geometry and diffraction can both be met to form a sharp image. This function is carried out by the lens. Light is bent when it enters a lens because glass has a greater density than air and the velocity of light is lower in the denser medium (Neblette and Murray, 1973). By converging the rays of light passing through the aperture, the lens makes it possible to use a large aperture yet obtain a sharp image. Although not a factor researched for this study, the camera lens affects optical performance. Several glass elements often comprise one camera lens. For each element, the refractive index varies with the wavelength of the incident light (Ray, 1976). This property, known as dispersion, varies with the production of each type of element. Dispersion is responsible for chromatic aberrations of a simple lens and affects distortion of the image seen (Ray, 1976). Multi-element lenses can decrease chromatic aberration.

When not using the concepts of equivalent exposure, randomly chosen apertures and shutter speeds can result in much darker or lighter prints than what suggested (via light meter readings) exposure settings would have produced. Lighter prints are obtained when film is exposed to too much light, whereas not enough light reaching the film is responsible for darker prints. There are no “accurate” settings from a photographer’s standpoint as it depends on the result the photographer is trying to achieve. Unstable lighting conditions such as that which natural daylight presents, necessitates taking light meter readings for each photograph individually.

Camera Filters

Camera filters are an additional element which affects optical performance (Hawken, 1976) and are used in color photography to carry out a variety of functions. Major groups of camera filters include conversion, light balancing, color compensating, and specialty filters. Light balancing filters produce shifts in color temperature and are used to balance the color temperature of film and lighting. Conversion filters are used primarily to correct for color differences between human eye sensitivity and that which the film is sensitive. Color compensating filters are used for special effects or for small color balancing requirements since these filters absorb one color of the spectrum allowing other colors to pass through (Burchfield et al, 1997; Hawken, 1976). Several different filters create effects such as mist and vignetting. Diffusion filters are used primarily in portraiture to "soften" the overall appearance of the image (Tiffen, 1999). Sky filters absorb UV and are commonly left on camera lenses to block UV rays and as an inexpensive exterior protection of the camera lens (Tiffen, 1999). Film is more sensitive to ultraviolet (UV) light than our eyes, so the use of some ultraviolet light absorbing filters can correct for the bluish look that UV light casts on photographic images. Haze filters absorb UV and help to improve image clarity by removing the "washed out" look UV light creates (Tiffen, 1999). Filters used for black and white photography (such as yellow, green, and red) are often used in color photography to add dramatic color effects. Eighty (80) series color conversion filters are used to correct differences in color temperature between the recording medium and the light source. The 80A filters are used for daylight film used in conjunction with tungsten lighting. The 80B series filters balance daylight film for use with tungsten photoflood lamps and are necessary when using 3400K photoflood lamps (Eastman Kodak Co., 1998; Cummings, 2000; Davis, 2000). Decamired (DM) (Tiffen, 2000) filters are light balancing and conversion filters that utilize the Mired system of color temperature measurement and are used in combinations to satisfy any color temperature requirement. Mired is an abbreviation for micro reciprocal degrees and is a unit of measurement related to color temperature. To convert Kelvin to Mired, divide one million by the color temperature in Kelvin. Divide the Mired value by ten to obtain DM. The DM set is comprised of eight filters, four red warming (R1 ½, R3, R6, R12) filters and four blue cooling (B1 ½, B3, B6, and B12) filters. The letter of the filter designates filter color (red or blue) and the number designates the DM value. Ten Mireds equals one DM. Photoflood lamps (500 watt) with a color temperature of 3400K have a DM value of 29, so the three filters B3, B6, B 1 ½ should be used (Tiffen, 2000). To lower the DM value or to cool, blue filters are used. To raise or warm the DM values, red filters are used. To calculate the DM filter values needed, the DM value of the light source is subtracted from the DM value of the film. If the number is positive, red filters are used. If the number is negative, blue filters are used. Then the closest number combination of the same color filters to match is selected. Photoflood lamps of 3400K have a Mired value of 294 (DM=29). Daylight print film with a color temperature rating of 5500K has a mired value of 182 (DM=18) The –112 difference can be closely matched with the DM filters of B6, B3, and B 1 ½ which total 115 Mireds (Tiffen, 2000).

With relation to soils, some filters can manipulate the image seen and may enhance or distort soil color and features, affecting soil interpretations. Color film sensitivity to different wavelengths of the spectrum can be overcome through the use of filters. When using artificial light sources, the use of light filters is often a necessity if optimal color rendition is to be obtained (Hawken, 1976). Many filters exist that are designed to intentionally change appearance (such as texture, for example). There is no right or wrong use of filters but more a matter of what effect the photographer is trying to achieve.

Camera Angles

Camera orientation, the photographer's vantage point, and the camera angle with respect to the subject all can change the pictoral content in a photograph (Hawken, 1976). At a forty-five degree angle from the frontal surface of the subject, the viewing component observed is gloss. To view an object's color, the object should be viewed directly in front of the viewer, centered with the eyes at a ninety degree angle from the frontal surface of the object (Evans, 1974; Kaufman and Kristensen, 1972; Kaufman, 1981). Other angles used may result in change in perspective (Hawken, 1976). Distortion of the image (Burchfield et al, 1997), which can occur when the angle chosen drastically affects perspective is avoided at a 90° angle. Eliminating shadows and distortion is crucial to accurately portraying soil color, features, and properties.

Time of Day

Soil color, features, and properties displayed appear to change with the time of day the soil is observed. Visibility, sharpness and detail seen in soils viewed with the sun low on the horizon are affected by interruption by the haze and dust of the atmosphere (Helprin et al, 1973). Soil profiles viewed too early or too late in the day are often shadowed by surrounding vegetation and soil aggregates. Soils viewed with the sun directly facing the soil profile at a sixty degree angle (Helpren et al, 1973) above the horizon receive the least interference from atmospheric distortion and the least shadowing. The recommended viewing conditions of objects (CIE, 1971) include an illumination angle of forty-five degrees to the object's surface with the object being viewed along the perpendicular to that surface (Melville and Atkinson, 1985). The time of day and sun's angle is important to viewing and photographing soils under the best possible field viewing conditions.

Night Photography

Most spontaneous photography occurs under daylight conditions. However, daylight may not present conditions that are reproducible since the constancy of daylight is not true (Henderson, 1977). In the field of color measurement, there are three major problems associated with daylight: inconsistent and varying spectral power distribution, changing conditions, and higher correlated color temperatures than can be achieved by artificial incandescent sources (Hunt, 1992). All three factors affect the conditions present at the time a photograph is taken, which, in turn, affects the photographer's ability to duplicate the conditions to reproduce the photograph. In order to conform to the scientific tenet of reproducibility, controlled lighting conditions should be considered for photographing soil profiles.

To accurately reproduce the photography of soil profiles, lighting conditions must be duplicated. Under natural lighting conditions, duplication would involve only shooting photographs during the narrow window of the same angle of sun, time of day, day of the year as the original photograph was taken. Time and weather conditions then limit the reproducibility of soil profile photographs. The use of artificial lighting, however, eliminates these obstacles by allowing conditions that can be consistently reproduced. For reliable control of artificial lighting, continuous artificial lighting (versus instantaneous artificial lighting such as flash bulbs) should be used (Burchfield et al, 1997). Using artificial lighting and photographing soil at night or within an enclosed light tight area creates repeatable conditions which confers with the scientific tenet of reproducibility. For soil color measurement, the USDA Soil Survey Manual (Soil Survey Staff, 1975) does not mention the need for standardizing the illuminating conditions (Melville and Atkinson, 1985). Photographing soil profiles at night or at any time of the day if the soil profile is enclosed may produce repeatable conditions that would aid in standardizing the illuminating conditions.

Standards and Color Matching

Munsell soil color chips, and Eastman Kodak's 18% gray card (Eastman Kodak Co., 1999) are accepted standards that can be used to assure color consistency in photographs. Munsell color chips are scientifically prepared to match under any illumination and designed to reflect light the same way in all parts of the visible spectrum resulting in the matching of natural objects under any illumination and with any color reproduction process (Allen, 2000). Eastman Kodak's 18% gray card is used to calibrate exposure meters, as a standard used to obtain light meter readings from a standard of known reflectance (18%), and can be submitted along with film to color labs to evaluate color balance and density (©Eastman Kodak Co., 1999).

Materials and Methods

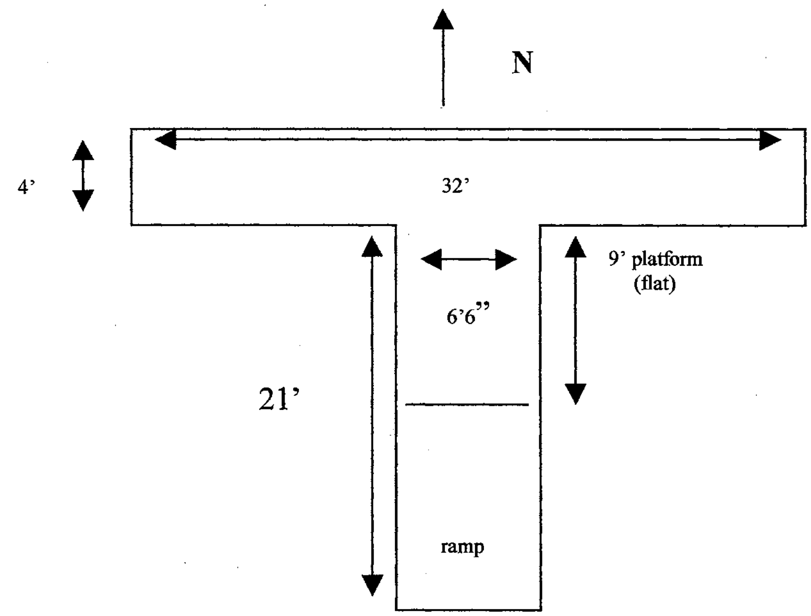
Soils - Two Soil Series

Two soil series including a taxadjunct to the Teller (Soil Survey Staff, 1996) soil series (sandy textured soil) and a taxadjunct to the Grainola (Soil Survey Staff, 1996) soil series (clayey textured soil) were chosen for this project. Soils were excavated (Figure 2-1) and described by three soil scientists.

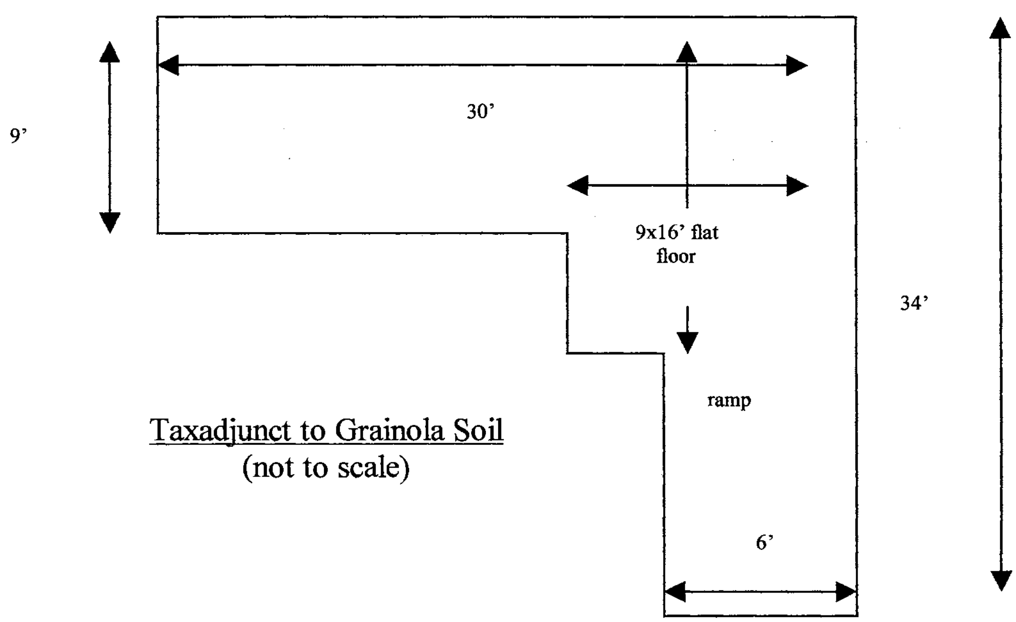
Taxadjunct soils do not meet all of the criteria of the series they represent. However, the criteria that separates soils as taxadjuncts would not change the use and management of that soil from the soil series. Through out this paper, for ease of communicating, the two taxadjunct soils used for this research are referred to as Teller or Grainola, respectively.

The taxadjunct to Teller soil used in this study classified as a Fine-loamy, mixed, active, thermic Udic Argiustoll (Soil Survey Staff, 1996). The soil excavation was located at the west end of the north half of the NW quarter of section. 34, Township (T) 18N., Range (R) 2E. at a latitude of 35°59'47.22753 and a longitude of -97°05'07.19432. This soil was a taxadjunct to the Teller series due to having mollisol order properties and containing buried horizons (Figure 2-2). These characteristics distinguish the soil from a true Teller soil which is an alfisol (not a mollisol) with a dark A horizon, and no mention of buried horizons in the range of characteristics allowed for the series (Appendix A). In the field description sheets (Figure 2-2), the taxadjunct to Teller soil had a brown hue for the top 80 cm and a red hue for the lower 60 cm. Horizons end at 26 cm (Ap), 43

Figure 2-1. Dimensions of Soil Excavations



Taxadjunct to Teller Soil
(not to scale)



Taxadjunct to Grainola Soil
(not to scale)

Figure 2-2
Field Description Sheet-Taxadjunct to Teller
June 1, 2000

Horizon*	Depth (cm)	Color Moist	Structure***	Texture	Consistence	Boundary	Special Features
Ap	0-26 [0-28]**	10YR 3/3	VF WK GR	sandy loam	loose	smooth abrupt	pH 7.5 Many fine to very fine roots
Apb	26-43 [28-48]**	10YR 2/2	WK Med. Sbk	fine sandy loam	very friable	wavy abrupt	pH 6.0 many fine to very fine roots; Few continuous lateral lamellae @ 46-47 cm
BAb	43-79 [48-84]**	7.5YR 4/4	WK Med. Sbk	loamy sand	friable	smooth gradual	pH 6.0 Many fine to very fine roots
Bt1b	79-110 [84-113]**	5YR 4/4	Mod. Med. Sbk	sandy clay loam	friable	smooth diffuse	pH 6.0 Common fine to very fine roots
Bt2b	110-147 [113-142]**	5YR 4/6	Mod. Str. Sbk	sandy clay loam	friable-firm		pH 6.0 Few fine to very fine roots

* Horizon designations follow Soil Survey Division Staff (1993) guidelines
** Due to rainfall, the soil profile was re-faced on 8/10/00 resulting in slightly different horizon depths
*** Structure: V = very, F = fine, WK = weak, GR = granular, SbK = subangular blocky, Str = strong, Med = medium, Mod = moderate

cm (Apb), 79 cm (BAb), 110 cm (Bt1b) and 147 cm (Bt2b). Boundaries were smooth/abrupt at 26 cm, wavy/abrupt at 43 cm, smooth/gradual at 79 cm, and smooth/diffuse at 110 cm. Weak granular surface structure changed to medium subangular blocky at 26 cm then to strong subangular blocky at 110 cm. The distinguishing features in this taxadjunct were a buried horizon (26-43 cm) and lamellae (Figure 2-2). These are the horizons, characteristics and features compared to the photographic prints corresponding to the Teller soil.

The taxadjunct to Grainola soil used in this study classified as a fine, smectitic, active, thermic Udic Haplustert (Figure 2-3). The soil excavation was located at the east end of the north half of the NW quarter of section 34, Township (T) 18N., Range (R) 2E at a

This soil was a taxadjunct to the Grainola series due to having soil properties that classified it as a Vertisol (not an Alfisol). The studied soil also did not have a dark A horizon, contained prominent slickensides, lacked calcium carbonate distribution enough not to have a letter "k" designation, contained a thick argillic horizon and was deep to reach paralithic contact. True soils of the Grainola series are Alfisols with a dark A horizon, commonly contain slickensides and enough of a distribution of calcium carbonate to denote a letter "k" designation, and have thinner argillic horizons and less depth to paralithic contact than the soils used in this study (Appendix B and Figure 2-3).

In the field description sheets (Figure 2-3), the taxadjunct to Grainola moist soil color changed overall from red (5YR ¾ to 34 cm), to redder (2.5YR 4/4 to 110 cm then to 10R 4/6). Horizons ended at 9 cm (Ap), 34 cm (Btss1), 73 cm (Btss2), 110 cm (Btss3), 140 cm (Btss4), and 160 cm (C). Boundaries were smooth/clear at 9, 34, and 140 cm, and smooth/gradual at 73 and 110 cm). Structure was weak subangular blocky down the soil

Figure 2-3
Field Description Sheet-Taxadjunct to Grainola
August 10, 2000

Horizon	Depth (cm)	Color	Structure	Texture	Consistence	Boundary	Special Features
Ap	0-9	5YR 4/4 d 5YR 3/4 m	wk fine Sbk	silty clay loam	sl. Hard	smooth clear	pH 6.5 Many medium roots; Few continuous and many discontinuous vertical and lateral slickensides
Btss1	9-34	2.5YR 3/4 d 5YR 3/4 m	strong v. coarse pr. parting to str. coarse Abk	clay	mod. hard	smooth clear	pH 7.0 Many fine roots; Slight effervescence Few continuous and many discontinuous vertical and lateral slickensides Continuous clay films on ped surfaces
Btss2	34-73	10R 4/6 d 2.5YR 4/4 m	strong v. coarse pr. parting to str. coarse Abk	clay	mod. hard	smooth gradual	pH 8.0 Common fine roots; Violently effervescent Few continuous and many discontinuous vertical and lateral slickensides Continuous clay films on ped surfaces
Btss3	73-110	10R 4/6 d 2.5YR 4/4 m	strong coarse and v. coarse Abk	clay	mod. hard	smooth gradual	pH 8.0 Few very fine roots; Violently effervescent Few continuous and many discontinuous vertical and lateral slickensides; Continuous clay films on ped surfaces; Few coarse and very coarse $CaCO_3$ nodules.

Figure 2-3, continued

Horizon	Depth (cm)	Color	Structure	Texture	Consistence	Boundary	Special Features
Btss4	110-140	10R 4/6 d 10R 4/6 m	strong v. coarse Abk	clay	hard	smooth clear	pH 8.0 Few very fine roots; Slight effervescence Few continuous and many discontinuous vertical and lateral slickensides; Continuous clay films on ped surfaces; Few coarse and very coarse $CaCO_3$ nodules 5GY 7/1 common medium oval and round depletions.
Cr	140-160+	10R 4/6 m	strong v. coarse Abk	clay	v. hard		pH 8.0; Few very fine roots Slight effervescence; Few coarse and very coarse $CaCO_3$ nodules 5GY 7/1 common medium oval and round depletions Permian shale soft rock material

Color: d = dry, m = moist, structure: wk = weak, sbk = subangular blocky, v = very, pr = prismatic, str = strong, Abk = angular blocky.
Consistence: sl = slightly, mod = moderately, v = very.

profile to 9 cm to strong angular blocky for the rest of the profile. Distinguishing features in this taxadjunct were slickensides from 34-140 cm, calcium carbonate nodules between 110-160 cm, clay films on ped faces from 9-140 cm, and depletions (redoximorphic features) from 110-160 cm. These are the horizons, characteristics and features compared to the photographic prints corresponding to the Grainola soil.

Preparation of Soil Excavations

Soil excavations (pits) were excavated to allow the soil profile as much direct sun exposure available at the times of day the soil was to be photographed. Figure 2-1 represents the dimensions of the two soil pits. Soil profiles were described by three soil scientists and the information recorded on field description sheets (Figures 2-2 and 2-3). The face of the soil profile was smoothed with the edge of a knife (Teller) or picked with the tip of a knife (Teller and Grainola) for uniformity and to best display soil properties and features. Sandy soils commonly display little or no soil structure, so the soil profile face is often smoothed flat with the edge of a knife. Other soils that have soil structure are commonly picked with the tip of a knife in an effort to reveal the natural structure by removing the scraped or damaged soil profile face surface.

An 18% gray card with centimeter increments was placed on the left side of the soil profile to appear along the edge of the photograph. A tarp was placed over the face of the soil profiles during interims between photographic sessions to protect the soil and conserve soil moisture until all work (observations, descriptions, and photography) was completed and the final products (negatives, contact sheets, and prints) produced. A number and letter card combination was placed to appear in the lower left hand side of the profile to distinguish photographs.

Melville and Atkinson (1985) noted that since soil moisture affects soil color, there is a need to standardize and specify the moisture content of a soil. Although soil moisture content samples were obtained for each day photography work was done, the moisture referred to with regards to the photographs in this study was water sprayed on the soil profile surface. Soil moisture content samples were obtained from an area down the length of and off to the left of each soil profile out of the viewing range of the camera. Soil samples were taken before and after, or just before or after each photographic session at vertical 25 cm intervals to obtain soil moisture content. Soils samples were taken at 25 cm intervals to correspond with soil depth classes of shallow (<25 cm), moderately shallow (25-50 cm), moderately deep (50-100 cm), deep (100-150 cm), very deep (>150 cm). Soil samples were placed in tins and transported back to the laboratory in a cooler where they were then weighed, dried in 105 degree Fahrenheit oven for a minimum of 72 hours before being weighed again to calculate soil moisture content. Soil moisture content samples were taken for each photographic session and were taken from a soil thickness of 2.5 cm. See Figure 2-4 for soil moisture content percentages.

Equipment

A Graflex Crown Graphic large format camera equipped with a 150 mm Steinheil München Unofokal 1:4.5 Compur lens was used, along with a Gossen Luna Pro light meter and Bogen tripod (Model 3021). The lens had F-stops of (1/) 4.5, 5.6, 8, 11, 16,

Figure 2-4. Soil Moisture Content

Soil Moisture Content
Gravimetric Water Content (%) With Soil Depth

Teller Soil

Date	Time	Depth (cm) 25	50	75	100	125	150
6/4/00	1:56 pm	13	12	12	15	13	12
6/6/00	11:00 am	13	11	12	15	13	11
6/7/00	12:30 pm	11	11	11	14	9	9
6/7/00	2:30 pm	11	12	11	14	12	8
6/8/00	12:30 pm	9	8	11	7	6	9
6/8/00	2:35 pm	7	6	11	5	5	6
7/6/00	12:45 pm	11	12	13	14	13	8
7/6/00	3:00 pm	10	9	11	6	5	5
8/2/00	12:05 pm	11	3	2	3	6	11
8/2/00	3:10 pm	10	1	2	3	5	9
8/17/00	7:00 pm	<1	<1	<1	1	2	1

Grainola Soil

Date	Time	Depth (cm) 25	50	75	100	125	150
7/15/00	12:05 pm	9	9	8	8	9	8
7/16/00	10:34 am	7	7	6	7	8	7
7/16/00	3:00 pm	7	6	5	6	5	5
7/26/00	11:45 am	8	8	5	6	7	7
7/26/00	2:30 pm	8	5	4	5	7	19
7/30/00	11:00 am	8	6	6	7	10	15
7/30/00	3:30 pm	7	5	4	5	5	11
7/31/00	3:00 pm	7	6	4	4	4	8
8/1/00	12:30 pm	7	5	5	5	5	13
8/17/00	7:20 pm	3	2	2	3	2	2

22, 32, and 44 and shutter speeds of (1/) 1, 2, 5, 10, 25, 50, 100, and 200. For night photography, two tungsten 3400K photoflood lamps were the illuminants, with one light positioned as a key light and one as a fill light. Filters, when used, were attached to the camera lens.

Photography

Soil Profile Photo Sheets 1 and 2 (Figures 2-5 and 2-6) were filled out for each photographic session.

Kodak Pro 100, Kodak Portra 160NC, and Kodak Vericolor (Eastman Kodak Co.) from three angles including 30, 60 and 90 degrees from the soil profile face (horizontally) with the lens centered vertically on the area to be captured. White pins appear were used in some photographs as a check to the photographer as to what area of soil was being captured. White pins were to be removed prior to taking pictures, however, some photographs were taken with pins included accidentally. Resultant prints were compared to the soil properties and features of the field description sheets to evaluate the presence, loss of, or distortion of visual soil properties and features. All photographs were taken on bright sunny days under a blue sky. The two soil profiles (Teller and Grainola) were photographed at five times (11:30 am, 12:30, 1:00-1:30 pm, 2:00-2:30 pm, and 3:30 pm) of day. The best time (the time resulting in the least shadows cast on the soil profile and the time which fully illuminated the soil profile) of day was chosen at the photographic session and used as the time of day for all other photographic work. For the Teller soil, this time was 1:00-1:30 pm. For the Grainola soil this time was 1:30-2:00 pm since much of the photography of the Grainola soil was done weeks to months later than the

Figure 2-5. Soil Profile Photo Sheet 1

Date__________________Day_________________Soil Series____

Camera Used_______________________________________Lens____

Photo #	Time	Film Type and Speed	Light Location	Lens Distance From Profile	Center of Lens Distance to Ground	F-Stop	Shutter Speed	Light Meter Reading	Filter	Adjustment Due to Filter

Profile Prepped____

Depth of Soil Samples, if Taken____

Soil Moisture Content of Soil Samples____

Comments____

Figure 2-6. Soil Profile Photo Sheet 2

Date__________________Day_________________Soil Series_____________
City/State of soil profile_________________Township/Range_____________Latitude/Longitude_______________
Dimensions of soil pit______________________

Type of light____________________Filters Used?_________Where? Camera lens/Bulb/Attached to Lighting
Angle between key light and camera__________How far away from camera lens?_______________
Color temperature of light____________Bulb wattage_______________ASCI code of the bulb________
Distance between center of key light and ground__________________
Angle between fill light and camera__________How far away from camera lens?_______________
Color temperature of light____________Bulb wattage_______________ASCI code of the bulb________
Distance between center of fill light and ground___________________
Angle between camera and soil profile________
Additional equipment used?____
For what purpose?____

Additional comments____

The above set-up applies to photo numbers____ photography of the Teller soil. As the summer proceeded, the best time changed to later in the day. Photographs were also taken at night after 10 pm using artificial lighting (tungsten photoflood (500 watt) lamps with a 3400K color temperature). Two lights, one positioned directly in back of the photographer and camera as a key light (replacing the direct illumination of the sun) and the other positioned at a forty-five degree angle from soil profile to camera lens as a fill light (replacing indirect light of the surroundings) were used. Filters were used to match the color temperature of the film to the lighting. Three different filters were used including Tiffen Photar 80B (Tiffen, 1999), Meade 80B (Meade, 2000), and a Tiffen Decamired (Tiffen, 2000) set of three filters (to be used together as a set) including B3, B6, and B1½ (with a cumulative Decamired value of 29 as the three films used in this study had Decamired values between 29-30). F-stops were bracketed and increased to compensate for filter use. Photographs taken at the five times of day as well as the night photographs were compared to the field description sheets to determine if soil features, color and properties displayed in the photographs adaquately reflected those of the written descriptions. Many photographs included 22 x 28 cm Munsell color chip, the closest visual match to a particular horizon of the soil profile.

All photographs not utilizing colored filters were color matched to the 18% gray card standard appearing as a measuring tape in most photographs.

Processing Film and Producing Prints

Film was purchased from Epperson Photo of Oklahoma City. Color Chrome in Norman, Oklahoma processed all film and produced all negatives, contact sheets, and prints. Color Chrome used the Internegative (vs Reversal) process termed C-41. The

Internegative process involves taking a slide and creating a print, whereas the Reversal process involves taking a slide and using reverse chemical paper.

Comparisons

Photographic prints of the soils for each factor or condition studied were compared to the written distinguishing key features and horizons obtained from field description sheets (recorded at the time the soils were excavated) used to describe the taxadjunct soils. Prints were visually evaluated to determine if each soil's distinguishing features and characteristics were visible in the photographs. The Munsell color sheet appearing in the prints was matched to the actual 22 x 28 cm Munsell color sheet represented in the print to determine if they visually matched. The Munsell color sheet appearing in the prints was then matched to soil color chips in Munsell Soil Color Charts to obtain the closest visual color match. The purpose of the visual evaluations of the key features and the Munsell color sheet was to determine differences between what was observed under field conditions and the image photographed to identify differences attributed to the factors studied.

Results

Pertaining to All Prints

Over three hundred photographs were taken for this project. A list containing only those negatives made into prints that appear within this document are listed in Figure 2-7. This document contains photocopies of the original prints. Appendix C lists all the prints produced from negatives. All negatives, contact sheets, and prints reside with Dr. Brian

Figure 2-7. Selected Photographs of the Prints Discussed Within This Paper
(A Subset of Appendix C)

Factor	Print	Figure	Factor	Print	Figure
Film	Fi8/2P1-Fi6	2-9	Film	Fi7/26P2-Fi4	2-12
Taxadjunct to Teller	Fi8/2P1-Fi1	2-10	Taxadjunct to Grainola	Fi7/26P2-Fi5a	2-13
8/2/00, surface smoothed	Fi8/2P1-Fi3	2-11	7/26/00	Fi7/26P2-Fi7	2-14
Distance	D8/2P1-D4	2-15	Distance/Area	D7/31P2-D2	2-18
Taxadjunct to Teller	D8/2P1-D10	2-16	Taxadjunct to Grainola	D7/31P2-D5	2-19
8/2/00, surface smoothed	D8/2P1-D16	2-17	7/31/00	D7/31P2-D8	2-20
Moisture	M8/4P1-M2	2-21	Moisture	M8/1P2-M4	2-24
Taxadjunct to Teller	M8/4P1-M3	2-22	Taxadjunct to Grainola	M8/1P2-M5	2-25
8/4/00, surface smoothed	M8/4P1-M5	2-23	8/1/00	M8/1P2-M7	2-26
Aperture/Shutter Speed	F7/8P1-F15a	2-27	Aperture/Shutter Speed	F7/26P2-F17	2-31
Taxadjunct to Teller	F7/8P1-F18	2-28	Taxadjunct to Grainola	F7/26P2-F16	2-32
7/8/00, surface smoothed	F7/8P1-F17	2-29	7/26/00	F7/26P2-F13	2-33
	F7/8P1-F16	2-30		F7/26P2-F15	2-34
				F7/26P2-F14a	2-35
				F7/26P2-F19	2-36
Filters	F7/6P1-1F17	2-37	Filters	F7/26P2-F11	2-42
Taxadjunct to Teller	F7/6P1-1F14	2-38	Taxadjunct to Grainola	F7/26P2-F4	2-43
7/6/00, surface smoothed	F7/6P1-1F10a	2-39	7/26/00	F7/26P2-F1	2-44
	F7/6P1-F10b	2-40		F7/26P2-F9	2-45
	F7/6P1-1F11	2-41		F7/26P2-F6	2-46
Angles	A8/4P1-A2	2-47	Angles	A8/1P2-A2	2-50
Taxadjunct to Teller	A8/4P1-A3	2-48	Taxadjunct to Grainola	A8/1P2-A3	2-51
8/4/00, surface smoothed	A8/4P1-A6	2-49	8/1/00	A8/1P2-A5	2-52
Time of Day	T6/6P1-T1d	2-53	Time of Day	T7/30P2-T2	2-58
Taxadjunct to Teller	T6/6P1-T2b	2-54	Taxadjunct to Grainola	T7/30P2-T7	2-59
6/6/00, surface picked	T6/6P1-H1a	2-55	7/30/00	T7/30P2-T10	2-60
	T6/6P1-T3b	2-56		T7/30P2-T14	2-61
	T6/6P1-T4a1	2-57	(cloudy conditions)	T7/30P2-T6	2-62
			(cloudy conditions)	T7/30P2-T8	2-63
Color Matched	C8/4P1-C4a	2-70	Color Matched	C8/4P2-C2a	2-72
Taxadjunct to Teller	C8/4P1-C3b	2-71	Taxadjunct to Grainola	C8/4P2-C2b	2-73
8/4/00, surface smoothed			8/4/00		
Night Photography	N8/17P1-N1h	2-64	Night Photography	N8/17P2-N2d	2-67
Taxadjunct to Teller	N8/17P1-N1e	2-65	Taxadjunct to Grainola	N8/17P2-N2e	2-68
8/17/00, surface smoothed	N8/17P1-N1b	2-66	8/17/00	N8/17P2-N2f	2-69

* The string of letters is specific to the print and the corresponding negative. The first letter or letters denotes the factor studied, next is the date, then the soil (Teller is P1 and Grainola is P2), then the code to the negative. For example, Fi8/2P1-Fi6 is film, photographed on 8/2/00, for the Teller soil (P1) where the corresponding negative is Fi6. Abbreviations are: Fi=film, D=distance, M=moisture, F=aperture/shutter speed or filters, A=angles, T=time of day, C=color matched, N=night photography.

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Due to unstable lighting conditions which photographing under natural daylight presents, light meter readings were set to the film speed of the film being used and taken prior to shooting each photograph.

Visual Matching of Standards

Figure 2-8 lists the prints by code number, whether or not the color of the Munsell in the print matched the actual 22 x 28 cm Munsell; if the two did not match, which chip in the Munsell Soil Color Charts most closely matched the Munsell in the print.

All prints containing an 18% reflectance gray card as a measuring tape were matched by the film processing and print making laboratory to an actual 18% reflectance gray card both visually and using a densitometer. The exceptions were those photographs in which filters were used.

Film

Figures 2-9 to 2-11 represent the Teller soil for the comparison of films. In the field soil description sheet (Figure 2-2) for Teller, the hue of the Teller soil under field conditions changed from brown for the top 80 cm to a red for the lower 60 cm of the soil profile, characteristics which are most obvious in the Pro 100 and Vericolor films and not so obvious in the Portra 160 NC film. For the Teller soil, the difference between the three films in prints is in the overall cast of color on the soil. Where Pro 100 film

Figure 2-8

Munsell in Prints Visually Matched to the 22 x 28 cm Munsell Color Sheet and to the Munsell Soil Color Charts

Print*	Figure	Visual Match With Munsell Color Sheet 7.5YR 4/4	Visual Match With Munsell Color Sheet 10R 4/6	Closest Visual Match to Munsell Soil Color Charts
Fi8/2P1-Fi6	2-9	no	-	7.5YR 6/4
Fi8/2P1-Fi1	2-10	no	-	10YR 6/4
Fi8/2P1-Fi3	2-11	no	-	7.5YR 6/4
Fi7/26P2-Fi4	2-12	-	no	10R 5/6
Fi7/26P2-Fi5	2-13	-	no	5R 4/8
Fi7/26P2-Fi7	2-14	-	no	2.5YR 4/6
D8/2P1-D4	2-15	yes	-	-
D8/2P1-D10	2-16	yes	-	-
D8/2P1-D16	2-17	no	-	5YR 5/4
D7/31P2-D2	2-18	-	no	10R 5/8
D7/31P2-D5	2-19	-	no	10R 6/6
D7/31P2-D8	2-20	-	no	10R 6/6
M8/4P1-M2	2-21	no	-	5YR 6/4
M8/4P1-M3	2-22	no	-	5YR 6/4
M8/4P1-M5	2-23	no	-	5 or 7.5YR 5/4
M8/1P2-M4	2-24	-	no	7.5R5/8
M8/1P2-M5	2-25	-	no	7.5R 5/8
M8/1P2-M7	2-26	-	no	7.5R 5/6
F7/26P2-F17	2-31	-	no	7.5R 6/6
F7/26P2-F16	2-32	-	no	10R 5/6
F7/26P2-F13	2-33	-	no	7.5R 5/6
F7/26P2-F15	2-34	-	no	7.5R 5/6
F7/26P2-F14a	2-35	-	no	7.5R 5/8
F7/26P2-F19	2-36	-	yes	10R 4/6
A8/4P1-A2	2-47	no	-	7.5YR 6/4
A8/4P1-A3	2-48	no	-	7.5YR 6/4
A8/4P1-A6	2-49	no	-	7.5YR 6/4
A8/1P2-A2	2-50	-	no	5R 5/6
A8/1P2-A3	2-51	-	no	7.5R 5/6
A8/1P2-A5	2-52	-	no	10R 6/8
T6/6P1-T1d	2-53	no	-	2.5YR 5/6
T6/6P1-T2b	2-54	no	-	5YR 5/4
T6/6P1-H1a	2-55	no	-	7.5YR 6/6
T6/6P1-T3b	2-56	no	-	7.5YR 5/4
T6/6P1-T4a-1	2-57	no	-	7.5YR 6/6
T7/30P2-T2	2-58	-	no	10R7/8 or 6/8
T7/30P2-T7	2-59	-	no	7.5R 5/8
T7/30P2-T10	2-60	-	no	10R 5/8
T7/30P2-T14	2-61	-	no	7.5R 5/8

Figure 2-8, continued

Print	Figure	Visual Match With Munsell Color Sheet 7.5YR 4/4	Visual Match With Munsell Color Sheet 10R 4/6	Closest Visual Match to Munsell Soil Color Charts
T7/30P2-T6	2-62	-	no	7.5R 4/6
T7/30P2-T8	2-63	-	no	10R 4/8
N8/17P1-N1h	2-64	no	-	5YR 6/4
N8/17P1-N1e	2-65	no	-	7.5YR 6/4
N8/17P1-N1b	2-66	no	-	10YR 7/3
N8/17P2-N2d	2-67	-	no	5R 5/6
N8/17P2-N2e	2-68	-	no	5R 4/8
N8/17P2-N2f	2-69	-	no	5R 5/4
C8/4P1-C4a	2-70	no	-	10YR 7/3
C8/4P1-C3b	2-71	no	-	7.5YR 6/4
C8/4P2-C2a	2-72	-	no	10R 7/4
C8/4P2-C2b	2-73	-	no	10R 6/6

* The string of letters is specific to the print and the corresponding negative. The first letter or letters denotes the factor studied, next is the date, then the soil (Teller is P1 and Grainola is P2), then the code to the negative. For example, Fi8/2P1-Fi6 is film, photographed on 8/2/00, for the Teller soil (P1) where the corresponding negative is Fi6. Abbreviations are: Fi=film, D=distance, M=moisture, F=aperture/shutter speed or filters, A=angles, T=time of day, C=color matched, N=night photography.

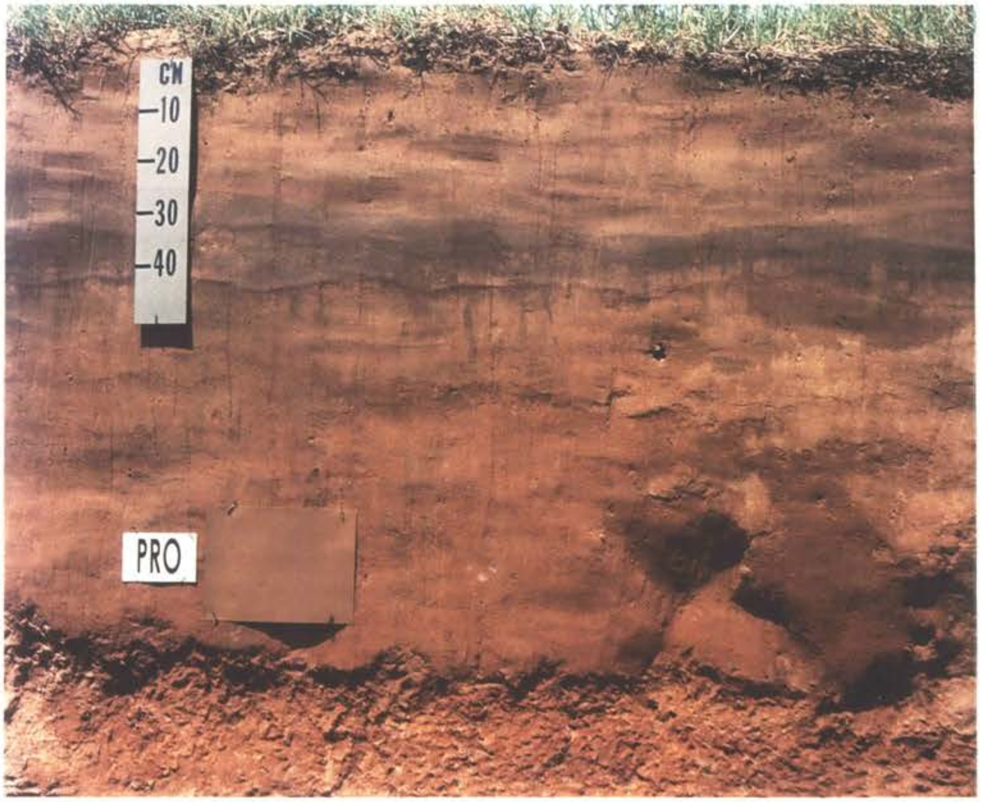

Fig. 2-9. Teller soil using Pro 100 film.

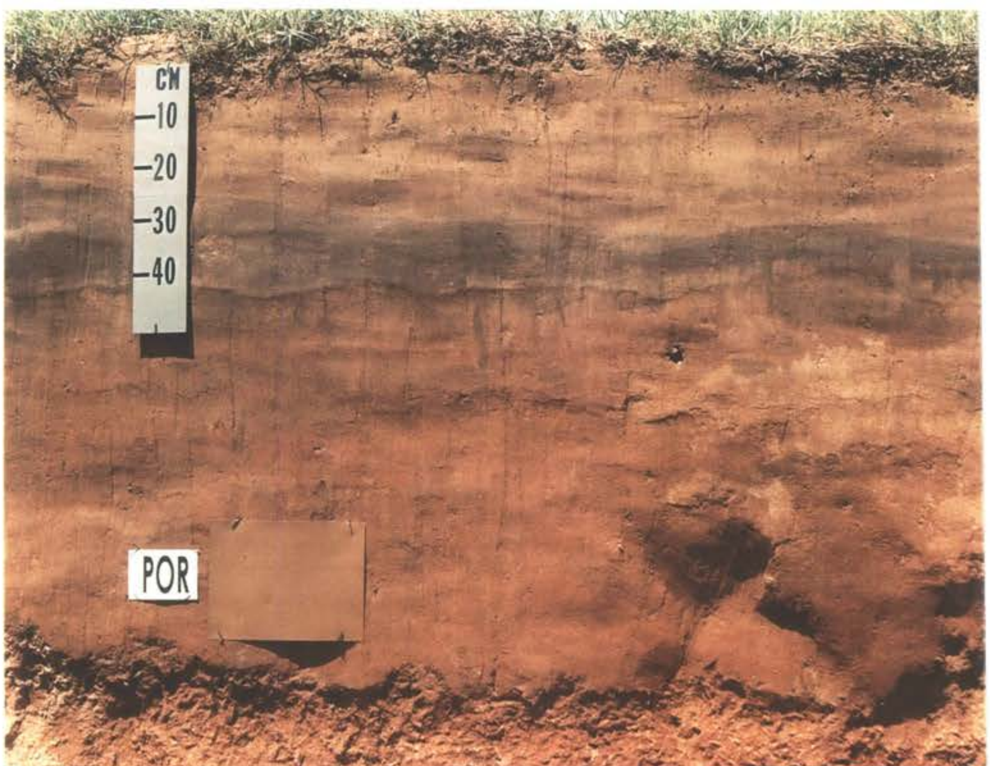

Fig. 2-10. Teller soil using Portra 160 NC film.

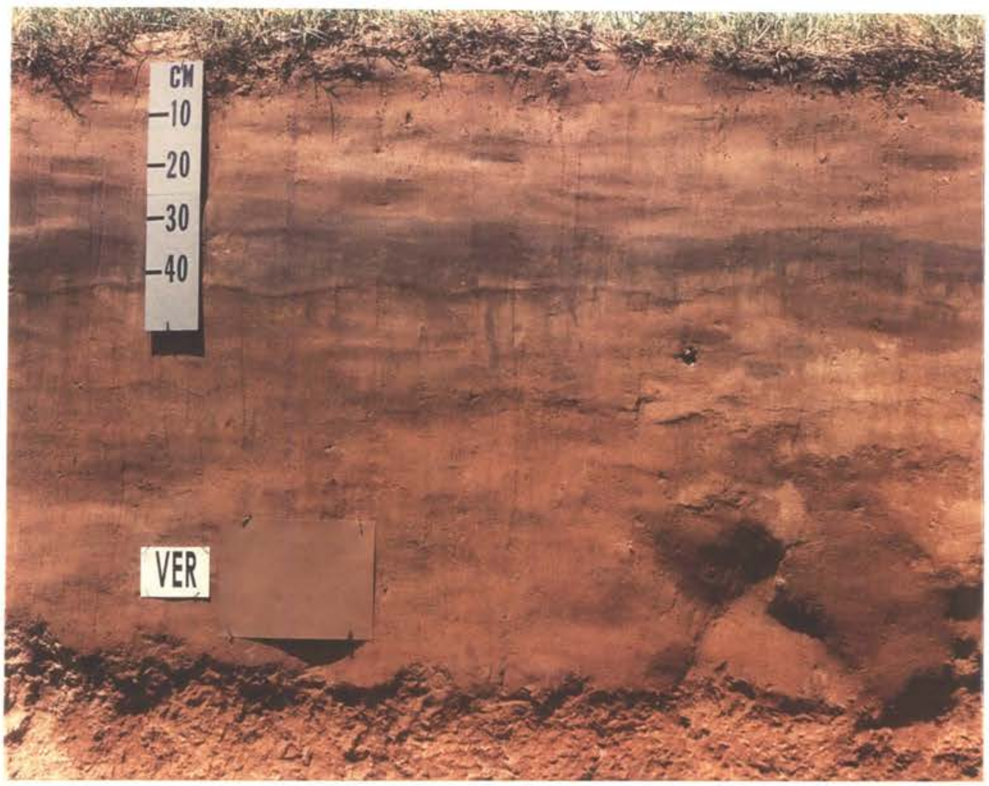

Fig. 2-11. Teller soil using Vericolor film.

(Fi8/2P1-Fi6) (Figure 2-9) cast an overall hue of brown to the soil, Portra 160NC film (Fi8/2P1-Fi1) (Figure 2-10) cast a hue of yellow to orange-brown. Vericolor (Fi8/2P1-Fi3) (Figure 2-11) cast a yellow hue to the bottom of the soil profile where the soil is actually redder, and a purplish hue to the brown and tan colors of the surface soil. Light meter readings prior to taking the photographs using Vericolor film indicated a need to change camera settings to compensate for changing lighting conditions. The Munsell chip in these three photos is below the soil it represents (43-79 cm). A camera aperture (F-stop) setting of 1/16+ and a shutter speed of 1/100 was used to obtain Figures 2-9 and 2-10 and F1/22.5 at a shutter speed of 1/100 was used to obtain Figure 2-11. Horizon boundaries are just as recognizable in all three prints. Although a granular surface is not obvious in any of the three prints, the strong subangular blocky structure in the lowest part of the profile is most prominent with the brown cast of the Pro 100 film (Figure 2-9). The lamellae and buried horizon are more apparent in the Pro 100 print. The buried soil in the Pro 100 print is noticeably darker in color than the Portra 160 NC print, whereas in the Vericolor print, the buried horizon is purplish in hue. The green grass is equally as bright in the Pro 100 and Portra 160 NC prints, but appears duller in the Vericolor print. Portra 160 NC film (Figure 2-10) displayed the most accurate representation of the soil as to what was observed at the time of the photographic session.

The Munsell color sheet used in Figures 2-9 to 2-11 prints was 7.5YR 4/4. When the Munsell color sheet in the photograph was visually matched to the Munsell Soil Color Charts, the Munsell appearing in the Pro 100 and Vericolor prints visually matched in hue and chroma (compared to the actual Munsell color chip of 7.5YR 4/4), but not in value (Figure 2-8). Portra 160 NC film matched only in chroma. Although the Munsell color sheet appearing in the Pro 100 film and Vericolor films were closest to 7.5YR 4/4 in Munsell notation, Portra 160 NC film best represented the soil features and characteristics of the Teller soil as seen under field conditions.

Figures 2-12 to 2-14 represent the Grainola soil for the comparison of films. In the field soil description sheets (Figure 2-3), the hue of the Grainola soil under field conditions went from red to redder with soil depth. The three prints (Grainola) of Fi7/26P2-Fi4 (Figure 2-12), Fi7/26P2-Fi5 (Figure 2-13), and Fi7/26P2Fi7 (Figure 2-14) represent Pro 100, Portra 160 NC, and Vericolor films, respectively (see Figures 2-12 to 2-14) and were photographed using an aperture (F-stop) of 1/ 22-32 with a shutter speed of 1/100.

The differences between prints utilizing the different films were with regards to overall soil hue. For the Grainola soil, the main difference between the three films in this very red soil is that use of Pro 100 film resulted in a gold-brown soil color, Portra 160 NC resulted in a red-brown soil color, and Vericolor resulted in a dark brown soil color. Paralithic (soft rock) contact can be seen at the very bottom of the soil profile is seen in all photographs. Reddening with depth is seen in the Portra 160 NC film, whereas Vericolor print shifts to lighter brown, and soil in the Pro 100 print appears lighter in color with depth. Although there were color differences at 34 and 110 cm, horizons of the Grainola soil based on color are very difficult to see in these prints. The surface horizon ending at 9 cm is most noticeable, due primarily to change in soil structure. Structure changes are noticeable in the lower most horizon (Figure 2-3) appearing in the prints. Slickensides, and clay films on ped faces are not obvious at the distance Figures 2-12 to 2-14 were photographed. The uneven rough surface of the soil profile as well as

Fig. 2-12. Grainola soil using Pro 100 film.

Fig. 2-13. Grainola soil using Portra 160 NC film.

Fig. 2-14. Grainola soil using Vericolor film.

being the same color as the soil obscures the ability to see the calcium carbonate nodules. The redoximorphic depletions from the 110-160 cm layer are obvious and pale blue (field color of 5GY 7/1) in color. The redness of the Portra 160 NC print contrasts the lightness of these redoximorphic depletion areas.

The Munsell color sheet appearing in Figures 2-12 to 2-14 is 10R 4/6. The Munsell color sheet appearing in the Pro 100 film print visually matched the actual Munsell color sheet in hue and chroma, but not value. The matching of hue and chroma but not value was also seen in the Teller print for Pro 100 film (Figure 2-9). The Portra 160 NC print matched the actual Munsell color sheet in value, but not in hue or chroma. The Vericolor print matched the actual Munsell color sheet in value and chroma, but not in hue (Figure 2-8).

<u>Distance From Camera Lens to Soil Profile</u>

Figures 2-15 to 2-17 represent the Teller soil for the comparison of distances from camera lens to soil profile using Portra 160 NC film with camera settings at an F-stop of 1/32 and a shutter speed of 1/100. Print D8/2P1-D4 (Figure 2-15) of the Teller soil was taken at 95 cm from the soil profile. Close proximity between the camera lens and soil profile results in clear visibility of the two key features of this soil, the lamellae and the buried horizon. Individual sand particles can be seen as well as numerous roots. At this close distance, the soil appears darker due to less light reaching the film. The lamellae slightly protruding away from the rest of the soil can be seen. With the camera lens at 200 cm from the soil profile (D8/2P1-D10) (Figure 2-16), the lateral continuance of the buried horizon and lamellae are expanded and structure change between horizons in the

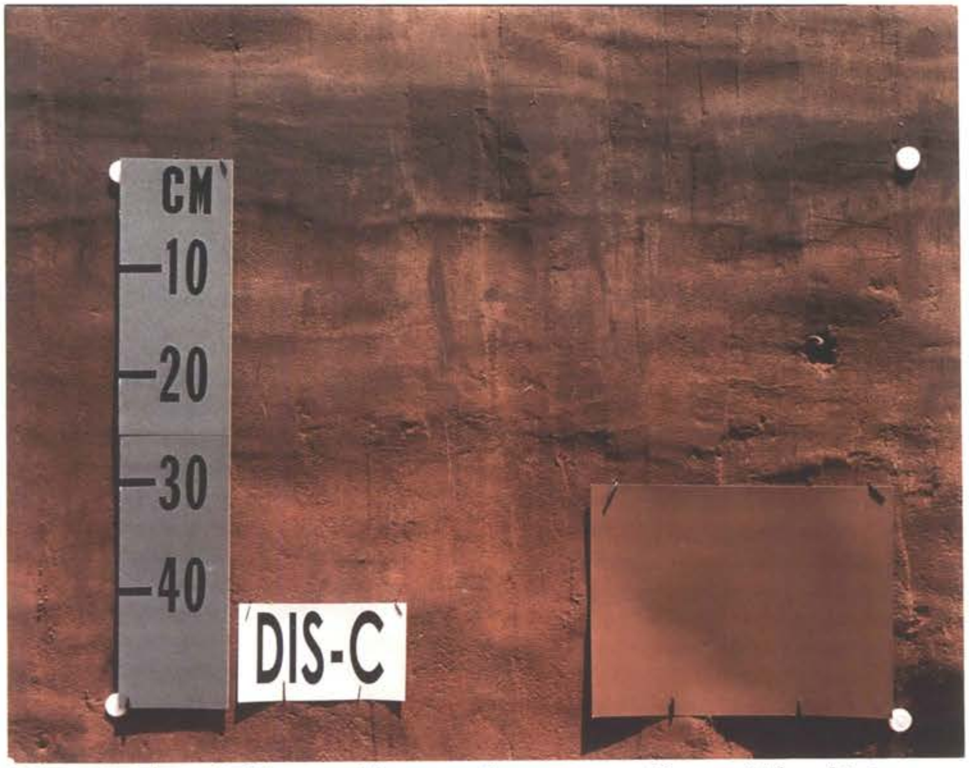

Fig. 2-15. Teller soil at a lens to soil profile distance of 95 cm.

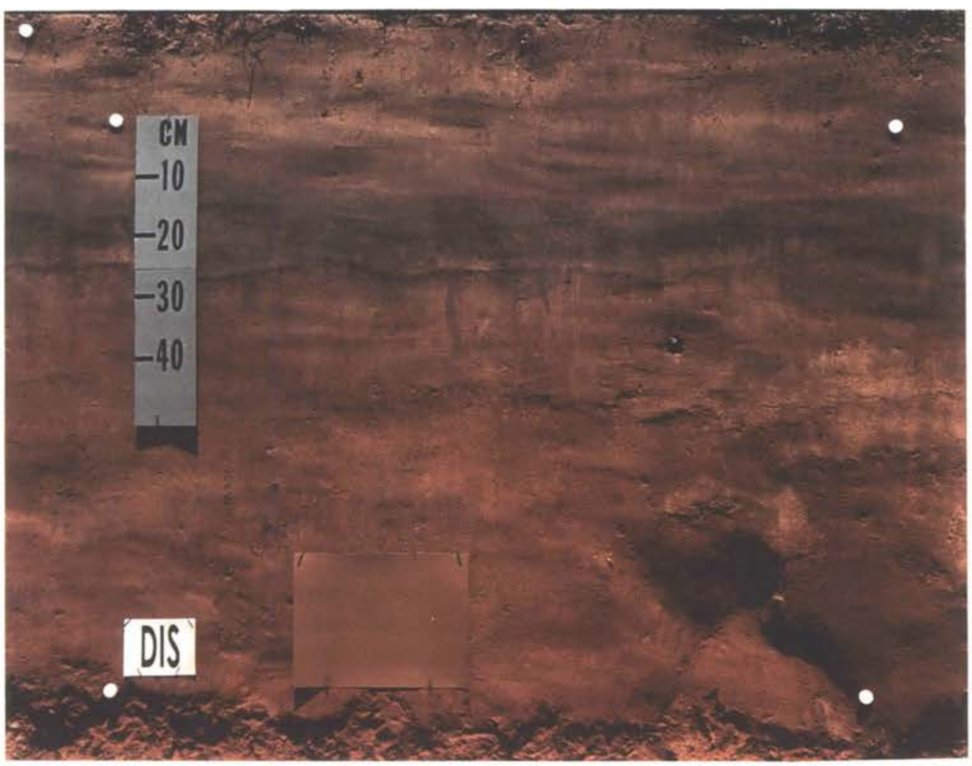

Fig. 2-16. Teller soil at a lens to soil profile distance of 200 cm.

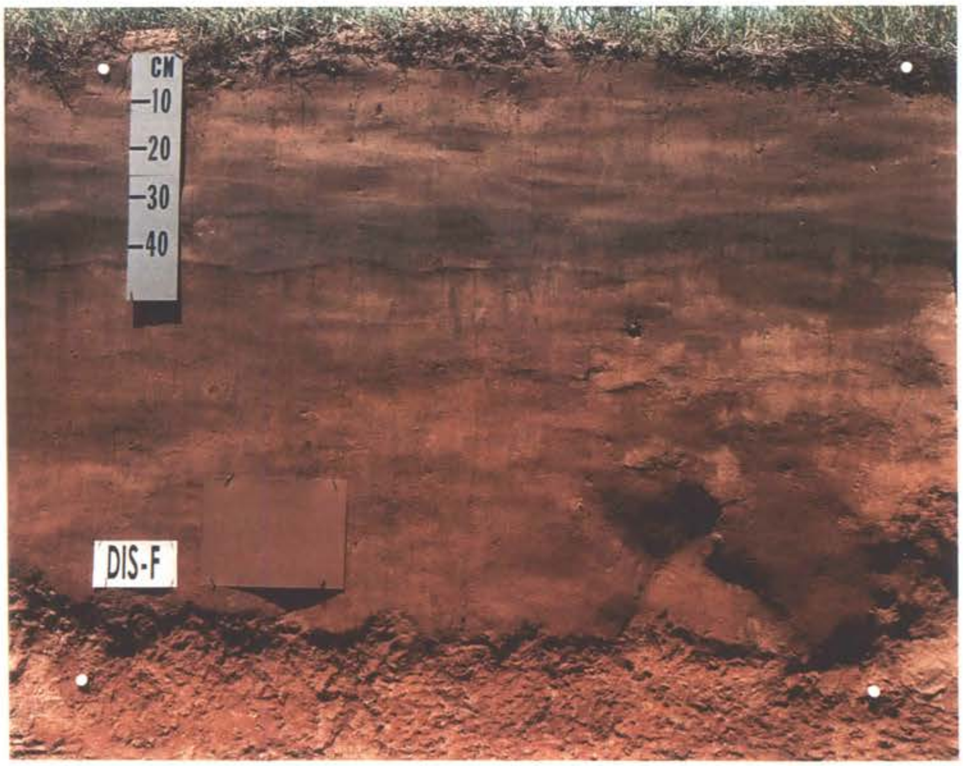

Fig. 2-17. Teller soil at a lens to soil profile distance of 240 cm.

lower profile can be seen. Some roots are visible. At 240 cm from lens to soil profile (D8/2P1-D16)(Figure 2-17), the structure change in the lower part of the soil profile is apparent. Due to more light and reflectance reaching the film, the soil appears lighter in color than the former two prints. The increased area of the soil in the print gives an indication of the soil's depth, an important characteristic which may not be seen at shorter distances from lens to soil profile. All three prints express the overall hue changing from brown to red with increasing depth.

The Munsell color sheet photographed in these three prints is 7.5YR 4/4. Photographs taken at 95 (Figure 2-15) and 200 cm (Figure 2-16) from lens to soil profile visually matched the actual Munsell (Figure 2-8) as well as the 7.5YR 4/4 Munsell color chip in Munsell Soil Color Charts. The Munsell in the print taken at a 240 cm (Figure 2-17) distance matched the actual Munsell only in chroma. Shorter distance between the lens and subject allowed less interference and reflection from the surroundings, which contributed to better matching.

Figures 2-18 to 2-20 represent the Grainola soil for the comparison of distance from camera lens to soil profile using Portra 160 NC film with an F-stop of 1/ 22.6 and a shutter speed of 1/100. For the Grainola soil, print D7/31P2-D2 (Figure 2-18) was taken at 98 cm from lens to soil profile. The clay nature of the soil and large vertic cracks are most noticeable at this close distance. Print D7/31P2-D5 (Figure 2-19) was taken at 192 cm from lens to soil profile, displays more of the change in soil structure with depth, and emphasizes numerous cracks in the soil. Depletions (redoximorphic features) pale blue in observed field color (Munsell 5GY 7/1) can be seen in the lower-most part of the soil profile. Print D7/31P2-D8 (Figure 2-20) taken at 241 cm from the soil profile (at an F-

Fig. 2-18. Grainola soil at a lens to soil profile distance of 98 cm.

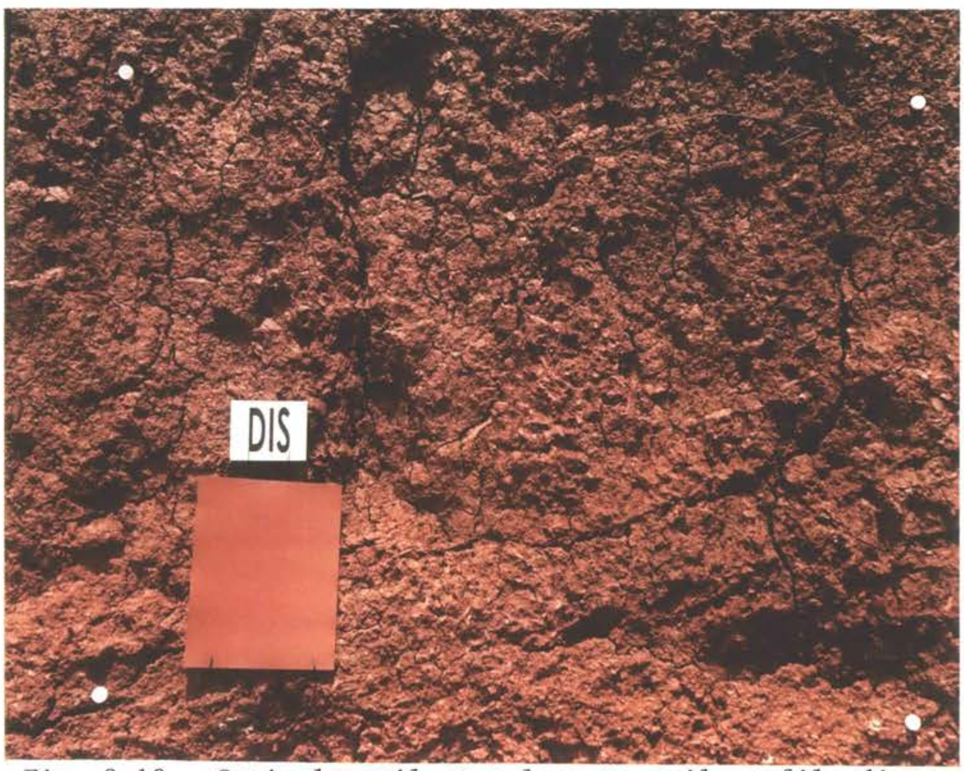

Fig. 2-19. Grainola soil at a lens to soil profile distance of 192 cm.

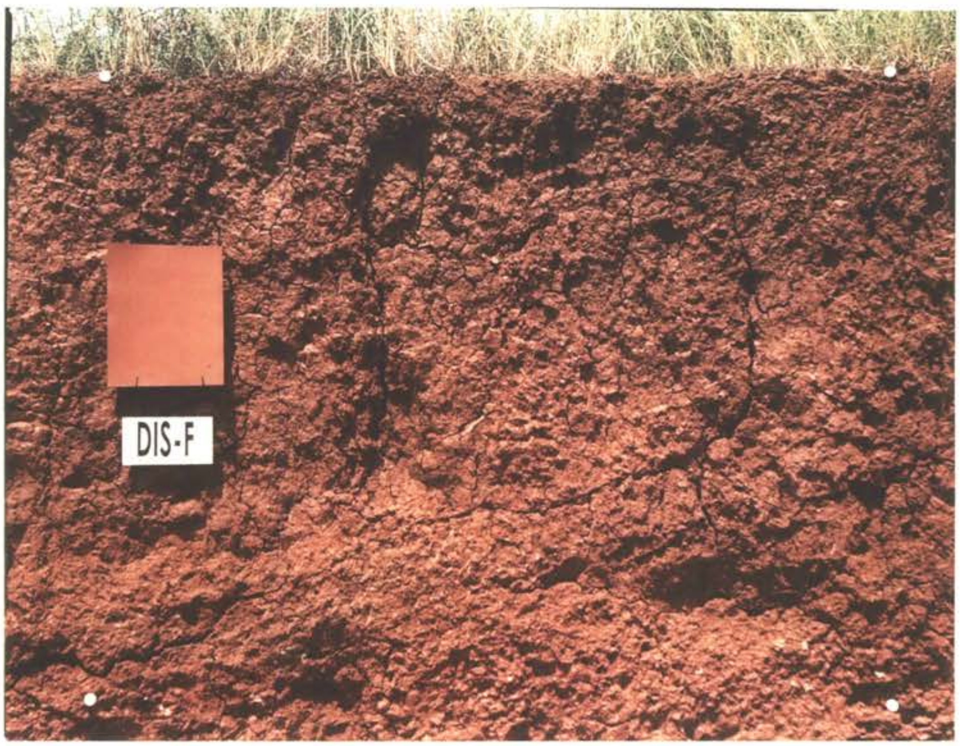

Fig. 2-20. Grainola soil at a lens to soil profile distance of 241 cm.

stop of 1/22.6 and a shutter speed of 1/100) displays some horizonation and changes in structure including the paralithic (soft rock) contact in the lower-most part of the soil profile. Overall hue becoming redder with depth is noticeable in all three prints.

The Munsell appearing in the three prints is 10R 4/6. For visual matching, Figures 2-19 and 2-20 matched the Munsell in hue and chroma, but not in value and most closely matched the Munsell color sheet notation of 10R 4/6 (Figure 2-8).

Soil Profile Surface Moisture

Figures 2-21 to 2-23 represent the Teller soil for the comparisons of soil profile surface moisture using Portra 160NC film. For the Teller soil, M8/4P1-M2 (print coded M-1) (Figure 2-21), M8/4P1-M3 (print coded M-2) (Figure 2-22), and M8/4P1-M5 (print coded M-3) (Figure 2-23) reveal apparent changes in soil color. The overall soil color darkens with increase in water. Camera settings used to obtain these prints included an F-stop of 1/22 and a shutter speed of 1/100. The M-1 code indicates no water sprayed on the soil profile. M-2 indicates 300 ml of water sprayed on the soil profile, and M-3 indicates an additional 400 ml of water sprayed on the soil profile face. The surface horizon appears to change from a pale tan color to a medium brown color with increased moisture. The lamellae is most noticeable in the print in which an additional 400 ml of water had been sprayed on the soil profile. The buried horizon becomes more prominent with increase in water sprayed. The overall hue changing with depth from brown to red is most evident in M-3 (Figure 2-23). The overall darkening of the soil contributes to a more prominent expression of the buried horizon and lamellae.

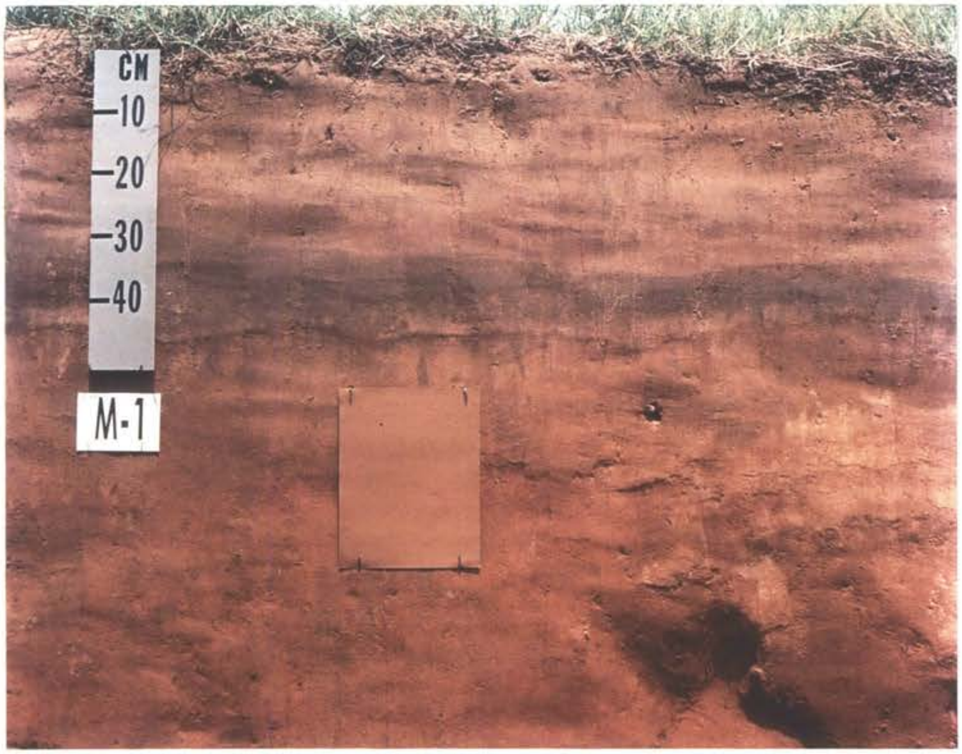

Fig. 2-21. Teller soil with no water sprayed on the soil profile.

Fig. 2-22. Teller soil profile sprayed with 300 ml of water.

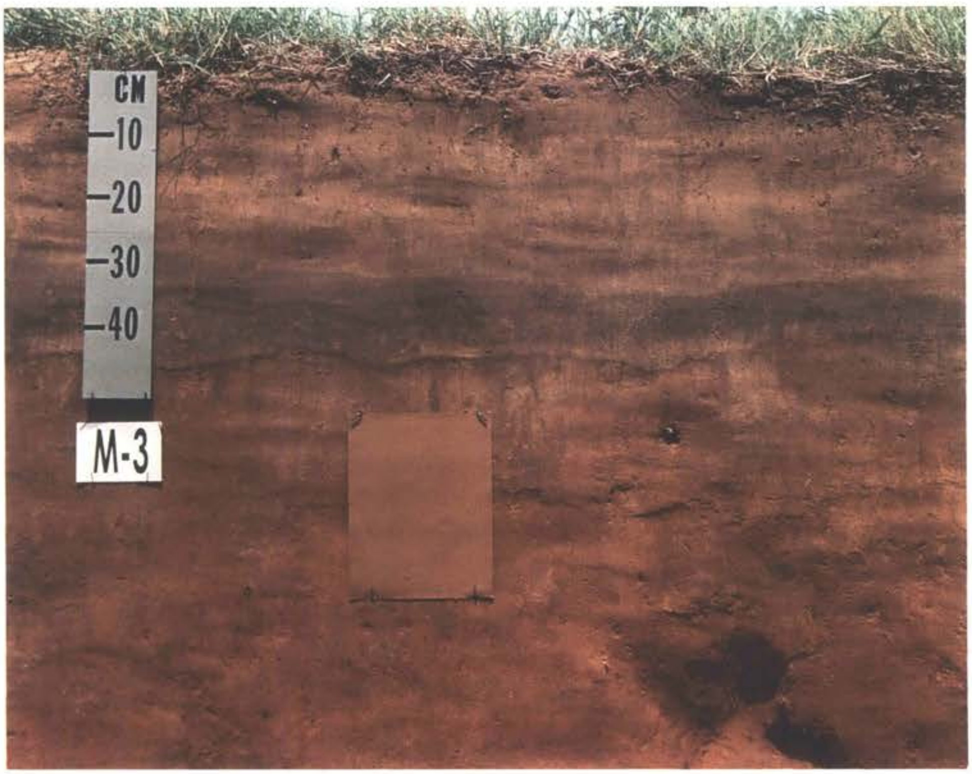

Fig. 2-23. Teller soil profile sprayed with 700 ml of water.

For visual matching, Figures 2-21 and 2-22 (prints coded M-1 and M-2) matched the actual Munsell (7.5 YR 4/4) in chroma only (Figure 2-8). Figure 2-23 (print coded M-3) matched the Munsell color chip in hue and chroma. These photographs were taken at the beginning of August when the soil was dry. Spraying the surface of the soil profile with water may have helped reduce reflections and interference on the Munsell color chip and into the camera lens, allowing for a more accurate color rendition.

The Munsell in Figure 2-23 is darker in color than the preceeding two prints. Lighting conditions may have changed after the light meter readings were taken and before taking the photograph which could account for some of the color differences. Subsequently, the soil was again photographed another day, increasing the amount of water sprayed to 650 ml. The overall difference in appearance between M-1 and M-3 were consistent with the prints representing 300 ml of water sprayed.

Figures 2-24 to 2-26 represent the Grainola soil for the comparisons of soil profile surface moisture using Portra 160 NC film. For the Grainola soil, M8/1P2-M4 (print coded M-1) (Figure 2-24) and M8/1P2-M5 (print coded M-2) (Figure 2-25) were photographed using an F-stop of 1/ 22-32 and a shutter speed of 1/100. Changing lighting conditions necessitated taking light meter readings for each photograph individually. M8/1P2-M7 (print coded M-3) (Figure 2-26) was taken using a smaller aperture opening (F-stop = 1/32) at the same shutter speed (1/100). The print coded M-1 had no water sprayed on the soil profile. The print coded M-2 had 500 ml of water sprayed on the soil profile, and the print coded M-3 represents an additional 500 ml of

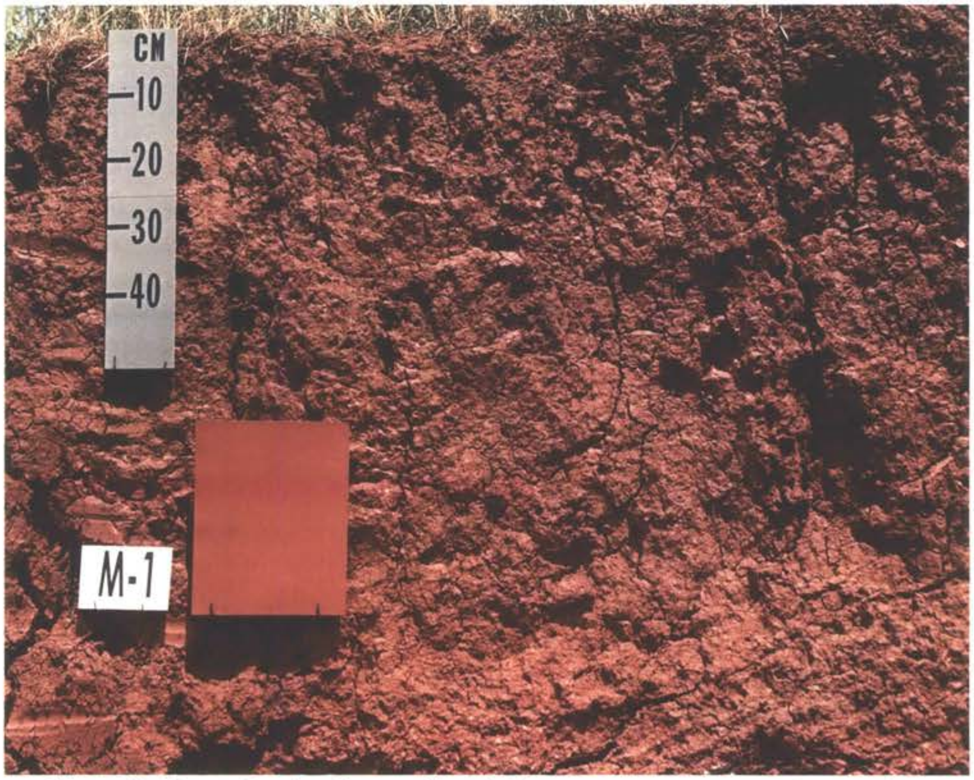

Fig. 2-24. Grainola soil with no water sprayed on the soil profile.

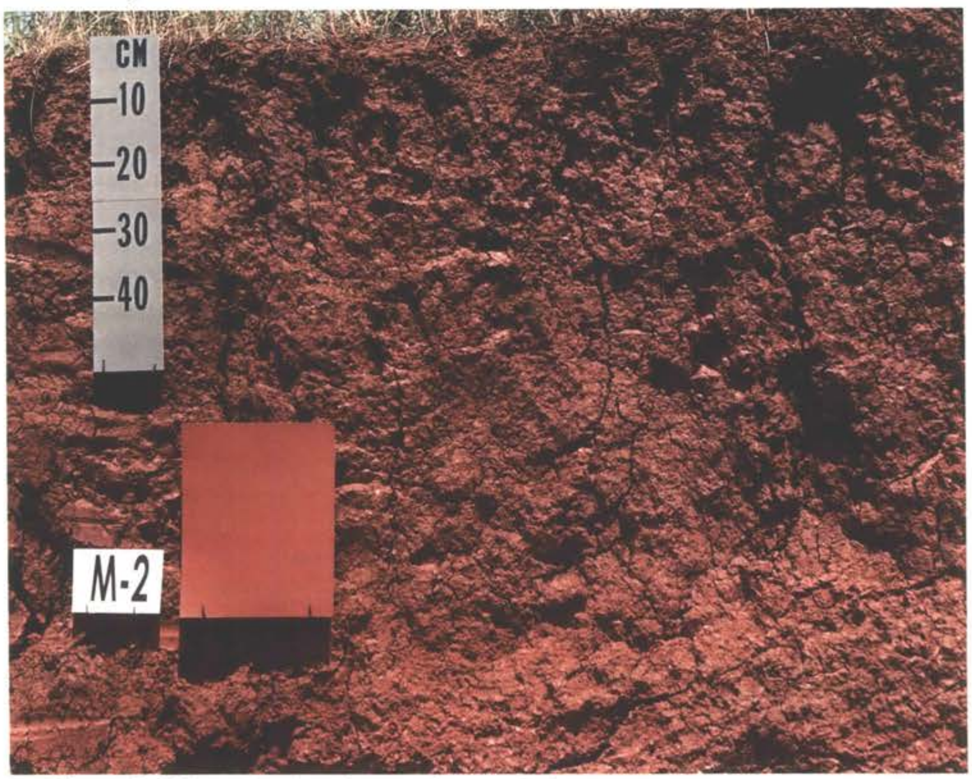

Fig. 2-25. Grainola soil profile sprayed with 500 ml of water.

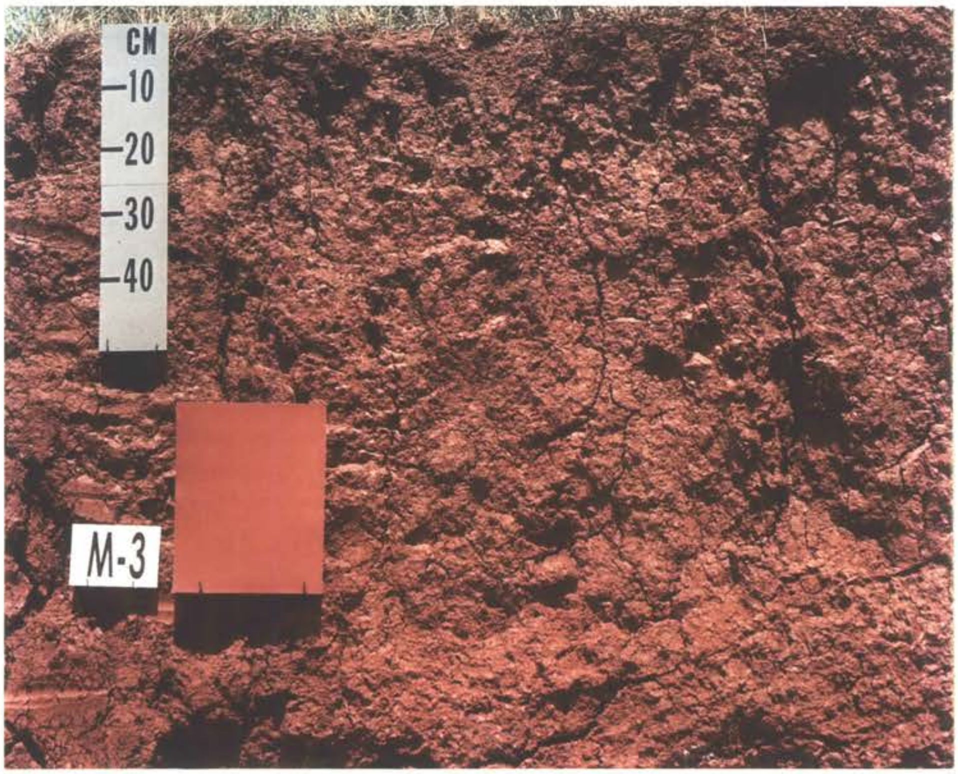

Fig. 2-26. Grainola soil profile sprayed with 1000 ml of water.

water sprayed on the soil profile. A darkening and change of hue of the soil is seen between prints coded M-1 and M-2 where the soil appears to change from red to red-brown. The spraying of water on the soil profile surface did not have a consistent darkening effect in M-3 (Figure 2-26). For the M-3 print, change in aperture setting resulted in a smaller opening to allow light into the camera and an overall browner versus redder hue than the previous two prints. This apparent color change was not due to the change in moisture conditions but to unstable lighting conditions. The lack of highly distinguishable visible differences between the prints is attributed to an already dark red soil color and rainfall one and one half weeks previous, the moisture of which is retained in the clayey soil compared to the sandy Teller soil during the same time period.

Visual comparisons between the Munsell (10R 4/6) photographed in the print and the actual Munsell resulted in no matches for hue, value, or chroma in Figures 2-24 or 2-25 (M-1 or M-2). Figure 2-26 (M-3) matched the actual Munsell in chroma only. There should have been no differences between the three Munsells for either soil, since the factor of moisture was applied to the soil, not the Munsell. Any differences in the Munsell in the prints then, are attributed to unstable lighting, camera settings and light meter readings.

Aperture and Shutter Speed

Figures 2-27 to 2-30 represent the Teller soil for the comparisons of aperture and shutter speed using Portra 160 NC film. For the Teller soil, the light meter reading recommended an F-stop of 1/32 with a 1/100 shutter speed which is represented in

Fig. 2-27. Teller soil photographed with an F-stop of 1/32 and a 1/100 shutter speed.

Fig. 2-28. Teller soil photographed with an F-stop of 1/16 and a 1/100 shutter speed.

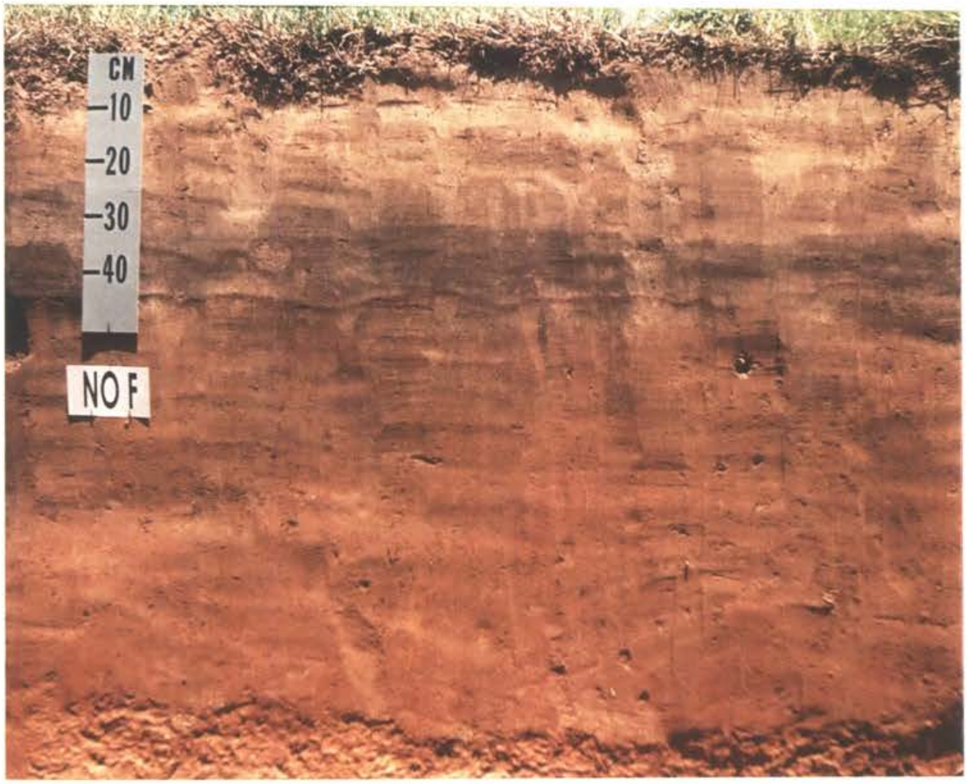

Fig. 2-29. Teller soil photographed with an F-stop of 1/22 and a 1/100 shutter speed.

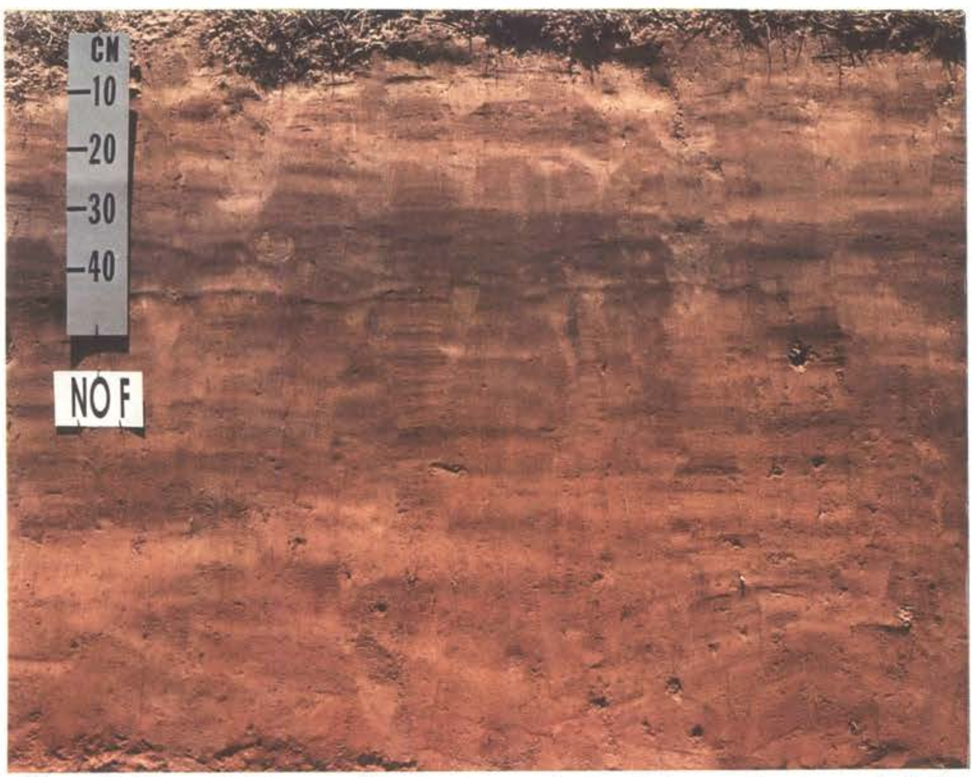

Fig. 2-30. Teller soil photographed with an F-stop of 1/44 and a 1/100 shutter speed.

F7/8P1-F15a (Figure 2-27). A larger F-stop opening of F 1/16 at a 1/100 shutter speed displayed a pale color to this sandy soil as seen in F7/8P1-F18 (Figure 2-28). Decreasing the F-stop opening to F 1/22 as in F7/8P1-F17 (Figure 2-29) resulted in a noticeably darker hue of light brown to the overall soil with an obvious darkening (but not as dark as an F-stop of 1/32) of the buried horizon compared to larger aperture openings such as F 1/16 as represented in Figure 2-28. Lamellae at 46 cm became more apparent with a decreased aperture opening. Decreasing the F-stop opening to F 1/44 as seen in F7/8P1-F16 (Figure 2-30) resulted in a print with a darker brown overall hue with purple overtones with a very noticeable lamellae, compared to 1/32 which had yellow-orange overtones.

Since no Munsell color sheet appeared in this set of prints, no visual matching to a Munsell color chip was done.

Figures 2-31 to 2-36 represent the Grainola soil for the comparison of aperture and shutter speed settings using Portra 160 NC film. Too large an F-stop of F 1/ 16-22 (F7/26P2-F17) (Figure 2-31) resulted in a light colored bright appearing soil. A smaller F-stop opening of F 1/ 22-32 (F7/26P2-F16) (Figure 2-32) resulted in a brownish hue to what was actually a red soil. At the time the six photographs (Figures 2-31 to 2-36) were taken, the light meter reading for an adequate exposure was an F-stop of 1/32 with a shutter speed setting of 1/100 and is represented in photograph F7/26P2-F13 (Figure 2-33). A smaller F-stop opening than F 1/32 such as F 1/ 32-44 contrasted and accentuated the relief and shadows shown in F7/26P2-F15 (at F 1/ 32-44) (Figure 2-34) and F7/26P2-F14a (at F 1/44) (Figure 2-35). Less light reaching the film with a smaller

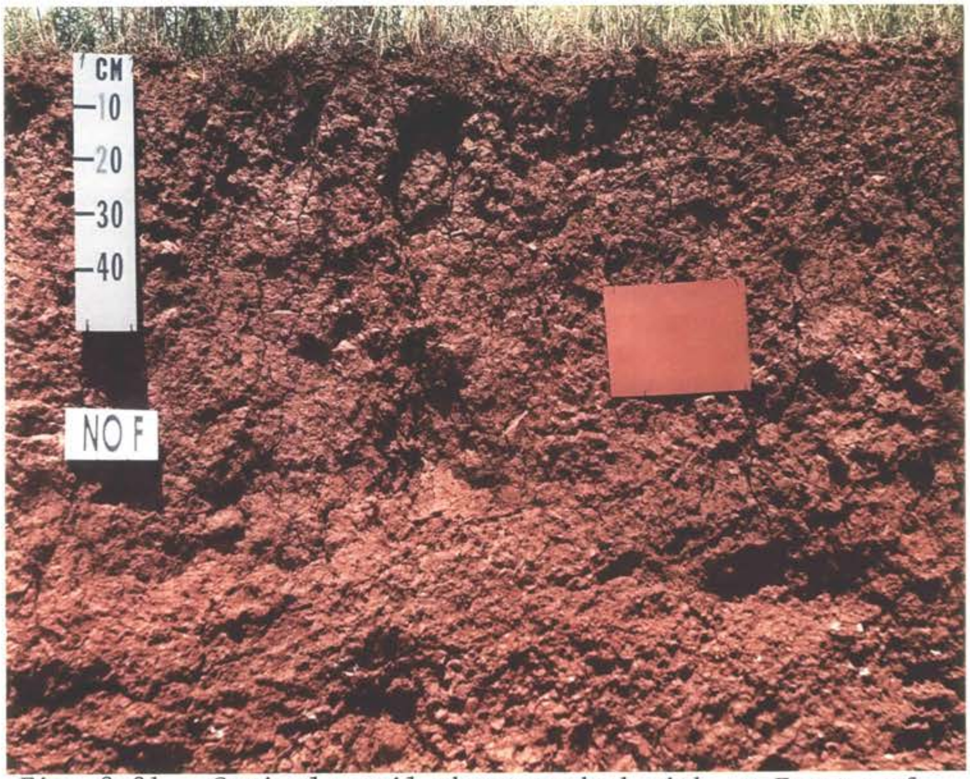

Fig. 2-31. Grainola soil photographed with an F-stop of 1/16-22 and a 1/100 shutter speed.

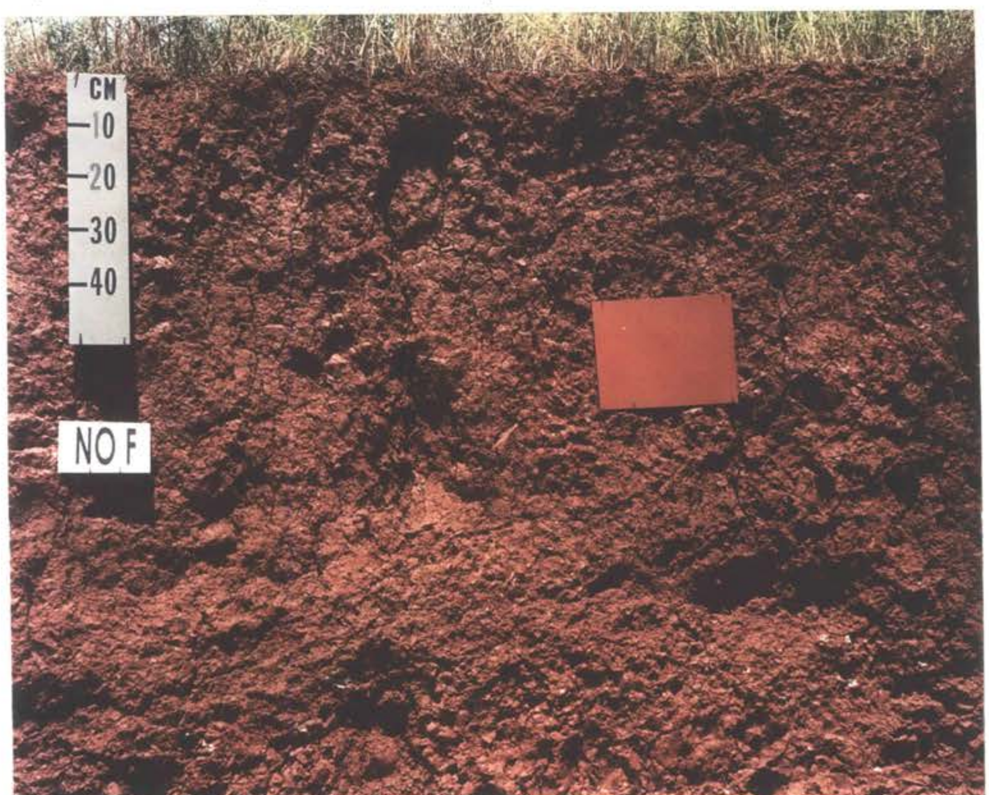

Fig. 2-32. Grainola soil photographed with an F-stop of 1/22-32 and a 1/100 shutter speed.

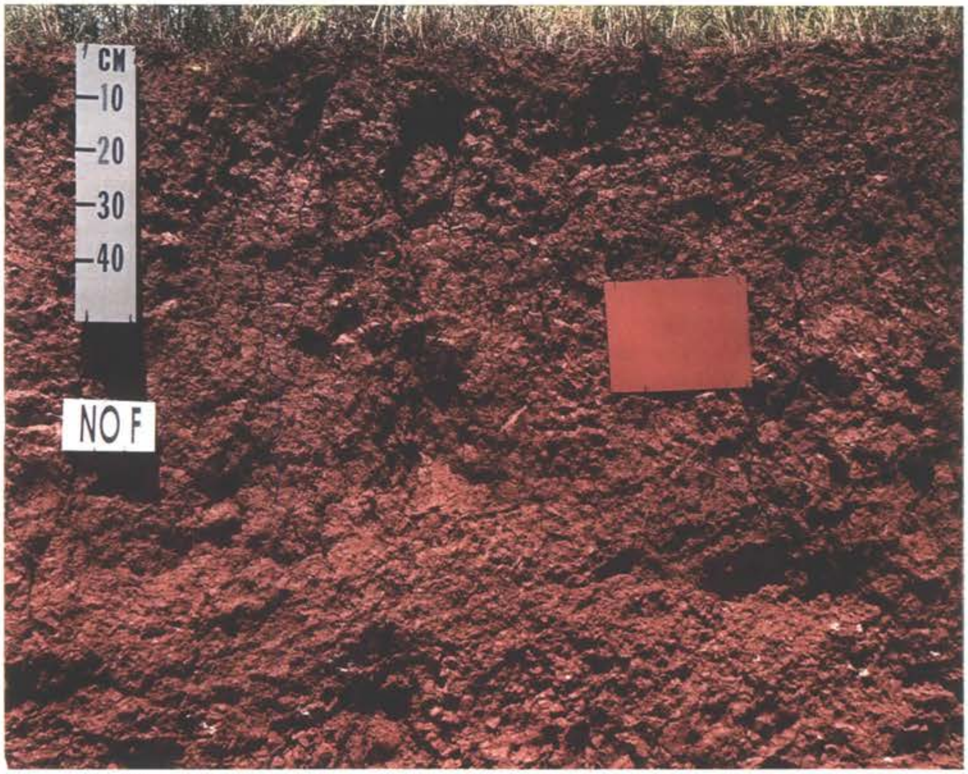

Fig. 2-33. Grainola soil photographed with an F-stop of 1/32 and a 1/100 shutter speed.

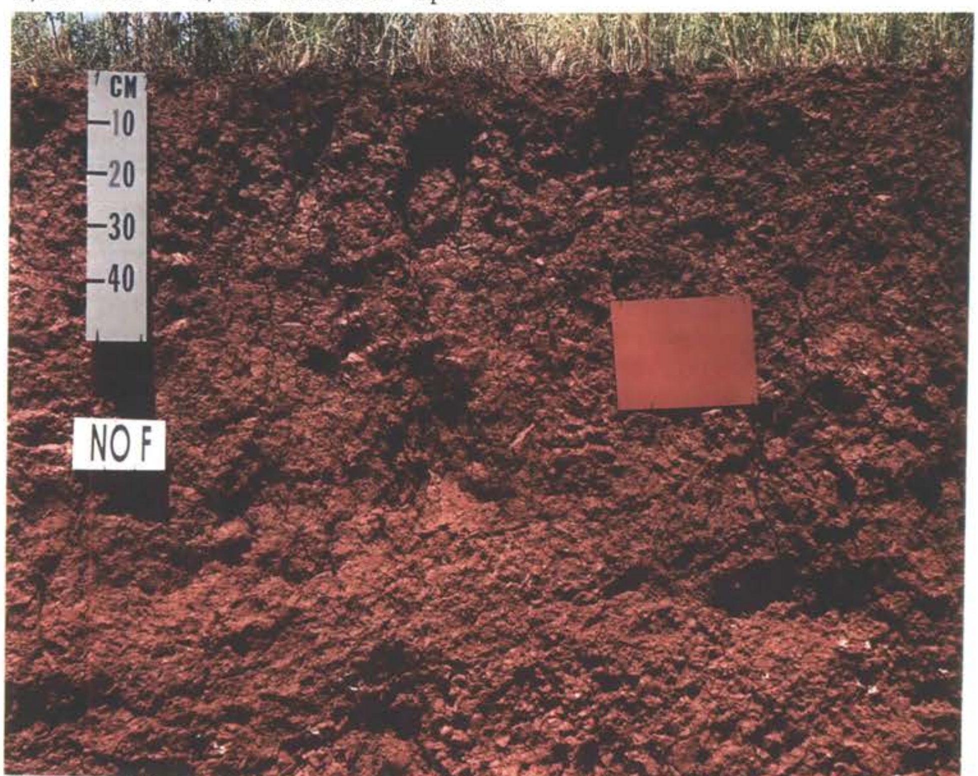

Fig. 2-34. Grainola soil photographed with an F-stop of 1/32-44 and a 1/100 shutter speed.

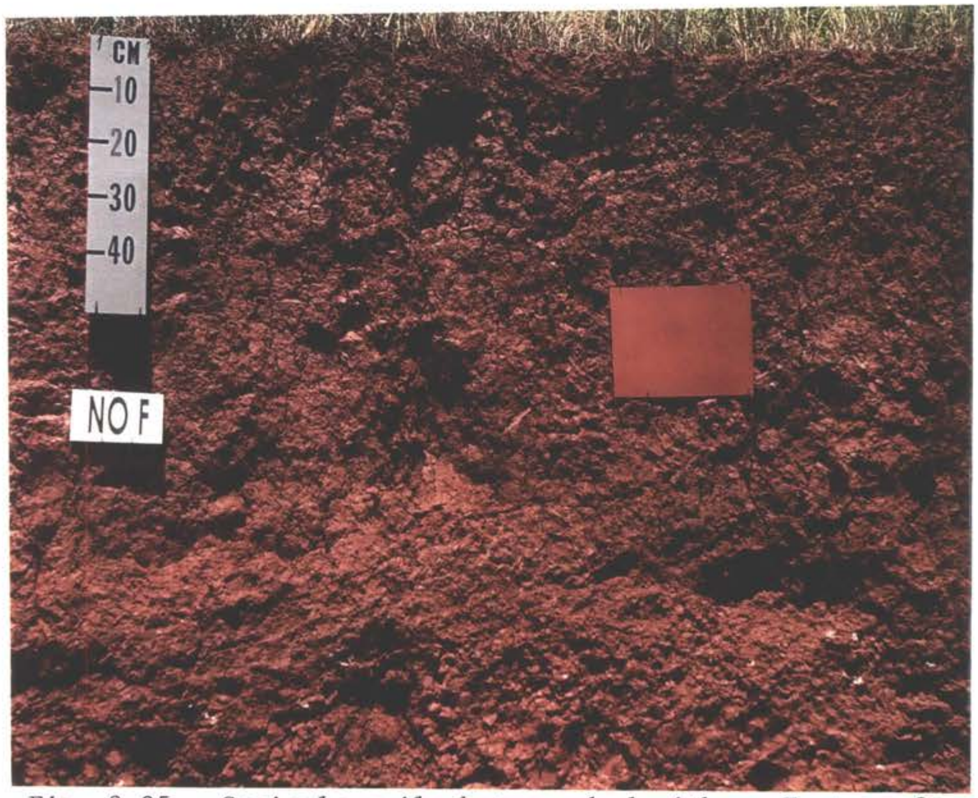

Fig. 2-35. Grainola soil photographed with an F-stop of 1/44 and a 1/100 shutter speed.

Fig. 2-36. Grainola soil photographed with an F-stop of 1/44+ and a 1/100 shutter speed.

F-stop opening such as F 1/44 (Figure 2-35) or 1/44+ (Figure 2-36), leaving the shutter speed constant at 1/100, resulted in loss of detail in the shadows (F7/26P2-F14a) (Figure 2-35) as well as complete darkening of the soil to a brown rather than red hue with an F stop of F 1/44+ (F7/26P2-F19) (Figure 2-36). Since cracks form shadows, the cracks, a distinguishing feature in this soil, are more evident in the lightest print. The darkest print reduces the sharpness of the blocky structure to give the soil a less rigid, loamy appearance. Horizon boundaries are difficult to distinguish in this soil. Structure change is evident from the weak subangular blocky structure at the soil surface to strong subangular blocky structure which extends down the soil profile through the soft rock material. Depletions (redoximorphic features) are more pronounced in Figures 33-35 than the lighter or darker appearing prints. The overall hue changing from red to redder with depth is most evident in Figures 2-33 and 2-35.

The Munsell that appeared in the prints was 10R 4/6. The Munsell in Figure 2-36 (representing the smallest aperture opening) matched the actual Munsell in hue, value, and chroma. Figure 2-32 (F 1/22-32) matched the Munsell color chip in hue and chroma, but was one chip off in value. Figures 2-33 and 2-34 matched the Munsell color chip in chroma, but was one chip off in value, and one page off in hue. Figure 2-31 matched the Munsell color chip in chroma only, and Figure 2-35 did not match the Munsell color chip in hue, value, or chroma.

Filters

Four commonly used filters were chosen for this study including skylight, haze, diffusing, and yellow filters. These filters were chosen as they are more commonly used than many other types of filters. Skylight and haze filters absorb ultraviolet light. Diffusing filters soften the overall effect on the image. Yellow filters are commonly used in black and white photography to accentuate clouds against a blue sky, for example.

Figures 2-37 to 2-41 represent the Teller soil for the comparison of filters using Portra 160 NC film (taken at an F-stop of 1/32 and a shutter speed of 1/100). For the Teller soil, comparing the use of a skylight (Kodak) filter (F7/6P1-1F17) (Figure 2-37) to no filter (F7/6P1-1F14) (Figure 2-38), the sky filter removed glare as the light colored surface soil is darker in Figure 2-37. Additionally, the soil is redder in the sky filter print versus brown in the print representing no filter. The diffusing filter (F7/6P1-1F10a) (Figure 2-39) print is more pink in hue compared to the brown cast of the print using no filter. The haze filter (Tiffen) (F7/8P1-F10b) (Figure 2-40) reduced the glare as compared to no filter (F7/6P1-1F14).

No filter as seen in Figure 2-38 print is the most accurate visual representation of the soil observed under field conditions at that time. Lamellae and the buried horizon are more pronounced in Figures 2-37 and 2-38 compared to Figures 2-39 to 2-41. Horizon boundaries were just as visible in all prints regardless of the filter used. Use of a yellow filter (Figure 2-41) (F7/6P-1F11) presents a yellow cast to the soil surface and a red cast on the lower part of the profile.

Figures 2-42 to 2-46 represent the Grainola soil for the comparison of filters using Portra 160 NC film with an F-stop of F 1/32 and a shutter speed of 1/100. When using no

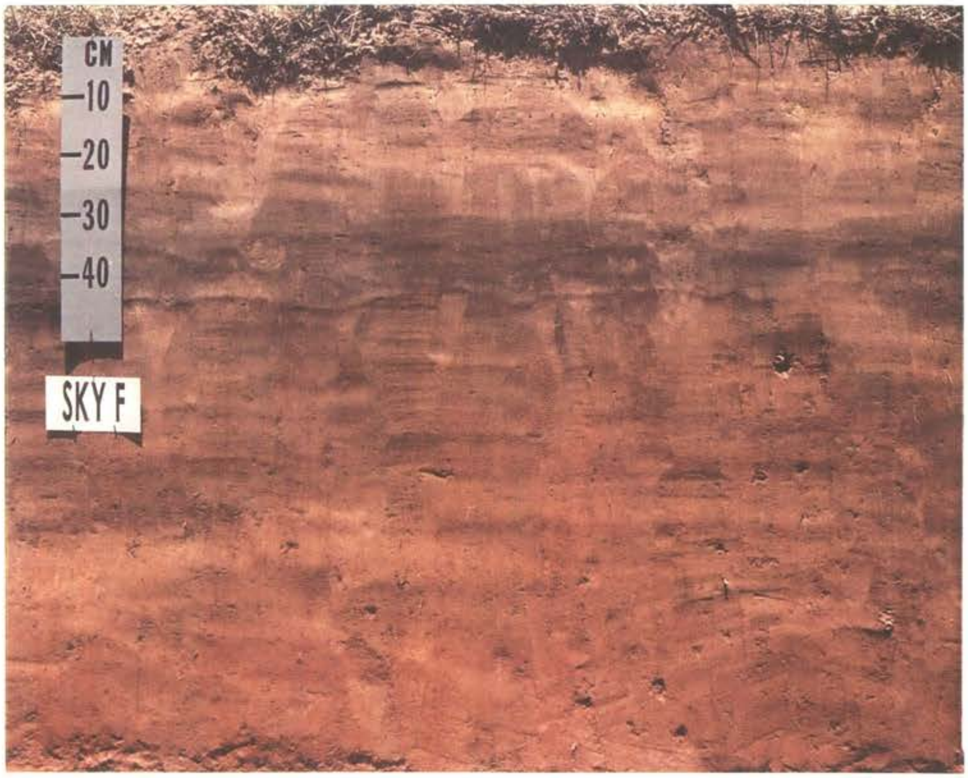

Fig. 2-37. Teller soil photographed using a Kodak Skylight filter.

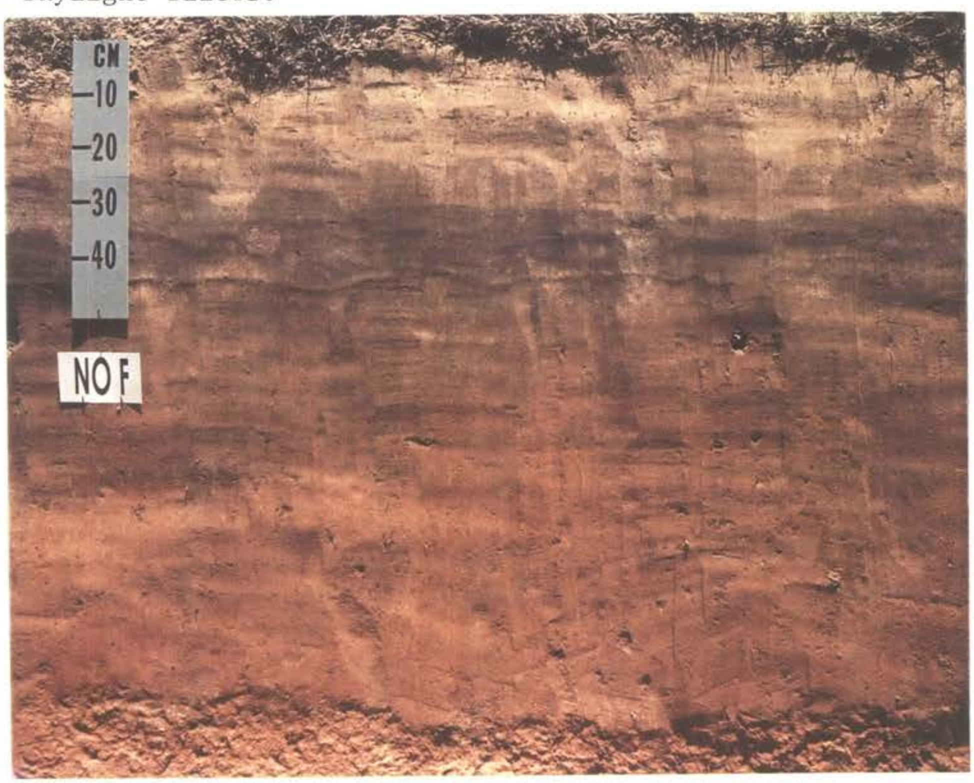

Fig. 2-38. Teller soil photographed using no filter.

Fig. 2-39. Teller soil photographed using a Spiralite Diffuser filter.

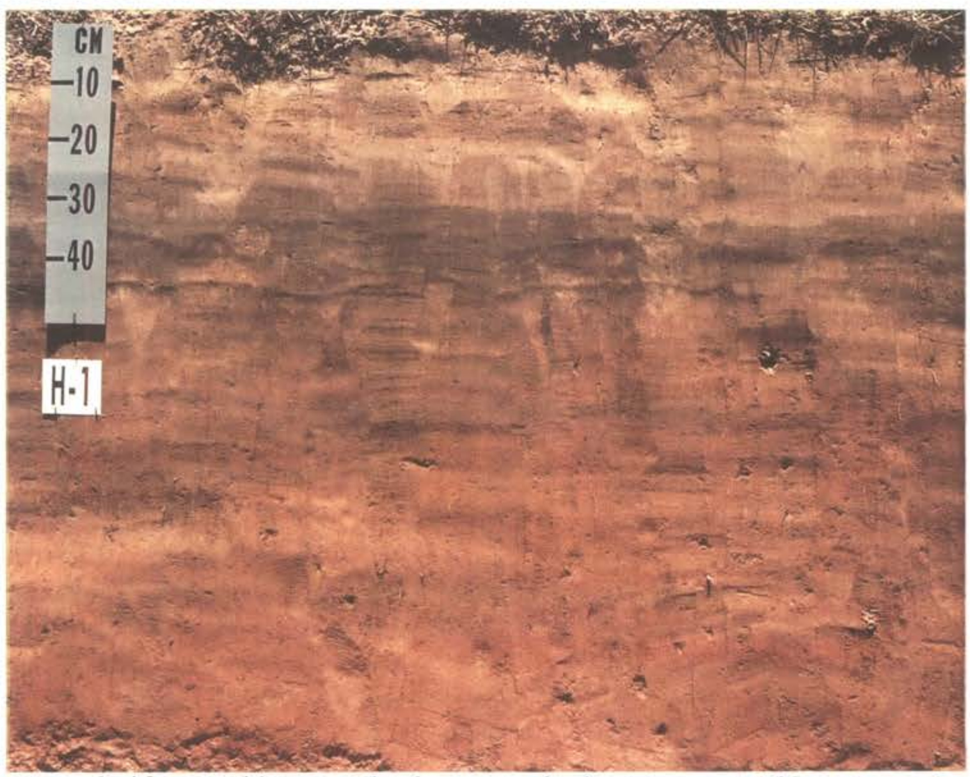

Fig. 2-40. Teller soil photographed using a Tiffen Haze 1 filter.

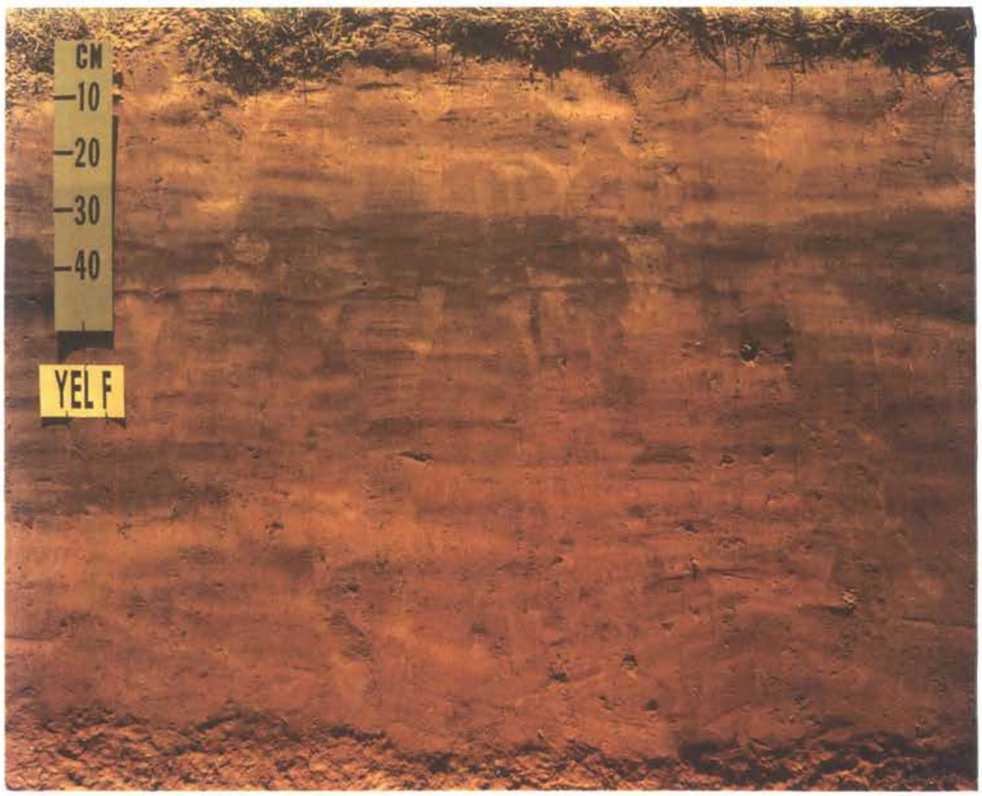

Fig. 2-41. Teller soil photographed using a Wratten K2 (yellow) filter.

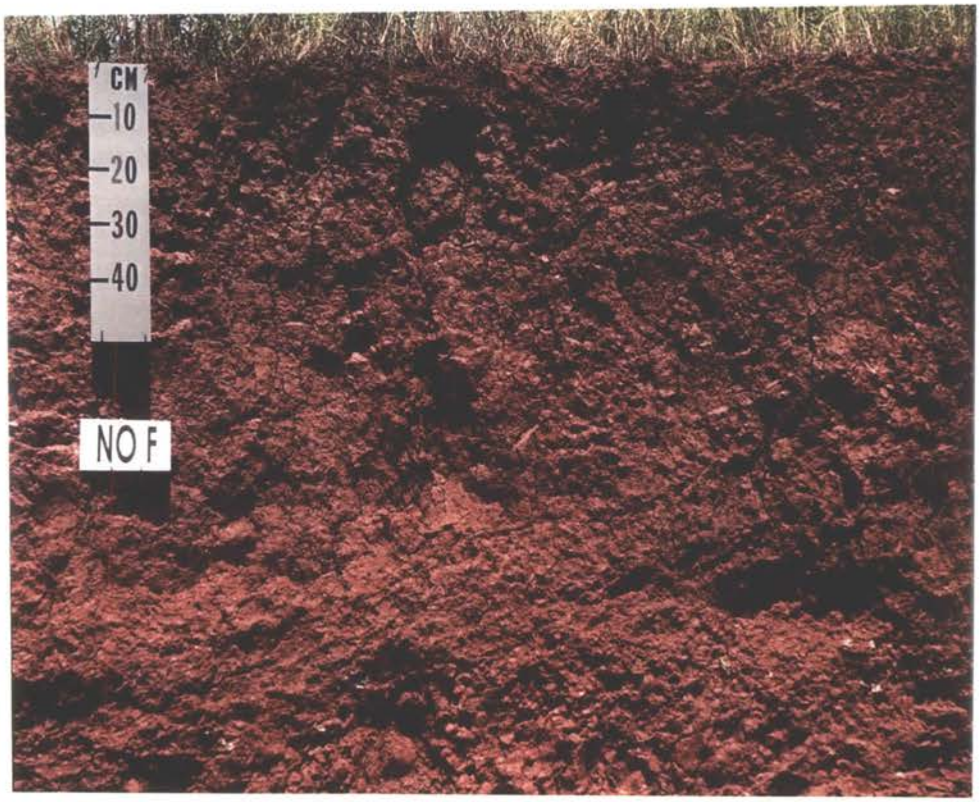

Fig. 2-42. Grainola soil photographed using no filter.

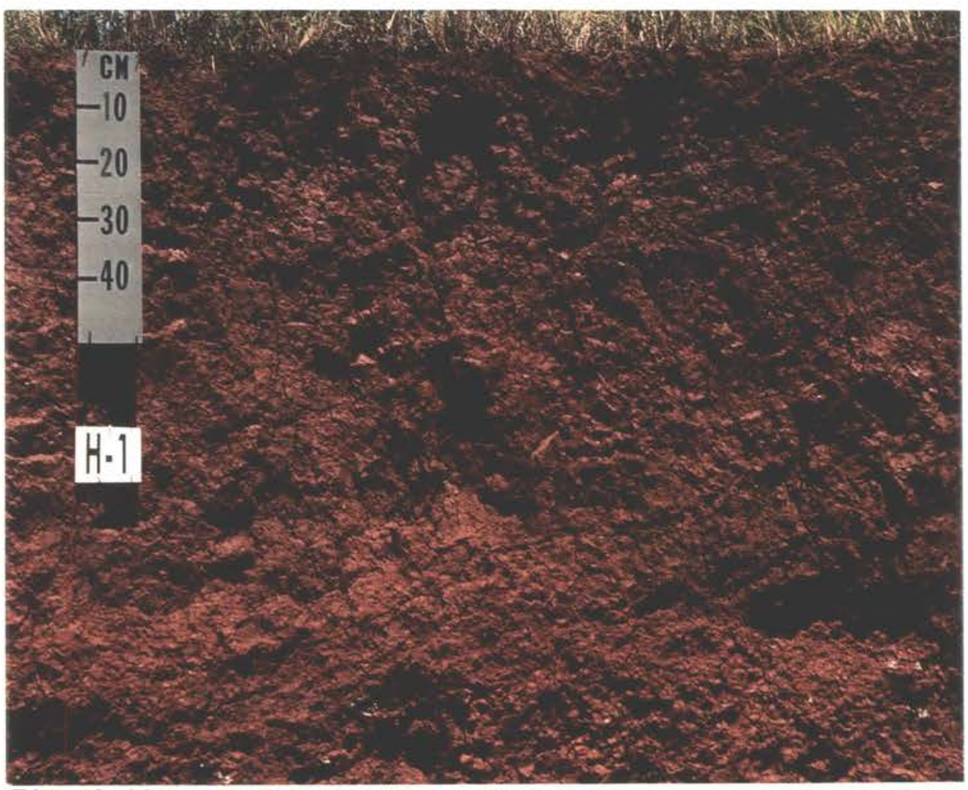

Fig. 2-43. Grainola soil photographed using a Tiffen Haze 1 filter.

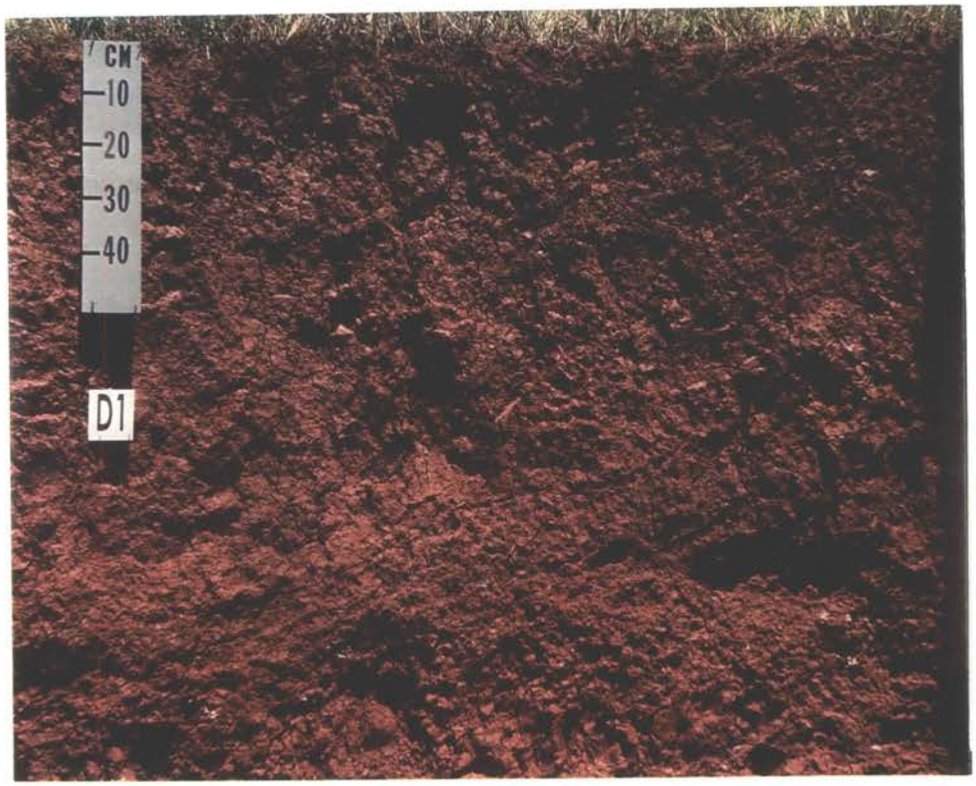

Fig. 2-44. Grainola soil photographed using a Spiralite Diffuser filter.

Fig. 2-45. Grainola soil photographed using a Kodak Skylight filter.

Fig. 2-46. Grainola soil photographed using a wratten K2 (yellow) filter.

filter, photographs of the soil were clear (F7/26P2-F11) (Figure 2-42), but the relief became more prominent when haze (Tiffen) (F7/26P2-F4) (Figure 2-43) or diffusing (Spiralite Diffuser) filters (F7/26P2-F1) (Figure 2-44) were used. Use of a skylight filter (Kodak) (F7/26P2-F9) (Figure 2-45) minimized glare, although the appearance of the soil displayed less relief than the haze and diffusing filters. Soil portrayed in prints having no filter (Figure 2-42) or a diffusing filter (Figure 2-44) portrayed redder soil than the haze or sky filter which tended to give the soil a brown overall hue (see Figures 2-42 to 2-45). Use of a yellow filter (Wratten K2) (designed for black and white photography), lent an overall yellow orange cast to red soil (F7/26P2-F6) (Figure 2-46). Using a yellow filter, the red hue of the Grainola soil appeared orange-brown and depletions were less noticeable (F7/26P2-F6)(Figure 2-46). Overall hue of red to redder with depth was most noticeable in Figures 2-42 to 2-44. Large vertic cracks are equally apparent in all prints with the exception of the yellow filter print. Changes in soil structure were just as evident in all prints. Depletions (redoximorphic features) are equally pronounced in all but the yellow filter print.

<u>Angles</u>

Figures 2-47 to 2-49 represent the Teller soil for comparisons of angle between the camera lens and soil profile using Portra 160 NC film. Print A8/4P1-A2 (Figure 2-47)) was obtained by photographing the soil at a 90° angle from the camera lens to the soil profile. Key features (buried horizon and lamellae) of the soil are clearly seen. In Figure 2-48 (A8/4P1-A3), photographed at a 60° angle from the soil profile, the clarity of the

Fig. 2-47. Teller soil photographed at a 90° angle.

Fig. 2-48. Teller soil photographed at a 60° angle.

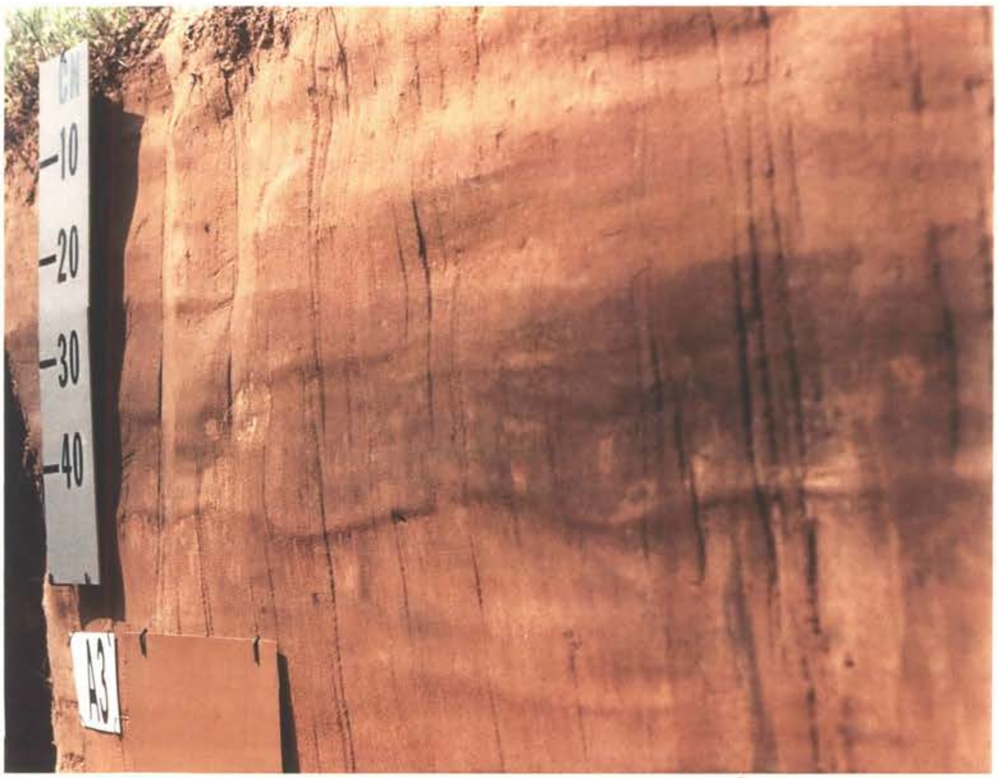

Fig. 2-49. Teller soil photographed at a 30^{o} angle.

soil face decreases, but the key features are just as prominent. In Figure 2-49 (A8/4P1-A6), photographed at a 30° angle from camera lens to soil profile, the overall soil and soil features are distorted. Soil appears darker close to the photographer due to less light reaching the film closest to the photographer.

Visual comparisons (Figure 2-8) revealed the Munsell appearing in all three prints had the same hue and chroma as the actual Munsell it represents (7.5YR 4/4), but not the same value.

Figures 2-50 to 2-52 represent the Grainola soil for the comparison of angles between the camera lens and soil profile using Portra 160 NC film. With reference to Grainola (A8/1P2-A2) (Figure 2-50) at a 90° angle from camera lens to soil profile, cracks are readily seen as is the color gradation from a red surface to a redder soil with depth. The angle is deceptive in print A8/1P2-A3 (Figure 2-51) where the camera is at a 60° angle but tilted to capture the grass and give the overall appearance of looking directly at the soil profile. The measuring tape, Munsell, and code card are the only indications that the photograph is taken off to one side. With a rough textured surface and almost homogenous appearance of color, the large cracks are less evident at this angle compared to Figure 2-50. In A8/1P2-A5 (Figure 2-52), the large cracks distinctive of this vertisol soil are obscured. Structure changes expressed vertically through the soil profile are less evident.

The Munsell color sheet that appeared in all three prints was 10R 4/6. At 90° and 60° from camera lens to soil profile, visual comparisons to Munsell Soil Color Charts resulted in the print matching 10R 4/6 in chroma but not in hue or value. The print representing a 30° angle matched in hue, but not in value or chroma (Figure 2-8).

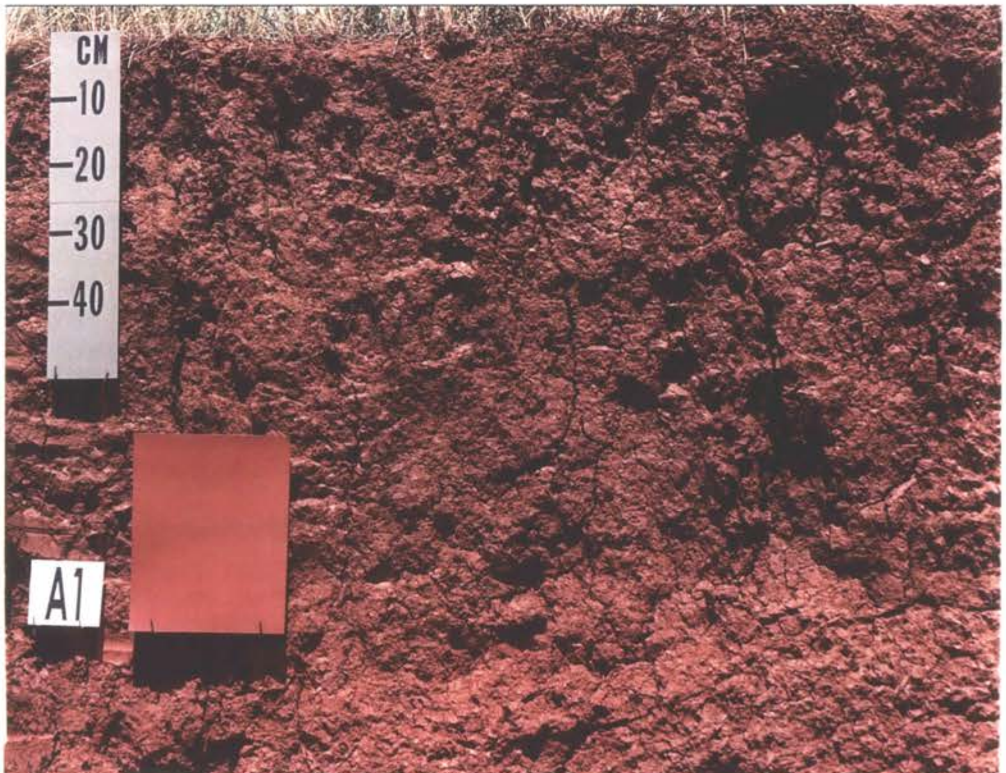

Fig. 2-50. Grainola soil photographed at a 90° angle.

Fig. 2-51. Grainola soil photographed at a 60° angle.

Fig. 2-52. Grainola soil photographed at a 30° angle.

Time of Day

The Teller soil for the comparison of time of day is represented in prints T6/6P1-T1d, T6/6P1-T2b, T6/6P1-H1a, T6/6P1-T3b, and T6/6P1-T4a1 (Figures 2-53 to 2-57) and represent photographs taken in early June at 11:30 am, 12:30 pm, 1:00 pm, 1:30 pm, and 2:30 pm, respectively. Pro 100 (Eastman Kodak Co.) film was used and all five photographs were taken at F 1/16-22 at a shutter speed of 1/100. The noticeable difference in the profiles of the prints is the amount and direction of shadowing on ped faces. Shadowing caused from the sun rising from the east (on the right hand side of the print coded T-1)(Figure 2-53) and setting in the west (from the left of the print coded T-4)(Figure 2-57) is noticeable in the prints. Prints coded H-1 (Figure 2-55) and T-3 (Figure 2-56) represent 1:00 and 1:30 respectively, the color changes of which are seen in the Munsell sheet appearing in the prints. These latter two prints represent the time of day when the sun was centered between the left and right side of the soil profile. The print coded T-1 (Figure 2-53) shows more contrast from the a.m. sun whereas T-4 (Figure 2-57) has a warm afternoon tone.

The Munsell sheet appearing in the prints was 7.5YR 4/4. The print containing the Munsell in T-3 (Figure 2-56) representing 1:30 pm had the correct hue and chroma as the actual Munsell (7.5YR 4/4), but was one chip off on value and was closest in Munsell notation to the Munsell color sheet of 7.5YR 4/4. T-1 (Figure 2-53) was redder in hue with a higher value and chroma than the actual Munsell color sheet. T-2 (Figure 2-54) was redder in hue with a higher value and correct chroma when compared to the actual Munsell color sheet. H-1 and T-4 (Figures 2-55 and 2-57) had the correct hue, but were

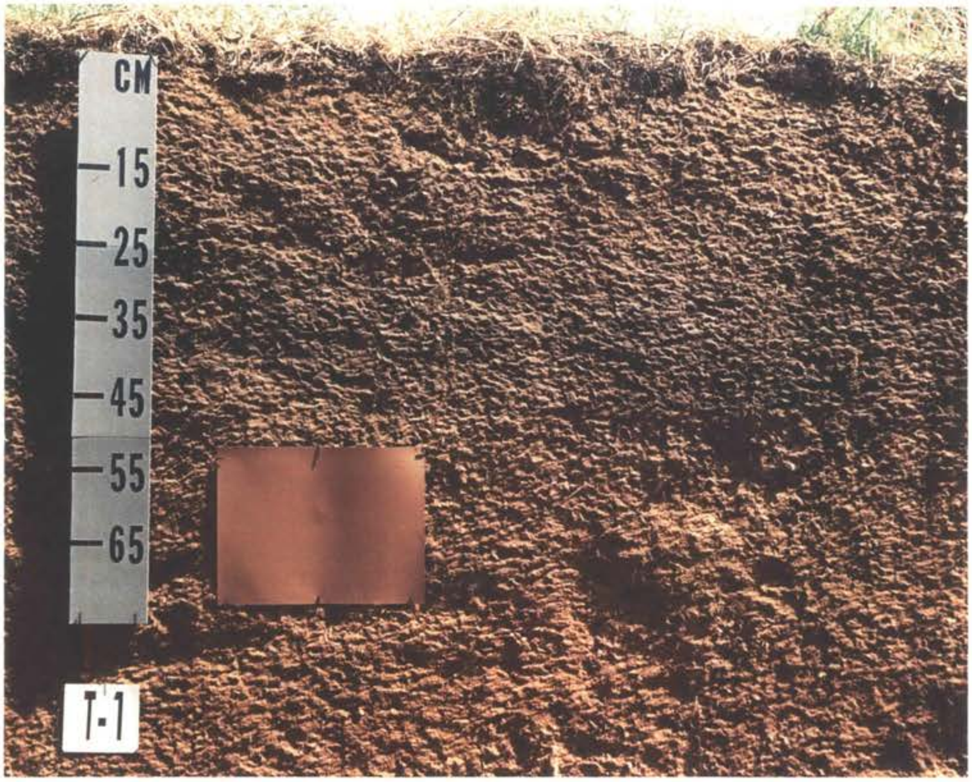

Fig. 2-53. Teller soil photographed at 11:30 a.m.

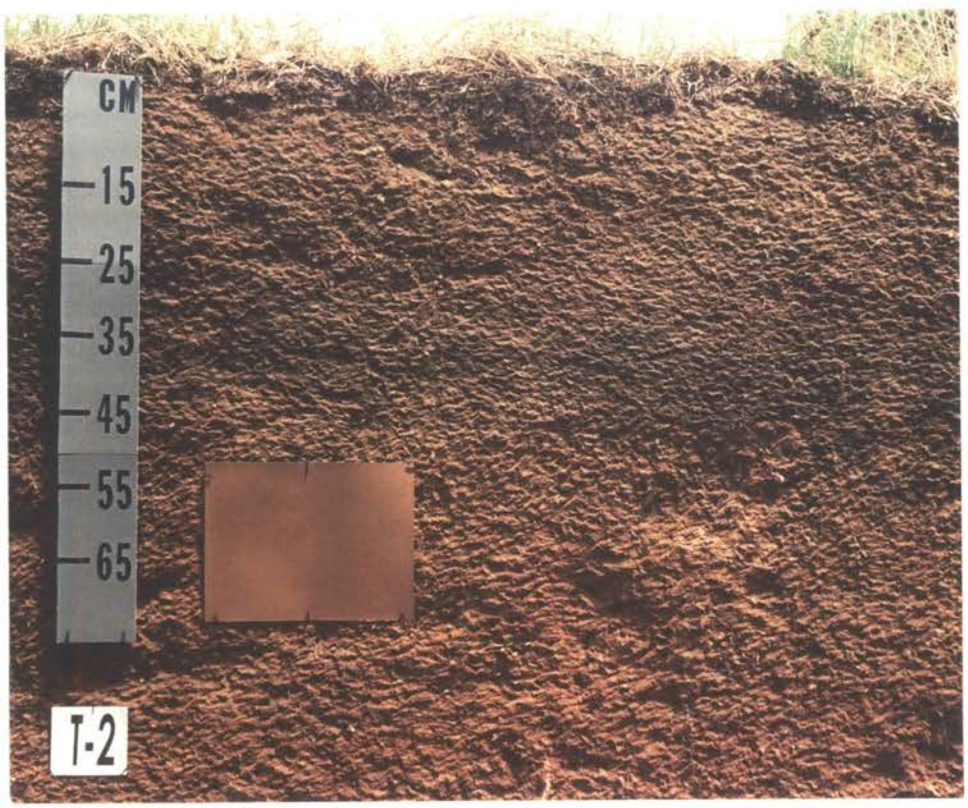

Fig. 2-54. Teller soil photographed at 12:30 p.m.

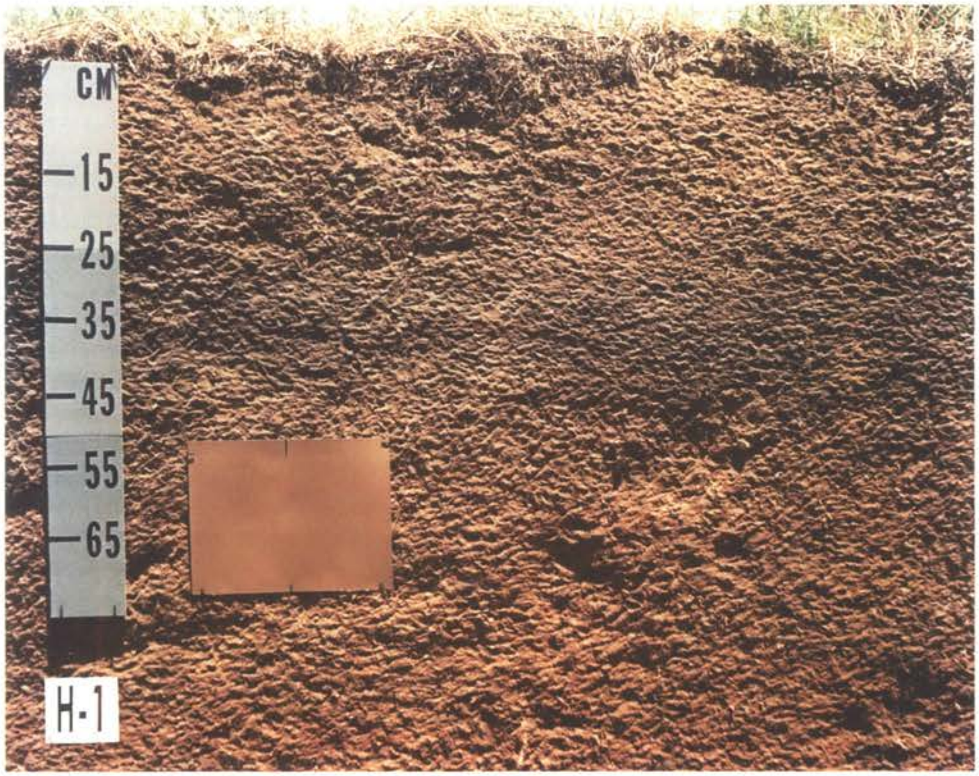

Fig. 2-55. Teller soil photographed at 1:00 p.m.

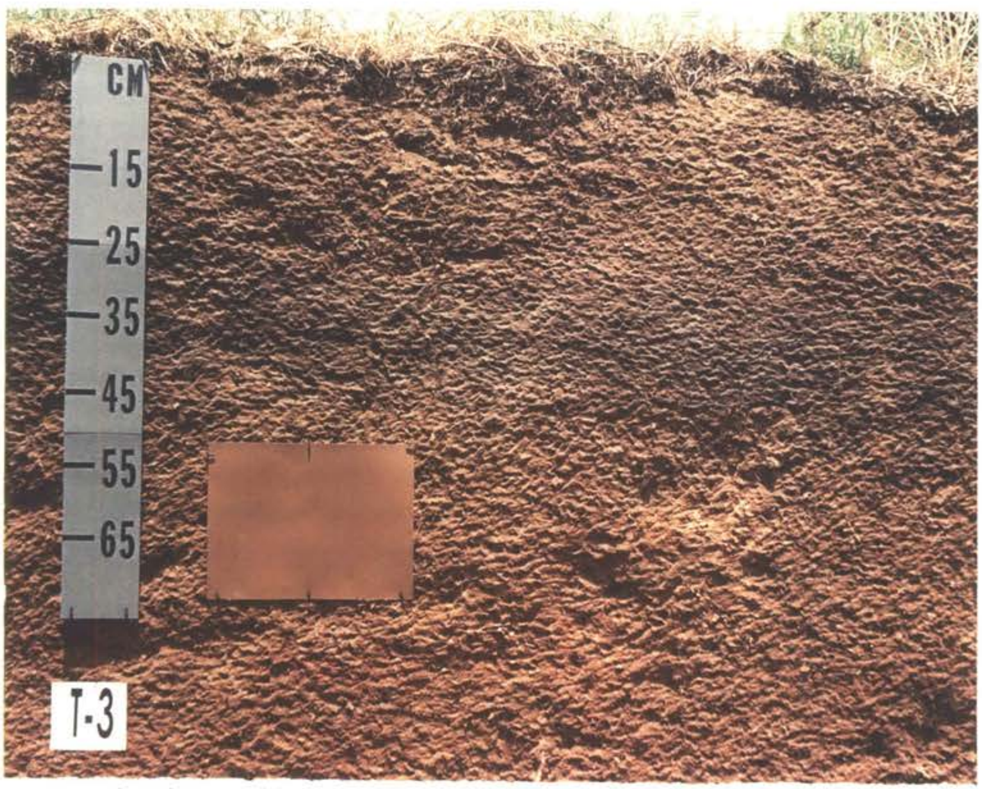

Fig. 2-56. Teller soil photographed at 1:30 p.m.

Fig. 2-57. Teller soil photographed at 2:30 p.m.

high in value and chromas. One thirty in the afternoon was then chosen as the best time (for early summer) for which to carry out all other photography work.

Figures 2-58 to 2-61 represent the Grainola soil for comparisons of time of day using Portra 160 NC film. Time of day prints (T7/30P2-T2, T7/30P2-T7, T7/30P2-T10, and T7/30P2-T14) (Figures 2-58 to 2-61) representing 11:30, 12:30, 1:30, and 2:30 respectively) of the Grainola soil display similar shadowing effects as the Teller soil but greater overall color differences. Portra 160 NC film was used to produce Figures 2-58 to 2-61 that were taken in July (versus Pro 100 used for the Teller soil Time of Day prints which were taken in early June).

The overall hue of the soil becoming redder with depth was most pronounced in T-3 (Figure 2-61) taken at 2:30 pm. T-3 also displays fewer shadows. Cracks and depletions as well as change in soil structure was evident in all four prints (less in the H-1 coded print due to being slightly out of focus). The soil wall on the right side of the first three prints shows the sun movement from east to west and subsequent shadowing. In the print coded T-1 (Figure 2-58, representing 11:30 am), the sun had risen from the right (east) side. The shadow eventually disappears as the sun moved west (print coded T-3 (Figure 2-61)).

Overall soil color was most accurately portrayed in T-3 (Figure 2-61). Shadows created by the morning sun results in an overall brown appearance to the soil as seen in the print coded T-1. At 12:30 (print coded T-2) (Figure 2-59) there is a brightness and a purplish cast on this red clayey soil. The 1:30 (print coded H-1) (Figure 2-60) sun allows the brown color rather than brightness to be more expressed whereas the 2:30 p.m. sun

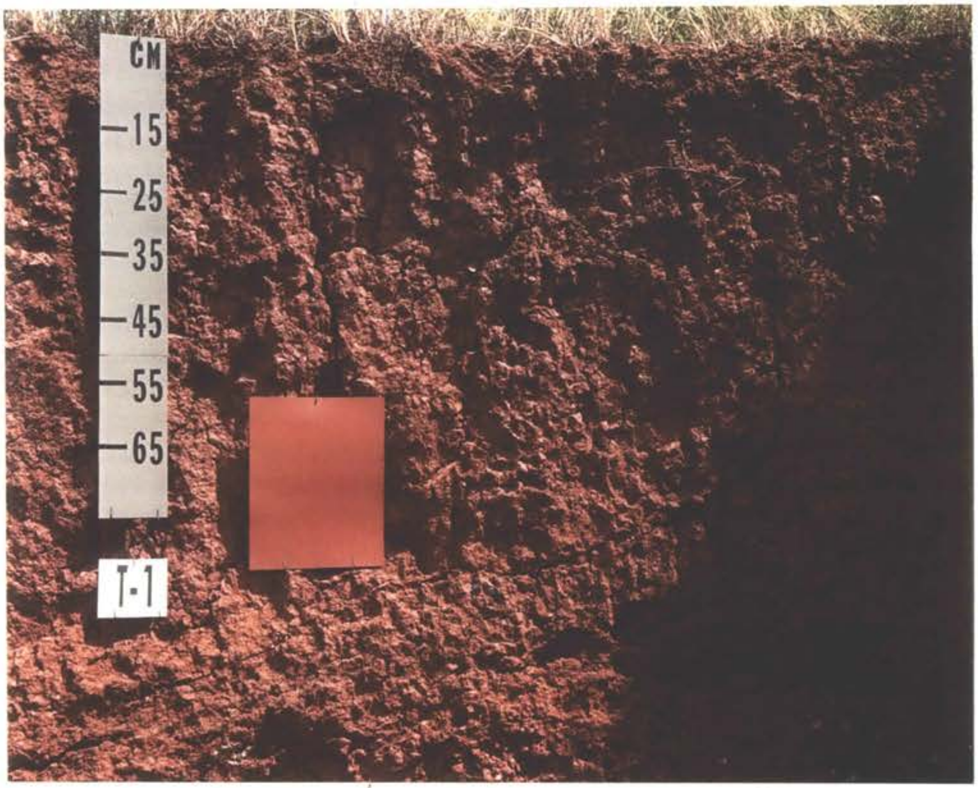

Fig. 2-58. Grainola soil photographed at 11:30 a.m.

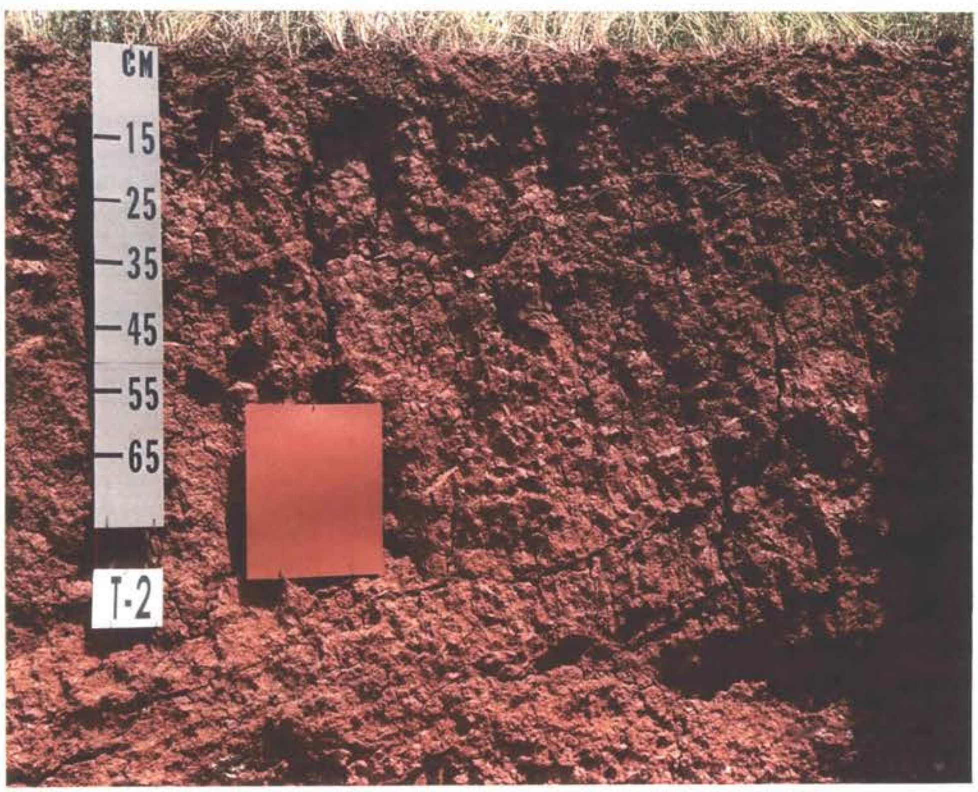

Fig. 2-59. Grainola soil photographed at 12:30 p.m.

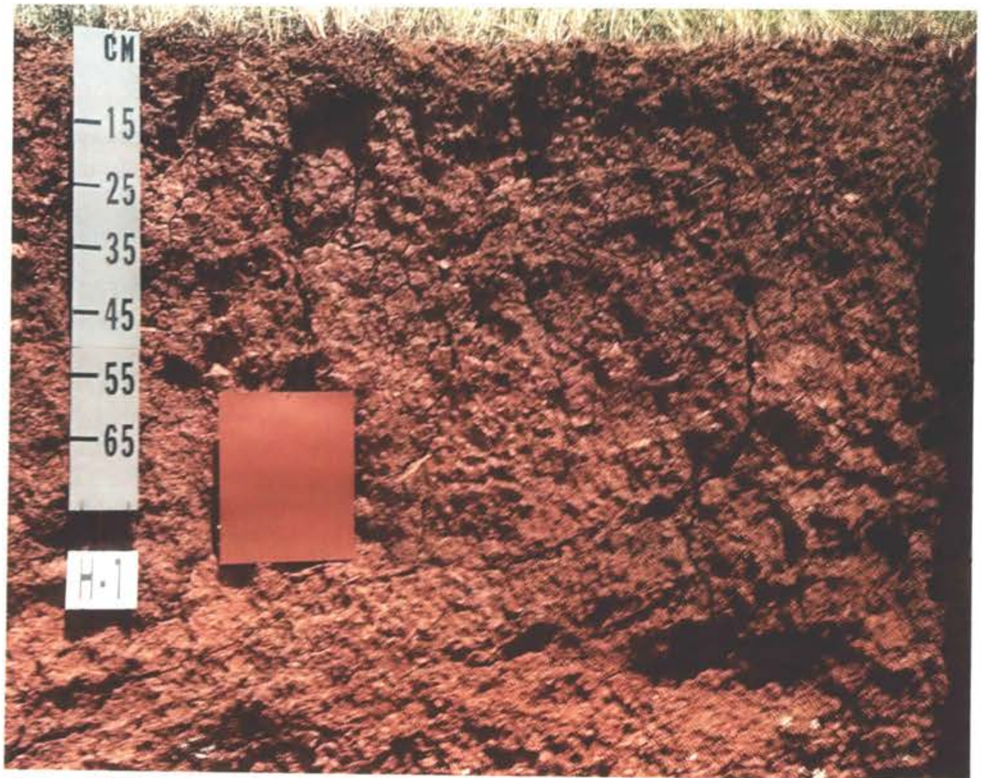

Fig. 2-60. Grainola soil photographed at 1:30 p.m.

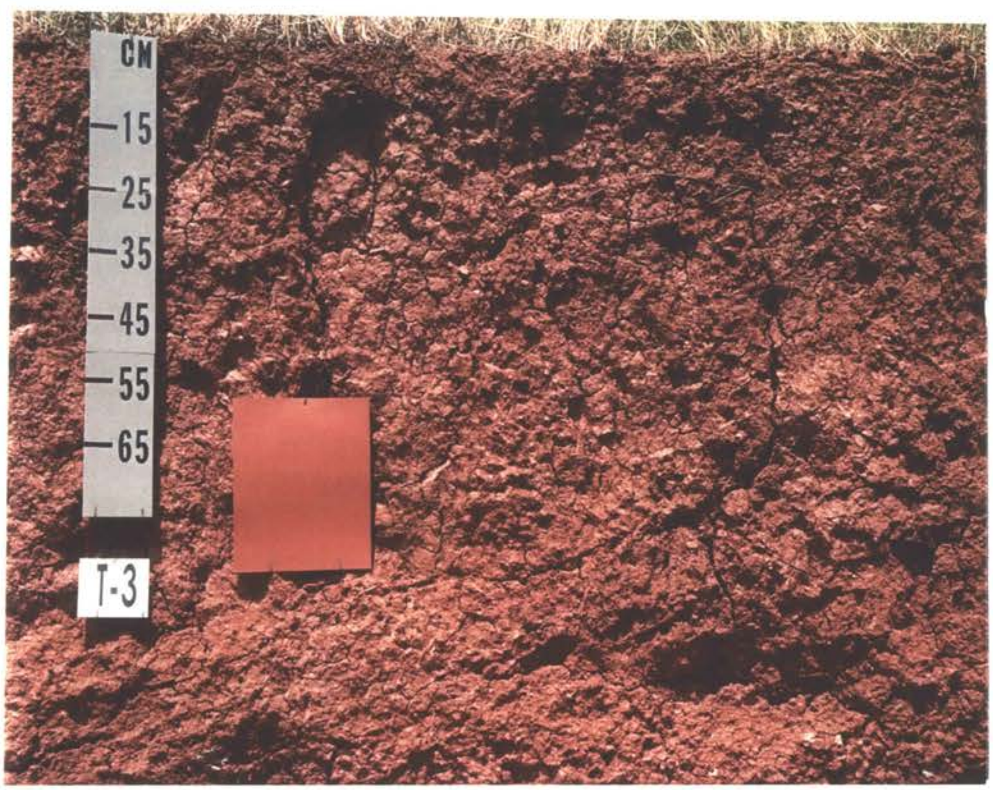

Fig. 2-61. Grainola soil photographed at 2:30 p.m.

(print coded T-3) (Figure 2-61) allows the red hues of this soil to be expressed. The shadow created by the measuring tape also indicates the direction of the sun. The measuring tape in the H-1 print reveals that the sun is shining directly at the soil profile. The measuring tape's shadow moves to the right of the tape in the print coded T-3.

Visual color matching of the Munsell color sheet (10R 4/6) in the prints to Munsell Soil Color Charts resulted in T-1 (Figure 2-58) and H-1 (Figure 2-60) having the same hue as the Munsell it represents but not the same value or chroma. T-2 (Figure 2-59) and T-3 (Figure 2-61) were one hue page, one value, and two chromas away from the hue, value, and chroma of the actual Munsell color sheet (Figure 2-8). The photograph taken at 1:30 pm was closest in Munsell notation to the Munsell color sheet of 10R 4/6.

Photographs taken under clouds created prints displaying soils with a uniform, homogenous appearance. Figures 2-62 (F-stop of 1/ 22-32 and a shutter speed of 1/100) and 2-63 (F-stop of 1/ 22.3) were taken as a cloud passed overhead during the time of day photography for the Grainola soil. Clouds have the effect of creating one large shadow or eliminating glare and excessive reflections as most of the light reaching the soil profile is diffused. Soil color (redder with depth), features (cracks and depletions), and soil characteristics (soil structure changes) are clearly visible in Figures 2-62 and 2-63. The clouds caused a uniform appearance rather than a patchy appearance caused by the peaks and shadows displayed when the profile is seen under bright sunny skies.

Visual matching of the Munsell color sheet in the print to Munsell Soil Color Charts resulted in a close match to the actual Munsell color sheet represented. The print in Figure 2-62 matched a 7.5R 4/6 color chip and the print in Figure 2-63 matched a 10R

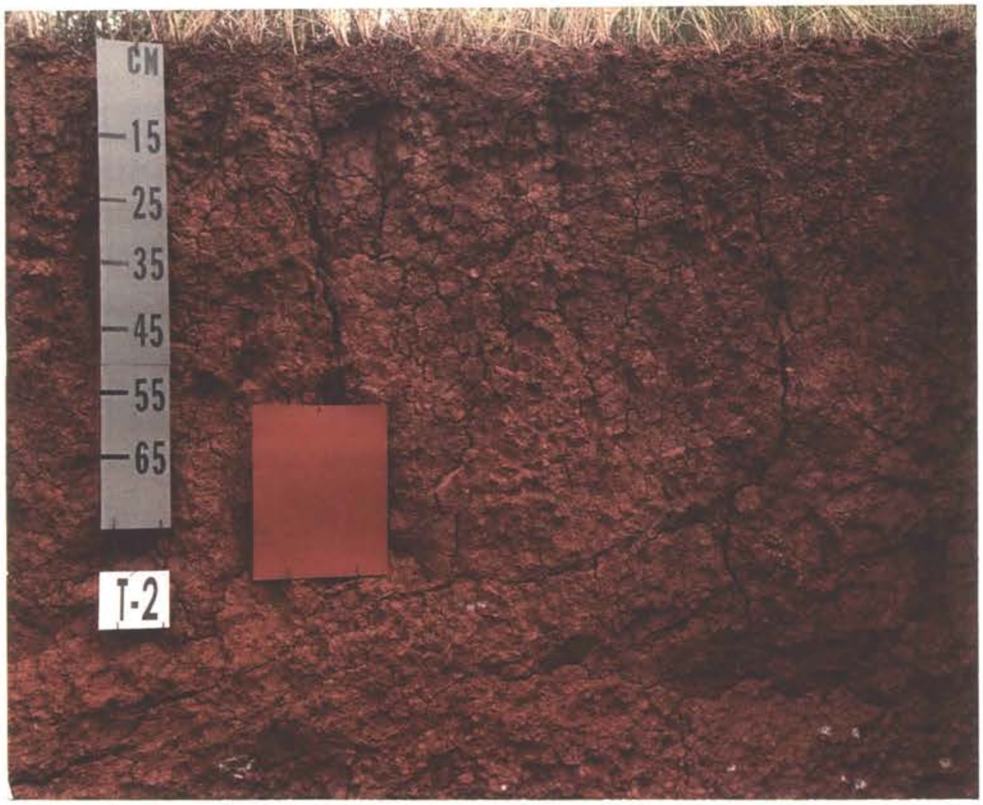

Fig. 2-62. Grainola soil photographed under clouds (F 1/22-32).

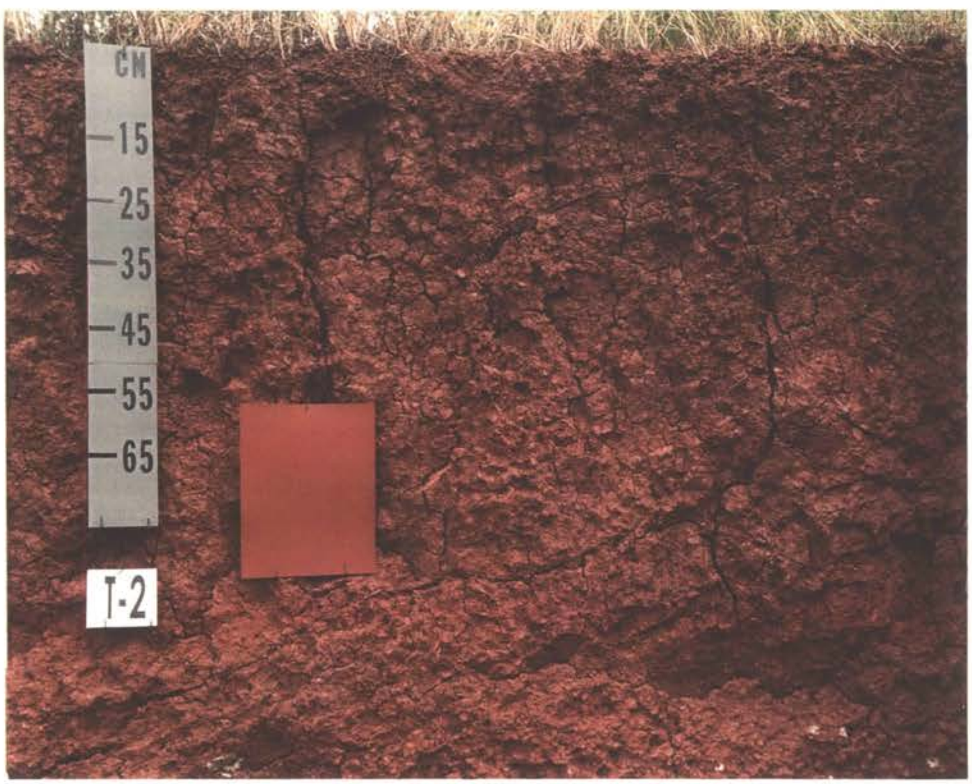

Fig. 2-63. Grainola soil photographed under clouds (F 1/22.3).

4/8 color chip. The Munsell in the print was actually 10R 4/6. Both prints are either one page apart in hue or one unit apart in chroma from the 10R 4/6 Munsell color sheet.

Preparation of the Soil Profile

Although not directly researched for this study, the preparation of the face of a soil profile influences observable soil features and characteristics. In addition to being used for comparisons of times of day, Figures 2-53 to 2-57 represent a soil profile face that has been picked with the tip of a knife. In all five prints, due to the soil profile face being picked rather than smoothed flat, the buried horizon blends in with the horizons above and below. Additionally, the lamellae is not evident. Picking the face of a sandy soil such as Teller with the tip of a knife creates many small reflective peaks and shadowed depression areas, both of which contribute to the blending of the key soil features with the rest of the soil. Subsequent rainfall allowed a re-facing of the Teller soil profile where the profile face was then smoothed flat. Due to the sandy nature of this Teller soil, all other prints used in this study display the soil smoothed rather than picked. It is clear that the appearance of the soil is affected by soil preparation techniques. In the time of day prints (Figures 2-53 to 2-57) where the Teller soil is picked, the lamellae and buried horizon are not well distinguished, blending in with horizons above and below. In all other prints produced in this study where the soil was smoothed (such as Figures 2-9 to 2-11, 2-16, 2-17, etc.), the buried horizon and lamellae (distinguishing features of this soil) were very well expressed.

Night Photography

Figures 2-64 to 2-66 represent the Teller soil for the comparison of photographs taken at night under artificial lighting using Portra 160 NC film. In the Teller soil, different blue filters can give variations in appearance to the same soil as seen in N8/17P1-N1h, N8/17P1-N1e, and N8/17P1-N1b (Figures 2-64 to 2-66). The Meade 80A filter (coded S-2 in the print) (Figure 2-64) was designed for use with telescopes for viewing celestial objects and the night sky. The print N8/17P1-N1h was photographed at F1/5.6 at a shutter speed of 1/10. A Tiffen 80B blue filter was used to photograph the soil in print N8/17P1-N1e (print coded B2) (Figure 2-65) and is a commonly used filter when using Tungsten photoflood lights and daylight film. The print N8/17P1-N1b (print coded D2) (Figure 2-66) was taken using an F-stop of 1/5.6 (+1/3) at 1/10 shutter speed and utilized Tiffen Decamired filters B-1 ½, B-3, and B-6. Of the three prints, the prints which first utilized the Tiffen 80B and then the Decamired filters (in that order) were most representative of the soil's appearance at that time. All three night photography prints utilizing Portra 160 NC film consistently and clearly portrayed the soil's features and characteristics, especially with regards to the many lamellae (not just one lamella as it appears in other prints).

The Munsell appearing in the prints was 7.5YR 4/4. Figure 2-65 (using a Tiffen 80B filter) was the closest match to the 7.5YR 4/4 Munsell color sheet. The Munsell in the print where the Meade filter was used (Figure 2-64) was redder (5YR) with a higher value than the Munsell it represents. The Munsell contained in the print where a Decamired filter (Figure 2-66) was used had a browner hue, a higher value and a lower

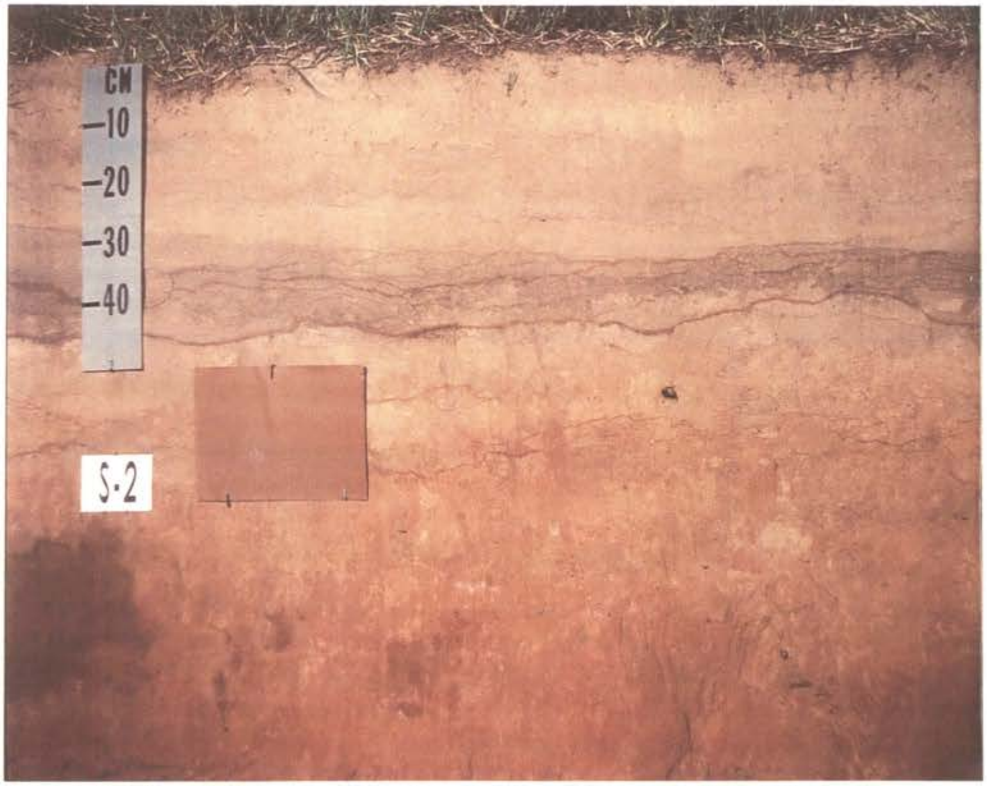

Fig. 2-64. Teller soil at night using artificial lighting and a Meade filter.

Fig. 2-65. Teller soil at night using artificial lighting and a Tiffen 80B filter.

Fig. 2-66. Teller soil at night using artificial lighting and Decamired filters.

chroma than the Munsell it represents (see Figure 2-8).

Figures 2-67 to 2-69 represent the Grainola soil for the comparison of photographs taken at night under artificial lighting using three different filters and Portra 160 NC film. The Grainola soil represented in prints N8/17P2-N2d, N8/17P2-N2e, N8/17P2-N2f (Figures 2-67 to 2-69) were taken using a standard Tiffen 80B filter to correct the color temperature of the Tungsten Photoflood lights to that of daylight film. All three prints were taken using Kodak Portra 160 NC film. The difference between the prints is the aperture and shutter speed settings. The print N8/17P2-N2d taken at F 1/8 with a 1/8- shutter speed results in a brown red hue to the soil. The print N8/17P2-N2e was taken at F 1/5.6 at an 1/8- shutter speed resulting in a red hue to the soil. Print N8/17P2-N2f taken at F 1/5.6 at 1/8 shutter speed resulted in a brown hue to the soil. All three prints clearly represented the soil features, but the soil in Figure 2-68 most accurately represented the actual soil color.

Although the Munsell color sheet appearing in the prints was a 10R 4/6, prints containing the Munsell color sheet most closely matched the 5R page, with the photograph taken at an F stop of 1/8 with an 1/8- shutter speed resulted in the closest visual match to the 10R 4/6 Munsell color sheet.

Color Matching to a Standard

Figures 2-70 to 2-71 represent the Teller soil for comparisons on not color matching versus color matching to a standard using Portra 160 NC film. Figures 2-72 to 2-73 represent the Grainola soil for comparisons of no color matching versus color matching

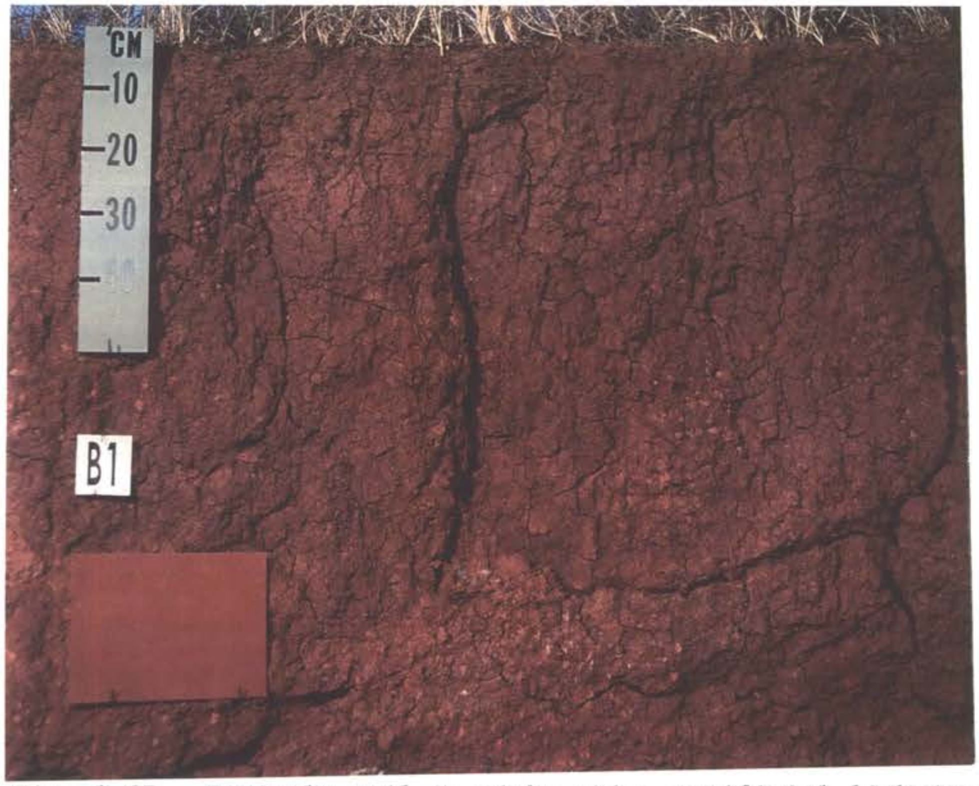

Fig. 2-67. Grainola soil at night using artificial lighting (F-stop = 1/8, shutter speed = 1/8).

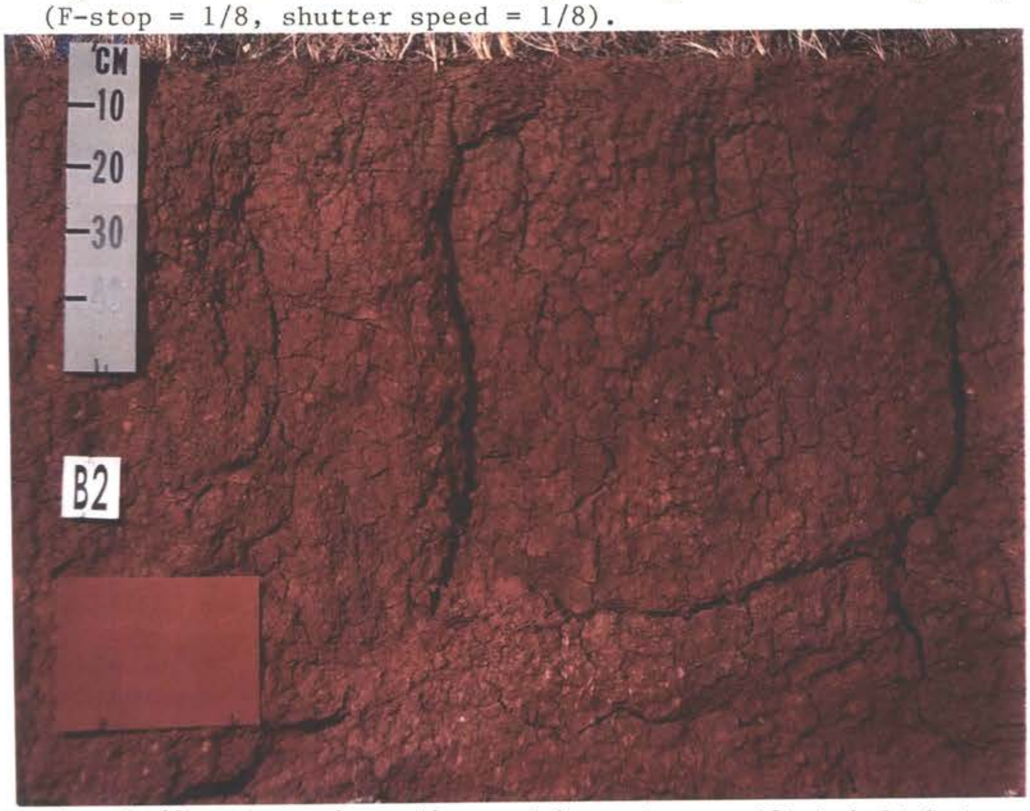

Fig. 2-68. Grainola soil at night using artificial lighting (F-stop = 1/5.6, shutter speed = 1/8-).

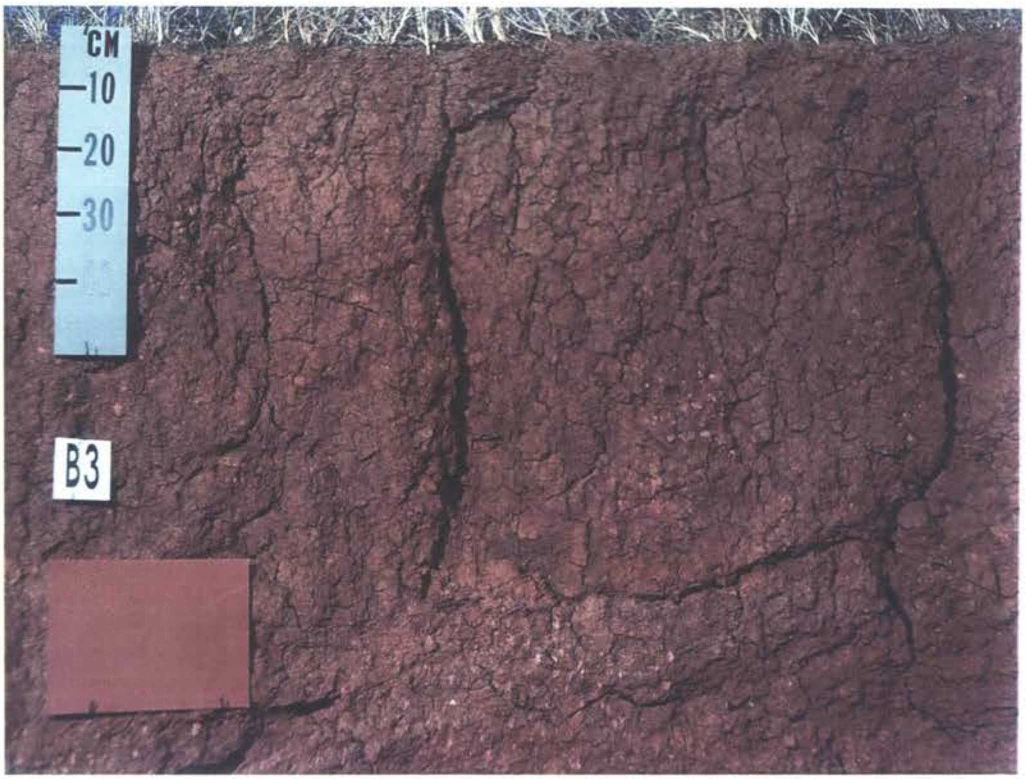

Fig. 2-69. Grainola soil at night using artificial lighting (F-stop = 1/5.6, shutter speed = 1/8).

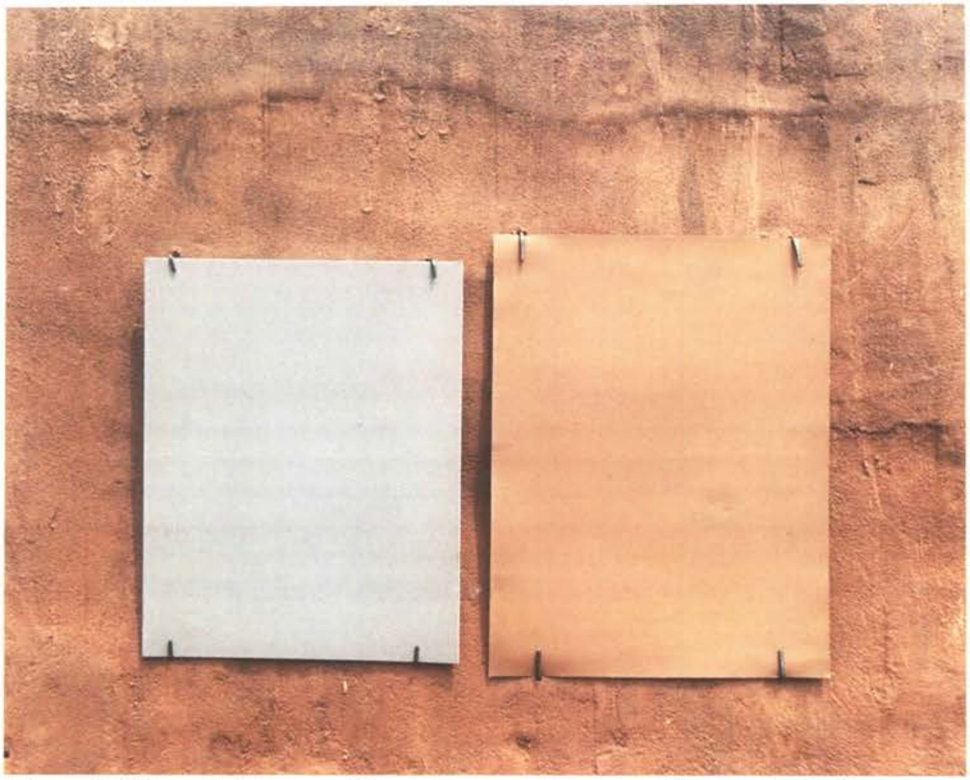

Fig. 2-70. Teller soil photograph not color matched to an 18% gray card.

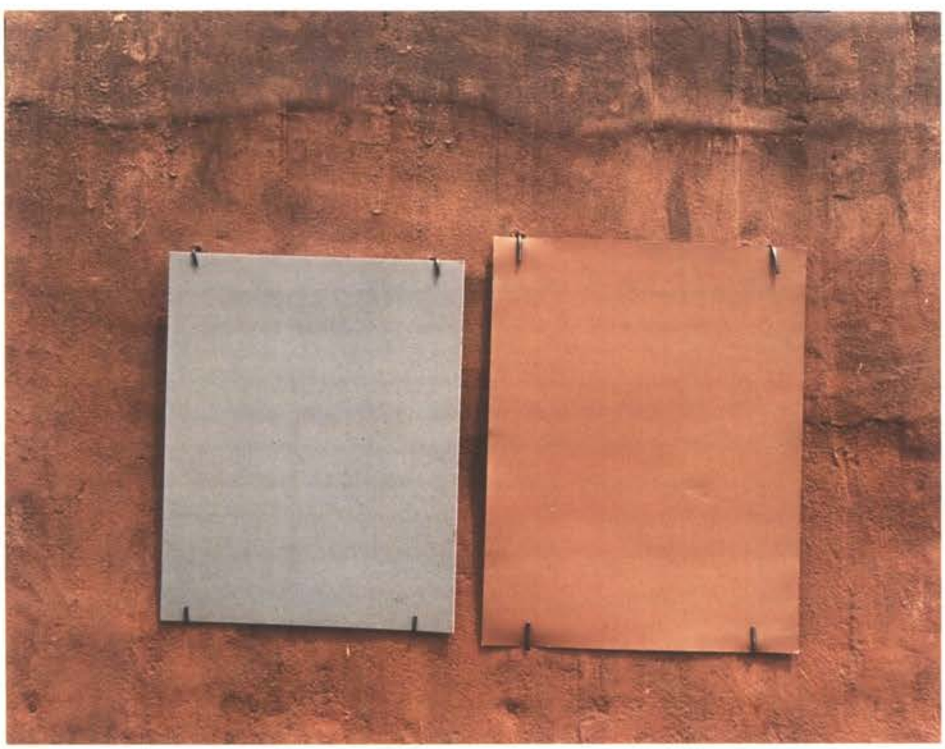

Fig. 2-71. Teller soil photograph color matched to an 18% gray card.

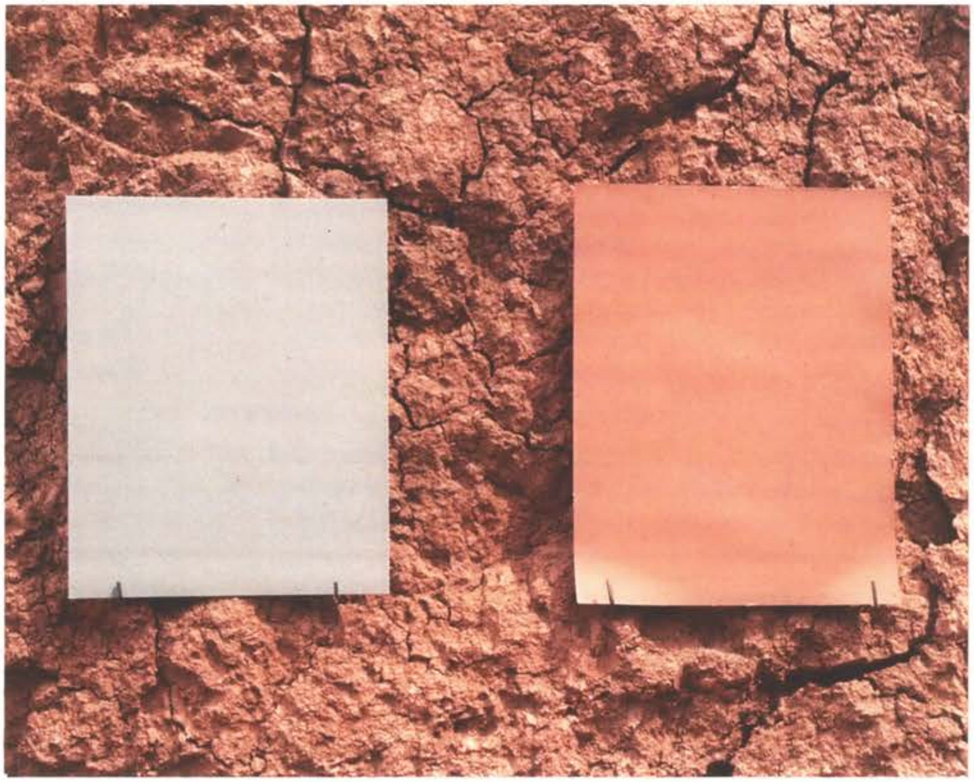

Fig. 2-72. Grainola soil photograph not color matched to an 18% gray card.

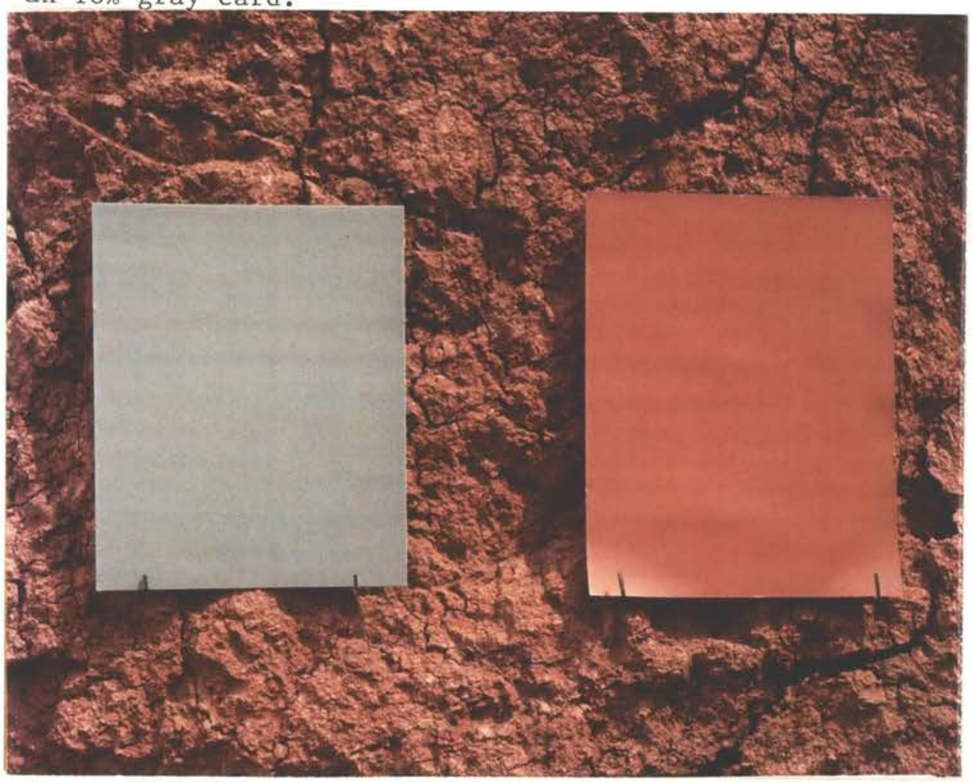

Fig. 2-73. Grainola soil photograph color matched to an 18% gray card.

using Portra 160 NC film. Print C8/4P1-C4a (Figure 2-70) for Teller and C8/4P2-C2a (Figure 2-72) for Grainola were both photographed with their respective Munsell chips which most closely matched a horizon of that soil (7.5YR 4/4 for Teller and 10R 4/6 for Grainola) and were not color-matched. C8/4P1-C3b (Figure 2-71) for Teller and C8/4P2-C2b (Figure 2-73) for Grainola were both color matched to the 18% reflectance gray card appearing in the photograph. The noticeable difference in the soil's appearance in the color matched photographs is the darkening of the colors. The buried horizon and lamellae in the Teller soil (C8/4P1-C4b) are much more obvious and vibrant than their non-color-matched counterparts. The overall hue of the Teller soil changed from a tan to a reddish tan. The vertical water flow marks which appear above the 18% gray card in the Teller soil prints exemplify the sandy nature of the soil profile. The clay nature and high relief of Grainola's soil produces a three dimensional effect. The cracks of this Vertisol soil are much more pronounced in the color-matched print. The color matched prints present the Teller and Grainola soils as seen under field conditions compared to the non-color matched prints.

For visual matching, the Munsell appearing in the Teller soil print that was not color matched (Figure 2-70) had Munsell notation of 10YR 7/3 whereas the color matched print (Figure 2-71) had Munsell notation of 7.5YR 6/4 when the actual Munsell color sheet had Munsell notation of 7.5YR 4/4. For the Grainola soil, the Munsell color sheet appearing in the print that was not color matched (Figure 2-72) had Munsell notation of 10R 7/4 whereas the color matched print (Figure 2-73) had Munsell notation of 10R 6/6 when the actual Munsell color sheet had Munsell notaion of 10R 4/6 (see Figure 2-8).

Both color-matched prints had visually matched Munsell notation closest to the actual Munsell color sheet.

Discussion

Trends in the Hue, Value, and Chroma Components (Figure 2-74)

The term "accurate" is used in the following sections to mean that the Munsell color sheet in the print matched the actual Munsell color sheet.

Figure 2-74 indicates that the chroma component of soil color is most consistently represented and the value component is least consistently represented in photographs of soil profiles. The trend seen in hue indicates a relatively high accuracy compared to value. When the soil hue is inaccurate in prints, it tends to be redder than the actual soil. Both values and chromas, when inaccurate, tend to be higher in these components in prints than the actual soil.

Film

Of the three films chosen for this study, Portra 160 NC film best represented the soil color and features in the prints of the soil as seen under field conditions. However, in comparing the color of the Munsell color sheet in the print to the actual Munsell color sheet, Pro 100 film was most consistent in the print having the same hue and chroma as the standard, and both Pro 100 and Vericolor prints each had more individual components of hue, value, and chroma correctly matched (4) compared to Portra 160 NC (2 component matches) (Figures 2-8 and 2-74).

Figure 2-74

Hue, Value, and Chroma Components of the Munsell Color Sheets in the Prints to the Actual Munsell Color Sheet

		Soil*	Hue**	Value***	Chroma***
<u>Film</u>					
Pro 100	Figure 2-9	T	√	H	√
	Figure 2-12	G	√	H	√
Portra 160NC	Figure 2-10	T	Y	H	√
	Figure 2-13	G	R	√	H
Vericolor	Figure 2-11	T	√	H	√
	Figure 2-14	G	Y	√	√
<u>Distance From Camera Lens to Soil Profile</u>					
95 cm	Figure 2-15	T	√	√	√
98 cm	Figure 2-18	G	√	H	H
200 cm	Figure 2-16	T	√	√	√
192 cm	Figure 2-19	G	√	H	√
240 cm	Figure 2-17	T	R	H	√
241 cm	Figure 2-20	G	√	H	√
<u>Soil Profile Surface Moisture</u>					
None	Figure 2-21	T	R	H	√
None	Figure 2-24	G	R	H	H
300 ml	Figure 2-22	T	R	H	√
500 ml	Figure 2-25	G	R	H	H
+300 ml	Figure 2-23	T	√	H	√
+500 ml	Figure 2-26	G	R	H	√
<u>Aperture and Shutter Speed</u>					
F 1/16-22	Figure 2-31	G	R	H	√
F 1/22-32	Figure 2-32	G	√	H	√
F 1/32	Figure 2-33	G	R	H	√
F 1/32-44	Figure 2-34	G	R	H	√
F 1/44	Figure 2-35	G	R	H	H
F 1/44+	Figure 2-36	G	√	√	√
<u>Angles</u>					
90°	Figure 2-47	T	√	H	√
90°	Figure 2-50	G	R	H	√
60°	Figure 2-48	T	√	H	√
60°	Figure 2-51	G	R	H	√
30°	Figure 2-49	T	√	H	√
30°	Figure 2-52	G	√	H	H

Figure 2-74, continued

		Soil*	Hue**	Value***	Chroma***
Time of Day					
11:30 am	Figure 2-53	T	R	H	H
11:30 am	Figure 2-58	G	√	H	H
12:30 pm	Figure 2-54	T	R	H	√
12:30 pm	Figure 2-59	G	R	H	H
1:00 pm	Figure 2-55	T	√	H	H
1:30 pm	Figure 2-56	T	√	H	√
1:30 pm	Figure 2-60	G	√	H	H
2:30 pm	Figure 2-57	T	√	H	H
2:30 pm	Figure 2-61	G	R	H	H
Clouds					
1/22-32	Figure 2-62	G	R	√	√
1/22.3	Figure 2-63	G	√	√	H
Night Photography					
Meade	Figure 2-64	T	R	H	√
Tiffen	Figure 2-65	T	√	H	√
Decamired	Figure 2-66	T	Y	H	L
1/8, 1/8-	Figure 2-67	G	R	H	√
1/5.6, 1/8-	Figure 2-68	G	R	√	H
1/5.6, 1/8	Figure 2-69	G	R	H	L
Color Matching					
Not matched	Figure 2-70	T	Y	H	L
Not matched	Figure 2-72	G	√	H	L
Matched	Figure 2-71	T	√	H	√
Matched	Figure 2-73	G	√	H	√

* Soil: T=Teller, G = Grainola
**Hue: √ = Hue component of the Munsell color sheet in the print is equal to the hue Munsell notation of the actual Munsell color sheet. Y and R = Hue of the Munsell color sheet in the print is yellower (Y) or redder (R) than the actual Munsell color sheet.
***Value and Chroma: √ = Value (or chroma) component of the Munsell color sheet in the print is equal to the value (or chroma) notation of the actual Munsell color sheet. H and L = Value (or chroma) of the Munsell color sheet in the print is higher or lower than the value (or chroma) notation of the actual Munsell color sheet.

For soil-related interpretations based on soil mineralogy, oxidized zones of redoximorphic (or wetness class) features, and organic matter content, all three components of hue, value, and chroma are considered. None of the three films were accurate in all three components of hue, value, and chroma. Color components of the resultant Portra 160 NC and Vericolor film prints tended to change based on the soil photographed. Pro 100 film was consistently accurate or high depending on the color component. None of the three films were accurate in hue and value (Figures 2-8 and 2-74), although Pro 100 film was consistent in each component for accuracy in hue and chroma and high values for both soils. Pro 100 film was the most accurate of the three films in both hue and chroma (Figures 2-8 and 2-74), whereas the hue and chroma components using Portra 160 NC and Vericolor films varied with the soil photographed.

For soil-related interpretations based on depletion zones of redoximorphic (or wetness class) features, the component of hue is most critical. Hue was consistently accurate in the Pro 100 prints and changed with the soils photographed in the Portra 160 NC and Vericolor prints (Figures 2-8 and 2-74).

For interpretations based on lightness and saturation difference, such as criteria used to distinguish epipedons, the components of value and chroma are most critical. Consistently accurate values and chromas were not found in any of the three films (Figures 2-8 and 2-74). Value and chroma in the Portra 160 NC and Vericolor prints varied with the soil photographed. Pro 100 film was most consistent in these components for both soils.

Munsell color sheets are a large version of the color chips found in Munsell Soil Color Charts, which are used for field description of soil color. Assuming the Munsell color sheet is an accurate representation of soil color, Pro 100 film is more accurate in presenting soil color and saturation (hue and chroma) (Figures 2-8 and 2-74) than Portra 160 NC or Vericolor films. Pro 100 film, however, results in too light (high values) a soil.

Use of Vericolor film on a brown soil such as Teller, has similar effects in value as the Pro 100 film, so the same camera adjustments as mentioned above are recommended. Use of Vericolor on red soils is not recommended as the resultant soil in the print produced is brown rather than red hues. Lightness and saturation (value and chroma) of red soil are accurate, however. The difference in hue would affect mineralogical, organic matter content, genesis, classification, and particle size interpretations made on the print of the photographed soil.

Use of Portra 160NC film on brown (Teller) soil resulted in a more yellow and too light of a hue than the actual soil, a redder and more saturated hue of the Grainola image than the actual soil. Based on the Munsell comparisons, Portra 160 NC film is not recommended.

However, based on qualitative features as seen under field conditions as stated earlier, Portra 160 NC film was chosen as the prints with soil features and characteristics most accurately displayed. After viewing the soil in the film comparison prints, the researcher (also the photographer) conducting this study chose Portra 160 NC film as the best representative print of the soil under field conditions at the time of the photographic session. The memory and eyesight of the photographer is subjective and prone to human error, however.

Based on this study, Pro 100 film would be recommended for accurate color and Portra 160 NC film would be recommended for accurate portrayal of the soil features.

Pro 100 and Vericolor color negative film (Eastman Kodak Co.) film were discontinued after this research had begun. The Portra (Eastman Kodak Co.) family of films are being developed to eventually replace other Kodak films. The Portra (Eastman Kodak Co.) family is designed so that various speeds of the same family will look the same (Color Chrome, 2000).

Films are discontinued, and new films that may have different color qualities, are substituted by the manufacturer. Choosing the best film, then, also depends upon what the market offers at that time. Although films may change, consideration must be given to the film chosen. Ideally, test batches using different films on the same soil should be carried out and photographs bracketed at partial F-stops above and below the light meter recommendations. Equally important, is the recording of the film name, speed, manufacturer, and the color-imparting qualities of the film, if known. Subjectivity and eyesight of the individual (s) evaluating the photographic image must also be considered to ensure that the photographic image most accurately represents the field soil.

Distance From Camera Lens to Soil Profile

The closest distance from camera lens to the soil profile displayed the most detail of the soil features and characteristics. However, not all of the features and characteristics of the two soils represented in this study can be seen in the close-up prints such as depletions (in the lower horizons) or structure change with depth. Soils of the Teller soil series are very deep (>150 cm) soils. Soils of the Grainola soil series are moderately deep (50-100 cm) soils. Shallow (< 25 cm) and moderately shallow (25-50 cm) soils would be well-represented at close distances between the camera lens and soil profiles, as all the key features and characteristics would be within view. Comparing the color of the Munsell color sheet in the print to the actual Munsell color sheet, the moderate distance (192-200 cm) prints were more consistent, and the farthest distance least consistent, in the print having the same hue, value, and chroma components as the standard (Figures 2-8 and 2-74).

Hues, values, and chromas, collectively, varied with the soil photographed (Figure 2-74). No distance was consistently accurate for both soils in all three components, although the moderately close distance was most accurate (Figures 2-8 and 2-74). For hue and value both matching between the print and the actual Munsell color sheet, the moderate and close distances were most accurate compared to the far distance, although no distance was consistently accurate for both soils (Figures 2-8 and 2-74). For hue and chroma both matching between the print and the actual Munsell color sheet, the moderate distance was accurate. The closest and furthest distances were equal in total hue and chroma components (Figures 2-8 and 2-74). Hue was consistently accurate in prints representing the moderate and close distances (Figures 2-8 and 2-74) for both soils. The hue of the soil becomes redder with increased distance between camera lens and soil profile.

Values were not consistently accurate with any one distance (Figures 2-8 and 2-74). At all three distances, values and chromas of soils in photographs, when inaccurate, will tend to be greater than the actual soil.

The Teller soil displays greater accuracy in the hue, value, and chroma components collectively at the moderate and close distances, whereas the Grainola soil displayed a greater accuracy in the three components collectively in the moderate and far distance prints (Figure 2-74).

Both the Teller ("brown colored" soil) and Grainola ("red colored" soil) were consistently accurate in hue and chroma at lens-to-profile distances of 192-200 cm (Figure 2-74). However, the 95-98 cm distance shows more detail of individual features. Additionally, the 240-241 cm distance allows for all of the soil horizon's, features, and characteristics to be viewed.

The soil solum (soil above the C horizon) of the soil being photographed should be the gauge as to what distance from (and area of) the soil profile is adequate for a given soil. The depth of the solum plus 25% of the solum depth should be the lowest depth in the photograph. The additional 25% of thethickness of the solum is included to capture soil characteristics which exist in the C horizon. Use of the soil solum plus 25% of solum thickness would ensure that profile development including pedogenic features be included. This would allow for a consistent area photographed (always the solum plus 25% solum thickness) that would include all of that soil's key features and characteristics. The lower boundary of the taxadjunct to Teller soil photographed for this study did not extend down to the C, but to a B horizon lower boundary of 147 cm. Based on the proposal of photographing soil profiles by soil solum plus 25% as described above, the entire length of the 147 cm would be photographed. The C horizon upper boundary for the taxadjunct to Grainola soil photographed for this study began at 140 cm. Based on the use of the solum as described above, 175 cm of soil depth would be photographed. Soils should be photographed at the distance needed to display the features and characteristics that separate one soil from the next. Distance specifics should be recorded and accompany all photographs published.

Using the soil solum plus 25% may result in the loss of some very deep soil characteristics. Supplementary photographs of close-up features, for example, can accompany the primary photograph, so long as the recorded information as named within these pages, accompanies those photographs as well. Additional photographs can be included that show close-up detail of key features, but these photographs should accompany, not replace the soil solum plus 25% photographs.

Soil Profile Surface Moisture

Water was sprayed on the soil profile, not on the Munsell color sheets, so the Munsell in the prints should have remained the same for all the prints of that sequence. The Munsell in these prints are included in tables and discussed only as an aid in understanding the changes in color from field to photographs. The Munsell color sheet was removed from the soil profile prior to spraying the soil profile with water, then re-positioned after spraying. Changes in the color components of hue, value, and chroma as seen in Figures 2-8 and 2-74 are attributed to other factors such as unstable lighting, inaccurate camera settings or light meter readings. However, the Teller and Grainola sequences were photographed on separate days. Hue is consistently redder by one hue page which is inconsistent in Portra film for the Teller soil, but consistent for Portra film in Grainola soil (see Film section). Value was consistently high by one to two units in all six photographs, which is inconsistent with the Portra film used on Grainola soil (see

Film section). Chromas agreed with the results as stated in the Film section in that chromas were accurate when using Portra 160 NC film on Teller soil, but high when using the same film on Grainola soil (see Film section).

The Teller soil prints displayed more accuracy in hue, value, and chroma components collectively, compared to the Grainola soil (Figure 2-74). This is consistent with this entire study in which, overall, there was more accuracy in the brown colored Teller soil than the red colored Grainola soil. Overall, the Munsell color sheet appearing in the prints measured consistently, which was expected.

Soil surface moisture affects the overall soil color seen which could, in turn, affect interpretations based on color difference, soil moisture, organic matter content, and mineralogy. Color differences in the soil of the prints are noticeable, where the soil appears darker with increased moisture. When water is sprayed on the soil profile, it should be noted as to the amount (ml) sprayed over what area and when (relative to photographing the soil). Spraying the soil profile darkened the soil color enough to advise caution when spraying soil profiles for photographic purposes in that soil color will darken.

Aperture and Shutter Speed

The Grainola print obtained with the smallest aperture opening (Figure 2-36) was accurate in all three components of hue, value, and chroma (Figure 2-74). All photographs of soil (when using Portra 160 NC film) can be expected to be either accurate or redder in hue, and accurate or high in value or chroma than the actual soil. For hue and chroma, the Grainola print of Figure 2-32 representing a relatively large aperture opening as well as Figure 2-36 representing the smallest aperture opening, measured accurately in both components (Figure 2-74). For hue and value, only the smallest aperture opening of Figure 2-36 resulted in accuracy in both components (Figure 2-74). Hue was accurate only in Figures 2-32 and 2-36 as mentioned above (Figure 2-74). The aperture opening that resulted in the correct notation of the Munsell color sheet was the smallest opening of 1/44+ that resulted in a dark brown soil. The actual soil, however, was much redder. Camera settings of F-stops and shutter speeds affect the overall soil color seen which could, in turn, affect interpretations based on color difference, organic matter content, and mineralogy.

Aperture and shutter speed settings used to obtain the corresponding print should be recorded and accompany all published photographs. Proper light meter readings should be obtained just prior to shooting each photograph, then bracketed (1/3 to ½ stops) above and below what the light meter determines is the correct exposure. Aperture settings of F 1/16 and F1/22 have been recommended for photography of uneven textured walls such as soil profiles. Light meter readings normally suggest aperture and shutter speed combinations that are required for proper exposure. Rules of equivalent exposure allow the photographer to choose a different aperture opening and shutter speed combination that is equal in the amount of exposure the film receives (Burchfield et al, 1997; Neblette and Murray, 1973).

Filters

Yellow filters should not be used in color photography of soil profiles of which accurate soil representation is the objective. There are no recommendations offered in this section as to which specific filter (skylight, haze, diffusing, or no filter) is best to use on red versus brown soils, as each of these filters used in this study imparted some visual benefit.

Filter use should be recorded as to the type of filter used (and where it was positioned (attached to the camera lens versus attached to the lighting). Attachment to the camera lens is recommended for consistency in positioning. Filter information should accompany the corresponding published photographs.

Angles

None of the measurements for angles were accurate in the three components of hue, value, and chroma, nor was any angle accurate in both hue and value. For hue and chroma both matching between the print containing the Munsell color sheet and the actual Munsell color sheet, none of the angles studied were consistently accurate. The Teller soil was consistently accurate in hue and chroma for all three angles studied (Figure 2-74). Photographs of soil profiles will tend to have accurate or redder hues, higher values, and accurate to high chromas than the actual soil. Hue was consistently accurate in prints for both soils representing the 30° angle and all three Teller soil prints (Figure 2-74). No angle studied was accurate in both value and chroma (Figure 2-74) although values were consistently high.

Figure 2-74 indicates that soil photographed at a 30° angle will result in more accurate soil color than 60° or 90°. However, for the best expression of key features and characteristics, soil profiles should be composed with the camera centered vertically and horizontally to the soil area photographed. The lens to soil profile should be positioned at a 90° angle to ensure the least distortion of the soil features and the area photographed. If other camera positions are required, (due to limitations imposed by the location of the soil excavation), they should be noted and submitted along with the corresponding print. Otherwise, it should be assumed that the photographs were taken 90° from lens to soil profile and centered horizontally and vertically to the soil area to be photographed.

Time of Day

None of the measurements for any one time of day were accurate in all three components of hue, value, and chroma, nor was there accuracy for the two components of hue and value. For hue and chroma, the Teller print representing 1:00 pm was accurate (Figure 2-74). Regardless of the time of the day photographed, photographed soils can be expected to have higher values than the actual soil. Chromas in photographs of soils are expected to be accurately represented or higher in chroma than the actual soil, whereas hues are expected to be accurately represented or redder than the actual soil. Hue was consistently accurate in prints representing 1:00-1:30 pm for both soils (Figure 2-74). No time of day was accurate in both components of value and chroma (Figure 2-74).

The Teller soil displayed more accuracy in the collective components of hue, value, and chroma (Figure 2-74). The times of 1:00-1:30 were chosen under field conditions as the best time (least shadowing) to carry out the remaining photography (other treatments) for the Teller soil. For the least shadowing in the Grainola soil, 1:30-2:00 was chosen. More accurate color components at these times as seen in Figure 2-74 reinforce the choices made under field conditions.

The best time of day chosen to photograph soil is that time period resulting in the least shadowing on the soil profile face. This time will change with location (township and range, latitude and longitude) and time of year. Ideally, preliminary daytime photographs should be taken centered on and before and after the time the sun is directly illuminating the soil to be photographed.

However, the resultant prints do not conform to the scientific tenet of reproducibility as daytime conditions are unstable and are everchanging. The best time to photograph soil profiles is under controlled lighting. In lieu of night photography using artificial lighting under an open sky, the soil profile can be enclosed by a black light tight tarp or enclosure and artificial lighting can then be used during daylight hours. Only night photography or enclosing the soil profile and using artificial lighting will produce conditions that are repeatable and conform to the scientific tenet of reproducibility. Time of day information should be recorded (Figures 2-5 and 2-6) and submitted along with the corresponding print.

Preparation of the Soil Profile

Although they were not factors specifically chosen for this study, the techniques (picking versus smoothing) used to prepare the soil profile can affect whether distinguishing features are visible. Picking the soil profile resulted in key soil features being less visible as compared to the same soil smoothed flat as seen in the Teller prints for time of day.

Clouds

Neither of the prints representing cloudy conditions were accurate in all three components of hue, value, and chroma, nor was either print accurate in the two components of hue and chroma. For hue and value both accurate, one of the two prints was accurate in both components. One of the two cloud prints displayed accuracy for both components of value and chroma. The difference between photographing the two prints was a fraction of an F-stop. Figure 2-74 indicates that uniform shade on the soil profile aids in accurate values. As seen in Figure 2-74, only the cloud factor consistently had correct values. Consistent with most other factors studied, hue tended to be accurate or redder, chroma tended to be higher than the actual Munsell color sheet and are expected to have the same effect on the actual soil.

Cloud cover imparts a uniform appearance to the soil, a condition that promotes a clearer display of soil features and characteristics. However, cloudy conditions including density and coverage vary and are not controllable.

Night Photography

None of the night photography prints were accurate in all three components of hue, value, and chroma, nor did any of the prints measure accurately for both hue and value. For hue and chroma, the print representing the Tiffen 80B filter of the Teller soil was accurate in these two components. Hue was accurate in the print representing the Tiffen 80B filter of the Teller soil. None of the night photography prints were accurate in both components of value and chroma.

Use of the Tiffen 80B filter resulted in more accuracy in color components than the Meade and Decamired filters and is expected to have the same effect on soil color. Both F-stops of 1/8 and 1/5.6 are acceptable for correct soil feature portrayal. The Tiffen 80B filter and either F-stops are recommended for use with Tungsten photoflood lights when photographing soils at night with no enclosure.

Soil features were best displayed using artificial lighting. However, lighting was not compared for this research, so no recommendations can be made on accurate color representaion using artificial lighting, or how to attain soil color representative of field conditions when photographing soil at night using artificial lighting. Since blue filters were used attached to the camera, the effect of artificial light on the soil profile was what was observed at the time of the photographic session.

Color Matching

None of the measurements for any of the four prints were accurate in all three components of hue, value and chroma, nor were any of the prints accurate in the components of both hue and value. For hue and chroma, both color matched prints were accurate in these two components. Figure 2-74 indicates that soils of non-color matched prints may result in yellower hues (in brown soils), higher values, and lower chromas than the actual soil. Hues and chromas were consistently accurate in both color-matched prints. None of the four prints were accurate in both components of value and chroma. Color matching to an 18% gray card resulted in more consistency and accuracy than the non-color matched prints (Figure 2-74). The Grainola soil displayed the most accuracy in components of hue, value, and chroma collectively.

The color-matched prints were all high in value regardless of whether they were color-matched. The unmatched prints for both the Teller and Grainola soils were low in chroma. The matched prints for both soils were accurate in both hue and chroma. The proximity of the camera lens to the soil profile was close (92-97 cm) for these four prints, at approximately the closest distance used for the distance from camera lens to soil profile sequence of prints. Soils would be expected to have more accurate portrayal of color when color matched to a standard.

For making individual color prints, asking that prints be color matched to a standard to ensure accurate color rendition is not consistently requested by all soil photographers. Color matching is a technique that should be requested at the time the film is submitted to the film processing laboratory. A standard must appear in a photograph in order for the color processing laboratory to attempt to match the photograph color of the standard to the actual standard. Changing the color of a photograph that contains a standard to accurately match the actual standard changes all of the color in the photograph to a truer observed color than when a color matching request is not requested. If the standard in the photograph were color matched to the actual standard when using color filters, the effect of the filter would be negated or exaggerated. Therefore, color matching cannot be carried out when color filters are used due to a neutralizing effect.

Color matching to an 18% reflectance gray card is advised. To fulfill this requirement without cluttering the photograph, the gray card should be incorporated as a measuring tape as was done in this study. The measuring tape should be large enough to allow measurement by the film processing and print making laboratory.

Information on whether or not the print was color matched to a standard should accompany the corresponding print. All pertinent information should be recorded and accompany photographs submitted for publication.

Factors and Error

The shutter speed was usually held constant at 100, leaving the F-stop as the varying camera setting (using equivalent exposure). Light meter readings, therefore, often suggested F-stop settings that were between the marked F-stops of the camera. Approximations were then necessary, and resulted in the use of fractions (or decimals) of F-stops and plus (+) or minus (-) signs when the recommendation was slightly above or below a designated number. Human error is a possibility. The film comparisons of the Teller soil are one example where the Pro 100 film (Figure 2-9) and Portra 160 NC film (Figure 2-10) prints were obtained using a 1/16+ F-stop setting whereas the Vericolor film (Figure 2-11) print was obtained using a 1/22.5 F-stop setting. The darker colors of the grass and gray card are possible indications of less light reaching the film. However, these were the settings (equivalent exposure adjusted) recommended by the light meter. Other sets of photographs comparing films in which there was no change in F-stop also displayed similar significant color differences between films, so the film comparisons are valid.

Errors associated with slight changes in lighting conditions should be avoided by using controlled lighting conditions in which the lighting remains the same through out the photographic session. Artificial lighting usually requires 15 minutes of "warm up" time for the lighting to stabilize. Beginning the photographic session after the lighting has stabilized ensures consistent, uniform illumination and error associated with partial F-stop or shutter speed settings can be avoided. Using controlled lighting, only one light meter reading would have been needed rather than one for every photograph. The closest designated F-stop and shutter speeds should then be used for all subsequent photographs of that photographic session. It is advised to bracket above and below the suggested F-stop.

The uneven surface topography of the soil profile is not conducive to relying solely on visual assessments of the soil color in prints. For this reason, evaluating the Munsell color sheet which most closely matched an horizon in each soil profile was used. Since Munsell color sheets and chips are used to determine field measurement of soil color, use of the Munsell sheets to assess color difference is an acceptable means of equating those differences to changes that can be expected in soil color.

Munsell color sheets are made of paper/card stock with a uniform film of paint covering the sheet. Soils are comprised of individual particles, reflecting and absorbing light differently than the Munsell sheet. The advantage to using the Munsell sheets are that they are flat, uniform in color, and large enough to visually compare Munsell color sheets appearing in prints to the small chips in Munsell Soil Color Charts.

The uneven topography of the soil profile face results in many shadowed parts in prints of the soils. Shadowed areas appearing in the prints are often black or dark brown and are not the color of the soil. These shadowed areas make it impossible to visually compare soils in the prints to the color chips in Munsell Soil Color Charts.

One way of assessing soil color directly (without the aid of Munsell color sheets) for comparative purposes as used in this research would be to smooth an area of soil on the soil profile the same size (or larger) as the Munsell color sheet. The soil areas smoothed would need to be field determined to have all the soil in the chosen area the same Munsell notation. The chosen soil area would then be marked or framed in order to easily identify the same area in subsequent photographs. The soil area chosen should have the same field determined Munsell notation in all parts of the designated framed or marked soil area. Additionally, the soil in this area must be smoothed flat to eliminate all shadows attributed to uneven topography. A buffer strip of smoothed soil around the designated area is recommended to eliminate shadows caused from soil overhanging the designated area. This smoothed area could also be used for spectrophotometric readings, if available.

Only one Munsell color sheet sheet appeared in most photographs. Different Munsell color sheets could represent other Munsell colors and could measure equally in color differences from field to photographs (as the Munsell color sheets used for this study). Several different Munsell color sheets, each matched to a particular horizon and all appearing in the same photograph may be a better way to evaluate if different colors appearing in the same photograph would change equally given the different factors studied for this research. Several horizons (or layers) of different color, structure, and texture combinations comprise a given soil profile. Determining if all soils that create a profile would change equally in color values from field to photograph would aid in the objective of accurate representation of the soil resource.

The measuring tape made from an 18% gray card that appears in most prints should have been matched to the actual 18% gray card by the film processing and print making laboratory (Color Chrome) as this service was requested. All the measuring tapes should be close with regards to lightness and darkness. By adjusting the measuring tape in the print to match the actual 18% gray card, the reasoning was to provide a control or something in the photograph that remains the same. By adjusting the color of the measuring tape in the print to the actual gray card, colors of the rest of the print change accordingly. Matching the gray card to itself provides a point of reference from which to compare color differences in the rest of the print.

Film processing and print making laboratories can match any standard appearing in the prints, so long as the actual standard is provided prior to print making. The standard is matched both visually and with the aid of a densitometer. In some photographs however, such as Figure 2-14, it appears as though the gray card was not matched. It is suggested therefore, when matching to a standard, that small batches of prints be completed at a time. Small batches of twelve photographs or less would allow for better control to eliminate wasted time, money, and supplies when several incorrectly matched prints are produced. Small batches would enable quick comparisons to ensure that batch was done correctly.

When Vericolor film was used and the measuring tape in the print did match the measuring tape in the prints representing Portra 160 NC and Pro 100 film, color differences attributed to the different film chosen as mentioned in the Results section, were apparent.

Numerous prints containing the measuring tape made of the 18% gray card are not expected to exactly match due to slightly different angles the measuring tape was set at for each photograph taken, since the measuring tape was removed at the end of each photographic session. Photographic sessions occurred on different days, so removal of all materials from the soil profile was carried out to minimize exposure to the elements (wind, dust, dew, rain, etc).

Some discrepancies were seen between the Munsell color sheet seen under field conditions and what is seen in the resultant prints. The Munsell color sheets photographed were not rigid and the soil profile surface was often irregular. The slight bending of the Munsell color sheet in order to fasten it to the soil profile resulted in a tonal difference in sheet color. This tonal color difference was not witnessed by the photographer at the time the photographs were taken. However, the film, being more sensitive than the human eye, was able to distinguish color differences due to slight curvature. These color differences can be seen in the closest distance prints of the Teller and Grainola soils (Figures 2-15 and 2-18, respectively), the Teller soil Time of Day prints (Figures 2-53 and 2-54), the Grainola Time of Day prints (Figures 2-58 through 2-61), the Grainola prints representing cloud conditions (Figures 2-62 and 2-63), and the color-matched prints of the Grainola soil (Figures 2-72 and 2-73).

Care must be taken when mounting the non-rigid material to ensure the adhesive used does not bleed through the paper and change the color of the standard. Tonal differences created by the curvature of the non-rigid Munsell color sheet can be safely eliminated by ordering these sheets pre-mounted to rigid cardstock material.

CHAPTER III

SPECTROPHOTOMETRIC COMPARISONS FROM FIELD TO PHOTOGRAPHS

Introduction

Visual color matching is one method of identifying color differences. Traditionally, visual field measurement of soil color has been accomplished with the aid of Munsell Soil Color Charts, where soil samples are positioned to show through the cut-out window located under each color chip (Bigham and Ciolkosz, 1993). Soil samples are then matched to the chip closest in color, and the corresponding hue, value, and chroma designation of the color chip are recorded. A soil viewed at 6 different times per day under changing daylight conditions is expected to match the same Munsell color chip since both the Munsell color chip and the soil profile are under the same changing light conditions. Soil particles such as sand grains have varying reflectance and absorbance values due to the conglomerate assemblage of parent rocks and minerals. The amount and intensity of light on the soil profile and the Munsell chip also affect appearance.

The human eye responds to differences in lighter colors more than changes in saturated colors. This lack of uniformity in what is perceived in color space presents difficulties in measuring color differences (Larish, 1992). Perceived color is influenced by the colors of the surrounding environment. How an object is illuminated and viewed directly affects the object's appearance (ASTM: E1767-95, 1998). An object seen as one apparent color appears to be a different color when viewed under different lighting conditions. Apparent color depends on the type of light, the reflectance (Melville and Atkinson, 1985), absorbance, and luminescent qualities imparted to the surface of the object. In practice, very few samples, a pair of which have tristimulus (X,Y,Z) values that are the same at any one matching condition (illuminant and observer), will look the same to any observer under any light source. Also, samples that should theoretically be the same, may have substantial differences in their numerical ((X, Y, Z) tristimulus) values and also in the perceived color sensation. Factors such as specular (gloss) reflection on ped faces and the presence of non-planar surfaces affect the reproducibility and the interpretation of data.

Obtaining numerical values derived from instrumental measurement is another method of identifying soil color. Instrumental measurement of color is often relied upon as a repeatable method of obtaining numerical values which eliminates variability in perceived colors between individuals and acceptably represents colors observed. Instrumental measurement of color or color difference consists of five parts including identifying the nature, source, and form of the samples being measured, naming the instrumental specifics and spectral properties of the illuminant and receiving bodies, identifying the standards, if used, listing the procedures followed, and naming the trichromatic color scales used (ASTM E 805-94, 1998). Several instruments are available which measure various components of color. Measurement of color is often carried out with the aid of instruments such as chroma meters, colorimeters, goniophotometers, spectrocolorimeters and spectrophotometers. Spectrophotometers, often used to measure reflectance as a function of wavelength (Hunter, 1975), are the most direct method for obtaining color difference data (ASTM E1347-97, 1998; ASTM E1164-94, 1998). Spectrophotometric measurement requires the determination of the reflectance factor or transmittance, the geometry of illumination and viewing, the spectral parameters such as wavelength range, measurement interval and spectral bandpass, identification of a standard reflectance factor, if used, the computation variables including the standard observer and standard illuminant, and the special requirements determined by the nature of the specimen (such as the type of illuminating source for fluorescent specimens) (ASTM E 1164-94, 1998).

Spectrophotometers do not measure the color of the illuminant of the surrounds (spectroradiometers do) (GretagMacbeth Seminar, 2000). The internal software in spectrophotometers contains numerical data on the various illuminants and observers obtained from years of data collecting around the world. When an illuminant and observer are selected (externally) on the equipment, the instrument internally selects the numerical spectral data associated with the chosen combinations. A microprocessor breaks down the wavelength of the sample and the spectrophotometer internally generates the reflectance data.

Spectrophotometers are used for the visible spectrum of approximately 400-700 nanometers (nm). The ratio of the amount of light reflected divided by the amount incident is the reflectance of a surface, a value between 0-1 which can be determined with the use of a spectrophotometer. The reflectance is determined for as many wavelength regions as the analytic situation requires, since reflectance measurements for the six spectral regions do not necessarily define the color of the reflecting surface with precision (MacAdam, 1985).

Instrumental measurement of color generates spectral reflectance output which is then converted to three figures (referred to as X,Y,Z tristimulus values) that define the color perceived by the human eye. Tristimulus values are the amounts of three values required to give a match with colored stimulus considered, in a given tristimulus system. Use of spectrophotometers allows quick measurements of reflectance which readily converts from one color system to another. Tristimulus values can then be converted to Munsell notation (whose variables are scaled to represent uniform color space) or other color systems.

Regardless of whether color measurements are visual or instrumental, the illuminant is an important consideration when measuring or observing color. A color temperature of sixty-five hundred Kelvin (6500 K) is received from the sun outside the earth's atmosphere. At an average rate of 0.135 watts/cm^2, 75% reaches the earth's surface at sea level on a clear day. The illumination of the earth's surface by the sun is > 10,000 foot candles (Kaufman and Christensen, 1972). Cloudy days produce <1,000 foot candles. The moon shining is reflected sunlight with illumination of 0.01 foot candles. Physically, light waves are the same as x-rays or radio waves, differing from them only in wavelength (Hunter, 1975). Visibility to the human eye distinguishes light waves from other electromagnetic waves.

Light leaving an object surface is either reflected or transmitted by the object. Reflected light leaves the object from the same side as was illuminated, and transmitted light exits the opposite side after penetration through the specimen. Light transmission and reflection from objects are then divided into four main types of light distribution: diffuse reflection, specular reflection, diffuse transmission, and specular transmission

(Hunter, 1975). The six areas of the visible spectral region and their respective wavelength ranges include violet (400-450 nm), blue (450-490 nm), green (490-560 nm), yellow (560-590 nm), orange (590-630 nm), and red (630-700 nm) (MacAdam, 1985). The human eye is most sensitive to light at about 550 nm and is insensitive to radiation outside the visible spectrum (MacAdam, 1985).

Photographs of soil profiles are often poor representatives of the soil actually seen in the field. The surface of a soil is rarely smooth. There may be apparent color differences between the soil observed under field conditions and subsequent photographs of the same soil. Soil is made up of individual particles of different minerals, each with varying reflectance and absorbance values that fluctuate greatly over very short distances. Numerical output from spectrophotometric readings of a soil vary greatly due to both the differences between the organic and mineral constituents of the soil and the non-planar soil surface. Inconsistent readings do not make valid comparisons for color difference. Munsell Soil Color Charts are an accepted standard used for field measurement of soil color. Evaluating apparent color difference in the color of a large (22 x 28 cm) Munsell color sheet under field conditions, then photographed, is an acceptable method which can be used to extrapolate apparent differences in the Munsell to simultaneous apparent differences in soil color from field to photograph.

The objective of this study was to evaluate color difference from field to photograph using comparisons between spectrophotometric and visual measurements. The justification is that instrumental evaluations of what was captured in the photographic media should numerically reinforce what was viewed under field conditions.

Review of Literature

Munsell Color System

Determination of field soil color is usually accomplished by matching a soil sample to a standard color chart such as Munsell Soil Color Charts. The Munsell system consists of three components, hue, value, and chroma. Hue is the the dominant spectral color as related to the wavelength of light and is the quality of the color or the attribute of color perception of which an object is chosen as red, yellow, blue, green or purple (MacAdam, 1985). The Munsell circle is comprised of 5 main hues and 5 intermediate hues. The circle has a range of 0-100 where 0 begins at the boundary between purple and red. Each intermediate hue has a range of 10 units and is noted by using notation such as 2.5 YR (Nickerson, 1940; Hunter, 1975; Simonson, 1993). Munsell Soil Color Charts have 10 hues although the charts used by soil scientists normally contain 7 hues (10R, 2.5YR, 5YR, 7.5YR, 10YR, 2.5Y, 5Y) and two gley pages. However, additional hue pages of 5R and 7.5R are available. Value (where 0 is absolute black and 10 is absolute white) is the degree of lightness or darkness and is related to the total amount of light reflected (MacAdam, 1985). Chroma is the the strength of the spectral color and is the degree of saturation expressed on a scale of 0 for gray to a maximum of 20 (Bourgin, 1999; MacAdam, 1985). Munsell Soil Color Charts utilize 0-8 chromas. There are other systems used to describe color, but Munsell is the most widely accepted and used for soil color (Melville and Atkinson, 1985; Kaufman and Kristensen, 1972).

CIE

The International Commission on Illumination (Commission Internationale de l'Eclairage), commonly referred to as CIE, is a group of specialists who recommend and revise methods for measurement of light and color (ASTM E 308-96, 1998; Bourgin, 1999; Evans, 1974; Hunter, 1975; Kaufman, 1981; Kaufman and Christensen, 1972; Kelly and Judd, 1955, 1976). The CIE defined a system using coordinates that classifies color according to hue, value and saturation (HVS). Hue is the attribute of a visual sensation in which an area appears to be similar to one, or two proportions of two, of the perceived colors, red, yellow, green and blue (MacAdam, 1985). Brightness (value) is the attribute of a visual sensation in which an area appears to exhibit more or less light (Bourgin, 1999). Colorfulness (saturation) is the attribute of a visual sensation according to which an area appears to exhibit more or less of its hue (MacAdam, 1985; Bourgin, 1999). The CIE system works by weighting the spectral power distribution (SPD) of an object in terms of three color-matching functions. These functions are sensitivities of a standard observer (based on measurements of the color-matching abilities of the average human eye) to light of different wavelengths. The weighting is performed over the visible spectrum in one nanometer (nm) intervals and the illuminant, lighting and viewing geometry are fully defined. This process produces the three tri-stimulus values, XYZ which describe the color. These XYZ values can be converted to various color systems including Munsell notation.

The CIE approach is most applicable with relation to color specification and measurement issues. The CIE system is based upon the premise that the stimulus for color is the product of the spectral power distribution of the illuminating light source, the spectral reflectance characteristics of the object, and the spectral response characteristics of the color detecting device (Evans, 1974; Kelly and Judd, 1955 and 1976; Hunter, 1975). The CIE specified the spectral power distributions of Standard Illuminants and Sources as well as the spectral response characteristics of an average, normal-visioned human observer (1931 CIE 2° Standard Observer and the 1964 CIE 10° Supplemental Standard Observer) in terms of three primary colors. The 1931 CIE Standard 2° observer was developed to represent an ideal observer with color matching functions $x\lambda$, $y\lambda$, and $z\lambda$ corresponding to a field of view subtending a 2° angle to the retina (ASTM, E308-96, 1998). In 1964, the CIE presented the 1964 CIE 10° Supplemental Standard Observer defined as an ideal colorimetric observer with color-matching functions $\overline{x_{10}}(\lambda)$, $\overline{y_{10}}(\lambda)$, $\overline{z_{10}}(\lambda)$ corresponding to a field of view subtending a 10° angle on the retina (ASTM, E 308-96, 1998). Numerical output utilizing the CIE system produces all colors in terms of three variables (X, Y, and Z tristimulus values), which are then converted to numerous existing color systems (including Munsell notation). The intent of the CIE system is only to tell whether two colors match (Melville and Atkinson, 1985).

The CIE Standard Illuminants include Illuminant A, which represents a tungsten filament lamp (incandescant lamp) at a color temperature of 2856 K, Illuminant C, which represents average daylight with a correlated color temperature of 6770 K, Illuminant D_{50}, used by graphic artists for viewing color transparencies and prints and represents noon sky daylight with a correlated color temperature of 5000K, Illuminant D_{65}, which represents average north sky daylight with a correlated color temperature of 6500 K and is used for general evaluation of color when correlating spectrophotometric instrumental readings, Illuminant D_{75}, which represents north sky daylight with a correlated color temperature of 7500 K and is used for the general evaluation of color and the evaluation of opaque materials. There are also CIE fluorescent illuminants such as F2, F7, and F11, which are not discussed here. For measurement of soil color, Illuminant D_{65} with a 10° observer has been recommended (Melville and Atkinson, 1985). Munsell soil colors were developed using Illuminant C with a 2° observer.

The fundamental basis of the CIE system assumes that the three attributes used to describe a color are in three dimensional space or color space (Melville and Atkinson, 1985). Other color spaces are subsets of this perceptual space. There are several color spaces and arrangements of attributes in color space, each suited to different applications. Television displays use RGB (red-green-blue phosphors (example: computer graphics) color space, a cube with red, green, and blue axis. This cube is a subset of our perceptual space because it is a subset of the spectrum of colors we can see. CMY (cyan-magenta-yellow (example: printing press and photography) color space can be represented by another cube occupying a different position within the perceptual space. A color space is a mathematical representation of our perception of color (Melville and Atkinson, 1985).

In 1978 CIE recommended two systems of describing uniform color space and the associated color-difference equasions. These two systems are the CIE 1976 (LUV) system and the CIE 1976 (LAB) system abbreviated CIELUV and CIELAB respectively (CIE, 1978; Melville and Atkinson, 1985). For measurement of soil color, CIELUV and CIELAB are the two most relevant color scales. With CIELUV, where L is luminancy, and U and V are chromanancy, chromaticity and saturation values can be obtained. CIELUV is usually used to distinguish small color differences, especially with additive colors. With CIELAB, where L is luminancy, and A and B refer to the red/blue and yellow/blue chromanancies, hue and chroma values can be obtained (Melville and Atkinson, 1985). For spectrophotometric measurement of soil color, both CIELAB and CIELUV are used and appears to be a matter of preference as to which system is best for representing soil color as both are imperfect and have been cited as being appropriate (Melville and Atkinson, 1985; Billmeyer and Saltzman, 1981; Dain and Powell, 1985).

Spectrophotometric Measurement of Color

Measurement of color is carried out with the aid of instruments such as chroma meters, colorimeters, goniophotometers, spectrocolorimeters and spectrophotometers (ASTM E 1347-97, 1998; ASTM E 1164-94, 1998). Chroma meters use basic reflectance data to compute an overall percent reflectance. Percent reflectance is most strongly correlated to Munsell value. Colorimeters are commonly three filter instruments that attempt to copy the visual process of the eye. Photoelectric tristimulus colorimeters have a source-filter photodetector combination that simulates the CIE Standard Observer functions. Tristimulus (filter) colorimeters, also known as color difference meters produce colorimetric data just as spectrophotometers do, but usually not the underlying spectral data from which the color coordinates were calculated (ASTM E 1347-97, 1998). Goniophotometers measure the quantity of light emitted from the object in different directions. Since values of light reflectance or transmittance are produced angle by angle, goniophotometers provide data about geometric attributes of appearance. Spectrocolorimeters are similar in principle to spectrophotometers, but can only produce colorimetric data as output (ASTM E 1164-94, 1998). Spectrophotometers measure reflectance and often transmittance as a function of wavelength (ASTM E 1164-94, 1998). In the visible spectrum, the only fundamental means of examining a color for analysis, standardizing, and specification is by means of spectrophotometry. Spectrophotometry is the only means of color standardization that is independent of material color standards and independent of abnormalities of human observers. Magnesium oxide (MgO), barium sulfate ($BaSO_4$), and ceramic tiles are used for calibration. Spectrophotometers measure the amount of light from an object wavelength by wavelength, and thus its readings relate primarily to the color of the object. Spectrophotometers have wavelength isolation systems through prisms, gratings, or systems of filters which provide true reflectance spectral data. Spectrophotometers, which measure reflectance as a function of wavelength (Hunter, 1975), are the most direct method for obtaining color difference data (ASTM E 1347-97, 1998; ASTM E 1164-94, 1998).

Although spectrophotometric measurements of reflectance can give much better accuracy and precision in color measurement than visual matching alone, instruments lack the versatility of the human eye (Hunter, 1975). Where an instrument recognizes only the specific attributes of an object, the human observer perceives a number of different attributes simultaneously. The eye and instrument sensitivities of the sensor, light source, and angle of refraction differ. The eye is sensitive to geometric factors of direction, pattern and shape, responds quickly to slight and continual changes, and uses available lighting. Instruments generating internal reflectance data use simulated light. The human eye makes evaluations that are subjective and vary with changes in viewing conditions and changes from one observer to another. Instruments quickly reduce appearance to numbers that correlate well with visual evaluations and are more repeatable than evaluations obtained with the human eye. The capability of the instrument as well as the accuracy of the output generated changes with manufacturer and mode (ASTM E 1347-97, 1998; ASTM E 1164-94, 1998; Hunter, 1975).

The instrumental measurement of soil color can best be carried out by choosing an illuminant designed for general evaluations of color, and one which has a color temperature that most closely resembles that of daylight (Melville and Atkinson, 1985). Daylight is represented by CIE Illuminants C, D50, D55, D65, and D75 (GretagMacbeth, 2000). Illuminants intended to be used for general evaluations of color include C, D50, D65, and D75. Illuminant C is mathematical representation of filtered tungsten halogen daylight with a color temperature of 6770 K which was obtained using an incandescent tungsten lamp as the source at a color temperature of 2856 K used with a liquid Davies-Gibson C filter (which raises the color temperature). Illuminant D50 is a mathematical representation of noon sky daylight with a color temperature of 5000 K. Illuminant D65 is a mathematical representation of the average north sky daylight with a color temperature of 6500 K. Illuminant D75 is a mathematical representation of north sky daylight with a color temperature of 7500 K. (GretagMacbeth, 2000). Field soil color is traditionally measured with the aid of Munsell Soil Color Charts, which were developed using Illuminant C with a 2° observer (GretagMacbeth, 2000; Glenn and Killian, 1940; Granville et al, 1943).

Spectrophotometers are numerically equipped with software that contains the color temperature and spectral reflectance data for each illuminant (CIE Illuminants A, C, D, etc). Lighting within the spectrophotometer does not change from incandescent to tungsten, for example. Lighting, usually zenon, is built into the spectrophotometric unit to illuminate the sample. The lighting of the surroundings outside of that which the sample is measured (outside of the spectrophotometer unit) is independent of the spectral reflectance data obtained for that sample (GretagMacbeth Seminar, 2000).

When highest measurement accuracy is mandatory, the wavelength range should extend from 360 to 830 nm, but 380 to 780 nm is sufficient. Each user must decide whether the loss of accuracy is acceptable for the purpose for which the data are obtained (ASTM E 1164-94, 1998). When highest accuracy is required, the wavelength measurement interval should be one nanometer (nm) or less. Use of a 10 nm or 20 nm wavelength measurement interval may result in significant loss of accuracy (ASTM E 1164-94, 1998). The spectral bandpass (width in nanometers at half energy of the band of wavelengths transmitted by the dispersive element) should, for best results, be equal to the wavelength measurement interval (ASTM E 1164-94, 1998). Each wavelength of light (in the visible spectrum, approximately 380-770 nm) has a relative power or spectral power distribution (energy radiated per unit time) (Melville and Atkinson, 1985). The relative power of standard light sources used to measure and describe color are the CIE Standard Illuminants. Two objects having identical spectral reflectance properties will be perceived as being the same color regardless of changes in illumination conditions. The Munsell soil color chip and a visually matched soil sample have different spectral reflectance properties, although the human eye can make an approximate match between the two. However, if the spectral power distribution of the illuminating source is changed, the apparent color of the soil and chip will no longer match. This property is known as "metamerism". Despite the differences in apparent color based on the illuminant used, the USDA Soil Survey Manual (Soil Survey Division Staff, 1993) does not specify illumination standards to be used when measuring soil color (Melville and Atkinson, 1985).

The 1931 Standard Observer measurements (CIE 2°) were obtained by utilizing the foveal region of the human eye (Melville and Atkinson, 1985). The degree field of vision represents a circle diameter of approximately 15 mm at a viewing distance of 450 mm. The 1964 Supplementary Observer (CIE 10°) corresponds to a circle of approximately 80 mm. Munsell Soil Color Charts have viewing holes with a 10 mm diameter. The 2° standard observer should be used when masks (black masks for soils with small Munsell values; gray masks for soils with high Munsell values) which accompany soil color charts are utilized. Use of the masks minimizes contrast and standardizes viewing conditions. In the absence of masks, the 10° Standard Observer should be used for spectrophotometric measurements related to soil (Melville and Atkinson, 1985). Due to the variability and subsequent errors between observers in matching soil to soil color chips, spectrophotometry has been recommended to overcome these errors (Shields et al, 1968; Melville and Atkinson, 1985). Several papers have been written to minimize hand calculations for converting from one color coordinate system to another through the use of tables and charts (Glenn and Killian, 1940; Granville et al, 1943; Kelly et al, 1943; Tyler and Hardy, 1940). Computer software is now available which eliminates the need for hand calculations (GretagMacbeth, 2000c).

Several companies manufacture spectrophotometers. Datacolor International manufactures a portable field unit, the Microflash. The Microflash unit, Model 100D measures visible light wavelengths of 400-700 nm, has a resolution of 3 nm and an effective bandwidth of 10 nm. The repeatability of the instrument is 0.05 CIE LAB ΔE on white ceramic tile. Reproducibility is less than 0.2 CIELAB ΔE on average of 12 BCRA tiles, 0.5 CIELAB maximum on any one tile (Datacolor International, 1999).

Differences in the appearance of color are often obvious. However, differences between two samples are often judged differently by different observers (Berger-Schunn, 1994). When there is agreement that both the Munsell (GretagMacbeth, 1994) color sheet and the soil visually match when describing a soil profile, and photographs are then taken of the Munsell color sheet against the soil profile, subsequent spectrophotometric measurements of the Munsell in the photographs should be close to the spectrophotometric readings of the actual Munsell soil color sheet. These evaluations can then be extrapolated back to the soil the Munsell color sheet represents.

The Munsell color system is the most accepted means of determining the color name which best describes object color (Berger and Schunn, 1994; MacAdam, 1985; Melville and Atkinson, 1985; Simonson, 1993). The Munsell system was designed using CIE Illuminant C and a 2° observer. Kelly et al (1943) measured the spectral reflectance of all the color standards in the Munsell Book of Color (Munsell Color Company, 1929). Several tables presenting tristimulus values at 1, 5, 10 and 20 nm wavelength intervals have been compiled, several of which are presented in ASTM E 308-96 (1998). Tristimulus values obtained in a laboratory setting (Granville et al 1943; Kelly et al 1943; Glenn and Killian, 1940), produced values for some Munsell color notations. For this study, field measured tristimulus values will be obtained (rather than using values obtained from past studies under laboratory conditions) to ensure consistency of the data with the spectrophotometric unit. Data obtained using tristimulus values are subjective in that very few samples have values that, under the same matching condition (illuminant-observer), will look the same to any observer under any light source. Samples that should be the same often vary in tristimulus values (Berger-Schunn, 1994). The intent of evaluating the numerical values obtained by using the spectrophotometer for this study was to gauge differences in order to obtain relevant data to discuss output in terms of Munsell notation values. Converting from CIELAB data to Munsell notation allows for the comparison of differences large enough to affect a change from one Munsell color chip to another.

Materials and Methods

Soils - Two Soil Series

Two soil series including a taxadjunct to Teller (a sandy textured soil) (Soil Survey Staff, 1996) (USDA-NRCS) and a taxadjunct to Grainola (a clayey textured soil) (Soil Survey Staff, 1996) (USDA-NRCS) previously described in Chapter Two were used for this project.

Through out this paper, for ease of communicating, the two taxadjunct soils used for this research are referred to as Teller or Grainola, respectively.

Photography

GretagMacbeth's Munsell color chips or sheets and Kodak's 18% gray card (Eastman Kodak, 1997) are accepted standards that are used to assure color consistency in photographs. Kodak's 18% gray card (Eastman Kodak, 1997) appeared in most photographs of soil profiles as a measuring tape. Spectrophotometric measurements were taken of the 22 x 28 cm matte finish Munsell color sheets appearing in the photographs obtained in the previous chapter. A 22 x 28 cm matte finish Munsell color sheet had been visually matched to a horizon in each soil profile. Spectrophotometric measurements were taken of the Munsell color sheet against the soil profile under field conditions and of the Munsell color sheet in finished prints. Photographs used were those described in Chapter Two which included photographic prints of the factors of film, distance between the camera lens and soil profile, soil profile surface moisture, camera settings (aperture and shutter speed), filters, camera angles, times of day, night photography, and color matching to a standard.

Spectrophotometric Measurements

Spectrophotometric measurement sheets such as those listed in Figure 3-1 were used to record all spectrophotometric data.

A spectrophotometer (Datacolor International, Microflash version 4.0, model 100D) was used to obtain numerical values of the Munsell color sheet (22 x 28 cm) under field conditions. The spectrophotometer was programmed with C as the CIE illuminant using a 2° observer and recording in CIELAB as the color coordinate system. Matte finish photographs of the soil profiles were produced. The spectrophotometer was then used to obtain numerical values for the Munsell color sheets in the matte finish photographs. Spectrophotometric measurements of the Munsell color sheet under field conditions was compared to the Munsell color sheet appearing in photographs. Field spectrophotometric readings in the field were obtained within the same hour that the corresponding photographs were taken. Spectrophotometric readings did not have to be carried out under field conditions, as the lighting of the surrounds is irrelevant. However, this

Figure 3-1

Spectrophotometric Measurements

Date:____________ Day:__________ Time:______ Weather____________ Photo Code____________

	L*	a*	b*	DL*	Da*	Db*	DE
Standard							
Meas. 1							
Meas. 2							
Meas. 3							
Meas. 4							
Meas. 5							
Meas. 6							

Date:____________ Day:__________ Time:______ Weather____________ Photo Code____________

	L*	a*	b*	DL*	Da*	Db*	DE
Standard							
Meas. 1							
Meas. 2							
Meas. 3							
Meas. 4							
Meas. 5							
Meas. 6							

procedure was carried out for consistency.

The two Munsell color sheets used in this study (7.5YR 4/4 and 10R 4/6) are referred to as standards when measurements were taken directly off the color sheets (vs prints containing the sheets). Standards (Figure 3-2) were measured initially under Illuminant C with a 2° observer with specular (gloss) included and excluded in order to gauge acceptable numbers. Six readings of each standard were then obtained (for each set of print readings) with the Microflash (Datacolor International, Microflash version 4.0, model 100D) and an average was mean determined internally within the instrument.

Conversions and Comparisons

Spectrophotometric output data was recorded in the CIE LAB color coordinate system and was then converted from CIE LAB numerical data to Munsell color notation using a Munsell Conversion Program (Applied Color Systems, Inc. or GretagMacbeth, 2000b) recommended by both Datacolor International (manufacturer of spectrophotometric equipment) and GretagMacbeth (manufacturer of Munsell products). Emphasis was not on the raw numerical output data but whether the numerical data generated would assign the Munsell color sheet (22 x 28 cm) under field conditions the same color notation once photographed.

Munsell Soil Color Chart (1994) hue pages each have an adjacent page which gives the descriptive notation (or the actual name) of that designated color. Comparisons were made to evaluate how many chips away from the standard the photographed Munsell color sheet in the prints measured and whether or not the same color name would be

Figure 3-2
Measurements Taken of 7.5YR 4/4 and 10R 4/6

Munsell Color Sheet	Instrument* Calibrated To	Measurements* Taken In	# of Measurements	Range in C/2**	(ISCC-NBS)*** Color Name and Number	Munsell*** Color Name
7.5YR 4/4	Spec. Inc.*	Spec. Inc.*	6	7.44-7.47YR 3.40-3.43/5.82-5.88	sb-55	sb
7.5YR 4/4	Spec. Inc.*	Spec. Exc.*	18	7.41-7.56YR 3.36-3.46/5.70-5.94	sb-55	sb
7.5YR 4/4	Spec. Exc.*	Spec. Exc.*	24	7.34-7.41YR 3.39-3.45/5.75-5.93	sb-55	sb
10R 4/6	Spec. Inc.*	Spec. Inc.*	6	1.57-1.75YR 3.24-3.35/8.24-8.44	srb-40	r
10R 4/6	Spec. Inc.*	Spec. Exc.*	18	1.65-1.71YR 3.42-3.43/8.37-8.48	srb-40	r
10R 4/6	Spec. Exc.*	Spec. Exc.*	24	1.49-2.03YR 3.17-3.37/8.01-8.46	srb-40	r

* Specular is the gloss component. Spec. Inc.=Specular Included – gloss is included in the calibration or measurement. Spec. Exc.=Specular excluded – gloss is excluded in the calibration or measurement.
** C/2 is Illuminant C with a 2° observer.
*** r=red, sb=strong brown, srb=strong reddish brown

assigned to the measured readings. Emphasis was placed on which prints came closest in hue, value, and chroma to the measurements of hue, value, and chroma of the Munsell color sheets of 7.5YR 4/4 and 10R 4/6.

Results and Discussion

Munsell Color Sheets as Standards

Munsell soil color chips in Munsell Soil Color Charts (1994) were used to determine the color of each horizon in the soil profile at the time the soil was described (see Chapter Two). Large (22 x 28 cm) color sheets of a color chip matching one or more horizons of each soil were used in this study. The Munsell 7.5YR 4/4 color sheet closely matched the BAb horizon between the depths of 43-79 cm in the profile of the Teller soil. The Munsell 10R 4/6 color chip closely matched the Btss4 and C horizons between the depths of 110-160 cm in the soil profile of the Grainola soil. The 7.5YR 4/4 and 10R 4/6 (22 x 28 cm) Munsell color sheets were the standards with which all spectrophotometric readings of the prints were compared.

Spectrophotometric readings of the Munsell color sheets with gloss components included and excluded are found in Figure 3-2.

Measurements and Conversions

Appendix D lists the prints by code number and the conversions from CIE LAB to X, Y, Z, and x,y values. Appendix E lists the prints by code number along with the Munsell standard used and the conversion to Munsell notation (hue, value and chroma), ISCC-NBS color names and Munsell descriptive notation. A compilation of Figure 2-8 and

Appendix E is Table 3-1, which is a summary of the visual results from Chapter Two and the spectrophotometric results from Chapter Three.

Drift tests and repeatability tests were administered to ensure the spectrophotometric equipment was functioning properly. Spectrophotometric readings of the above named Munsell sheets (7.5YR 4/4 and 10R 4/6) were taken periodically to assure consistency in measurement. In Munsell Soil Color Charts, 7.5YR 4/4 is "brown", where "brown" encompasses the 6 chips of 7.5YR 5/2, 5/3, 5/4, 4/2, 4/3, and 4/4. All measurements taken of the 7.5YR 4/4 (22 x 28 cm) sheet using the spectrophotometer set at an illuminant/observer of C/2, then converted to Munsell notation, classified as "strong brown", color number 55 (Appendix E) in the ISCC-NBS (National Bureau of Standards) color designation and as "strong brown" using Munsell descriptive notation in Munsell Soil Color Charts regardless of whether the instrument was calibrated in or whether the Munsell was measured in the specular included or excluded (the gloss component) modes. In Munsell Soil Color Charts, "strong brown" currently encompasses the three soil chips 7.5YR 5/6, 5/8, and 4/6.

In Munsell Soil Color Charts, 10R 4/6 is "red" where "red" encompasses the 4 chips of 10R 5/6, 5/8, 4/6, and 4/8. All measurements taken of the 10R 4/6 (22 x 28 cm) color sheet using the spectrophotometer set at illuminant/observer of C/2, then converted, classified as "strong reddish brown", color number 40 (Appendix E) in the ISCC-NBS color designation. In the descriptive notation of Munsell Soil Color Charts, "strong reddish brown" is not included as a soil color within the 11 soil pages (2 gley pages, 5R, 7.5R, 10R, 2.5YR, 5YR, 7.5YR, 10YR, 2.5Y, and 5Y).

Table 3-1

Comparison of Visual and Spectrophotometric Data*

Figure	Factor	Visual Matching			Spectrophotometric Measurements		
		Hue	Value	Chroma	Hue	Value	Chroma
	<u>Film</u>						
2-9	Fi8/2P1-Fi6	√	2↑	√			
2-10	Fi8/2P1-Fi1	2.5Y	2↑	√			
2-11	Fi8/2P1-Fi3	√	2↑	√			
2-12	Fi7/26P2-Fi4	√	1↑	√			
2-13	Fi7/26P2-Fi5a	5R	√	2↑			
2-14	Fi7/26P2-Fi7	2.5Y	√	√			
	<u>Distance From Lens to Soil Profile</u>						
2-15	D8/2P1-D4	√	√	√	4.18R	0.77↑	0.89↓
2-16	D8/2P1-D10	√	√	√	3.3R	0.34↑	0.68↑
2-17	D8/2P1-D16	2.5R	1↑	√	2.53R	1.18↑	0.56↑
2-18	D7/31P2-D2	√	1↑	2↑	1.91R	1.18↑	1.31↓
2-19	D7/31P2-D5	√	2↑	√	1.31R	1.92↑	0.73↓
2-20	D7/31P2-D8	√	2↑	√	1.15R	2.48↑	1.9↓
	<u>Soil Profile Surface Moisture</u>						
2-21	M8/4P1-M2	2R	2↑	√	3.5R	1.9↑	0.43↓
2-22	M8/4P1-M3	2R	2↑	√	3.49R	1.55↑	0.19↑
2-23	M8/4P1-M5	√	1↑	√	2.19R	0.99↑	0.03↑
2-24	M8/1P2-M4	2.5R	1↑	2↑	3.6R	1.35↑	0.05↓
2-25	M8/1P2-M5	2.5R	1↑	2↑	3.78R	1.21↑	0.01↑
2-26	M8/1P2-M7	2.5R	1↑	√	2.91R	1.9↑	0.78↓
	<u>Aperture/Shutter Speed</u>						
2-31	F7/26P2-F17	2.5R	2↑	2↑			
2-32	F7/26P2-F16	√	1↑	√			
2-33	F7/26P2-F13	2.5R	1↑	√			
2-34	F7/26P2-F15	2.5R	1↑	√			
2-35	F7/26P2F14a	2.5R	1↑	2↑			
2-36	F7/26P2-F19	√	√	√			

Table 3-1, continued

Figure	Factor	Visual Matching			Spectrophotometric Measurements		
		Hue	Value	Chroma	Hue	Value	Chroma
	<u>Angles</u>						
2-47	A8/4P1-A2	√	2↑	√	2.04R	2.16↑	0.20↓
2-48	A8/4P1-A3	√	2↑	√	1.91R	2.26↑	0.17↓
2-49	A8/4P1-A6	√	2↑	√			
2-50	A8/1P2-A2	5R	1↑	√	7.23R	1.6↑	0.41↓
2-51	A8/1P2-A3	2.5R	1↑	√	3.86R	1.41↑	0.26↓
2-52	A8/1P2-A5	√	2↑	2↑			
	<u>Time of Day</u>						
2-53	T6/6P1-T1d	2.5R	1↑	√	4.43R	1.07↑	0.70↓
2-54	T6/6P1-T2b	2.5R	1↑	√	1.83R	1.05↑	0.89↓
2-55	T6/6P1-H1a	√	2↑	2↑	0.04R	1.9↑	0.07↑
2-56	T6/6P1-T3b	√	1↑	√	2.2R	1.41↑	0.52↓
2-57	T6/6P1-T4a	√	2↑	2↑	1.11R	1.55↑	0.85↑
2-58	T7/30P2-T2	√	2↑	2↑	1.27R	1.85↑	1.15↓
2-59	T7/30P2-T7	2.5R	1↑	2↑	4.17R	1.32↑	0.67↓
2-60	T7/30P2-T10	√	1↑	2↑	2.79R	1.61↑	0.75↓
2-61	T7/30P2-T14	2.5R	1↑	2↑	3.55R	1.44↑	0.63↓
	<u>Clouds</u>						
2-62	T7/30P2-T6	2.5R	√	√	2.23R	0.24↑	0.24↑
2-63	T7/30P2-T8	√	√	2↑	1.73R	0.53↑	0.19↑
	<u>Night Photography</u>						
2-64	N8/17P1-N1h	2.5R	2↑	√	4.77R	2.41↑	1.74↓
2-65	N8/17P1-N1e	√	2↑	√	0.35R	2.98↑	1.16↓
2-66	N8/17P1-N1b	2.5Y	3↑	1↓	1.8Y	2.96↑	2.59↓
2-67	N8/17P2-N2d	5R	1↑	√	8.31R	0.71↑	1.82↓
2-68	N8/17P2-N2e	5R	√	2↑	9.22R	0.31↑	0.07↓
2-69	N8/17P2-N2f	5R	1↑	√			
	<u>Color Matching</u>						
2-70	C8/4P1-C4a	2.5Y	3↑	1↓	0.83R	3.28↑	1.86↓
2-71	C8/4P1-C3b	√	2↑	√	2.05R	2.23↑	0.38↓
2-72	C8/4P2-C2a	√	3↑	2↓	3.31R	3.38↑	3.34↓
2-73	C8/4P2-C2b	√	2↑	√	2.27R	2.15↑	1.05↓

Table 3-1, continued

*√ indicates the same numerical value as the standard (Munsell color sheet),
↑ = indicates numbers higher than the standard (Munsell color sheet),
↓ = indicates numbers lower than the standard (Munsell color sheet),
R = redder than,
Y = yellower than,
For example, spectrophotometric measurement of the Munsell color sheet of the print in Figure 2-73 is 2.27 units redder (R) in hue, 2.15 units higher (↑) in value, and 1.05 units lower in chroma than the Munsell color sheet measured.

Measurements of the Munsell color sheets were consistent regardless of whether the instrument was calibrated in or whether the Munsells were measured in specular included or excluded (the gloss component) modes (Figure 3-2). The standards were measured in both specular included and excluded modes in Figure 3-2 to observe differences in the output at these settings. Measurements recorded in Appendix D and E were obtained calibrating in the specular included mode (as recommended by the Microflash manufacturer) and obtaining measurements in the specular excluded mode. Munsell renotation in Circular 553 (Kelly and Judd, 1955) and Special Publication 440 (Kelly and Judd, 1976) of the National Bureau of Standards designates the Munsell color chip 10R 4/6 as "moderate reddish brown" and includes chips 2.5 to 4.5 in values and 3 to 7 in chromas. On the same page of the circular, "strong reddish brown" is shown to contain values of 2.5 to 3.5 and chromas of 7 to 14 (if they existed for soils). The latter mentioned values and chromas in the Munsell Soil Color Charts categorize into "dark red" which presently only includes one chip, 3/6.

Data are discussed in terms of Illuminant C with a 2° observer and Munsell notation. To evaluate how close the six measurements were to the actual Munsell color sheet measurement, the page (hue pages 5R, 7.5R, 10R, 2.5YR, 5YR, 7.5YR, 10YR, 2.5Y, 5Y, and two gley pages) with the closest hue number was chosen. Likewise, the values and chromas to which the measurements of the prints came closest was chosen. Values and chromas in Munsell Soil Color Charts are in incremental units of one.

Comparison of Visual and Spectrophotometric Data (Table 3-1)

Visual and spectrophotometric methods both offer advantages and disadvantages as discussed in the Review of Literature. Neither method is perfect. However, most soils data for a specific soil profile is recorded using visual observations at the time the soil is excavated. Visual data, then, is most relevant to actual use and practices by soil scientists as most soil scientists are not equipped with a spectrophotometer when excavating a soil profile and recording soils information on field soil description sheets. Soil scientists are, when describing a soil, usually equipped with Munsell Soil Color Charts.

Table 3-1 suggests that soils appearing in photographs tend to be redder and lighter in color than the actual soil. Redder hues and high values were consistent in both the spectrophotometric measurements and the visual matching of the Munsell color sheets. Chromas were not as consistent. The cause of redder hues and high values could be any one or a combination of factors, including the films chosen, the film's sensitivity to wavelengths of light that the eye is not able to perceive, the chemical processing of the negatives and prints, or some other unexplored factor. If the redder hues and higher values were solely from using Portra 160 NC film, all Portra 160 NC prints should be redder and lighter. Pro 100 film used in the Teller time of day prints also resulted in some prints with redder hues and lighter values, similar to the redder hues and lighter values seen in the Portra 160 NC film prints. Use of Pro 100 film (from Chapter Two) resulted in a browner hue of the soil than use of Portra 160 NC or Vericolor film. In Munsell Soil Color Charts, hue becomes browner with increase in yellow. If the redder trend as seen in the Portra 160 NC film was solely a result of the film used, Pro 100 prints would have been yellower (Y) not redder (R) as seen in Table 3-1 in the Teller time of day prints. The dominant color then, was also influenced by the other factors studied. With the exception of the time of day and night photography prints for both soils, all prints were photographed within the same daylight hours for each of the two soils. Daylight and corresponding wavelengths of light for that time of day affected the hue measured in the print. However, use of controlled lighting and tungsten photofloods with the recommended filter of 80B (Tiffen) at various F-stop settings, resulted in prints with redder hues than the standard. Based on the prints produced for this research, redder hues and lighter (higher) values can be expected in prints of soils taken under these conditions.

Chroma, or the saturation of the hue, was not consistently in agreement between the visual and spectrophotometric comparisons. In Munsell Soil Color Charts, hue pages are in increments of 2.5. Value and chroma units are both noted in incremental units of 1. Table 3-2 represents Table 3-1 with the hue measurements rounded off to the nearest 0.5, and the value and chroma measurements rounded off to the nearest whole unit. This adjustment results in more reasonable compatability between the visual and spectrophotometric data with Figure 2-74.

For hue, no print measured spectrophotometrically was in agreement with the standard, compared to twenty-five prints in agreement when matched visually. For value, three prints measured spectrophotometrically were in agreement with the standard, compared to eight prints in agreement when matched visually. For chroma, fourteen prints measured spectrophotometrically were in agreement with the standard, compared to thirty-three prints in agreement when matched visually (Table 3-2).

Table 3-2

Adjusted Table 3-1*

Figure	Factor	Visual Matching Hue	Visual Matching Value	Visual Matching Chroma	Spectrophotometric Measurements Hue	Spectrophotometric Measurements Value	Spectrophotometric Measurements Chroma
	<u>Film</u>						
2-9	Fi8/2P1-Fi6	√	2↑	√			
2-10	Fi8/2P1-Fi1	2.5Y	2↑	√			
2-11	Fi8/2P1-Fi3	√	2↑	√			
2-12	Fi7/26P2-Fi4	√	1↑	√			
2-13	Fi7/26P2-Fi5a	5R	√	2↑			
2-14	Fi7/26P2-Fi7	2.5Y	√	√			
	<u>Distance From Lens to Soil Profile</u>						
2-15	D8/2P1-D4	√	√	√	4R	1↑	1↓
2-16	D8/2P1-D10	√	√	√	3.5R	√	1↑
2-17	D8/2P1-D16	2.5R	1↑	√	2.5R	1↑	1↑
2-18	D7/31P2-D2	√	1↑	2↑	2R	1↑	1↓
2-19	D7/31P2-D5	√	2↑	√	1.5R	2↑	1↓
2-20	D7/31P2-D8	√	2↑	√	1R	2↑	2↓
	<u>Soil Profile Surface Moisture</u>						
2-21	M8/4P1-M2	2R	2↑	√	3.5R	2↑	√
2-22	M8/4P1-M3	2R	2↑	√	3.5R	2↑	√
2-23	M8/4P1-M5	√	1↑	√	2R	1↑	√
2-24	M8/1P2-M4	2.5R	1↑	2↑	3.5R	1↑	√
2-25	M8/1P2-M5	2.5R	1↑	2↑	4R	1↑	√
2-26	M8/1P2-M7	2.5R	1↑	√	3R	2↑	1↓
	<u>Aperture/Shutter Speed</u>						
2-31	F7/26P2-F17	2.5R	2↑	2↑			
2-32	F7/26P2-F16	√	1↑	√			
2-33	F7/26P2-F13	2.5R	1↑	√			
2-34	F7/26P2-F15	2.5R	1↑	√			
2-35	F7/26P2F14a	2.5R	1↑	2↑			
2-36	F7/26P2-F19	√	√	√			

Table 3-2, continued

Figure	Factor	Visual Matching Hue	Value	Chroma	Spectrophotometric Measurements Hue	Value	Chroma
	Angles						
2-47	A8/4P1-A2	√	2↑	√	2R	2↑	√
2-48	A8/4P1-A3	√	2↑	√	2R	2↑	√
2-49	A8/4P1-A6	√	2↑	√			
2-50	A8/1P2-A2	5R	1↑	√	7R	2↑	√
2-51	A8/1P2-A3	2.5R	1↑	√	4R	1↑	√
2-52	A8/1P2-A5	√	2↑	2↑			
	Time of Day						
2-53	T6/6P1-T1d	2.5R	1↑	√	4.5R	1↑	1↓
2-54	T6/6P1-T2b	2.5R	1↑	√	2R	1↑	1↓
2-55	T6/6P1-H1a	√	2↑	2↑	√	2↑	√
2-56	T6/6P1-T3b	√	1↑	√	2R	1↑	1↓
2-57	T6/6P1-T4a	√	2↑	2↑	1R	2↑	1↑
2-58	T7/30P2-T2	√	2↑	2↑	1.5R	2↑	1↓
2-59	T7/30P2-T7	2.5R	1↑	2↑	4R	1↑	1↓
2-60	T7/30P2-T10	√	1↑	2↑	3R	2↑	1↓
2-61	T7/30P2-T14	2.5R	1↑	2↑	3.5R	1↑	1↓
	Clouds						
2-62	T7/30P2-T6	2.5R	√	√	2R	√	√
2-63	T7/30P2-T8	√	√	2↑	2R	1↑	√
	Night Photography						
2-64	N8/17P1-N1h	2.5R	2↑	√	5R	2↑	2↓
2-65	N8/17P1-N1e	√	2↑	√	0.5R	3↑	1↓
2-66	N8/17P1-N1b	2.5Y	3↑	1↓	2Y	3↑	3↓
2-67	N8/17P2-N2d	5R	1↑	√	8.5R	1↑	2↓
2-68	N8/17P2-N2e	5R	√	2↑	9R	√	√
2-69	N8/17P2-N2f	5R	1↑	√			
	Color Matching						
2-70	C8/4P1-C4a	2.5Y	3↑	1↓	1R	3↑	2↓
2-71	C8/4P1-C3b	√	2↑	√	2R	2↑	√
2-72	C8/4P2-C2a	√	3↑	2↓	3.5R	3↑	3↓
2-73	C8/4P2-C2b	√	2↑	√	2.5R	2↑	1↓

Table 3-2, continued

*√ indicates the same numerical value as the standard (Munsell color sheet),
↑ = indicates numbers higher than the standard (Munsell color sheet),
↓ = indicates numbers lower than the standard (Munsell color sheet),
R = redder than,
Y = yellower than,
For example, spectrophotometric measurement of the Munsell color sheet of the print in Figure 2-73 is 2.5 units redder (R) in hue, 2 units higher (↑) in value, and 1 unit lower in chroma than the Munsell color sheet measured.

Distance Between the Camera Lens and Soil Profile

The print codes of D8/2P1-D4, D8/2P1-D10, and D8/2P1-D16 refer to the Teller soil in Figures 2-15 to 2-17 in Chapter Two. The notation of 7.5YR 4/4 classified as a Munsell "brown" in Munsell Soil Color Charts. Descriptive notation of the standard (7.5YR 4/4) measured was "strong brown".

The closest distance between the camera lens and the soil profile was 95 cm, represented in Figure 2-15 (D8/2P1-D4). Descriptive notation of the print readings classified either as Munsell "red' or Munsell "reddish brown" (Appendix E). Figures 2-16 (D8/2P1-D10) and 2-17 (D8/2P1-D16) represented distances from camera lens to soil profile of 200 and 240 cm, respectively. Descriptive notation for both prints measurements were Munsell "yellowish red".

Measurements of the three prints indicate a more accurate Munsell hue for the 200 cm distance, better accuracy in Munsell value for the 95 and 200 cm distances, and a more accurate Munsell chroma for the 95 cm distance compared to the 200 and 240 cm distances. In descriptive notation, Munsell "yellowish red" occupies the same hue and value areas on the 5YR page of the Munsell Soil Color Charts as "strong brown" occupies on the 7.5YR page, and Munsell "red" on the 2.5YR hue page is a subset of this area. None of the three prints matched the standard in descriptive notation.

Spectrophotometric measurements of the Teller prints were more accurate in hue with increased distance from the soil profile, opposite of what the visual data indicated (Table 3-2). Values and chromas were not consistent between visual and spectrophotometric measurements. Visual measurements indicated that the 95 and 200 cm distances were more accurate in color (hue, value, and chroma) than the 240 cm distance.

Spectrophotometric measurements were inconclusive, as hue became more accurate with increased distance from the camera lens to the soil profile, value was more accurate at 200 cm and chroma was no more accurate in given any distance.

The Grainola soil is represented in Figures 2-18 to 2-20 (D7/31P2-D2, D7/31P2-D5, and D7/31P2-D8) (Chapter Two) and represent distances from camera lens to soil profile of 98, 192, and 241 cm, respectively. For descriptive notation, the measurement of the standard classified as a Munsell "dark red". Munsell notation of 10R 4/6 classified as a Munsell "red" and the six readings of each print all classified as Munsell "red" (Appendix E).

Visual measurements were more accurate than the spectrophotometric measurements in both Grainola and Teller soils. In the spectrophotometric measurements in Table 3-2, the camera lens moving away from the soil profile resulted in progressively closer hues to the standard. Hue was most accurate in the furthest distance for the spectrophotometric readings whereas the visual measurements were least accurate in the furthest distance. Spectrophotometric values for both soils were accurate or higher than the standard for both the spectrophotometric and visual data. Visual measurements were more accurate in chroma than the spectrophotometric measurements, which were inconsistent. Agreement in both visual matching and spectrophotometric measurements of the Munsell color sheets were inconsistent in reinforcing the distance that best represented true color of the soil. The distance chosen should be the distance that not only best represents a soil's color attributes, but also allows the soil's key features and characteristics to be clearly seen. As discussed in Chapter Two, photographing the soil solum plus 25% of the depth of the soil solum would capture a soil's key features and characteristics.

Soil Profile Surface Moisture

Figures 2-21 to 2-23 (M8/4P1-M2, M8/4P1-M3, and M8/4P1-M5) refer to the Teller prints (Chapter Two) and represent no water sprayed, 300 ml of water sprayed, and an additional 400 ml of water sprayed on the soil profile, respectively. For descriptive notation, measurement of the standard classified as Munsell "strong brown". Munsell notation of 7.5YR 4/4 classified as Munsell "brown" and all six readings of each print classified as Munsell "yellowish red". None of the three prints matched the standard in descriptive notation.

Figures 2-24 to 2-26 (M8/1P2-M4, M8/1P2-M5, and M8/1P2-M7) refer to the Grainola prints (Chapter Two) and represent no water sprayed, 500 ml of water sprayed, and an additional 500 ml of water sprayed on the soil profile surface, respectively. For descriptive notation, measurement of the standard classified as Munsell "dark red". Munsell notation of 10R 4/6 classified as Munsell "red" and all six readings of each print classified as Munsell "red" (Table 3-1 and Appendix E).

As mentioned in Chapter Two, the treatment (water) was applied to the soil profile, not to the Munsell color sheets, so the Munsell in the prints should have remained the same for all the prints of that sequence. Data on the Munsell in the prints are included in Table 3-2 and discussed only as an aid in understanding the changes in color from field to photographs. The Munsell color sheet was removed from the soil profile prior to spraying the soil profile with water, then re-positioned after spraying. Changes in the color components of hue, value, and chroma are attributed to other factors such as unstable lighting, inaccurate camera settings or light meter readings.

Teller and Grainola sequences were photographed on separate days. Visual and spectrophotometric trends were consistent with one another in the Teller prints, but not in the Grainola prints (Table 3-2). Most of the inconsistencies in color matching in this research have involved the red color of the Grainola soil and the corresponding 10R 4/6 Munsell color sheet. One factor that may have affected Figures 2-21 to 2-26 and the inability to obtain consistency in measurements between the prints, is the slight angular difference due to re-positioning the Munsell color sheet after the soil treatments.

Camera Angles

Figures 2-47 to 2-49 (A8/4P1-A2, A8/4P1-A3, A8/4P1-A6) refer to the Teller prints (Chapter Two) and represent camera angles of 90°, 60°, and 30°, respectively, from camera lens to the soil profile. For descriptive notation, measurement of the standard classified as Munsell "strong brown". Munsell notation of 7.5YR 4/4 classified as Munsell "brown" and all six readings of the former two prints classified as Munsell "yellowish red". In Figure 2-49 the Munsell part of the print was cut off while composing the picture. Consequently, no spectrophotometric readings of the Munsell were taken.

Neither print representing the Teller soil (Figures 2-47, 2-48) matched the standard in descriptive notation. Both prints were approximately as low or high in hue, value, and chroma of the spectrophotmetric measurements. Spectrophotometric measurements were redder than visual measurements for hue. Value and chroma matched for both the spectrophotometric and visual data.

Figures 2-50 to 2-52 (A8/1P2-A2, A8/1P2-A3, and A8/1P2-A5) refer to the Grainola prints (Chapter 2) and represent camera angles of 90°, 60°, and 30°, respectively, from camera lens to the soil profile. For descriptive notation, measurement of the standard classified as Munsell "dark red". Munsell notation of 10R 4/6 classified as Munsell "red" and all six readings of the former two prints classified as Munsell "red". Figure 2-52 (A8/1P2-A5) represented a photograph taken with the camera lens at a 30° angle from the soil profile in which the Munsell was cut off while composing the picture. Consequently, no spectrophotometric readings of the Munsell were taken.

Spectrophotometric measurements in Table 3-2 indicate that a 60° angle will result in a closer hue to the actual soil for red soils. The angle's effect on hue appears to be insignificant in the browner soils. In Table 3-2, trends and consistency between the visual measurements are in agreement with the exception of the redder hues in spectrophotometric measurements of the Teller soil. More accurate color with less angle as seen in Table 3-2 is due to more indirect light reaching the film as the photographer and camera re-positioned in order to change the angle. Although the visual data displayed more accuracy in color measurement, both spectrophotometric and visual data expressed the same trends. The 30° and 60° angles produced more accurate Munsell colors. However, the 90° angle allowed the accurate portrayal (no distortion) of the soil features.

Time of Day

Figures 2-53 to 2-57 (T6/6P1-T1d, T6/6P1-T2b, T6/6P1-H1a, T6/6P1-T3b, T6/6P1-T4a1) refer to the Teller prints (Chapter Two) and represent times of 11:30 a.m., 12:30

p.m., 1:00 p.m., 1:30 p.m., and 2:30 p.m. For descriptive notation, measurement of the standard classified as Munsell "strong brown". Munsell notation of 7.5YR 4/4 classified as Munsell "brown". All six measurements of Figure 2-53 classified as Munsell "red" whereas measurements of Figure 2-54 classified as Munsell "reddish brown" and measurements of Figures 2-55 and 2-57 classified as Munsell "strong brown". All six measurements of Figure 2-56 classified as Munsell "yellow red".

Figures 2-58 to 2-61 (T7/30P2-T2, T7/30P2-T7, T7/30P2-T10, T7/30P2-T14) refer to the Grainola prints (Chapter 2) and represent times of 11:30, 12:30, 1:30, 2:30, respectively. For descriptive notation, measurement of the standard classified as Munsell "dark red". Munsell notation of 10R 4/6 classified as Munsell "red" and all six readings of each print classified as Munsell "red".

Spectrophotometric measurements for hue are inconsistent with time of day in that they varied (no trend) as the day progressed and with the soil (Table 3-2). Figure 2-55 (representing 1:00 pm) of the Teller soil was consistent in either having the same notation as the standard or being consistently close in notation between the visual and spectrophotometric measurements (Table 3-2). Prints of the Grainola soil were not consistent between visual and spectrophotometric measurements (Table 3-2). Values were consistently higher than the standard in both the spectrophotometric and the visual measurements for both soils. When not accurate in hue, visual measurements were redder by the same numerical value, compared to the spectrophotometric measurements, which fluctuated in numerical values. The times of 1:00-1:30 pm as seen in Chapter Two were chosen as the best time to photograph the Teller and Grainola soils at their locations at the time of the summer they were photographed. The designated times of 1:00-1:30

p.m. were chosen prior to analyzing the visual and spectrophotometric data. As seen in Table 3-2, the designated times of 1:00-1:30 p.m. were reinforced in more accurate color components in visual and spectrophotometric data with the exception of the Grainola soil spectrophotometric data in which 11:30 a.m. resulted in a more accurate hue than 1:30 p.m.

Clouds

Figures 2-62 (T7/30P2-T6) and 2-63 (7/30P2-T8) refer to the Grainola soil prints (Chapter Two) and prints taken under cloudy conditions at aperture settings of 1/ 22-32 and 1/ 22.3 (shutter speed of 1/100), respectively. For descriptive notation, measurement of the standard classified as Munsell "dark red". Munsell notation of 10R 4/6 classified as Munsell "red" and all six readings of each print classified as Munsell "dark red".

The uniform diffuse light distribution the soil profile received under cloud cover (which eliminated bright peaks and dark shadows) resulted in closer agreement between prints and the standard for several components. Spectrophotometric measurements did not mirror the visual measurements exactly in both prints, but they were close. The Grainola soil print measured redder spectrophotometrically for hue than the visual measurements (Table 3-2).

Night Photography

Figures 2-64 to 2-66 (N8/17P1-N1h, N8/17P1-N1E, N8/17P1-N1b) refer to the Teller prints (Chapter Two) and represent use of Meade, Tiffen 80B, and Tiffen Decamired filters, respectively. For descriptive notation, measurement of the standard classified as

Munsell "strong brown". Munsell notation of 7.5YR 4/4 classified as Munsell "brown". All six measurements of Figure 2-64 classified as Munsell "red brown". All six measurements of Figure 2-65 classified as Munsell "light brown". All six measurements of Figure 2-66 classified as Munsell "pale brown".

Figures 2-67 to 2-69 (N8/17P2-N2d, N8/17P2-N2e, N8/17P2-N2f) refer to the Grainola prints (Chapter Two) and represent use of a Tiffen 80B filter with F-stop (F) and shutter speed (SS) settings of F1/8 with 1/8- SS, F1/5.6 with 1/8- SS, and F1/5.6 with 1/8 SS, respectively. For descriptive notation, measurement of the standard classified as Munsell "dark red". Munsell notation of 10R 4/6 classified as Munsell "red". All six measurements of Figure 2-67 classified as Munsell "red" whereas all six measurements of Figure 2-68 classified as Munsell "dark red". The six measurements of Figure 2-69 did not classify as descriptive Munsell notation in Munsell Soil Color Charts (Appendix E).

For the Teller soil, hue measured accurately in the prints in which the Tiffen 80B filter was used. Tiffen 80B was the recommended filter for matching the color temperature of the photoflood lighting to the film. Values measured high for readings of prints for all three filters. Chroma measured correctly on the print representing the Meade filter.

Visual and spectrophotometric measurements were consistent in Figure 2-66 where a yellower hue change was seen as well as higher values by three units. Figure 2-68 was the light meter recommended setting for the three prints of the Grainola soil all obtained by using the Tiffen 80B filter. Hue measurements were very high in the Grainola soil and could be due to taking measurements of prints of red soil affected by the use of a blue filter (Table 3-2). Visual measurements were more accurate in color components than the spectrophotometric measurements. The 80B filter used in the Teller soil was closest in hue for both the spectrophotometric and the visual measurements. Both visual and spectrophotometric measurements agreed in having excessive red color in the Grainola prints, lighter values, and inconsistent chromas (compared to the standard) (Table 3-2).

The recommended light meter readings and use of the Tiffen 80B filter with the lighting and film used in this study is best for accurate portrayal of soil features and characteristics under controlled lighting conditions. Other adjustments that affect (decrease redness) will have to be considered when photographing red soils.

Color Matching

Figures 2-70 (C8/4P1-C4a) and 2-71 (C8/4P1-C3b) refer to the Teller prints in Chapter Two. For descriptive notation, measurement of the standard classified as Munsell "strong brown". Munsell notation of 7.5YR 4/4 classified as Munsell "brown".

Figure 2-70 (C8/4P1-C4a) represents a photograph (of an 18% gray card and 7.5YR 4/4 Munsell color sheet against the Teller soil profile) not color matched to the 18% reflectance gray card. All six spectrophotometric measurements of the print classified as Munsell "light brown". Figure 2-71 (C8/4P1-C3b) represents a photograph (of an 18% gray card and 7.5YR 4/4 Munsell color sheet against the Teller soil profile) color matched between the 18% reflectance gray card appearing in the photograph to the actual gray card. All six spectrophotometric measurements of the print classified as Munsell "red brown".

Figures 2-72 (C8/4P2-C2a) and 2-73 (C8/4P2-C2b) refer to the Grainola prints (containing an 18% gray card and 10R 4/6 Munsell color sheet against the Grainola soil profile) in Chapter Two and represent no color matching and color matching, respectively, to an 18% reflectance gray card. For descriptive notation, measurement of the standard classified as Munsell "dark red". Munsell notation of 10R 4/6 classified as Munsell "red". All six measurements of Figure 2-72 classified as Munsell "pale red" whereas all six measurements of Figure 2-73 classified as Munsell "red".

Visual observations were more accurate in color and did not coincide consistently with spectrophotometric measurements in either soil for the not color matched or the color matched prints for hue or chroma. Values for both sets of prints were the same for visual and spectrophotometric measurements (Table 3-2). Where the visual observations measured more yellow in the Teller print not color matched, the spectrophotometric measurements were redder.

Spectrophotometric measurements were consistently redder than visual measurements in Table 3-2. Color matching to a standard can aid in bringing the soil up to visual agreement with the field soil color, although instrumental measurement may indicate redder colors.

Accuracy and Error

Production tolerance for stock Munsell colors is + or – 2 divided by chroma for hue, + or – 0.05 for value, and + or – 0.2 for chroma (Allen, 2000). The 7.5YR 4/4 Munsell color sheet used as a standard for the Teller soil in this study is assigned the tolerances of 7.0-8.0YR (hue), 3.95-4.05 (value), and 3.8-4.2 (chroma). The 10R 4/6 Munsell color sheet used as a standard for the Grainola soil is assigned the tolerances of 9.67-10.33R (hue), 3.95-4.05 (value), and 5.8-6.2 (chroma). All of the spectrophotometric measurements of the 7.5YR 4/4 Munsell color sheet were within hue tolerance, whereas none of the spectrophotometric measurements of the 10R 4/6 Munsell color sheet were within hue tolerance (Figure 3-2, Appendix E). Alternately, none of the measurements of either Munsell color sheet were within the tolerance levels allowed for values or chromas (Figure 3-1, Appendix E). The measurements (versus the supposed notation) of the standards were what was used for comparative purposes for this part of the research (Tables 3-1 and 3-2).

The Munsell color sheets of 7.5YR 4/4 and 10R 4/6 used as standards, did not result in spectrophotometric data, that, once converted, matched in hues, values and chromas to the actual notation. Differences could be attributed to the notation of the Munsell color sheet being incorrectly identified at the Munsell laboratory, or a defect in the internal measurement configurations in the spectrophotometer used.

As mentioned in the Discussion section of Chapter Two, the soil can be used for spectrophotometric readings assuming the area designated is smoothed flat, and field determined to be the same Munsell notation through out. Reflectance of a small circular sample removes structural features and may not be representative of the actual soil condition. Additionally, a much larger measurement port on the instrument would be required to eliminate the variability in many particles of different colors within a small area. Standard spectrophotometers are not equipped to handle the measurement of soils as measurement ports are normally 18 mm or less in diameter. A piece of equipment currently used for measuring color difference in carpeting has been recommended

(GretagMacbeth Seminar, 2000), as the measurement port has a diameter of approximately 125 mm. A measurement port of 125 mm diameter would allow better measurement and averaging of soil colors in the field. Standard sized (5mm-18mm) spectrophotometric measurement ports would still be used on photographs, however, since the resultant print would not accommodate a 125 mm diameter measurement port. A calculation factor may have to be devised to adjust for measurements taken between two different instruments of two different measurement port sizes.

CHAPTER IV

SUMMARY AND GUIDELINES

Summary

Many factors contribute to the appearance of soil in photographic media. Selecting the condition or factors which most accurately display the characteristics that represent a given soil is imperative to facilitate and promote correct visual information for the purpose of interpretations, education, and accurate documentation of the soil resource. Not identifying the conditions at the time of the photographic session results in the presentation of photographs which often exaggerate or de-emphasize characteristics of the soil. A reproducible approach to photographing soil profiles can be used to clearly represent the soil properties seen under field conditions, establishing a systematic procedure to documenting soils. Compliance with standards established for soil profile photography are just as viable as following an established procedure and methodology as all scientific standards demand.

Guidelines

Table 4-1 lists the proposed guidelines for photographing soil profiles based on this research. The following numbered list corresponds to the guidelines listed in Table 4-1:

Table 4-1

Proposed Guidelines

1. Use film size that matches or is larger than the final product size.
2. Choose a film based on the qualities the film imparts (or does not impart) to the final product.
3. Mount the camera to a sturdy, heavy tripod to minimize movement caused from wind and slight pressure.
4. If filters are used, record and state purpose.*
5. If any additional equipment is used that would modify or enhance the resultant image, list and state purpose.
6. Take light meter readings of an 18% gray card against the soil to be photographed after filters are in place and just prior to photographing the soil profile. Bracket photographs by changing the aperture and shutter speed settings above and below (1/3 to ½ F-stop increments) what the light meter recommends.*
7. Choose the distance from lens to soil profile which encompasses the soil solum plus 25% of the soil depth of the soil solum of the soil represented.
8. The camera should be positioned at a 90° angle and vertically centered from the soil profile.
9. Record the aperture and shutter speed settings used.
10. Use an 18% gray card as a measuring tape.*
11. Advise film processing and print producing laboratory not to crop photographs.
12. Advise film processing and print producing laboratory to color match using an 18% gray card.*
13. Record all information, including camera make, model, and film size, and submit with all published photographs.
14. Record lighting equipment and assessories (reflectors, diffusers, etc).
15. If filters are used, attach filters to camera lens for a custom fit (filters tend to shift position when attached to the lighting frame). Use filter manufacturer recommendations for F-stop adjustments to compensate for filter use, then bracket above and below those settings.*
16. Photograph soils within a light tight enclosure to control lighting conditions.
17. Record wattage, number of lights, and color temperature rating of the illuminant.
18. Use an 80B Tiffen filter attached to the camera lens to compensate for color temperature difference between 500 watt tungsten photofloods and daylight film. Use filter manufacturer recommendations for F-stop adjustment to compensate for filter use, then bracket above and below those settings.*
19. For artificial lighting, state the location (distance, angle and height) of the lighting in relation to both the camera and the soil profile.*
20. For artificial lighting, the key light should be placed directly in back of and above the camera and tripod (at a 90 degree angle from the soil profile).
21. For artificial lighting, the fill light should be placed at a 45 degree angle between the key light and the soil profile.
22. Note location of excavation (city and state, township and range, latitude and longitude). Record the direction of the face of the soil profile photographed.
23. Record the excavation dimensions.
24. A flat area of the pit floor should be large enough to accommodate necessary equipment. At least 9' in width and 16' in length is recommended.

25. Preparation of the soil profile. Prepping the soil profile can include picking with the tip of a knife, smoothing with a flat-edged tool, leveling the face, or misting with water as needed. Soils with little or no structure should be smoothed flat with the edge of a knife or similar tool. Other soils can be picked with the tip of a knife to reveal the soil structure.
26. Record all information and enclose with photographs submitted for publication.

* Photography involving the use of colored filters should not be color matched to an 18% gray card, as the effect of the color filter will be distorted or eliminated.

1) Use a film size that matches or is larger than the final product size. Image sharpness and detail is lost as the print produced increases in size from the negative the print was produced from.

2) Choose film based on the qualities the film imparts (or does not impart) to the final product. Ideally, test batches using different films on the same soil should be carried out and photographs bracketed at partial F-stops above and below the light meter recommendations. Films are discontinued, and new films that may have different color qualities, are substituted. Choosing the best film, then, also depends upon what the market offers at that time. Both visual and spectrophotometric measurements indicated that soils portrayed in photographs tend to be redder and lighter in dominant color, and either accurate or less saturated in color than the actual soil the photograph represents. Films for photographing soil profiles should be chosen based on the ability to adjust for excessive red. In this study, Pro 100 film, which tended to "brown" the soil image, imparted some color qualities that adjusted for excessive red. Record the film name, speed, manufacturer, and the color-imparting qualities of the film, if known.

3) Mount the camera to a sturdy, heavy tripod to minimize movement caused from wind and slight pressure.

4) If filters are used, record and state purpose. There are no recommendations offered in this section as to which specific filter (skylight, haze, diffusing, or no filter) is best to use on soils, as each of these filters used in this study imparted some visual benefit. Yellow filters, however, should not be used in color

photography of soil profiles of which accurate soil representation is the objective. Filter use should be recorded as to the type of filter used (and where it was positioned (attached to the camera lens versus attached to the lighting). Attachment to the camera lens is recommended for consistency in positioning. Filter information should accompany the corresponding published photographs.

5) If any additional equipment is used that would modify or enhance the resultant image, list and state purpose.

6) Take light meter readings of an 18% gray card against the soil to be photographed after filters are in place and just prior to photographing the soil profile. The light meter recommendations do not have to be used, but serve as a guide from which to adjust camera settings above and below. All photographs should be bracketed above and below (1/3 to ½ F-stop increments) the recommended settings to see the effect of varying camera settings with the film chosen under given lighting, etc. It serves as an aid to tailoring and improving soil profile photography to each specific soil.

7) Choose the distance from lens to soil profile which encompasses the soil solum plus 25% of the soil solum depth of the soil represented. The soil solum (soil above the C horizon) plus 25% as mentioned above, should be the gauge as to what distance from the soil profile is adequate for a given soil. Use of the soil solum as described above would ensure that soil profile development including pedogenic features be included. This would allow for a consistent area photographed (the soil solum plus 25%) that would include all of that soil's key features and characteristics. Supplementary photographs of close-up features, for

example, can accompany the primary photograph, so long as the recorded information as named within these pages, accompanies those photographs as well. Additional photographs can be included that show close-up detail of key features, but these photographs should accompany, not replace the soil solum plus 25% of soil solum depth photographs. Photographs should have only enough vegetation showing to recognize the soil surface as such. This would allow the capture of more soil detail. Distance specifics should be recorded and accompany all photographs published.

8) The camera should be positioned at a 90° angle and vertically centered from the soil profile. Although the 30° and 60° angles produced more accurate Munsell colors, the 90° angle allowed the accurate portrayal (no distortion) of the soil features. For the best expression of key features and characteristics, soil profiles should be composed with the camera centered vertically and horizontally to the soil area photographed. The lens to soil profile should be positioned at a 90° angle to ensure the least distortion of the soil features and the area photographed. If other camera positions are required, (due to limitations imposed by the location of the soil excavation) they should be noted and submitted along with the corresponding print. Otherwise, it should be assumed that the photographs were taken 90° from lens to soil profile and centered horizontally and vertically to the soil area to be photographed.

9) Record all aperture and shutter speed settings used. The aperture opening that resulted in the correct notation of the Munsell color sheet for this study was the smallest opening of 1/44+. The actual soil, however, was observed as being

redder. Camera settings of F-stops and shutter speeds affect the overall soil color seen which could affect interpretations based on color difference, organic matter content, and mineralogy. Aperture and shutter speed settings used to obtain the corresponding print should be recorded and accompany all published photographs. Proper light meter readings should be obtained just prior to shooting each photograph, then bracketed (1/3 to ½ stops) above and below what the light meter determines is the correct exposure. Aperture settings of F 1/16 and F1/22 have been recommended for photography of uneven textured walls such as soil profiles. Light meter readings normally suggest aperture and shutter speed combinations that are required for proper exposure. Rules of equivalent exposure allow the photographer to choose a different aperture opening and shutter speed combination equal in the amount of exposure the film receives.

10) Use an 18% gray card as a measuring tape. To reduce clutter in the photograph and yet supply a standard that can be used for color matching, the gray card should be incorporated as a measuring tape as was done in this study. The measuring tape should be large enough to allow measurement by the film processing and print making laboratory.

11) Advise film processing and print-producing laboratory not to crop photographs Cropping photographs of soil profiles can result in the loss of key soil features.

12) Advise film processing and print-producing laboratory to color match using an 18% gray card measuring tape (that appears in the photograph). Color matching is a technique that should be requested at the time the film is submitted to the film processing laboratory. A standard must appear in a photograph in order for the

color processing laboratory to attempt to match the photograph color of the standard to the actual standard. Changing the color of a photograph that contains a standard to accurately match the actual standard changes all of the color in the photograph to a truer observed color than when color matching is not requested. Color matching to a standard can aid in bringing the soil up to visual agreement with the field soil color, although instrumental measurement may indicate redder colors. Although there were inconsistencies in requesting the color matching of the measuring tape to the 18% gray card, this request is still seen as a viable method of standardizing a part of each photographic image while allowing comparisons of differences between prints in a series. When colored filters are used, color matching should not be requested. If the standard in the photograph were color matched to the actual standard when using color filters, the effect of the filter would be negated or exaggerated. Information on whether or not the print was color matched to a standard should accompany the corresponding print.

13) Record all information including camera make and model, and submit with all published photographs.
14) Record lighting equipment and assessories (reflectors, diffusers, etc.) used.
15) If filters are used, attach filters to camera lens for custom fit (filters tend to shift position when attached to the lighting frame). Use filter manufacturer recommendations for F-stop adjustments to compensate for filter use, then bracket above and below those settings.
16) The best time of day chosen to photograph soil is that time period resulting in the least shadowing on the soil profile face. This time will change with location

(township and range, latitude and longitude) and time of year. Preliminary daytime photographs should be taken centered on the peak time the sun is at its' highest. It should be noted however, that the resultant prints do not conform to the scientific tenet of reproducibility as daytime conditions are unstable and are everchanging. The best method to photograph soil profiles is under controlled lighting. In lieu of night photography using artificial lighting under an open sky (used in this study), the soil profile can be enclosed by a black light tight tarp or enclosure and artificial lighting can then be used during daylight hours. Only night photography or enclosing the soil profile and using artificial lighting will produce conditions that are repeatable and conform to the scientific tenet of reproducibility. Controlled lighting would solve many of the problems associated with lack of consistency such as the errors mentioned in the Discussion sections of Chapters Two and Three. Once the errors associated with inconsistent lighting, F-stops and shutter speeds are eliminated, differences due only to the factors studied can be clearly evaluated. Types of artificial lighting need to be closely examined to determine which lighting most closely mimics daylight.

17) Record wattage, number of lights, and color temperature rating of the illuminant. In the night photography prints studied, two 500 watt Tungsten photoflood lights with a color temperature of 3400K were used. Although soil features and characteristics are clearly seen, the overall appearance of the prints is not that of daylight conditions. Other available lighting may offer a truer to daylight appearance without losing detail the artificial lighting offers.

18) Use an 80B Tiffen filter attached to the camera lens to compensate for color difference between 500 watt tungsten photoflood lights and daylight film. The Tiffen 80B filter resulted in more accuracy in color components than the Meade and Decamired filters and is expected to have the same effect on soil color. The recommended light meter readings and use of the Tiffen 80B filter with the lighting and film used in this study was best for the most accurate portrayal of soil features and characteristics under controlled lighting conditions. Controlling lighting to create repeatable conditions which produces photographs of soil profiles displaying a uniform (rather than bright peaks and shadowed depression areas) soil profile surface is best for viewing all key features and characteristics of a soil (Chapter Two) as well as for seeing relative differences in color between horizons (Chapter Three). For complying with the scientific tenet of reproducibility, controlled lighting conditions provide repeatable conditions and should be mandatory.

19) For artificial lighting, state the location (distance, angle, and height) of the lighting in relation to both the camera and the soil profile.

20) For artificial lighting, the key light should be placed directly in back of and above the camera and tripod (at a 90° degree angle from the soil profile).

21) The fill light should be placed at a 45° angle between the key light and the soil profile.

22) Note the location of the excavation (city and state, township and range, latititude and longitude). Record the direction of the face of the soil profile photographed.

23) Record the excavation dimensions. Dimensions of the excavation are significant with regards to eliminating shadows of surrounding soil/wall on the face to be

photographed, accommodating all necessary equipment in the pit without shadowing the soil profile, and height of the soil profile wall to be photographed.

24) A flat area of the pit floor should be large enough to accommodate necessary equipment. At least 2.7m in width and 4.9m in length is recommended.

25) Preparation of the soil profile. Since film is more sensitive than the human eye, the uniformly colored surface of the Munsell color sheets as seen under field conditions was seldom expressed in subsequent prints. Care must be taken when excavating the soil profile to ensure the surface to be photographed does not angle from the top of the soil profile to the lower-most area to be photographed. In this study, picking the soil profile resulted in key soil features being less visible as compared to the same soil smoothed flat as seen in the Teller soil prints for time of day. When soils have little or no structure, the soil should be smoothed flat with the edge of a knife or similar tool. Other soils can be picked with a tip of a knife to reveal the soil structure. Care must be taken not to leave blade marks in the soil. Soil surface moisture affects the overall soil color seen which could affect interpretations based on color difference, soil moisture, organic matter content, and mineralogy. Color differences in the soil of the prints in this study are noticeable, where the soil appears darker with increased moisture. Spraying the soil profile darkened the soil color enough to warrant caution when spraying soil profiles for photographic purposes. If the soil was sprayed with water, record how much water (in ml) was sprayed over what area, and how long after spraying was the photography work completed. If soil moisture content samples are taken, they should be obtained at 25 cm intervals down the soil profile.

Grouping of Conditions and Factors

An outcome of this research was the recognition of two major groupings of Conditions and Factors and two subgroups for each category.

Under the category of Conditions, one subgroup is Natural Conditions, which include conditions such as atmospheric haze, soil moisture, and change in natural lighting and cloud cover. These conditions are not controllable and were not studied in this research. The second subgroup is Viewer Controlled Conditions, which include conditions such as the distance from lens to soil profile, camera angles, light illuminating the soil profile, light to the camera, and the time of day or night of the photographic session. These are controllable conditions which can be designed to override the limitations imposed by Natural Conditions. This research focused on this subgroup.

Under the category of Factors, one subgroup is Photographic Factors which includes factors such as camera settings, film used, filters and lenses. These factors are all equipment related, some of which were studied for this research. The second subgroup is Post Photographic Factors and includes factors under the primary control of the film processing and print making laboratory. These factors include color matching to a standard, the ability to change colors and contrast, photographic papers used, gloss component of the print, cropping, and the enlarging and focusing abilities of the individual running the equipment as well as the equipment. These factors can be influenced and may be controlled depending on whether specific instructions are carried out by the film processing and print making laboratory. This research focused primarily on color matching and not cropping requests of this subgroup.

Both categories need to be considered and explored further in order to be able to quantify changes in soil appearance due to variations within these groupings.

Consistency

Photographic images of soil profiles are seldom taken with consistency. Professional journals often publish photographs which are not properly exposed, taken at various angles and distances from the soil profile, and present soil colors untrue to the actual soil represented. These conditions often result in diminished or obscured soil features. As seen in the prints displayed for this research chapter, many factors can alter soil appearance, so it is crucial to record all the conditions and equipment at the time of the photographic session. Consistency is the primary factor in obtaining reproducible conditions and final products (prints, transparencies, etc.). Recording all information and consistency in procedure are requirements to conforming to the scientific tenet of reproducibility.

BIBLIOGRAPHY

Aandahl, A. R. 1982. Soils of the great plains: land use crops and grasses. University of Nebraska Press, Lincoln and London.

Abbott, B. 1941. The view camera. p. 158-175. *In* W. D. Morgan and H. M. Lester, Graphic graflex photography: The master book for the larger camera. Morgan and Lester Publishers, N.Y., N.Y.

Allen, E. 2000. Visual Products Specialist. Personal Communication. <Allen@GretagMacbeth.com>.

Am. Soc. Test. Mater., E 308-96. 1998. Standard practice for computing the colors of objects by using the CIE system *In* 1998 annual book of ASTM standards, West Conshohocken, PA. 06:01:682-711.

Am. Soc. Test. Mater., E 312-96. 1998. Standard practice for description and selection of conditions for photographing specimens *In* 1998 annual book of ASTM standards, West Conshohocken, PA. 06:01:713-719.

Am. Soc. Test. Mater., E 805-94. 1998. Standard practice for identification of instrumental methods of color or color-difference measurement of materials *In* 1998 annual book of ASTM standards, West Conshohocken, PA 06:01:734-737.

Am. Soc. Test. Mater., E 1164-94. 1998. Standard practice for obtaining spectrophotometric data for object-color evaluation *In* 1998 annual book of ASTM standards, West Conshohocken, PA. 06:01:783-789.

Am. Soc. Test. Mater., E 1347-97. 1998. Standard test method for color and color difference measurement by tristimulus (filter) colorimetry *In* 1998 annual book of ASTM standards, West Conshohocken, PA. 06:01:807-810.

Applied Color Systems, Inc. 2000. http://www.munsell.com/download.htm. Munsell Conversion Program, Beta Software Download, version 4.01. Munsell to XYZ to Lab to RGB to CMYK Conversion. July. Munsell is a division of GretagMacbeth, New Winsor, New York.

Bigham, J.M. and E.J. Ciolkosz, (eds.) 1993. Soil color. SSSA Publication #31. SSSA, Madison, WI.

Bourgin, D. 1999. http://www.well.com/user/rld/vidpage/color_faq.html. Color spaces FAQ. p. 1-24. 6/24/99.

Buol, S.W., F.D. Hole, and R.J. McCracken. 1989. Soil genesis and classification. 3rd ed. Iowa State Univ. Press, Ames.

Burchfield, J., M. Jacobs and K. Kokrda. 1997. Photography in focus. 5th ed. NTC Pub. Grp, Lincolnwood, Illinois.

Commission Internationale de l'Eclairage. 1931. Proceedings of the eighth session, Cambridge, England. Bureau Central de la CIE, Paris.

Commission Internationale de l'Eclairage. 1971. Colorimetry: Official recommendations of the International Commission on Illumination. Publication CIE NO. 15 (E-1.3.1). Bureau Central de la CIE, Paris.

Commission Internationale de l'Eclairage. 1978. Recommendations on uniform color spaces, color difference equasions, and psychometric color terms. Supplement No. 2 to Publication CIE No. 15 (E1.3.1), 1971/(TC-1.3). Bureau Central de la CIE, Paris.

Cummings, S. 2000. Product Specialist, Tiffen Filter Co. Personal Communication. scummings@tiffen.com.

Dain and Powell *In* Melville, M.D. and G. Atkinson. 1985. Soil colour: its measurement and its designation in models of uniform colour space. J. Soil Sci. 36:495-512.

Datacolor International. 1999. Microflash spectrophotometers. http://www.datacolor.com/mf200 tech.htm

Davis, T. 2000. Product Specialist, Tiffen Filter Co. Personal Communication. saunders@aol.com.

Eastman Kodak Co.©, 1998. Kodak Professional Division, Rochester, NY.

Eastman Kodak Co.©, 1999. KODAK gray Cards, Publication R-27, Rochester, NY.

Editorial Board, 1999. Soil Science Society of America Journal. SSSA, Madison, WI.

Evans, R.M. 1974. The perception of color. John Wiley and Sons, New York.

Glenn, J.J. and J.T. Killian. 1940. Trichromatic analysis of the munsell book of color. J. Opt. Soc. Am. 30:7:609-616.

Granville, W.C., D. Nickerson, and C.E. Foss. 1943. Trichromatic specifications for intermediate and special colors of the Munsell system. J.O.S.A. 33:7:376-385.

GretagMacbeth. 1994. Munsell soil color charts. New Windsor, New York.

Gretag Macbeth. 2000a. Fundamentals of Color and Appearance. GretagMacbeth, New Windsor, New York.

Gretag Macbeth. 2000b. Fundamentals of Color and Appearance, seminar. 9/26/00-9/27/00. Overland Park, Kansas. Sponsored by GretagMacbeth, New Windsor, New York.

Hawken, W.R. 1976. You and your lenses. Amphoto Pub., Garden City, New York.

Helprin, B. and the editors of Photographic Magazine. 1973. Peterson's guide to photo lighting techniques. Petersen Pub. Co., Los Angeles, CA.

Hunt, R.W.G. 1992. Measuring colour. Ellis Horwood Ltd, New York.

Hunter, R. S. 1975. The measurement of appearance. John Wiley & Sons, New York.

Judd, D.B. (assoc. ed.) 1940. Foreword *In* D. Nickerson, History of the Munsell color system and its scientific application. J. Opt. Soc. Am. 30:574-586.

Kaufman, J.E. (ed.) 1981. IES lighting handbook. 1981 Ref. Vol. Illum. Eng. Soc., New York.

Kaufman, J.E. and J.F. Christensen (eds.) 1972. IES lighting handbook, 5th ed., Illum. Eng. Soc. Waverly Press, Inc., Baltimore, Md.

Kelly, K.L., K.S. Gibson, and D. Nickerson. 1943. Tristimulus specification of the Munsell Book of Color from spectrophotometric measurements. J. Opt. Soc. Am. 33:7:355-376.

Kelly, K.L. and D.B. Judd. 1955. The ISCC-NBS method of designating colors and a dictionary of color names. U.S. Dept. of Commerce, NBS Circular 553, U.S. Gov. Print. Off., Washington, D.C.

Kelly, K.L. and D.B. Judd. 1976. Color: universal language and dictionary of color names. U.S. Dept. of Commerce, NBS Spec. Pub. 440, U.S. Gov. Print. Off., Washington, D.C.

Klein, C. and C.S. Hurlbut. 1993. Manual of mineralogy. John Wiley and Sons, Inc., New York.

Kohnke, H. 1986. Soil science simplified, 3rd ed. Waveland Press, Inc., Prospect Heights, Illinois.

Kondrat'yev, K.Y. and P.P. Fedchenko, 1983. Investigation of humus in soils from their colours. Sov. Soil Sci. 15:108-111.

Lamb, T. and J. Bourriau (eds.) 1995. Colour: art and science. Cambridge Univ. Press.

Larish, J. 1992. Digital photography: Pictures of tomorrow. Micro Publishing Press, Torrance, CA.

MacAdam, D.L. 1985. Color measurement, theme and variations. Springer-Verlag, Berlin.

McFarlane, J. W. 1941a. How to use filters. p. 57-75. *In* W. D. Morgan and H. M. Lester, Graphic graflex photography: The master book for the larger camera. Morgan and Lester Publishers, N.Y., N.Y.

McFarlane, J. W. 1941b. Kodachrome photography. p. 95-106. *In* W. D. Morgan and H. M. Lester, Graphic graflex photography: The master book for the larger camera. Morgan and Lester Publishers, N.Y., N.Y.

Meade. 2000. Meade Instruments Corporation. Irvine, California.

Melville, M.D. and G. Atkinson. 1985. Soil colour: Its measurement and its designation in models of uniform colour space. J. Soil Sci. 36: 495-512.

Mieth, H. 1941. Science pictures for publication. p. 303-318. *In* W. D. Morgan and H. M. Lester, Graphic graflex photography: The master book for the larger camera. Morgan and Lester Publishers, N.Y., N.Y.

Morgan, W.D. and H.M. Lester. 1941. Graphic graflex photography: The master book for the larger camera. Morgan and Lester Publishers, N.Y., N.Y.

Munsell Color Company. 1929. Munsell book of color. Munsell Color, Macbeth Division of Kollmorgen Corporation, Baltimore, Maryland.

National Bureau of Standards. 1955. The ISCC-NBS method of designating colors and a dictionary of color names. U.S. Dept. of Commerce. U.S. Gov. Print. Off., Washington, D.C.

Neblette, C.B. and A.E. Murray. 1973. Photographic lenses. Morgan and Morgan, Publishers, Fountain Press, London.

Nickerson, D. 1940. History of the Munsell color system and its scientific application. J. Opt. Soc. Am. 30:574-586.

Pierzynski, G.M., J.T. Sims, and J.F. Vance. 1994. Soils and environmental quality. Lewis Publishers, CRC Press, Boca Raton.

Ponte, K.J. and B.J. Carter. 1999. Sorting soils by key soil properties to meet users' needs. Soil Surv. Horiz. 40:1:7-20.

Ray. S. 1976. The lens in action. Hastings House Publishers, New York.

Rockwell Jr., H.P. 1941. Negative exposure and development. p. 21-42. *In* W.D. Morgan and H.M. Lester, Graphic graflex photography: The master book for the larger camera Morgan and Lester, Publishers, N.Y., N.Y.

Shields, J.A., E.A. Paul, R.J. St. Arnaud, and W.K. Head, 1968. Spectrophotometric measurement of soil color and its relationship to moisture and organic matter. Can. J. Soil Sci. 48: 271-280.

Simonson, R.W. 1993. Soil color standards and terms for field use – history of their development. p. 9-13. *In* J.M. Bigham and E.J. Ciolkosz (eds.) Soil color. SSSA Publication #31. Soil Sci. Soc. Am., Madison, WI.

Soil Survey Division Staff. 1993. Soil survey manual. USDA, Handbook #18. U.S. Gov. Prtg. Off., Washington, D.C.

Soil Survey Staff. 1996. Keys to soil taxonomy. U.S.D.A., SCS. Pocahontas Press, Inc. Blacksburg, Va.

Stroebel, L. 1993. View camera technique, 6th ed. Focal Press, Boston and London.

Tiffen, 1999. The Tiffen Company, Consumer Marketing and Distribution, Rochester, NY.

Tiffen, I. 2000. Camera filters. www.tiffen.com/camera_filtersby_ira_tiffen.htm

Tyler J.E. and A.C. Hardy. 1940. An analysis of the original Munsell Color System. J.O.S.A. 30:587-590.

Zisman, S.B. 1941. Modern educational photography. p. 205-220. *In* W. D. Morgan and H. M. Lester, Graphic graflex photography: The master book for the larger camera Morgan and Lester Publishers, N.Y., N.Y.

APPENDIX A

Teller Soil Series Description Sheet

LOCATION TELLER OK+TX
Established Series
Rev. CEW:JFH:CRC
07/98

TELLER SERIES

The Teller series consists of very deep, well drained, moderately permeable soils that formed in loamy sediments of Pleistocene age. These nearly level to sloping soils are on broad, smooth prairie upland terraces in the Central Rolling Red Prairies (MLRA-80A). Slopes are 0 to 8 percent. Mean annual precipitation is 34 inches. Mean annual temperature is 61 degrees F.

TAXONOMIC CLASS: Fine-loamy, mixed, active, thermic Udic Argiustolls

TYPICAL PEDON: Teller fine sandy loam--cultivated. (Colors are for dry soil unless otherwise stated.)

Ap--0 to 6 inches; brown (10YR 5/3) fine sandy loam, dark brown (10YR 3/3) moist; weak fine and medium granular structure; slightly hard, very friable; moderately acid; clear smooth boundary. (0 to 11 inches thick)

A--6 to 15 inches; brown (10YR 4/3) fine sandy loam, dark brown (10YR 3/3) moist; moderate medium and fine granular structure; slightly hard, friable; moderately acid; gradual smooth boundary. (6 to 15 inches thick)

BA--15 to 20 inches; brown (7.5YR 4/4) fine sandy loam, dark brown (7.5YR 3/4) moist; weak medium subangular blocky structure parting to moderate medium granular; hard, friable; moderately acid; gradual smooth boundary. (0 to 8 inches thick)

Bt1--20 to 32 inches; yellowish red (5YR 4/6) sandy clay loam, yellowish red (5YR 3/6) moist; weak coarse prismatic structure parting to moderate medium subangular blocky; hard, firm; thin nearly continuous clay films on faces of peds; moderately acid; gradual smooth boundary. (6 to 20 inches thick)

Bt2--32 to 42 inches; yellowish red (5YR 5/6) sandy clay loam, yellowish red (5YR 4/6) moist; weak coarse prismatic structure parting to weak medium subangular blocky; hard, firm; patchy clay films on faces of peds; moderately acid; gradual smooth boundary. (6 to 20 inches thick)

Bt3--42 to 60 inches; yellowish red (5YR 5/6) fine sandy loam, yellowish red (5YR 4/6) moist; weak coarse prismatic structure; hard, friable; patchy clay films on faces of peds; moderately acid; diffuse smooth boundary. (10 to 30 inches thick)

C--60 to 70 inches; yellowish red (5YR 5/6) fine sandy loam, yellowish red (5YR 4/6) moist; massive; slightly hard, friable; moderately acid.

TYPE LOCATION: Payne County, Oklahoma; about 1 mile west and 1 mile north of Perkins. 2,100 feet north and 80 feet east of the southwest corner of sec. 36, T. 18 N., R. 2 E.

RANGE IN CHARACTERISTICS: Solum thickness is more than 50 inches thick. The mollic epipedon is less than 20 inches thick.

The Ap or A horizon has hue of 5YR to 10YR, value of 3 to 5, and chroma of 2 to 4. Texture is fine sandy loam, loam, silt loam, or very fine sandy loam. Reaction is moderately acid or slightly acid. Some pedons that have been limed are neutral in reaction.

The BA horizon has hue of 5YR or 7.5YR, value of 4 or 5, and chroma of 2 to 4. Texture and reaction are the same as the A horizon.

The Bt1 and Bt2 horizons have hue of 2.5YR or 5YR, value of 4 to 6, and chroma of 4 to 8. Texture is sandy clay loam or clay loam. The upper 20 inches of the argillic horizon averages 18 to 30 percent clay, 15 to 45 percent material coarser than very fine sand, and less than 20 percent material coarser than fine sand. Reaction ranges from moderately acid to neutral.

The Bt3 horizon has hue of 2.5YR to 7.5YR, value of 4 to 6, and chroma of 4 to 8. Texture is fine sandy loam, loam, clay loam, sandy clay loam, or very fine sandy loam. Reaction is moderately acid to neutral. Some pedons have Bt4 and Bt5 horizons that are similar in color, texture and reaction to Bt3.

Some pedons have BC horizons. The BC horizon has hue of 2.5YR to 7.5YR, value of 4 to 6, and chroma of 4 to 8. Texture is loam, fine sandy loam, or very fine sandy loam. Reaction ranges from slightly acid to slightly alkaline.

The C horizon has the same color and texture as the BC horizon. Reaction ranges from moderately acid to slightly alkaline in the upper part. Some pedons are moderately alkaline and calcareous below a depth of 70 inches.

COMPETING SERIES: These are the Carmen, Chickasha, Lovedale, Milan, Naron, Navina, Ravia, Stoneburg, Teval, Waynoka, and Zaneis series. Carmen soils are less acid in the Bt horizons. The Chickasha, Stoneburg, and Zaneis soils have a solum less than 60 inches thick. In addition, Chickasha soils have a Bt2 horizon with hue of 7.5YR or yellower. Lovedale, Milan, and Naron soils contain more than 20 percent material coarser than fine sand in the upper 20 inches of the argillic horizon. In addition, Naron soils have hue of 7.5YR or yellower in the argillic horizon. Ravia soils have 10 to 30 percent by volume of coarse fragments in the control section. Navina soils have Bt horizons with hue of 7.5YR or browner. Teval soils have more than 20 percent fragments 2 to 76 mm within 60 inches of the surface. Waynoka soils have a discontinuity with a clay increase in the lower part of the solum.

GEOGRAPHIC SETTING: Teller soils are on nearly level to sloping prairie upland terraces in the Central Rolling Red Prairies (MLRA 80A). Slopes are 0 to 8 percent. They formed in loamy sediments of Pleistocene Age. The mean annual precipitation ranges from 26 to 38 inches. The mean annual air temperature ranges from 58 to 63 degrees F. The Thornthwaite annual PE indices range from 44 to 64. The soil moisture regime is Udic-Ustic.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Dougherty, Konawa, Minco, Navina, Norge, Pond Creek, Slaughterville, and Vanoss series.
Dougherty and Konawa soils are in slightly higher positions and lack a mollic epipedon. Minco soils are in higher positions or in areas between terraces and lack an argillic horizon. Norge, Pond Creek, and Vanoss soils are in slightly lower positions and have fine-silty control sections. Navina soils are on similar positions.
Slaughterville soils are on slightly lower positions nearer major streams, and lack argillic horizons.

DRAINAGE AND PERMEABILITY: Well drained; negligible to medium runoff; moderate permeability.

USE AND VEGETATION: Mainly cultivated to small grains, sorghums, peanuts, or cotton. Lesser amounts are used for tame pasture or native range. The native vegetation is tall prairie grasses.

DISTRIBUTION AND EXTENT: Central Rolling Red Prairies of Oklahoma, Kansas, and possibly Texas. The series is of moderate extent.

MLRA OFFICE RESPONSIBLE: Temple, Texas

SERIES ESTABLISHED: Johnston County, Oklahoma; 1906.

ADDITIONAL DATA: NSSL lab.data sample number S90OK-083-006

REMARKS: Soil Interpretation Record No. OK0037

Diagnostic horizons and features recognized in the pedon are:

Mollic epipedon - the zone from the surface of the soil to a depth of 15 inches (A horizons and sometimes the BA horizon).

Argillic horizon - the zone from 20 inches to a depth of 60 inches (Bt horizons).

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APPENDIX B

Grainola Soil Series Description Sheet

LOCATION GRAINOLA OK+KS

Established Series
Rev. CRC:CEW:CS
06/1999

GRAINOLA SERIES

The Grainola series consists of moderately deep, well drained, slowly permeable upland soils that formed in material weathered from shale of Permian age. These soils are on very gently sloping to steep convex uplands in the Central Rolling Red Prairies (MLRA-80A). Slopes range from 1 to 25 percent. Mean annual precipitation is 33 inches. Mean annual air temperature is 60 degrees F.

TAXONOMIC CLASS: Fine, mixed, active, thermic Udertic Haplustalfs

TYPICAL PEDON: Grainola silty clay loam--rangeland. (Colors are for dry soil unless otherwise stated.)

Ak--0 to 6 inches; reddish brown (5YR 4/3) very gravelly silty clay loam, dark reddish brown (5YR 3/3) moist; strong medium granular structure; hard, friable; about 25 percent by volume of flat limestone fragments that range from 2 mm to 76 mm diameter and about 10 percent by volume of flat limestone fragments greater than 76 mm in diameter; about 5 percent calcium carbonate concretions that range from 2 mm to 76 mm in diameter; calcareous; moderately alkaline; clear smooth boundary. (4 to 10 inches thick)

BAk--6 to 13 inches; reddish brown (5YR 5/3) silty clay loam, reddish brown (5YR 4/3) moist; moderate medium granular structure; hard, firm; about 7 percent by volume of flat limestone fragments that range from 2 mm to 76 mm in diameter; about 5 percent calcium carbonate concretions that range from 2 mm to 76 mm in diameter; calcareous; moderately alkaline; gradual smooth boundary. (0 to 10 inches thick)

Btk1--13 to 28 inches; reddish brown (2.5YR 4/4) silty clay, dark reddish brown (2.5YR 3/4) moist; with common fine light olive gray spots of weathered shale; weak medium blocky structure; very hard, very firm; nearly continuous clay films or pressure faces on faces of peds; about 5 percent by volume of sandstone fragments that range from 2 mm to 76 mm in diameter; few calcium carbonate concretions; few masses of calcium carbonate; calcareous; moderately alkaline; clear wavy boundary. (8 to 16 inches thick)

Btk2--28 to 36 inches; reddish brown (2.5YR 4/4) very gravelly silty clay, dark reddish brown (2.5YR 3/4) moist; weak medium blocky structure; very hard, very firm; patchy clay films on faces of peds; about 40 percent by volume of dark reddish brown and olive gray shale fragments that range from 2 mm to 76 mm in diameter; few calcium carbonate concretions; common masses of calcium carbonate; calcareous; moderately alkaline; clear wavy boundary. (0 to 16 inches thick)

Cr--36 to 42 inches; weak red (2.5YR 5/2) shale bedrock; laminated; calcium carbonate films on faces of some fragments; calcareous.

TYPE LOCATION: Osage County, Oklahoma; about 4 miles west and 3 miles north of Shidler; 1,060 feet east and 280 feet south of the northwest corner of sec. 14, T. 27 N., R. 5 E.

RANGE IN CHARACTERISTICS: Solum thickness and depth to soft siltstone or shale bedrock ranges from 20 to 40 inches. This soil has cracks within 125 cm of the soil surface that are 5 mm or more wide through a thickness of 30 cm or more for some time in most years, and slickensides or wedge-shaped aggregates in a layer 15 cm or more thick that has it upper boundary within 125 cm of the soil surface; or a linear extensibility of 6.0 cm or more between the soil surface and a depth of 100 cm or a paralithic contact, whichever is shallower. Coarse fragments are typically sandstone, sandstone cemented with hematite, limestone, and calcium carbonate concretions and nodules. Masses of calcium carbonate range from 0 to 5 percent by volume in a subhorizons. Some areas have stones or boulders which cover 3 to 35 percent of the soil surface.

The A horizon has hue of 2.5YR to 7.5YR, value of 4 or 5, and chroma of 2 to 4. Where the A horizon is 18 cm or more thick, the chroma is higher than 3, or organic carbon is less than 0.6 percent. Texture is silt loam, loam, silty clay loam or clay loam, and their gravelly, cobbly, or stony counterparts. Content of coarse fragments ranges from 0 to 55 percent by volume. Coarse fragments of hard limestone or sandstone less than 76 mm in diameter range from 0 to 35 percent by volume, and coarse fragments 76 mm to 250 mm in diameter range from 0 to 20 percent by volume. Coarse fragments 250 mm to 375 mm in diameter range from 0 to 20 percent by volume. Reaction is neutral to moderately alkaline and some pedons are noncalcareous.

The BA horizon has hue of 2.5YR to 7.5YR, value of 4 or 5, and chroma of 2 to 4. Texture is silty clay loam, clay loam, clay, or silty clay and their gravelly, cobbly, stony, or bouldery counterparts. Content of coarse fragments is the same as the A horizon. Reaction is moderately alkaline and calcareous.

The Btk1 horizon has hue of 2.5YR or 5YR, value of 4 or 5, and chroma of 3 to 8. The Bt1 horizon is streaked or spotted with shades of grayish or olive colors in some pedons, which are believed to be inherited from the bedrock parent material. This horizon has texture of silty clay loam, clay loam, clay, or silty clay. The clay content of the Btk1 horizon averages 42 percent, but ranges from 35 to 60 percent. Soft shale fragments less than 76 mm in diameter that slake in water within 15 hours range from 0 to 15 percent by volume. Reaction is moderately alkaline and calcareous.

The Btk2 horizon has hue of 2.5YR to 7.5YR, value of 4 or 5, and chroma of 2 to 8. Texture is clay loam, silty clay loam, clay, and silty clay. Soft shale fragments less than 76 mm in diameter that slake in water within 15 hours range from 5 to 45 percent by volume. Masses of calcium carbonate range from 0 to 10 percent by volume. Reaction is moderately alkaline and calcareous.

The BC horizon, where present, has hue of 10R to 5YR, value of 4 to 6, and chroma of 2 to 8. Texture is clay loam, silty clay loam, clay, or silty clay. Soft shale fragments less than 76 mm in diameter that slake in water within 15 hours range from 5 to 70 percent by volume. Reaction is moderately alkaline and calcareous.

The Cr horizon has hue of 10R to 5YR, value of 3 to 5, and chroma of 2 to 6. Some pedons are streaked or spotted with shades of grayish, brownish, yellowish, or olive colors. Thin strata of limestone or sandstone are interbedded with shales in some pedons. This material has high or very high excavation difficulty due to the interbedding of hard sandstone and limestone. It is dense enough to be root restrictive. Fractures are greater than 10 cm apart. The Cr is composed mostly of shale, which will slake in water within 15 hours.

COMPETING SERIES: There are no other series in this family. Soils in similar families are Agan, Aydelotte, Culp, Durant, Foraker, Lofton, Normangee, Piedmont, Ponder, Renthin, Steedman, Tabler, Throck, and Vernon series. Agan and Aydelotte soils have a solum more than 60 inches thick. Culp, Durant, Foraker, Lofton, Piedmont, Renthin, and Tabler soils have a mollic epipedon. In addition, Durant, Foraker, and Tabler soils have smectitic mineralogy. Normangee and Ponder soils have a solum more than 40 inches thick and have smectitic mineralogy. Steedman soils are more acid in the A and Bt1 horizons and have smectitic mineralogy. Throck and Vernon soils do not have an argillic horizon.

GEOGRAPHIC SETTING: Grainola soils are on very gently sloping to steep convex ridgetops and side slopes of uplands in the Central Rolling Red Prairies. Slopes range from 1 to 25 percent. They formed in material weathered from shale of Permian age. The climate is moist subhumid. Mean Annual Precipitation is 26 to 40 inches. Mean Annual Temperature is 58 to 64 degrees F. Thornthwaite Annual P-E indices is 44 to 64. Average number of frost free days is 200 to 220. Elevation ranges from 800 to 1500 feet.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the competing Aydelotte and Foraker series and Apperson, Corbin, Kiti, Lucien, Masham, Piedmont, Renfrow, Renthin, Shidler, and Tamford series. Aydelotte and Foraker soils usually occur on broad ridges that are slightly higher. Apperson, Corbin, and Renfrow soils have a mollic epipedon and usually occur on broad ridges that are slightly higher than Grainola soils. Kiti, Lucien, and Shidler soils are less than 20 inches thick, lack an argillic horizon, have a mollic epipedon, and occur on ridgetops. Masham soils are less than 20 inches thick and typically occur slightly lower in the landscape than Grainola soils. Tamford soils do not have argillic horizons and occur on foot slopes. Piedmont and Renthin soils have a mollic epipedon and typically occur on slightly higher, smoother areas of the landscape.

DRAINAGE AND PERMEABILITY: Well drained; slow permeability; runoff is medium on slopes of 1 to 5 percent, high on slopes of 5 to 20 percent and very
high on slopes greater than 20 percent.

USE AND VEGETATION: Nearly all used for range. Native vegetation is short and midgrass prairie.

DISTRIBUTION AND EXTENT: Central Rolling Red Prairies (MLRA 80A) of Oklahoma and possibly Kansas. The series is moderately extensive.

MLRA OFFICE RESPONSIBLE: Temple, Texas

SERIES ESTABLISHED: Osage County, Oklahoma; 1975.

REMARKS: Grainola soils were formerly included in the Vernon series.

Diagnostic horizons and features in this pedon are:

Ochric epipedon 0 to 6 inches.

Argillic horizon: 13 to 36 inches of depth.

Paralithic contact at 36 inches.

Ustic moisture regime: Moisture control section is dry in some part more than 90 days per year.

Udertic: Moisture control section is dry in some part from 90 to 150 days. Clay content is greater than 35 percent within 15 inches of the surface.

Soil Interpretation Records: OK0175 - Grainola Series
OK0329 - Gravelly
OK0310 - Cobbly
OK0288 - Stony
OK0311 - Bouldery

ADDITIONAL DATA: Oklahoma State University laboratory data 73-OK-57-18, 76-OK-52-(1-6), 72-OK-60-(1-5), and 74-OK-10-(1-5).

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APPENDIX C
All Prints Produced from Negatives

PRINTS MADE*	
Time of Day	T6/6P1-T1a
Taxadjunct to Teller	T6/6P1-T1b
6/6/00	T6/6P1-T1c
surface picked	T6/6P1-T1d
	T6/6P1-T1e
	T6/6P1-T2a
	T6/6P1-T2b
	T6/6P1-H1a
	T6/6P1-T3a
	T6/6P1-T3b
	T6/6P1-T4a1
	T6/6P1-T4a2
	T6/6P1-T4b1
	T6/6P1-T4b2
	T6/6P1-T4c
	T6/6P1-T4d
Time of Day	T7/16P2-T1a
Taxadjunct to Grainola	T7/16P2-T1b
7/16/00	T7/16P2-T1c
	T7/16P2-T1d
	T7/16P2-T1E
	T7/16P2-T1F
	T7/16P2-T1G
	T7/16P2-T1H
	T7/16P2-T1I
	T7/16P2-T1Ja
	T7/16P2-T1Jb
Time of Day	T7/30P2-T1
Taxadjunct to Grainola	T7/30P2-T2
7/30/00	T7/30P2-T3
	T7/30P2-T4
	T7/30P2-T5
	T7/30P2-T6
	T7/30P2-T7
	T7/30P2-T8
	T7/30P2-T10
	T7/30P2-T11
	T7/30P2-T12
	T7/30P2-T13
	T7/30P2-T14
	T7/30P2-T15
	T7/30P2-T16
	T7/30P2-T17
	T7/30P2-T18
	T7/30P2-T19
	T7/30P2-T20

PRINTS MADE*	
Angles	A6/7P1-A1a
Taxadjunct to Teller	A6/7P1-A1b
6/7/00	A6/7P1-A2a
surface picked	A6/7P1-A2b
	A6/7P1-A3a
	A6/7P1-A3b
Angles	A8/1P2-A1
Taxadjunct to Grainola	A8/1P2-A2
8/1/00	A8/1P2-A3
	A8/1P2-A4
	A8/1P2-A5
	A8/1P2-A6
Angles	A8/4P1-A1
Taxadjunct to Teller	A8/4P1-A2
8/4/00	A8/4P1-A3
surface smoothed	A8/4P1-A4
	A8/4P1-A5
	A8/4P1-A6
Distance/Area	D7/31P2-D2
Taxadjunct to Grainola	D7/31P2-D5
7/31/00	D7/31P2-D9
	D7/31P2-D10
	D7/31P2-D3
	D7/31P2-D6
	D7/31P2-D7
	D7/31P2-D8
Distance/Area	D6/8P1-D7a
Taxadjunct to Teller	D6/8P1-D7b
6/8/00	D6/8P1-D8a
surface picked	D6/8P1-D8b
Distance/Area	D8/2P1-D2
Taxadjunct to Teller	D8/2P1-D3
8/2/00	D8/2P1-D4
surface smoothed	D8/2P1-D5
	D8/2P1-D6
	D8/2P1-D8
	D8/2P1-D9
	D8/2P1-D10
	D8/2P1-D12
	D8/2P1-D14
	D8/2P1-D15
	D8/2P1-D16
	D8/2P1-D18

PRINTS MADE*	
Moisture	M6/7P1-Mo1a
Taxadjunct to Teller	M6/7P1-Mo1b
6/7/00	M6/7P1-Mo2a
surface smoothed	M6/7P1-Mo2b
	M6/7P1-Mo3a
	M6/7P1-Mo3b
Moisture	M7/8P1-FM1
Taxadjunct to Teller	M7/8P1-FM2
7/8/00	M7/8P1-FM3
surface smoothed	M7/8P1-FM4
	M7/8P1-FM5
	M7/8P1-FM6
	M7/8P1-FM7
	M7/8P1-FM8
Moisture	M8/1P2-M1
Taxadjunct to Grainola	M8/1P2-M2
8/1/00	M8/1P2-M3
	M8/1P2-M4
	M8/1P2-M5
	M8/1P2-M6
	M8/1P2-M7
	M8/1P2-M8
	M8/1P2-M9
	M8/1P2-M10
Moisture	M8/4P1-M1
Taxadjunct to Teller	M8/4P1-M2
8/4/00	M8/4P1-M3
surface smoothed	M8/4P1-M4
	M8/4P1-M5
	M8/4P1-M6
Film	Fi7/6P1-Fi1
Taxadjunct to Teller	Fi7/6P1-Fi2
7/6/00	Fi7/6P1-Fi3
surface smoothed	Fi7/6P1-Fi4
	Fi7/6P1-Fi5
	Fi7/6P1-Fi6
	Fi7/6P1-Fi7
	Fi7/6P1-Fi8
	Fi7/6P1-Fi9
	Fi7/6P1-Fi10
Film	Fi7/26P2-Fi1
Taxadjunct to Grainola	Fi7/26P2-Fi2
7/26/00	Fi7/26P2-Fi3
	Fi7/26P2-Fi4
	Fi7/26P2-Fi5a
	Fi7/26P2-Fi5b
	Fi7/26P2-Fi6
	Fi7/26P2-Fi7
	Fi7/26P2-Fi8a
	Fi7/26P2-Fi8c
	Fi7/26P2-Fi8b

PRINTS MADE*	
Film	Fi8/2P1-Fi1
Taxadjunct to Teller	Fi8/2P1-Fi2
8/2/00	Fi8/2P1-Fi3
surface smoothed	Fi8/2P1-Fi4
	Fi8/2P1-Fi5
	Fi8/2P1-Fi6
Filters	F7/6P1-1F4
Taxadjunct to Teller	F7/6P1-1F11
7/6/00	F7/6P1-1F12
surface smoothed	F7/6P1-1F17
	F7/6P1-1F18a
	F7/6P1-1F18b
	F7/6P1-1F9
	F7/6P1-1F10
	F7/6P1-1F13
	F7/6P1-1F14
Filters	F7/8P1-F4
Taxadjunct to Teller	F7/8P1-F7
7/8/00	F7/8P1-F8
surface smoothed	F7/8P1-F9
	F7/8P1-F10
	F7/8P1-F11
	F7/8P1-F12
	F7/8P1-F13
	F7/8P1-F14
	F7/8P1-F15
Filters	F7/26P2-F1
Taxadjunct to Grainola	F7/26P2-F2
7/26/00	F7/26P2-F3
	F7/26P2-F4
	F7/26P2-F5
	F7/26P2-F6
	F7/26P2-F7
	F7/26P2-F8
	F7/26P2-F9
	F7/26P2-F10
	F7/26P2-F11
Aperture/Shutter Speed	F7/8P1-F15a
Taxadjunct to Teller	F7/8P1-F16
7/8/00	F7/8P1-F17
surface smoothed	F7/8P1-F18
Aperture/Shutter Speed	F7/26P2-F12
Taxadjunct to Grainola	F7/26P2-F13
7/26/00	F7/26P2-F14a
	F7/26P2-F14b
	F7/26P2-F15
	F7/26P2-F16
	F7/26P2-F17
	F7/26P2-F18
	F7/26P2-F19
	F7/26P2-F20

PRINTS MADE*	
Close-ups	C8/4P1-C3a
Taxadjunct to Teller	C8/4P1-C4a
8/4/00	C8/4P1-C3b
surface smoothed	C8/4P1-C4b
Close-ups	C8/4P2-C1a
Taxadjunct to Grainola	C8/4P2-C2a
8/4/00	C8/4P2-C1b
	C8/4P2-C2b
Night	N8/17P1-N1a
Taxadjunct to Teller	N8/17P1-N1b
8/17/00	N8/17P1-N1c
surface smoothed	N8/17P1-N1d
	N8/17P1-N1e
	N8/17P1-N1f
	N8/17P1-N1g
	N8/17P1-N1h
	N8/17P1-N1j
	N8/17P1-N1k
	N8/17P1-N1L
	N8/17P1-N1M
	N8/17P1-N1N
	N8/17P1-N1O
	N8/17P1-N1P
	N8/17P1-N1Q
	N8/17P1-N1R
	N8/17P1-N1S

PRINTS MADE*	
Night	N8/17P2-N2a
Taxadjunct to Grainola	N8/17P2-N2b
8/17/00	N8/17P2-N2c
	N8/17P2-N2d
	N8/17P2-N2e
	N8/17P2-N2f
	N8/17P2-N2g
	N8/17P2-N2h
	N8/17P2-N2j
	N8/17P2-N2k
	N8/17P2-N2l
	N8/17P2-N2M
	N8/17P2-N2N
	N8/17P2-N2O
	N8/17P2-N2P
	N8/17P2-N2Q
	N8/17P2-N2R
	N8/17P2-N2S

* The string of letters is specific to the print and the corresponding negative. The first letter or letters denotes the factor studied, next is the date, next is the soil (Teller is P1 and Grainola is P2), then the code to the negative. For example, Fi8/2P1-Fi6 is film, photographed on 8/2/00, for the Teller soil (P1) where the corresponding negative is Fi6.

APPENDIX D

Conversions From CIE L a b data to X Y Z and x y Values-Prints

Calibrated in specular inc.; standard measured in specular exc.; sample measured in specular exc

Munsell or Print	Illum/Obs*	Meas.	L*	a*	b*	X	Y	Z	x	y
7.5YR 4/4	C/2	std	35.02	13.84	32.96	10.02	8.51	2.46	0.4774	0.4055
D8/2P1-D4	C/2	1	43.11	17.06	22.82	15.76	13.23	7.30	0.4342	0.3646
Figure 2-15		2	42.87	17.34	23.17	15.63	13.07	7.09	0.4366	0.3652
		3	43.00	17.38	23.20	15.73	13.16	7.15	0.4365	0.3651
		4	43.52	17.14	23.09	16.08	13.51	7.43	0.4344	0.3650
		5	43.34	17.11	22.85	15.94	13.39	7.41	0.4339	0.3644
		6	43.00	17.27	23.10	15.71	13.16	7.18	0.4359	0.3651
7.5YR 4/4	C/2	std	35.28	13.66	32.19	10.14	8.64	2.62	0.4737	0.4037
D8/2P1-D10	C/2	1	38.19	20.63	32.00	12.88	10.19	3.42	0.4862	0.3847
Figure 2-16		2	38.98	20.35	31.02	13.37	10.65	3.83	0.4801	0.3824
		3	38.36	20.59	31.92	12.99	10.29	3.49	0.4853	0.3845
		4	38.71	20.37	31.10	13.19	10.49	3.73	0.4811	0.3827
		5	38.50	20.47	31.43	13.06	10.37	3.61	0.4830	0.3835
		6	39.71	19.74	29.05	13.76	11.08	4.44	0.4701	0.3783
7.5YR 4/4	C/2	std	35.02	13.84	32.96	10.02	8.51	2.46	0.4774	0.4055
D8/2P1-D16	C/2	1	47.89	18.52	32.97	19.91	16.71	6.79	0.4587	0.3849
Figure 2-17		2	47.26	18.70	33.11	19.40	16.22	6.47	0.4610	0.3853
		3	47.77	18.71	33.30	19.85	16.61	6.65	0.4604	0.3854
		4	46.94	18.71	33.27	19.13	15.97	6.29	0.4621	0.3859
		5	47.06	18.85	33.61	19.26	16.07	6.26	0.4632	0.3864
		6	47.09	18.52	32.97	19.22	16.09	6.43	0.4605	0.3854
10R 4/6	C/2	std	33.73	30.07	32.95	11.45	7.88	2.17	0.5326	0.3664
D7/31P2-D2	C/2	1	46.97	26.30	23.50	20.70	16.00	9.09	0.4521	0.3494
Figure 2-18		2	45.92	26.86	23.47	19.88	15.21	8.53	0.4558	0.3487
		3	45.33	26.87	23.22	19.37	14.78	8.30	0.4564	0.3482
		4	45.65	26.85	24.10	19.64	15.01	8.20	0.4584	0.3503
		5	46.18	26.67	23.13	20.07	15.40	8.77	0.4536	0.3481
		6	45.88	26.95	23.48	19.87	15.18	8.51	0.4561	0.3486
10R 4/6	C/2	std	34.64	30.52	34.39	12.08	8.32	2.19	0.5348	0.3683
D7/31P2-D5	C/2	1	54.53	27.89	28.62	28.68	22.48	11.87	0.4550	0.3567
Figure 2-19		2	54.70	27.82	28.57	28.85	22.64	12.00	0.4544	0.3566
		3	54.39	28.00	28.83	28.55	22.34	11.70	0.4561	0.3570
		4	54.58	27.89	28.46	28.73	22.53	11.96	0.4545	0.3563
		5	54.24	28.11	28.79	28.41	22.20	11.61	0.4566	0.3568
		6	54.43	27.94	28.77	28.58	22.38	11.75	0.4557	0.3569
10R 4/6	C/2	std	34.64	30.52	34.39	12.08	8.32	2.19	0.5348	0.3683
D7/31P2-D8	C/2	1	60.83	22.45	23.45	34.68	29.05	19.13	0.4185	0.3506
Figure 2-20		2	60.16	22.81	23.96	33.94	28.30	18.26	0.4216	0.3515
		3	60.39	22.69	23.77	34.20	28.56	18.56	0.4205	0.3512
		4	60.39	22.66	23.80	34.19	28.56	18.55	0.4205	0.3513
		5	60.06	22.90	23.93	33.84	28.19	18.19	0.4219	0.3514
		6	59.36	23.31	24.30	33.09	27.42	17.40	0.4248	0.3519

Munsell or Print	Illum/Obs*	Meas.	L*	a*	b*	X	Y	Z	x	y
7.5YR 4/4	C/2	std	35.41	13.54	32.12	10.20	8.71	2.67	0.4728	0.4036
M8/4P1-M2	C/2	1	54.88	16.16	25.58	26.11	22.81	13.32	0.4195	0.3665
Figure 2-21		2	54.94	16.12	25.38	26.16	22.87	13.44	0.4187	0.3661
		3	55.15	15.99	25.15	26.35	23.08	13.69	0.4175	0.3656
		4	54.90	16.12	25.49	26.12	22.83	13.37	0.4191	0.3664
		5	55.06	16.11	25.42	26.28	22.99	13.51	0.4186	0.3661
		6	55.16	15.99	25.22	26.36	23.09	13.67	0.4177	0.3658
7.5YR 4/4	C/2	std	35.41	13.54	32.12	10.20	8.71	2.67	0.4728	0.4036
M8/4P1-M3	C/2	1	51.29	18.29	29.00	22.99	19.52	9.73	0.4401	0.3737
Figure 2-22		2	51.29	18.27	29.01	22.99	19.52	9.72	0.4401	0.3737
		3	51.63	18.04	28.57	23.26	19.82	10.07	0.4377	0.3728
		4	51.63	18.02	28.55	23.26	19.82	10.08	0.4376	0.3728
		5	51.35	18.18	28.87	23.02	19.57	9.81	0.4394	0.3735
		6	51.57	18.05	28.57	23.21	19.76	10.04	0.4378	0.3729
7.5YR 4/4	C/2	std	35.41	13.54	32.12	10.20	8.71	2.67	0.4728	0.4036
M8/4P1-M5	C/2	1	45.39	16.66	30.45	17.45	14.82	6.33	0.4521	0.3840
Figure 2-23		2	46.12	16.32	29.45	17.98	15.36	6.91	0.4467	0.3815
		3	45.48	16.55	30.30	17.51	14.89	6.40	0.4512	0.3837
		4	46.11	16.33	29.52	17.97	15.35	6.89	0.4470	0.3817
		5	45.35	16.64	30.39	17.42	14.79	6.32	0.4520	0.3839
		6	45.59	16.56	30.11	17.60	14.97	6.50	0.4504	0.3832
10R 4/6	C/2	std	33.73	30.07	32.95	11.45	7.88	2.17	0.5326	0.3664
M8/1P2-M4	C/2	1	47.64	32.92	24.04	22.75	16.51	9.29	0.4685	0.3402
Figure 2-24		2	48.41	32.44	23.45	23.38	17.12	9.92	0.4637	0.3395
		3	47.24	33.35	24.80	22.46	16.20	8.82	0.4730	0.3412
		4	48.02	32.72	23.92	23.07	16.81	9.54	0.4668	0.3402
		5	48.08	32.82	23.98	23.15	16.86	9.56	0.4670	0.3401
		6	47.71	33.00	24.19	22.83	16.57	9.28	0.4690	0.3404
10R 4/6	C/2	std	33.73	30.07	32.95	11.45	7.88	2.17	0.5326	0.3664
M8/1P2-M5	C/2	1	45.69	33.88	24.17	21.13	15.04	8.20	0.4763	0.3390
Figure 2-25		2	46.83	32.94	23.02	21.98	15.89	9.16	0.4673	0.3378
		3	45.14	34.12	24.68	20.68	14.64	7.77	0.4800	0.3398
		4	47.13	32.81	22.91	22.24	16.12	9.37	0.4659	0.3378
		5	46.57	33.37	23.57	21.83	15.69	8.85	0.4708	0.3384
		6	46.40	33.50	23.76	21.70	15.57	8.70	0.4722	0.3387
10R 4/6	C/2	std	33.73	30.07	32.95	11.45	7.88	2.17	0.5326	0.3664
M8/1P2-M7	C/2	1	53.94	28.27	22.71	28.12	21.92	13.84	0.4402	0.3431
Figure 2-26		2	53.47	28.60	23.22	27.69	21.48	13.29	0.4433	0.3439
		3	53.48	28.60	23.29	27.70	21.49	13.27	0.4435	0.3441
		4	53.19	28.74	23.46	27.42	21.22	12.99	0.4449	0.3443
		5	53.25	28.67	23.28	27.47	21.28	13.11	0.4441	0.3440
		6	53.19	28.63	23.28	27.39	21.22	13.07	0.4441	0.3441
7.5YR 4/4	C/2	std	35.40	13.66	32.12	10.21	8.70	2.66	0.4732	0.4034
A8/4P1-A2	C/2	1	57.69	14.96	29.13	28.86	25.64	13.86	0.4222	0.3751
Figure 2-47		2	58.04	14.74	28.34	29.19	26.00	14.46	0.4191	0.3733
		3	57.27	14.93	29.43	28.38	25.20	13.43	0.4235	0.3761
		4	57.80	14.77	29.22	28.93	25.75	13.90	0.4218	0.3755
		5	57.55	14.86	29.16	28.67	25.49	13.75	0.4222	0.3754
		6	57.90	14.74	28.61	29.03	25.86	14.24	0.4200	0.3740

Munsell or Print	Illum/Obs*	Meas.	L*	a*	b*	X	Y	Z	x	y
7.5YR 4/4	C/2	std	35.40	13.66	32.12	10.21	8.70	2.66	0.4732	0.4032
A8/4P1-A3	C/2	1	58.95	14.56	29.12	30.18	26.97	14.81	0.4194	0.3748
Figure 2-48		2	58.43	14.71	29.30	29.63	26.42	14.34	0.4210	0.3753
		3	58.87	14.57	29.08	30.09	26.89	14.77	0.4195	0.3747
		4	58.59	14.76	29.37	29.82	26.59	14.43	0.4210	0.3753
		5	58.26	14.81	29.78	29.46	26.24	14.00	0.4227	0.3764
		6	58.67	14.57	29.24	29.86	26.67	14.54	0.4202	0.3752
10R 4/6	C/2	std	33.73	30.07	32.95	11.45	7.88	2.17	0.5326	0.3664
A8/1P2-A2	C/2	1	50.69	32.37	14.76	25.66	19.00	14.86	0.4311	0.3192
Figure 2-50		2	50.78	32.40	14.87	25.76	19.08	14.88	0.4313	0.3195
		3	50.79	32.52	14.86	25.80	19.09	14.89	0.4316	0.3193
		4	50.04	32.96	15.29	25.13	18.45	14.14	0.4354	0.3197
		5	50.47	32.64	15.07	25.50	18.81	14.56	0.4331	0.3196
		6	49.45	33.33	15.68	24.62	17.96	13.54	0.4387	0.3200
10R 4/6	C/2	std	33.73	30.07	32.95	11.45	7.88	2.17	0.5326	0.3664
A8/1P2-A3	C/2	1	48.59	31.99	22.58	23.46	17.26	10.33	0.4595	0.3382
Figure 2-51		2	48.22	32.26	22.89	23.16	16.97	10.00	0.4619	0.3385
		3	48.67	31.99	22.28	23.53	17.33	10.48	0.4583	0.3375
		4	47.94	32.36	23.16	22.91	16.75	9.75	0.4637	0.3390
		5	47.35	32.74	23.95	22.43	16.29	9.15	0.4685	0.3402
		6	49.31	31.43	21.78	24.04	17.85	11.06	0.4540	0.3371
7.5YR 4/4	C/2	std	35.41	13.54	32.12	10.20	8.71	2.67	0.4728	0.4036
T6/6P1-T1d	C/2	1	49.16	16.94	23.37	20.71	17.72	10.40	0.4242	0.3629
Figure 2-53		2	46.30	17.24	22.58	18.30	15.49	9.01	0.4276	0.3619
		3	45.73	17.40	22.73	17.87	15.07	8.66	0.4296	0.3623
		4	45.82	17.35	22.77	17.93	15.14	8.69	0.4294	0.3625
		5	45.88	17.37	22.70	17.98	15.18	8.75	0.4291	0.3622
		6	46.26	17.20	22.43	18.26	15.46	9.04	0.4271	0.3616
7.5YR 4/4	C/2	std	35.41	13.54	32.12	10.20	8.71	2.67	0.4728	0.4036
T6/6P1-T2b	C/2	1	46.06	13.52	24.63	17.41	15.31	8.25	0.4249	0.3738
Figure 2-54		2	46.43	13.76	26.12	17.75	15.59	8.00	0.4294	0.3771
		3	46.63	13.75	26.17	17.91	15.74	8.08	0.4292	0.3771
		4	46.73	13.72	26.07	17.99	15.81	8.17	0.4286	0.3768
		5	45.52	13.69	25.17	17.01	14.92	7.82	0.4280	0.3753
		6	46.69	13.79	26.31	17.97	15.78	8.07	0.4296	0.3774
7.5YR 4/4	C/2	std	35.41	13.54	32.12	10.20	8.71	2.67	0.4728	0.4036
T6/6P1-H1a	C/2	1	54.71	13.05	33.46	25.18	22.65	10.22	0.4338	0.3902
Figure 2-55		2	54.66	13.06	33.68	25.13	22.60	10.11	0.4345	0.3907
		3	54.81	13.02	33.37	25.28	22.75	10.31	0.4333	0.3899
		4	55.01	12.95	32.95	25.47	22.94	10.58	0.4318	0.3889
		5	54.74	13.03	33.50	25.21	22.68	10.22	0.4338	0.3903
		6	54.78	13.00	33.37	25.24	22.72	10.29	0.4333	0.3900
7.5YR4/4	C/2	std	35.41	13.54	32.12	10.20	8.71	2.67	0.4728	0.4036
T6/6P1-T3b	C/2	1	50.21	14.70	26.98	21.20	18.60	9.78	0.4276	0.3751
Figure 2-56		2	49.95	14.74	27.26	20.97	18.38	9.54	0.4289	0.3759
		3	49.90	14.79	27.23	20.93	18.34	9.52	0.4291	0.3758
		4	50.05	14.72	27.13	21.05	18.46	9.64	0.4283	0.3756
		5	49.94	14.76	27.26	20.96	18.37	9.53	0.4290	0.3759
		6	50.18	14.67	26.96	21.16	18.57	9.77	0.4275	0.3751

Munsell or Print	Illum/Obs*	Meas.	L*	a*	b*	X	Y	Z	x	y
7.5YR4/4	C/2	std	35.41	13.54	32.12	10.20	8.71	2.67	0.4728	0.4036
T6/6P1-T4a-1	C/2	1	51.32	16.50	36.33	22.62	19.55	7.48	0.4556	0.3937
Figure 2-57		2	51.32	16.50	36.40	22.62	19.55	7.47	0.4558	0.3938
		3	51.46	16.60	36.82	22.78	19.67	7.41	0.4568	0.3945
		4	51.55	16.51	36.63	22.84	19.75	7.51	0.4559	0.3941
		5	51.27	16.46	36.23	22.57	19.50	7.49	0.4553	0.3935
		6	51.92	16.36	36.21	23.17	20.07	7.79	0.4540	0.3934
10R 4/6	C/2	std	34.64	30.52	34.39	12.08	8.32	2.19	0.5348	0.3683
T7/30P2-T2	C/2	1	54.02	26.33	26.97	27.71	21.99	12.17	0.4479	0.3555
Figure 2-58		2	53.76	26.52	27.11	27.48	21.75	11.94	0.4492	0.3556
		3	53.66	26.52	27.28	27.37	21.66	11.81	0.4499	0.3560
		4	53.27	26.83	27.53	27.03	21.29	11.46	0.4521	0.3562
		5	55.08	25.80	26.02	28.75	23.01	13.28	0.4420	0.3538
		6	53.42	26.65	27.27	27.14	21.43	11.65	0.4507	0.3559
10R 4/6	C/2	std	34.64	30.52	34.39	12.08	8.32	2.19	0.5358	0.3683
T7/30P2-T7	C/2	1	47.26	32.27	22.72	22.24	16.22	9.50	0.4637	0.3381
Figure 2-59		2	49.05	31.11	21.23	23.71	17.63	11.10	0.4521	0.3363
		3	48.14	31.74	21.88	22.96	16.90	10.30	0.4577	0.3369
		4	49.32	31.00	21.10	23.95	17.86	11.32	0.4508	0.3361
		5	47.87	31.85	21.95	22.73	16.69	10.12	0.4588	0.3370
		6	48.58	31.47	21.58	23.33	17.26	10.68	0.4551	0.3366
10R 4/6	C/2	std	34.64	30.52	34.39	12.08	8.32	2.19	0.5348	0.3683
T7/30P2-T10	C/2	1	51.68	28.60	26.97	25.78	19.86	10.66	0.4579	0.3528
Figure 2-60		2	51.48	28.81	27.43	25.62	19.69	10.38	0.4601	0.3535
		3	51.71	28.70	27.29	25.83	19.89	10.57	0.4590	0.3533
		4	50.62	29.40	28.73	24.88	18.94	9.43	0.4672	0.3557
		5	51.68	28.60	27.82	25.78	19.86	10.36	0.4603	0.3547
		6	51.09	29.06	28.11	25.28	19.35	9.91	0.4635	0.3547
10R 4/6	C/2	std	34.64	30.52	34.39	12.08	8.32	2.19	0.5348	0.3683
T7/30P2-T14	C/2	1	48.68	31.75	24.19	23.49	17.34	9.83	0.4637	0.3422
Figure 2-61		2	49.11	31.37	23.81	23.82	17.68	10.22	0.4606	0.3419
		3	51.02	30.14	22.26	25.47	19.29	11.99	0.4488	0.3399
		4	49.48	31.14	23.55	24.14	17.99	10.53	0.4584	0.3416
		5	50.40	30.56	22.95	24.93	18.76	11.32	0.4532	0.3410
		6	48.79	31.55	23.84	23.55	17.42	10.01	0.4619	0.3417
10R 4/6	C/2	std	34.64	30.52	34.39	12.08	8.32	2.19	0.5348	0.3683
T7/30P2-T6	C/2	1	37.09	34.80	29.00	14.37	9.59	3.61	0.5213	0.3477
Figure 2-62		2	37.08	34.80	29.03	14.36	9.58	3.60	0.5214	0.3478
		3	37.17	34.85	29.08	14.44	9.63	3.62	0.5214	0.3478
		4	37.17	24.66	28.61	14.41	9.63	3.70	0.5193	0.3472
		5	37.35	34.30	27.96	14.47	9.73	3.87	0.5155	0.3465
		6	36.81	34.98	29.34	14.20	9.44	3.47	0.5240	0.3481
10R 4/6	C/2	std	34.64	30.52	34.39	12.08	8.32	2.19	0.5348	0.3683
T7/30P2-T8	C/2	1	40.24	33.40	30.51	16.46	11.40	4.33	0.5113	0.3541
Figure 2-63		2	40.58	33.28	30.30	16.71	11.60	4.49	0.5092	0.3539
		3	40.24	33.41	30.50	16.46	11.40	4.33	0.5113	0.3540
		4	39.79	33.67	30.97	16.16	11.12	4.10	0.5150	0.3545
		5	40.03	33.56	30.81	16.32	11.27	4.20	0.5134	0.3544
		6	40.03	33.56	30.71	16.32	11.27	4.22	0.5131	0.3542

Munsell or Print	Illum/Obs*	Meas.	L*	a*	b*	X	Y	Z	x	y
7.5YR 4/4	C/2	std	35.28	13.66	32.19	10.14	8.64	2.62	0.4737	0.4037
N8/17P1-N1h	C/2	1	59.92	13.16	17.45	30.94	28.03	21.55	0.3842	0.3481
Figure 2-64		2	60.22	13.04	17.22	31.26	28.37	21.98	0.3830	0.3476
		3	60.23	13.04	17.26	31.27	28.38	21.97	0.3831	0.3477
		4	60.11	13.04	17.34	31.13	28.25	21.81	0.3834	0.3479
		5	60.07	13.11	17.21	31.10	28.20	21.84	0.3833	0.3476
		6	60.19	13.07	17.31	31.23	28.33	21.90	0.3833	0.3478
7.5YR 4/4	C/2	std	35.28	13.66	32.19	10.14	8.64	2.62	0.4737	0.4037
N8/17P1-N1e	C/2	1	65.78	10.11	25.62	37.40	35.04	22.68	0.3932	0.3684
Figure 2-65		2	65.72	10.12	25.70	37.32	34.96	22.57	0.3934	0.3686
		3	65.77	10.08	25.70	37.37	35.03	22.62	0.3933	0.3686
		4	65.79	10.12	25.64	37.41	35.05	22.67	0.3932	0.3684
		5	65.80	10.10	25.64	37.42	35.07	22.68	0.3932	0.3685
		6	65.84	10.11	25.64	37.48	35.12	22.72	0.3932	0.3684
7.5YR 4/4	C/2	std	35.28	13.66	32.19	10.14	8.64	2.62	0.4737	0.4037
N8/17P1-N1b	C/2	1	65.64	4.78	19.69	35.59	34.86	26.20	0.3682	0.3607
Figure 2-66		2	65.65	4.80	19.64	35.61	34.87	26.24	0.3681	0.3605
		3	65.60	4.80	19.70	35.54	34.81	26.15	0.3683	0.3607
		4	65.57	4.83	19.68	35.51	34.77	26.13	0.3684	0.3607
		5	65.59	4.80	19.63	35.53	34.80	26.18	0.3682	0.3606
		6	65.63	4.82	19.65	35.59	34.85	26.21	0.3682	0.3606
10R 4/6	C/2	std	34.13	30.46	34.39	11.75	8.07	2.08	0.5366	0.3685
N8/17P2-N2d	C/2	1	41.72	28.96	10.46	16.81	12.32	10.43	0.4249	0.3115
Figure 2-67		2	41.38	29.15	10.79	16.58	12.10	10.11	0.4273	0.3120
		3	41.83	28.84	10.60	16.87	12.39	10.44	0.4249	0.3121
		4	41.35	29.11	10.85	16.55	12.08	10.07	0.4275	0.3123
		5	41.87	28.74	10.57	16.88	12.42	10.48	0.4244	0.3121
		6	41.24	29.14	10.98	16.47	12.02	9.96	0.4283	0.3125
10R 4/6	C/2	std	34.13	30.46	34.39	11.75	8.07	2.08	0.5366	0.3685
N8/17P2-N2e	C/2	1	38.07	37.07	10.71	15.46	10.13	8.29	0.4563	0.2989
Figure 2-68		2	38.44	36.12	9.75	15.57	10.34	8.79	0.4488	0.2979
		3	36.88	37.92	11.07	14.74	9.47	7.59	0.4635	0.2979
		4	36.92	37.86	10.86	14.76	9.49	7.67	0.4623	0.2975
		5	37.00	37.91	11.19	14.82	9.54	7.61	0.4636	0.2983
		6	36.96	37.96	11.18	14.80	9.52	7.60	0.4638	0.2982
10R 4/6	C/2	std	34.13	30.46	34.39	11.75	8.07	2.08	0.5366	0.3685
N8/17P2-N2f	C/2	1	50.48	19.38	-1.11	22.46	18.82	22.88	0.3500	0.2934
Figure 2-69		2	50.28	19.55	-1.07	22.31	18.65	22.66	0.3506	0.2932
		3	50.25	19.59	-0.98	22.29	18.63	22.57	0.3510	0.2934
		4	50.51	19.47	-1.01	22.51	18.85	22.85	0.3505	0.2936
		5	50.09	19.64	-0.98	22.15	18.49	22.41	0.3512	0.2933
		6	51.03	19.29	-0.96	22.96	19.29	23.36	0.3500	0.2940

Color matched

Calibrated in specular inc.; standard measured in specular exc.; sample measured in specular exc.

7.5YR 4/4	C/2	std	35.09	13.72	32.58	10.04	8.54	2.52	0.4757	0.4047
C8/4P1-C3b	C/2	1	58.11	14.49	28.65	29.21	26.08	14.38	0.4192	0.3743
Figure 2-71		2	58.28	14.36	28.22	29.36	26.26	14.70	0.4176	0.3734
		3	58.10	14.43	28.27	29.18	26.07	14.54	0.4181	0.3735
		4	57.98	14.51	28.45	29.06	25.94	14.37	0.4190	0.3739
		5	57.95	14.50	28.31	29.03	25.91	14.41	0.4186	0.3736
		6	57.85	14.55	28.51	28.93	25.80	14.25	0.4194	0.3741

Munsell or Print	Illum/Obs*	Meas.	L*	a*	b*	X	Y	Z	x	y
10R 4/6	C/2	std	34.14	30.54	33.99	11.77	8.08	2.13	0.5356	0.3675
C8/4P2-C2b	C/2	1	53.95	26.84	24.52	27.77	21.93	13.10	0.4422	0.3492
Figure 2-73		2	55.09	26.20	23.71	28.86	23.02	14.26	0.4364	0.3480
		3	57.35	27.30	24.51	31.78	25.28	15.65	0.4371	0.3477
		4	57.03	27.49	24.79	31.45	24.95	15.27	0.4388	0.3482
		5	57.71	27.42	24.83	32.25	25.66	15.78	0.4376	0.3482
		6	57.27	27.61	24.82	31.77	25.20	15.44	0.4387	0.3480

Not color matched
<u>Calibrated in specular inc.; standard measured in specular exc.; sample measured in specular exc.</u>

Munsell or Print	Illum/Obs*	Meas.	L*	a*	b*	X	Y	Z	x	y
7.5YR 4/4	C/2	std	35.09	13.72	32.58	10.04	8.54	2.52	0.4754	0.4047
C8/4P1-C4a	C/2	1	68.70	8.91	21.51	41.03	38.93	28.51	0.3783	0.3589
Figure 2-70		2	68.25	9.10	22.06	40.46	38.31	27.60	0.3803	0.3602
		3	68.55	8.96	21.49	40.83	38.72	28.34	0.3784	0.3589
		4	68.56	8.96	21.56	40.85	38.74	28.31	0.3786	0.3590
		5	68.98	8.96	21.72	41.44	39.32	28.69	0.3786	0.3592
		6	68.47	8.99	21.53	40.73	38.61	28.22	0.3787	0.3590
10R 4/6	C/2	std	34.64	30.52	34.39	12.08	8.32	2.19	0.5348	0.3683
C8/4P2-C2a	C/2	1	69.21	18.29	14.56	44.96	39.64	34.23	0.3784	0.3336
Figure 2-72		2	69.16	18.37	14.93	44.91	39.57	33.87	0.3795	0.3343
		3	69.02	18.49	14.93	44.74	39.37	33.69	0.3798	0.3342
		4	69.10	18.43	14.88	44.84	39.48	33.83	0.3795	0.3342
		5	69.18	18.33	14.65	44.93	39.59	34.12	0.3787	0.3337
		6	69.13	18.35	14.66	44.86	39.53	34.04	0.3788	0.3337

The Munsell in Figures Fi8/2P1-Fi6, Fi8/2P1-Fi1, Fi8/2P1-Fi3, Fi7/26P2-Fi5, Fi7/26P2-Fi7 , Fi7/26P2-Fi4, F7/26P2-F14a, F7/26P2-F19, A8/4P1-A6, and A8/1P2-A5 were not large enough for the spectrophotometer measurement port, so no measurements were taken.

APPENDIX E

CIE LAB Conversions to Munsell Notation

[Using Illuminant C with a 2° Observer]

Munsell Std/Print	Measurement	Hue No.	H/V/C*	ISCC-NBS** Name & No.	Munsell Color§ Name and Number
Standard-7.5YR 4/4	std	17.41	7.41YR 3.41/5.92	sb-55	sb,dr,r,yr
D8/2P1-D4	1	13.24	3.24YR 4.18/4.98	mb-58	rb,b,db,drb
Figure 2-15	2	13.22	3.22YR 4.16/5.06	sb-55	r,sb,dr,yr
	3	13.21	3.21YR 4.17/5.07	sb-55	r,sb,dr,yr
	4	13.26	3.26YR 4.22/5.03	sb-55	r,sb,dr,yr
	5	13.21	3.21YR 4.20/4.99	mb-58	rb,b,db,drb
	6	13.23	3.23YR 4.17/5.04	sb-55	r,sb,dr,yr
Standard-7.5YR 4/4	std	17.37	7.37YR 3.43/5.79	sb-55	sb,yr,dr,r
D8/2P1-D10	1	14.18	4.18YR 3.71/6.62	sb-55	yr,sb,dr,r
Figure 2-16	2	14.06	4.06YR 3.79/6.46	sb-55	yr,sb,dr,r
	3	14.17	4.17YR 3.73/6.61	sb-55	yr,sb,dr,r
	4	14.08	4.08YR 3.76/6.47	sb-55	yr,sb,dr,r
	5	14.11	4.11YR 3.74/6.53	sb-55	yr,sb,dr,r
	6	13.83	3.83YR 3.86/6.13	sb-55	yr,sb,dr,r
Standard-7.5YR 4/4	std	17.41	7.41YR 3.41/5.92	sb-55	sb,dr,r,yr
D8/2P1-D16	1	14.88	4.88YR 4.64/6.44	bo-54	yr,r
Figure 2-17	2	14.85	4.85YR 4.58/6.47	bo-54	yr,r
	3	14.87	4.87YR 4.63/6.50	bo-54	yr,r
	4	14.88	4.88YR 4.55/6.49	bo-54	yr,r
	5	14.89	4.89YR 4.56/6.55	bo-54	yr,r
	6	14.90	4.90YR 4.56/6.43	bo-54	yr,r
Standard-10R 4/6	std	11.46	1.46YR 3.28/8.07	srb-40	dr
D7/31P2-D2	1	9.55	9.55R 4.55/6.69	gro-39	r,Lr
Figure 2-18	2	9.41	9.41R 4.45/6.77	mrb-43	r,dr,drb,duR,rb,wr
	3	9.35	9.35R 4.40/6.75	mrb-43	r,dr,drb,duR,rb,wr
	4	9.64	9.64R 4.43/6.81	mrb-43	r,dr,drb,duR,rb,wr
	5	9.34	9.34R 4.48/6.72	mrb-43	r,dr,drb,duR,rb,wr
	6	9.39	9.39R 4.45/6.79	mrb-43	r,dr,drb,duR,rb,wr
Standard-10R 4/6	std	11.55	1.55YR 3.37/8.31	srb-40	dr
D7/31P2-D5	1	10.24	0.24YR 5.29/7.57	mro-37	r,Lr
Figure 2-19	2	10.24	0.24YR 5.31/7.56	mro-37	r,Lr
	3	10.26	0.26YR 5.28/7.60	mro-37	r,Lr
	4	10.20	0.20YR 5.29/7.56	mro-37	r,Lr
	5	10.22	0.22YR 5.26/7.61	mro-37	r,Lr
	6	10.27	0.27YR 5.28/7.59	mro-37	r,Lr
Standard-10R 4/6	std	11.55	1.55YR 3.37/8.31	srb-40	dr
D7/31P2-D8	1	10.36	0.36YR 5.91/6.32	gro-39	r,Lr
Figure 2-20	2	10.43	0.43YR 5.85/6.42	gro-39	r,Lr
	3	10.40	0.40YR 5.87/6.39	gro-39	r,Lr
	4	10.42	0.42YR 5.87/6.38	gro-39	r,Lr
	5	10.39	0.39YR 5.84/6.43	gro-39	r,Lr
	6	10.38	0.38YR 5.77/6.52	gro-39	r,Lr

Munsell Std/Print	Measurement	Hue No.	H/V/C*	ISCC-NBS** Name & No.	Munsell Color§ Name and Number
Standard-7.5YR4/4	std	17.42	7.42YR 3.44/5.76	sb-55	sb,dr,r,yr
M8/4P1-M2	1	13.94	3.94YR 5.32/5.36	lb-57	¶yr,b,Lb,Lrb,rb
Figure 2-21	2	13.90	3.90YR 5.33/5.34	lb-57	¶yr,b,Lb,Lrb,rb
	3	13.90	3.90YR 5.35/5.30	lb-57	¶yr,b,Lb,Lrb,rb
	4	13.94	3.94YR 5.33/5.35	lb-57	¶yr,b,Lb,Lrb,rb
	5	13.92	3.92YR 5.34/5.34	lb-57	¶yr,b,Lb,Lrb,rb
	6	13.92	3.92YR 5.35/5.30	lb-57	¶yr,b,Lb,Lrb,rb
Standard-7.5YR 4/4	std	17.42	7.42YR 3.44/5.76	sb-55	sb,dr,r,yr
M8/4P1-M3	1	13.93	3.93YR 4.97/5.99	lb-57	¶yr,b,Lb,Lrb,rb
Figure 2-22	2	13.94	3.94YR 4.97/5.99	lb-57	¶yr,b,Lb,Lrb,rb
	3	13.93	3.93YR 5.01/5.92	lb-57	¶yr,b,Lb,Lrb,rb
	4	13.93	3.93YR 5.01/5.91	lb-57	¶yr,b,Lb,Lrb,rb
	5	13.94	3.94YR 4.98/5.96	lb-57	¶yr,b,Lb,Lrb,rb
	6	13.92	3.92YR 5.00/5.92	lb-57	¶yr,b,Lb,Lrb,rb
Standard-7.5YR4/4	std	17.42	7.42YR 3.44/5.76	sb-55	sb,dr,r,yr
M8/4P1-M5	1	15.26	5.26YR 4.40/5.86	sb-55	yr,dr,r,sb
Figure 2-23	2	15.17	5.17YR 4.47/5.69	sb-55	yr,dr,r,sb
	3	15.28	5.28YR 4.41/5.82	sb-55	yr,dr,r,sb
	4	15.18	5.18YR 4.47/5.70	sb-55	yr,dr,r,sb
	5	15.26	5.26YR 4.40/5.84	sb-55	yr,dr,r,sb
	6	15.23	5.23YR 4.42/5.80	sb-55	yr,dr,r,sb
Standard-10R 4/6	std	11.46	1.46YR 3.28/8.07	srb-40	dr
M8/1P2-M4	1	7.85	7.85R 4.62/8.03	mro-37	r
Figure 2-24	2	7.75	7.75R 4.69/7.91	mro-37	r
	3	7.99	7.99R 4.58/8.16	mro-37	r
	4	7.85	7.85R 4.65/7.99	mro-37	r
	5	7.84	7.84R 4.66/8.02	mro-37	r
	6	7.88	7.88R 4.62/8.06	mro-37	r
Standard-10R 4/6	std	11.46	1.46YR 3.28/8.07	srb-40	dr
M8/1P2-M5	1	7.75	7.75R 4.43/8.18	dro-38	r
Figure 2-25	2	7.56	7.56R 4.54/7.95	mro-37	r
	3	7.86	7.86R 4.38/8.25	dro-38	r
	4	7.55	7.55R 4.57/7.92	mro-37	r
	5	7.65	7.65R 4.51/8.06	mro-37	r
	6	7.69	7.69R 4.50/8.10	dro-38	r
Standard-10R 4/6	std	11.46	1.46YR 3.28/8.07	srb-40	dr
M8/1P2-M7	1	8.40	8.80R 5.23/7.21	mro-37	r
Figure 2-26	2	8.48	8.48R 5.19/7.29	mro-37	r
	3	8.50	8.50R 5.19/7.30	mro-37	r
	4	8.52	8.52R 5.16/7.32	mro-37	r
	5	8.49	8.49R 5.16/7.30	mro-37	r
	6	8.50	8.50R 5.16/7.29	mro-37	r
Standard-7.5YR 4/4	std	17.36	7.36YR 3.44/5.78	sb-55	sb,dr,r,yr
A8/4P1-A2	1	15.29	5.29YR 5.60/5.61	lb-57	¶yr,b,Lb,Lrb,rb
Figure 2-47	2	15.21	5.21YR 5.64/5.50	lb-57	¶yr,b,Lb,Lrb,rb
	3	15.39	5.39YR 5.56/5.64	lb-57	¶yr,b,Lb,Lrb,rb
	4	15.41	5.41YR 5.61/5.60	lb-57	¶yr,b,Lb,Lrb,rb
	5	15.36	5.36YR 5.59/5.60	lb-57	¶yr,b,Lb,Lrb,rb
	6	15.28	5.28YR 5.62/5.53	lb-57	¶yr,b,Lb,Lrb,rb

Munsell Std/Print	Measurement	Hue No.	H/V/C*	ISCC-NBS** Name & No.	Munsell Color§ Name and Number
Standard-7.5YR 4/4	std	17.36	7.36YR 3.44/5.78	sb-55	sb,dr,r,yr
A8/4P1-A3	1	15.45	5.45YR 5.73/5.58	lb-57	¶yr,b,Lb,Lrb,rb
Figure 2-48	2	15.43	5.43YR 5.67/5.61	lb-57	¶yr,b,Lb,Lrb,rb
	3	15.44	5.44YR 5.72/5.57	lb-57	¶yr,b,Lb,Lrb,rb
	4	15.42	5.42YR 5.69/5.63	lb-57	¶yr,b,Lb,Lrb,rb
	5	15.50	5.50YR 5.66/5.68	lb-57	¶yr,b,Lb,Lrb,rb
	6	15.49	5.49YR 5.70/5.59	lb-57	¶yr,b,Lb,Lrb,rb
Standard-10R 4/6	std	11.46	1.46YR 3.28/8.07	srb-40	dr
A8/1P2-A2	1	4.15	4.15R 4.91/7.59	mr-15	r
Figure 2-50	2	4.19	4.19R 4.92/7.60	mr-15	r
	3	4.16	4.16R 4.92/7.63	mr-15	r
	4	4.27	4.27R 4.85/7.72	mr-15	r
	5	4.23	4.23R 4.89/7.65	mr-15	r
	6	4.38	4.38R 4.79/7.80	mr-15	r
Standard-10R 4/6	std	11.46	1.46YR 3.28/8.07	srb-40	dr
A8/1P2-A3	1	7.57	7.57R 4.71/7.77	mro-37	r,Lr
Figure 2-51	2	7.63	7.63R 4.67/7.84	mro-37	r,Lr
	3	7.45	7.45R 4.72/7.76	mro-37	r,Lr
	4	7.71	7.71R 4.65/7.87	mro-37	r,Lr
	5	7.88	7.88R 4.59/7.98	mro-37	r,Lr
	6	7.38	7.38R 4.78/7.64	mro-37	r,Lr
Standard-7.5YR4/4	std	17.42	7.42YR 3.44/5.76	sb-55	sb,dr,r,yr
T6/6P1-T1d	1	13.19	3.19YR4.77/5.14	lb-57	¶r,b,Lb,Lrb,rb
Figure 2-53	2	12.95	2.95YR4.49/5.03	sb-55	r,sb,dr,yr
	3	12.95	2.95YR 4.43/5.06	sb-55	r,sb,dr,yr
	4	12.98	2.98YR 4.44/5.06	sb-55	r,sb,dr,yr
	5	12.94	2.94YR 4.45/5.06	sb-55	r,sb,dr,yr
	6	12.92	2.92YR 4.48/5.01	sb-55	r,sb,dr,yr
Standard-7.5YR4/4	std	17.42	7.42YR 3.44/5.76	sb-55	sb,dr,r,yr
T6/6P1-T2b	1	15.39	5.39YR 4.47/4.70	mb-58	rb,b,db,drb
Figure 2-54	2	15.65	5.65YR 4.50/4.93	lb-57	rb,b,Lb,Lrb
	3	15.66	5.66YR 4.52/4.93	lb-57	rb,b,Lb,Lrb
	4	15.65	5.65YR 4.53/4.92	lb-57	rb,b,Lb,Lrb
	5	15.48	5.48YR 4.41/4.79	mb-58	rb,bdb,drb
	6	15.68	5.68YR 4.53/4.96	lb-57	rb,b,Lb,Lrb
Standard-7.5YR 4/4	std	17.42	7.42YR 3.44/5.76	sb-55	sb,dr,r,yr
T6/6P1-H1a	1	17.38	7.38YR 3.44/5.76	sb-55	sb,dr,r,yr
Figure 2-55	2	17.41	7.41YR 5.30/5.88	lb-57	¶sb,rb,b,Lb,Lrb
	3	17.37	7.37YR 5.32/5.84	lb-57	¶sb,rb,b,Lb,Lrb
	4	17.33	7.33YR 5.34/5.78	lb-57	¶sb,rb,b,Lb,Lrb
	5	17.39	7.39YR 5.31/5.86	lb-57	¶sb,rb,b,Lb,Lrb
	6	17.38	7.38YR 5.31/5.84	lb-57	¶sb,rb,b,Lb,Lrb
Standard-7.5YR4/4	std	17.42	7.42YR 3.44/5.76	sb-55	sb,dr,r,yr
T6/6P1-T3b	1	15.19	5.19YR 4.87/5.22	lb-57	¶yr,b,Lb,Lrb,rb
Figure 2-56	2	15.25	5.25YR 4.84/5.26	lb-57	¶yr,b,Lb,Lrb,rb
	3	15.22	5.22YR 4.84/5.26	lb-57	¶yr,b,Lb,Lrb,rb
	4	15.22	5.22YR 4.85/5.24	lb-57	¶yr,b,Lb,Lrb,rb
	5	15.24	5.24YR 4.84/5.26	lb-57	¶yr,b,Lb,Lrb,rb
	6	15.20	5.20YR 4.86/5.22	lb-57	¶yr,b,Lb,Lrb,rb

Munsell Std/Print	Measurement	Hue No.	H/V/C*	ISCC-NBS** Name & No.	Munsell Color§ Name and Number
Standard-7.5YR4/4	std	17.42	7.42YR 3.44/5.76	sb-55	sb,dr,r,yr
T6/6P1-T4a-1	1	16.29	6.29YR 4.98/6.59	bo-54	¶sb,r,yr
Figure 2-57	2	16.30	6.30YR 4.98/6.60	bo-54	¶sb,r,yr
	3	16.33	6.33YR 4.99/6.67	bo-54	¶sb,r,yr
	4	16.33	6.33YR 5.00/6.63	bo-54	¶sb,r,yr
	5	16.29	6.29YR 4.97/6.57	bo-54	¶sb,r,yr
	6	16.33	6.33YR 5.03/6.58	bo-54	¶sb,r,yr
Standard-10R 4/6	std	11.55	1.55YR 3.37/8.31	srb-40	dr
T7/30P2-T2	1	10.29	0.29YR 5.24/7.14	mro-37	r,Lr
Figure 2-58	2	10.28	0.28YR 5.21/7.17	mro-37	r,Lr
	3	10.33	0.33YR 5.20/7.19	mro-37	r,Lr
	4	10.31	0.31YR 5.17/7.25	mro-37	r,Lr
	5	10.15	0.15YR 5.34/7.00	mro-37	r,Lr
	6	10.29	0.29YR 5.18/7.20	mro-37	r,Lr
Standard-10R 4/6	std	11.55	1.55YR 3.37/8.31	srb-40	dr
T7/30P2-T7	1	7.61	7.61R 4.58/7.81	mro-37	r,Lr
Figure 2-59	2	7.28	7.28R 4.75/7.53	mro-37	r,Lr
	3	7.40	7.40R 4.67/7.68	mro-37	r,Lr
	4	7.25	7.25R 4.78/7.51	mro-37	r,Lr
	5	7.42	7.42R 4.64/7.69	mro-37	r,Lr
	6	7.33	7.33R 4.71/7.62	mro-37	r,Lr
Standard-10R 4/6	std	11.55	1.55YR 3.37/8.31	srb-40	dr
T7/30P2-T10	1	9.62	9.62R 5.01/7.47	mro-37	r,Lr
Figure 2-60	2	9.69	9.69R 4.99/7.54	mro-37	r,Lr
	3	9.68	9.68R 5.01/7.51	mro-37	r,Lr
	4	9.90	9.90R 4.91/7.72	mro-37	r,Lr
	5	9.86	9.86R 5.01/7.52	mro-37	r,Lr
	6	9.82	8.82R 4.95/7.62	mro-37	r,Lr
Standard-10R 4/6	std	11.55	1.55YR 3.37/8.31	srb-40	dr
T7/30P2-T14	1	8.11	8.11R 4.72/7.84	mro-37	r,Lr
Figure 2-61	2	8.07	8.07R 4.76/7.75	mro-37	r,Lr
	3	7.83	7.83R 4.95/7.45	mro-37	r,Lr
	4	8.02	8.02R 4.80/7.69	mro-37	r,Lr
	5	7.95	7.95R 4.89/7.56	mro-37	r,Lr
	6	8.05	8.05R 4.73/7.78	mro-37	r,Lr
Standard-10R 4/6	std	11.55	1.55YR 3.37/8.31	srb-40	dr
T7/30P2-T6	1	9.35	9.35R 3.61/8.58	dro-38	¶dr,r
Figure 2-62	2	9.36	9.36R 3.60/8.58	dro-38	¶dr,r
	3	9.35	9.35R 3.61/8.59	dro-38	¶dr,r
	4	9.29	9.29R 3.61/8.52	dro-38	¶dr,r
	5	9.19	9.19R 3.63/8.41	dro-38	¶dr,r
	6	9.41	9.41R 3.58/8.63	dro-38	¶dr,r
Standard-10R 4/6	std	11.55	1.55YR 3.37/8.31	srb-40	dr
T7/30P2-T8	1	9.81	9.81R 3.91/8.48	dro-38	¶dr,r
Figure 2-63	2	9.76	9.76R 3.94/8.44	dro-38	¶dr,r
	3	9.80	9.80R 3.91/8.48	dro-38	¶dr,r
	4	9.88	9.88R 3.86/8.56	dro-38	¶dr,r
	5	9.85	9.85R 3.89/8.53	dro-38	¶dr,r
	6	9.83	9.83R 3.89/8.52	dro-38	¶dr,r

Munsell Std/Print	Measurement	Hue No.	H/V/C*	ISCC-NBS** Name & No.	Munsell Color§ Name and Number
Standard-7.5YR 4/4	std	17.37	7.37YR 3.43/5.79	sb-55	sb,dr,r,yr
N8/17P1-N1h	1	12.63	2.63YR 5.82/4.08	lrb-42	rb,Lrb,pr,wr
Figure 2-64	2	12.58	2.58YR 5.85/4.04	lrb-42	rb,Lrb,pr,wr
	3	12.60	2.60YR 5.85/4.04	lrb-42	rb,Lrb,pr,wr
	4	12.64	2.64YR 5.84/4.05	lrb-42	rb,Lrb,pr,wr
	5	12.55	2.55YR 5.84/4.05	lrb-42	rb,Lrb,pr,wr
	6	12.61	2.61YR 5.85/4.05	lrb-43	rb,dr,drb,duR,r,wr
Standard-7.5YR 4/4	std	17.37	7.37YR 3.43/5.79	sb-55	sb,dr,r,yr
N8/17P1-N1e	1	17.01	7.01YR 6.41/4.63	lb-57	Lb,b,Lrb,rb
Figure 2-65	2	17.02	7.02YR 6.40/4.64	lb-57	Lb,b,Lrb,rb
	3	17.05	7.05YR 6.41/4.63	lb-57	Lb,b,Lrb,rb
	4	17.01	7.01YR 6.41/4.63	lb-57	Lb,b,Lrb,rb
	5	17.02	7.02YR 6.41/4.63	lb-57	Lb,b,Lrb,rb
	6	17.01	7.01YR 6.42/4.63	lb-57	Lb,b,Lrb,rb
Standard-7.5YR 4/4	std	17.37	7.37YR 3.43/5.79	sb-55	sb,dr,r,yr
N8/17P1-N1b	1	19.19	9.19YR 6.40/3.20	lyb-76	pb,by,Lyb,pi,vpb
Figure 2-66	2	19.17	9.17YR 6.40/3.19	lyb-76	pb,by,Lyb,pi,vpb
	3	19.18	9.18YR 6.39/3.20	lyb-76	pb,by,Lyb,pi,vpb
	4	19.16	9.16YR 6.39/3.20	lyb-76	pb,by,Lyb,pi,vpb
	5	19.17	9.17YR 6.39/3.19	lyb-76	pb,by,Lyb,pi,vpb
	6	19.16	9.16YR 6.39/3.20	lyb-76	pb,by,Lyb,pi,vpb
Standard-10R 4/6	std	11.58	1.58YR 3.32/8.29	srb-40	dr
N8/17P2-N2d	1	3.15	3.15R 4.05/6.45	gr-19	r,wr
Figure 2-67	2	3.29	3.29R 4.02/6.50	gr-19	r,wr
	3	3.23	3.23R 4.06/6.44	gr-19	r,wr
	4	3,33	3.33R 4.01/6.49	gr-19	r,wr
	5	3.23	3.23R 4.06/6.41	gr-19	r,wr
	6	3.39	3.39R 4.00/6.50	gr-19	r,wr
Standard-10R 4/6	std	11.58	1.58YR 3.32/8.29	srb-40	dr
N8/17P2-N2e	1	2.34	2.34R 3.70/8.15	mr-15	¶dr,r
Figure 2-68	2	1.99	1.99R 3.73/7.93	mr-15	¶dr,r
	3	2.46	2.46R 3.59/8.30	mr-15	¶dr,r
	4	2.37	2.37R 3.59/8.29	mr-15	¶dr,r
	5	2.50	2.50R 3.60/8.31	mr-15	¶dr,r
	6	2.49	2.49R 3.59/8.32	mr-15	¶dr,r
Standard-10R 4/6	std	11.58	1.58YR 3.32/8.29	srb-40	dr
N8/17P2-N2f	1	95.59	5.59RP 4.89/4.56	gpr-262	-
Figure 2-69	2	95.65	5.65RP 4.87/4.59	gpr-262	-
	3	95.72	5.72RP 4.87/4.60	gpr-262	-
	4	95.68	5.68RP 4.90/4.58	gpr-262	-
	5	95.73	5.73RP 4.86/4.60	gpr-262	-
	6	95.68	5.68RP 4.95/4.56	gpr-262	-

Color matched

Calibrated in specular inc.; standard measured in specular exc.; sample measured in specular exc.

Munsell Std/Print	Measurement	Hue No.	H/V/C*	ISCC-NBS** Name & No.	Munsell Color§ Name and Number
Standard-7.5YR 4/4	std	17.41	7.41YR 3.41/5.85	sb-55	sb,dr,r,yr
C8/4P1-C3b	1	15.41	5.41YR 5.64/5.50	lb-57	¶yr,b,Lb,Lrb,rb
Figure 2-71	2	15.37	5.37YR 5.66/5.43	lb-57	¶yr,b,Lb,Lrb,rb
	3	15.35	5.35YR 5.64/5.45	lb-57	¶yr,b,Lb,Lrb,rb
	4	15.36	5.36YR 5.63/5.48	lb-57	¶yr,b,Lb,Lrb,rb
	5	15.33	5.33YR 5.63/5.46	lb-57	¶yr,b,Lb,Lrb,rb
	6	15.36	5.36YR 5.62/5.49	lb-57	¶yr,b,Lb,Lrb,rb

Munsell Std/Print	Measurement	Hue No.	H/V/C*	ISCC-NBS** Name & No.	Munsell Color§ Name and Number
Standard-10R 4/6	std	11.50	1.50YR 3.32/8.26	srb-40	dr
C8/4P2-C2b	1	9.39	9.39R 5.23/7.05	mro-37	r,Lr
Figure 2-73	2	9.30	9.30R 5.34/6.91	gro-39	r,Lr
	3	9.15	9.15R 5.57/7.27	mro-37	r,Lr
	4	9.18	9.18R 5.54/7.31	mro-37	r,Lr
	5	9.20	9.20R 5.60/7.33	mro-37	r,Lr
	6	9.15	9.15R 5.56/7.35	mro-37	r,Lr
Not color matched					
Calibrated in specular inc.; standard measured in specular exc.; sample measured in specular exc					
Standard-7.5YR 4/4	std	17.41	7.41YR 3.41/5.85	sb-55	sb,dr,r,yr
C8/4P1-C4a	1	16.59	6.59YR 6.71/3.97	myp-29	¶Lb,pi
Figure 2-70	2	16.63	6.63YR 6.66/4.06	myp-29	¶Lb,pi
	3	16.55	6.55YR 6.69/3.97	myp-29	¶Lb,pi
	4	16.57	6.57YR 6.69/3.98	myp-29	¶Lb,pi
	5	16.60	6.60YR 6.73/4.00	myp-29	¶Lb,pi
	6	16.55	6.55YR 6.68/3.98	myp-29	¶Lb,pi
Standard-10R 4/6	std	11.55	1.55YR 3.37/8.31	srb-40	dr
C8/4P2-C2a	1	8.17	8.17R 6.76/4.94	myp-29	¶pr,pi
Figure 2-72	2	8.32	8.32R 6.75/4.98	myp-29	¶pr,pi
	3	8.27	8.27R 6.74/5.00	myp-29	¶pr,Lr,pi
	4	8.27	8.27R 6.75/4.99	myp-29	¶pr,pi
	5	8.20	8.20R 6.75/4.95	myp-29	¶pr,pi
	6	8.20	8.20R 6.75/4.96	myp-29	¶pr,pi

Fi8/2P1-Fi6, Fi8/2P1-Fi1, Fi8/2P1-Fi3, Fi7/26P2-Fi5, Fi7/26P2-Fi7, Fi7/26P2-Fi4, D8/2P1-D18, F7/26P2-F15, F7/26P2-F14a, F7/26P2-F19 = Munsell not large enough for spectrophotometer measurement port.

* H/V/C = Munsell notation hue, value, and chroma

** ISCC-NBS color name abbreviations as follows: bo-54 represents ISCC-NBS color brownish orange #54; dro-38 represents ISCC-NBS color dark reddish orange #38; gp-228 represents ISCC-NBS color grayish purple #228. gr-19 represents ISCC-NBS color grayish red #19; gro-39 represents ISCC-NBS color grayish reddish orange #39; lb-57 represents ISCC-NBS color light brown #57; lrb-42 represents ISCC-NBS color light reddish brown #42; lyb-76 represents ISCC-NBS color light yellowish brown #76; mb-58 represents ISCC-NBS color moderate brown #58.; mo-53 represents ISCC-NBS color moderate orange #53; mr-15 represents ISCC-NBS color moderate red #15; mrb-43 represents ISCC-NBS color moderate reddish brown #43; mro-37 represents ISCC-NBS color moderate reddish orange #37.; myp-29 represents ISCC-NBS color moderate yellowish pink #29; pp-227 represents ISCC-NBS color pale purple #227; sb-55 represents ISCC-NBS color strong brown #55; srb-40 represents ISCC-NBS color strong reddish brown #40; pv-214 represents ISCC-NBS color strong pale violet #214.

§ Munsell descriptive color name abbreviations as follows: b represents Munsell color brown; by represents Munsell color brownish yellow; db represents Munsell color dark brown; dr represents Munsell color dark red; drb represents Munsell color dark reddish brown; duR represents Munsell color dusky red; Lb represents Munsell color light brown; Lr represents Munsell color light red; Lrb represents Munsell color light reddish brown; Lyb represents Munsell color light yellowish brown; pb represents Munsell color pale brown; pi represents Munsell color pink; pr represents Munsell color pale red; r represents Munsell color red; rb represents Munsell color reddish brown; ry represents Munsell color reddish yellow; sb represents Munsell color strong brown; vpb represents Munsell color very pale brown; wr represents Munsell color weak red; yr represents Munsell color yellowish red.

All color names under the heading of "Munsell Name" are the Munsell Colors obtained by looking up the ISCC-NBS color number and the referral to USDA Soil Color Charts. (Kelly and Judd, 1976)
Underlined abbreviations were obtained by looking up the hue, value, and chroma in Munsell Soil Color Charts and locating the corresponding descriptive notation on the opposite page.

¶-Used when the color name underlined (as represented by the abbreviation) is not listed as a Munsell color included in the ISCC-NBS color number for that hue, value, and chroma. (Kelly and Judd, 1976)
- implies there is no Munsell hue page close to representing this color in soil

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VITA

Kelly J. Ponte

Candidate for the Degree of

Doctor of Philosophy

Thesis: EVALUATING DIFFERENCES IN SOIL APPEARANCE FROM FIELD TO PHOTOGRAPHS TO AID IN DEVELOPING SOIL PROFILE PHOTOGRAPHY GUIDELINES

Major Field: Soil Science

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