Standard Practice for Determination and Comparison of Color by Visual Observation in Forensic Soil Examination

Geological Materials Subcommittee
Chemistry/Instrumental Analysis Scientific Area Committee
Organization of Scientific Area Committees (OSAC) for Forensic Science

OSAC Proposed Standard Practice

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Geological Materials Subcommittee
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Standard Practice for Determination and Comparison of Color by Visual Observation in Forensic Soil Examination[1]

This standard is issued under the fixed designation X XXXX; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 The purpose of this document is to recommend best practices for describing the color of forensic soil/geologic material determined by visual assessment and comparison to a reference color chart. This document encompasses the human visual characterization of soil color in the Munsell color system and provides criteria in forensic soil comparisons to exclude that soils came from the same source. Characterization of color of forensic soils by instrumental methods is not within the scope of this guide. Depending on case requirements, soil color may be used for: screening samples, soil comparisons, or to aid in geographic attribution.

1.2 *Units* - The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

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[1] This practice is under the jurisdiction of ASTM Committee E30 on Forensic Sciences and is the direct responsibility of Subcommittee E30.01 on Criminalistics.

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2. Referenced Documents

2.1 *ASTM Standards*:

D1535 Standard Practice for Specifying Color by the Munsell System

3. Terminology

3.1 *Definitions:*

3.1.1 *Munsell color system*, n – An ordered system to quantify and describe color based on the three qualities or attributes: *hue* (H), *value* (V), and *chroma* (C) (FIG. 1), see D1535.

3.1.1.1 *hue* (H), n – Hue is that attribute of a color by which we distinguish red from green, blue from yellow, etc.

Discussion: The *Munsell color system* has principle *hues* of red (R), yellow (Y), green (G), blue (B), and purple (P), placed at equal intervals around a neutral point. Between the principle hues are five intermediate hues: yellow-red (YR), green-yellow (GY), blue-green (BG), purple-blue (PB) and red-purple (RP) (FIG. 1). Munsell hue is designated with an alpha-numeric code (e.g. 7.5YR) (adapted from **1**[2]).

3.1.1.2 *value* (V), n – The lightness of a color, from 0 (pure black) to 10 (pure white) in the *Munsell color system* (adapted from **1**).

3.1.1.3 *chroma* (C), n – The saturation or brilliance of a color, from 0 (no color) to ~8 (for vividly colored soils) or higher (for non-soil materials) in the Munsell color system (adapted from **1**).

[2] The boldface numbers in parentheses refer to the list of references at the end of this guide.

3.1.1.4 *Munsell color code*, n - Munsell color is recorded as alpha-numeric *Hue Value/Chroma*, H V/C (e.g., 7.5YR 5/4 or 5R 6/4); neutral colors, lacking a hue tone, (chroma = 0) are designated with a "hue" of N and omit chroma or list it as zero (N 3/ or N 3/0).

3.1.2 *color blindness*, n – total or partial inability to differentiate certain hues and chromas.

3.1.3 *questioned sample*, n - An item located at a crime scene or of undetermined origin that is analyzed in an attempt to identify or associate it with a known exemplar or sample (adapted from **2**).

Discussion – Soil evidence of unknown origin, or *questioned soil sample*, typically consists of: debris adhering to an evidentiary object (tire, wheel well, garment, shoe, digging tool); exogenous soil left at a crime scene (transferred from a shoe/tire, or adhering to a re-buried body/object); or debris recovered from within a body (nasal, stomach or lung contents).

3.1.4 *known sample* –Of established origin associated with the matter under investigation **2**).

Discussion– *Known soil samples* are intentionally collected, typically from crime scene or alibi locations, for comparison to a *questioned soil sample*. Soils are heterogeneous mixtures of organic matter and minerals that vary with depth and across the landscape. Typically, a greater number known soils samples are needed than manufactured materials to represent the range of variation (**3**).

3.1.5 *aggregate(s) [clump(s)]*, n – a group of soil particles that cohere to each other more strongly than to other surrounding particles.

Discussion. Soil aggregates may be natural (a *ped*) or formed by human activities (a *clod*). Often the genesis of evidentiary soil aggregates is unknown, so aggregate is often a preferred term in descriptions of soil evidence

3.1.6 *matrix color*, n – dominant or background color component of a soil aggregate, ped, clod or horizon (adapted from **1**).

3.1.7 *mottles, mottling*, n (*mottled*, adj.) or *non-matrix color* - Segregations within the soil matrix with different color or shades of color interspersed with the dominant (*matrix*) color.

Discussion. The National Soil Survey reserves the term *mottles* for color variations that cannot be associated with compositional properties of the soil, and specify color variations attributable to compositional variations with distinct terms (redoximorphic features, concentrations, ped coatings, etc.)(**1**), but in a forensic laboratory mottling is often used to describe any *color contrast* within a soil aggregate, regardless of its origin.

3.1.8 *color contrast*, n - the degree of visual difference that is evident between one soil color compared with another in close proximity (adapted from **4**).

Discussion: Within this document, color contrast refers to color difference between evidentiary soil samples.

3.1.8.1 *color contrast classes*, n – Degree of color distinction (*color contrast*) between colors within a soil are categorized as *faint*, *distinct* and *prominent* (**1**).

Discussion: Within *this* document, these contrast classes are used to describe the degree of color distinction between two evidentiary soil samples, whereas the National Soil Survey uses these contrast classes to describe color distinction with soil horizons. *Faint* color contrast is evident only on close examination. *Distinct* color contrast is readily seen but contrasts only moderately with the color to which it is compared. *Prominent* indicates colors which contrast strongly with the color to which it is compared; prominent colors are commonly the most obvious color feature of the section described. The National Soil Survey's thresholds between faint and distinct color contrast **(4)** are adapted as exclusion criteria in forensic soil comparisons (9.6).

3.1.8.2 *metamerism*, n - When colors are perceived to be matching despite having different spectral profiles; these spectral differences may be apparent under different illumination conditions.

4. Summary of Practice

4.1 Color is an easily observable characteristic of soils and is integral to the taxonomic classifications of soils (**5**-**6**). Most soil pigmentation is derived from soil organic matter and iron/manganese bearing minerals (**7**). The factors controlling these colors include the parent material, hydrology, vegetation, and extent of soil weathering, making soil color a valuable diagnostic tool for forensic examination purposes. Soils and sediments are often inadvertently transferred to people, garments, shoes, tools, or vehicles and subsequently collected as forensic evidence. Forensic examination of soils can have several goals, most commonly identifying materials as being soil, comparing soil evidence to known exemplars collected from crime scene or alibi locations, and analyzing soil for indications of its likely geographic or environmental origin to provide investigative leads or aid in searches. Forensic soil examiners have adapted the Munsell color characterization methods used by soil scientists in field settings to evidentiary soils in a laboratory setting (**1**,**8**) and soil color has been shown to be a reliable method for differentiation of forensic soil evidence (**9**-**10**).

4.2 The color of soil evidence is characterized in the Munsell color system by direct visual comparison to pigmented chips in a soil color chart.

4.3 When comparing colors of soil evidence, use similar conditions among all samples (illumination (7.2), sample treatments (9.4.2), moisture levels (6.2.1), soil color book (7.1.3)).

5. Significance and Use

5.1 *Color determination for soil comparisons* – Soil color is typically determined early in the examination scheme of forensic soil comparisons because this property can be characterized quickly, non-destructively, and with minimal or no sample modification. Determining distinct or prominent color differences between two soils, in the absence of an interference (see 6.2 to 6.6), is sufficient to permit an exclusion of a common source of the soils. Soils with somewhat similar color will require additional examinations to draw further conclusions.

5.2 *Comparisons of soil color to reference data* – Determination of soil color by visual comparison to a soil color chart may be used to compare the color of questioned soils to reference data published by soil surveys (**11**-**13**).

5.2.1 Comparison to reference data may be used to describe the prevalence or rarity of a soil color within an area of interest.

5.2.2 Comparison to reference data may be used as an investigative lead to define more likely source locations for a questioned soil.

5.3 *Soil color in prioritization*– When numerous known soils are collected from a crime scene or alibi location (an optimal situation), side-by-side color comparison of each known sample to a questioned sample allows the forensic scientist to prioritize the forensic soil examination to the known samples with the colors most similar to the questioned soil for targeted and more detailed examinations (9.3).

6. Interferences:

6.1 *Color blindness* – People who are partially or fully color blind will not be able to perform this examination accurately.

6.2 *Moisture* – Differences in moisture content can change Munsell value by as much as 2.0 units and hue by as much as 0.3 (**14**).

6.2.1 If comparing the colors of soil samples (9.6), the soils must have similar moisture contents. Creating similar soil moisture conditions among evidentiary soils is most easily achieved by air drying the samples at room temperature. Do not compare soils on the basis of color when the soils have different moisture levels.

6.2.2 If comparing soil colors to reference data (5.2), the soil evidence must be in the same moisture condition as the reference data (moist or dry).

6.3 *Contamination* – Contamination of soil evidence with exogenous material (e.g. human decomposition products, mold, soot/char, rust from sample storage containers) can alter the color of the soil. When visual inspection of soil evidence or case circumstances indicate possible contamination of one of the soils, do not compare the soils on the basis of color.

6.4 *Alteration* – Soil evidence can be altered from its source by a number of factors, including: size fractionation, fire, change in the reduction-oxidation state (**15**-**16**), exposure to stomach acid, etc. Such alterations can impact soil color. When visual inspection of soil evidence or case circumstances indicate possible alteration of one of the soils, do not compare the soils on the basis of color.

6.5 *Soils unsuitable for color comparison*: If the quantity of a questioned soil is so small that the observer cannot determine its color without magnification, do not compare soils on the basis of color. Questioned soil samples consisting of mixtures of soils from more than one source are unsuitable for color determination unless these soils can be physically segregated or if different soil types can be characterized *in situ*.

6.6 *Non-representative known soil samples*: The known soils submitted to a forensic laboratory for comparison to a questioned soil do not always represent the full range of colors at the source location due to mottling and/or sparse sampling. A forensic soil analysis should acknowledge that any comparison is limited by how well the known samples represent the source area. Recommendations for collection of better known soil exemplars are described in (**3**).

6.7 *Contamination or fading of the standard color chart* – Soil color charts, particularly those used in field settings, may become contaminated with soil, obscuring the true colors of the pigmented chips. Some studies have indicated that the chips in Munsell color books do not fade or change color over decades (**17**) while others have observed fading with use (**18**-**19**). Laboratories should have a procedure for verifying the accuracy of their soil color charts. The accuracy of the charts should be verified on a regular basis (e.g. by colorimetry, or comparison to suitable standard). For Munsell soil color charts used exclusively in a laboratory setting, every four years is a reasonable frequency of verification.

7. Materials

7.1 *Soil color charts* – Soil color charts consist of pigmented chips of color standards, labeled with Munsell color notations which span a range of colors common in soils.

7.1.1 *Munsell Soil Color Charts* - Munsell soil color charts (X-Rite, **20**) contain standard soil color chips organized with pages of specific hues from 5R to 5Y in increments of 2.5 hue units, supplemented by “10G-5GY” (for glauconitic or other green-hued soils), two “GLEY” pages (for soil colors formed under anaerobic conditions), and “WHITE” (e.g. evaporites, carbonate accumulations, albic horizon, and E-horizons). Each hue page, from 5R to 5Y, has a grid of chips that systematically range in both value (dark to light) and chroma (weak to vivid) (FIG. 2).

7.1.2 *GLOBE Soil Color Book* - Global Learning and Observations to Benefit the Environment (GLOBE) program has produced a book of pigmented color chips for use in determining the Munsell color of soils samples (**21**). The GLOBE color chips are comparable to the X-Rite Munsell Soil Color Chart (**17**,**22**), but are physically arranged in a different configuration. The GLOBE soil color book may be used *in lieu* of the X-Rite Munsell Soil Color Chart for forensic soil color determination, but will not be referred to further in this guide.

7.1.3 *Use of a single color book* – Within a case, use a single soil color book for all color determinations and document the book used.

7.2 *Light source* - Soil color determinations may be made in a variety of illumination conditions. When performing forensic comparison of soils, use the same illumination conditions for all color determinations. When comparing soil color to published reference data (5.2), use an illuminant for color measurement similar to that which was used for the reference data (e.g. for soils colors from the National Soil Survey databases determined in field settings (**11**-**13**), the illuminant should be similar to sunlight, D-65). Use of multiple illuminants might facilitate visualization of metamerism (9.4.1.1).

8. Hazards

8.1 When soil evidence could be contaminated with potentially hazardous materials, use personal protective equipment appropriate to the suspected hazard.

9. Procedure

9.1 *Preliminary Visual Examination* – During the initial assessment of questioned soil samples, the forensic scientist should examine the soil(s) for aggregates of varying color and texture. If possible, aggregates of different color(s), particle size, or morphology(s) should be segregated and analyzed separately. Aggregates with distinctly different colors can indicate the presence of more than one soil source within the sample or mottling of the source material. If segregation of the visually distinct soils is not possible, then the varied colors of the soil aggregates may be determined while intact.

9.2 *In situ soils* - The color of soil adhering to an item of evidence, like a garment, may be determined *in situ* so long as the soil completely obscures the color of the underlying substrate.

9.3 *Prioritization of known soils by color* – When numerous known soil exemplars are submitted for forensic soil comparison, visual color comparison, along with other morphological and textural properties, may be used to triage samples for detailed examination of select known soils for comparison to a questioned soil. This prioritization permits known soils with color within the thresholds described in 9.6.2 to be excluded from detailed subsequent examination in favor of known soils with colors and textures more similar to the questioned sample.

9.4 *Soil Color Determination* - Soil color is determined by visual comparison to the pigmented chips of the Munsell Soil Color Charts.

9.4.1 *Illumination* - Illuminate the sample and place the soil color chart atop of it, so that both the sample and standard chips can be viewed simultaneously. View the sample through the holes (when using the Munsell charts) and determine which color chip most closely resembles the color of each soil or component of interest (e.g. matrix, mottles, etc.).

9.4.1.1 The use of multiple illuminants, adding and removing ultraviolet (UV) light in particular, assists in soil color comparisons by permitting documentation of metamerism (7.2).

9.4.2 *Possible sample treatments*

9.4.2.1 If the sample is of sufficient size, disaggregation and subsequent particle size fractionation (i.e. sieving or sedimentation, **23**) or other treatments (heating, removal of iron oxides **9**-**10**) may be conducted prior to color determination.

9.4.2.2 Visual color determination of a heterogeneous material, for example coarse sand composed of multi-colored grains, will benefit from de-focusing one's eyes or removing corrective eyewear to "integrate" the color of the soil across the field of view.

9.4.3 *Reporting of soil color(s)* - Report color to the nearest chip, and when a soil color is intermediate between two Munsell color chips on the basis chroma or value, the examiner may interpolate the Munsell color to be intermediate between the adjacent chips (e.g. 10YR 4.5/4 or between 10YR 4/4 and 10YR 5/4.) Do not interpolate between hue pages.

9.5 *Comparison of soil color(s)* - In addition to recording the Munsell soil color of different samples of soil, the analyst should examine questioned and known soils side-by-side to directly compare their colors.

9.5.1 When comparing color between soil samples, the analyst should ensure that the observations are conducted under the same lighting (9.4.1), moisture (6.2), and physical conditions (9.4.2.1).

9.5.2 If two or more soil samples are nominally similar in color (e.g., their colors are determined to be the same or adjacent chips on the Munsell color chart), but there is a visually observable, but unquantifiable, color difference between the samples, the examiner may report a statement such as "soils A and B were each determined to have a Munsell color of 5YR 4/3; however, soil A was visibly redder/darker than B."

9.6 *Interpretation of color differences in forensic soil comparisons and exclusion criteria*

9.6.1 One of the primary reasons for conducting a forensic soil examination is to compare a questioned soil to a known soil or to compare two or more questioned soils to determine if they could share a common source. In the absence of potential interferences (6.2 to 6.6), if soil colors are suitably different, then color determination alone can provide sufficient information to permit exclusion of a common source.

9.6.1.1 The National Soil Survey soil color contrast classes provide a framework for evaluating the similarities between two soil color determinations. The National Soil Survey uses color contrast categories of: *faint* (color contrast is evident only on close examination), *distinct* (color contrast is readily seen but contrasts only moderately with the color to which it is compared) and *prominent* (color contrasts strongly with the color to which it is compared) to characterize color differences within a soil horizon (**4**) and provides specific boundaries between these color contrast classes. Conceptually, *faint* color contrast in forensic soil comparisons, in the absence of interferences (6.2 to 6.6), would indicate additional forensic examinations are warranted to determine if the soils originated from separate sources. *Distinct* and *prominent* color contrast between forensic soils, in the absence of interferences (6.2 to 6.6), provides sufficient evidence to permit exclusion of a common source.

9.6.2 *Evaluation criteria for soil color comparisons* - The following criteria describe color contrast thresholds beyond which soils colors are sufficiently distinct to permit a statement that excludes a common source for the soils. When soil colors are within these thresholds, additional methods of examination are required to reach a conclusion. However, even if the color differences between two or more soils exceed these thresholds, an examiner may choose to conduct additional soil examinations beyond color comparisons at their discretion (e.g., suspected interferences). These criteria integrate some of the National Soil Survey thresholds for faint versus distinct color contrast but are slightly more expansive in the faint color contrast class. Sections 9.6.2.1 through 9.6.2.3 must be considered in sequence and are summarized in FIG. 3.

9.6.2.1 *Colors of low chroma and low value* - When the Munsell color of two soils each have values ≤ 3 (dark) and chromas ≤ 2 (low color saturation), determination of the hue is difficult and they meet the National Soil Survey faint color contrast class (**4**). These colors are sufficiently similar to indicate additional soil characterization is needed to complete the forensic soil comparison.

9.6.2.2 *Colors of low chroma and the same value* – When comparing soils with chromas <2 (low color saturation), the same values >3, and hue offsets ≤ 3 pages (≤ 7.5 hue units), the color contrast is faint. These colors are sufficiently similar to indicate additional soil characterization is needed to complete forensic soil comparison. Kirillova et al (**19**) demonstrated the low color contrast present among low chroma chips on the Munsell soil color chart.

9.6.2.3 *Adjacent soil color chips* - When comparing soil colors, if the hue is from the same or adjacent hue pages (≤ 2.5 hue units) with a difference in value ≤ 1, and difference in chroma ≤ 1, the color contrast class is faint (**4**) and indicates additional soil characterization is needed to complete forensic soil comparison. This is the soil color difference criterion suggested in (**10**) for forensic soil comparison.

9.6.2.4 When the color contrast between two soils exceeds all three criteria in 9.6.2.1 through 9.6.2.3 the examiner may conclude that they originated from distinct sources (exclusion). However, the examiner may choose to conduct additional methods of examination, particularly if they suspect some kind of interference.

10. Precision and Bias

10.1 The text below briefly reviews the precision and bias of soil color determined by visual comparison to a color chart derived from a few studies from soil science scholarship and not specifically for *forensic* soil examinations; there may be additional limitations in color determination of very small evidentiary soil samples.

10.2 *Precision of color determinations*: The precision of soil colors determined by visual comparison to the Munsell soil color chart is largely limited by the resolution of the chart. It is possible for an experienced examiner to note that a color is intermediate between two color chips, and perhaps closer to one chip than another (**24**). Post et al (**14**) reported the standard deviation of dry soil color determinations among experienced soil scientists to be 0.54 hue pages, 0.53 value units and 0.65 chroma units. The reproducibility of soil color determinations by different individuals, while applying the uncertainty threshold of the adjacent color chips (analogous to 9.6.2.3) is 99.6% in hue, 98.0% in value and 92.3% in chroma (**25**). There are also a number of additional studies comparing soil color determinations made by different individuals (**26**-**27**).

10.3 *Repeatability of color determinations:* Four individuals visually determined soil color on 276 diverse soil specimens each at two different dates in (**25**) and showed mean repeatability of 83.4% for hue, 63.6% for value, 69.3% for chroma, and 40.0% for full Munsell color. This repeatability significantly improved when the criteria were relaxed to a one chip offset in hue, value, and chroma (color contrast thresholds in 9.6.2.3) yielding average repeatability of 99.6% for hue, 98.0% for value, 92.2% for chroma, and 92.0% for full Munsell color.

10.4 *Bias in soil color determinations*: Different illumination conditions can cause slight color bias in some samples; but use of the same illuminant in soil color comparisons mitigates this bias (7.2). On average, visual soil color determination is slightly biased relative to instrumentally determined soil color. Torrent et al (**28**) found visual observations to be: redder by 0.5 hue units, higher in value by 0.3 units and higher in chromas by 10%. This bias of visual color determinations toward higher value and chroma was also confirmed in (**14**,**25**). Replicate color determinations by the same individuals, separated in time, are more reproducible than those made by different observers, indicating some bias derived from the observer (**25**).

10.5 *Applicability of these uncertainties to forensic soil comparisons*: Studies have not yet been conducted to assess the potential biases in soil color determinations made on exceedingly small soil specimens like those that may be encountered in forensic soil examinations. The exclusion criterion in 9.6.2.3 has a threshold based on the resolution of the soil color chart (**10**) and is similar to the precision of color determinations by different observers and repeat observations by the same observer (**25**).

11. Keywords

11.1 Forensic soil examination, forensic soil comparison, soil color.

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FIGURES

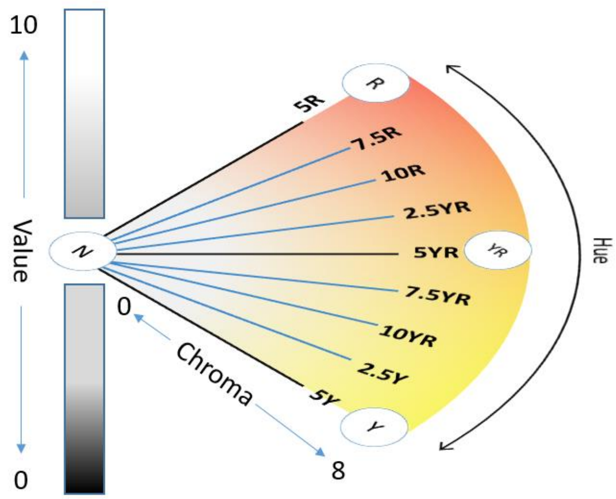

FIG. 1 Schematic representation of the Munsell soil color dimensions

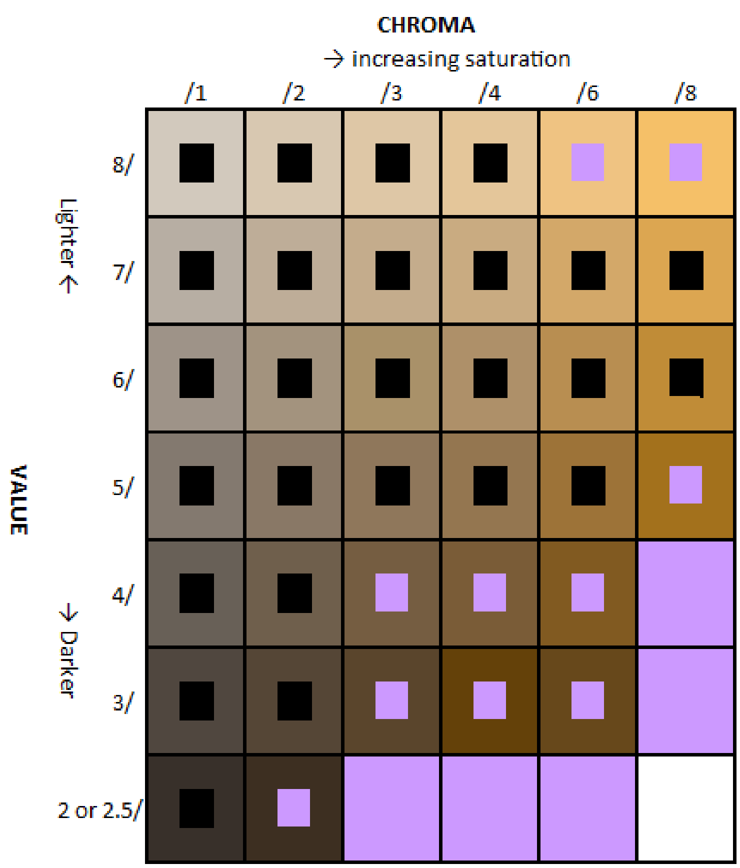

FIG. 2 Arrangement and population of hue pages (5R to 5Y) in the Munsell color charts. Black cells indicate value/chroma chips that are present on all hue pages, and purple cells indicate value/chroma chips that are present on some of the hue pages. Colors approximate the 10YR hue page.

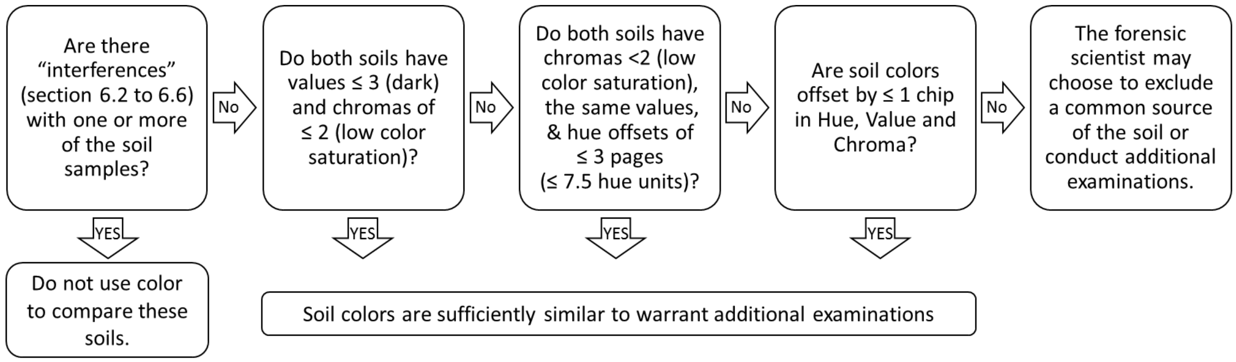

FIG. 3 Flow chart to aid in determining if exclusion of a common source of soil is recommended based on soil color.