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PEDOLOGY NOTES

Field conditions and the accuracy of visually determined Munsell soil color

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Abstract

This study evaluated the effect of variable natural lighting on the accuracy of soil color determination using the Munsell color charts. The effect of clouds, shade, and time of day were measured by calculating the distance between colors determined with the Munsell charts and colors measured with a chromameter. The only condition found to negatively affect accuracy was early-morning light on sunny days, and this effect was only significant for individuals with high overall accuracy at reading soil color. Regressions of visual color relative to chromameter color showed a reduction in slope and R^2 value for chromas measured early in the morning (m = 0.56, $R^2 = 0.75$) compared with mid-day (m = 0.67, $R^2 = 0.93$) on sunny days. Overall, these results suggest that variation in natural lighting does not have a large impact on visual color determination; however, sunny mornings should be avoided when accuracy is critical.

1 | INTRODUCTION

Soil color is a critical soil property that is often observed in the course of field descriptions and conveys a wealth of information related to properties that are far less apparent. Mineralogy, hydrology, and organic matter content are among the properties that affect soil color, for which direct observation involves costly and time-consuming laboratory analyses or years of field monitoring (Lindbo, Rabenhorst, & Rhoton, 1998; Richardson & Daniels, 1993; Schulze et al., 1993; Schwertmann, 1993). Consequently, soil color is relied on heavily in soil science for a wide variety of practical applications. In *Soil Taxonomy*, 43% of diagnostic horizons include Munsell color as a criterion (Soil Survey Staff, 2014), and in the World Reference Base, 39% of diagnostic horizons include Munsell color as a criteria (IUSS Working Group WRB, 2015). Soil color is also used extensively in the delineation of hydric soils and assessment of wetlands. Of the 45 indicators in the current version of the *Field Indicators of Hydric Soils of the United States*, seven have requirements related to hue, 32 specify a required range of value, and another 32 specify a required range of chroma (USDA-NRCS, 2018). Soil color can also be used to quantify soil development and estimate soil age (Harden, 1982; Turk, Goforth, Graham, & Kendrick, 2008), to distinguish types of archaeological ceramics (Ruck & Brown, 2015), and to determine the origin of forensic soil samples (Fitzpatrick, Raven, & Forrester, 2009; Lee, Williamson, & Graham, 2002).

The standard method for evaluating soil color is by visually matching the soil sample to a chip in the Munsell Soil Color Book. Using this method, previous studies have shown that soil scientists may achieve agreement on all three components of Munsell color 52% of the time and agree on each individual color component 71% of the time (Post et al., 1993). Possible reasons for disagreement include variations in spectral response of the user's eyes (Melville & Atkinson, 1985), colors that are difficult to assign because they fall midway between two chips in of the Munsell charts (Rabenhorst, Matovich, Rossi, & Fenstermacher, 2014), the physical condition of the Munsell book used (Cooper, 1990), and the lighting conditions under which color was determined (Melville & Atkinson, 1985). This study aims to better understand the impact of lighting conditions commonly encountered during field work on the accuracy of soil color determination.

Most soil scientists are aware that the field conditions under which Munsell color is evaluated have an effect on accuracy. However, limited data exist to document how various factors affecting light (e.g., clouds, shade, time of day) influence the accuracy of Munsell colors or the magnitude and direction of errors created by less-than-optimum lighting in the field. The *Soil Survey Manual* states that colors determined with the Munsell color charts may be inaccurate early in the morning or late in the evening and when the incidental light falls at an acute angle (Soil Science Division Staff, 2017). Cloudy days and shaded environments create conditions in which right-angle incident light is not possible. However, the *Soil Survey Manual* also suggests that it is possible to make adjustments for nonstandard lighting conditions with practice (Soil Science Division Staff, 2017). The goal of this study is to gather quantitative data to help soil scientists understand how to make such adjustments.

This study poses the question: How is the accuracy of soil color determination with Munsell color charts affected by early morning light and light arriving at acute incidence angles due to clouds or shade? We hypothesized that errors in visual determination of soil color would be increased under shade, under clouds, and in early-morning light. We expected to achieve the highest accuracy in the mid-day under sunny conditions.

Core Ideas

- On sunny days, early-morning light reduces accuracy of Munsell colors.
- Hue and chroma are the components of color most affected by early-morning light.
- On cloudy days, early-morning light has no effect on accuracy of Munsell colors.
- Cloudy weather and shade do not reduce accuracy of Munsell colors.

2 | METHODOLOGY

2.1 | Sample selection

The samples used in this study were selected from a collection of samples used for teaching soil science classes at the University of Nebraska-Lincoln. This collection includes more than 100 samples from a variety of locations around the United States, which have been collected on trips to soil judging contests and other travel by soil science instructors. To select the study samples, we started by sorting the collection into four broad color groups: dark brown, light brown, gray, and red/orange. We subsequently created five sample sets, each including one sample from each broad color group. In creating the samples sets, preference was given to samples with more homogeneous colors and to those that were most representative of the color group to which they were assigned.

2.2 | Lighting conditions

Five lighting conditions were selected for study: sunny mornings, cloudy mornings, sunny middays, cloudy middays, and shaded environments. Evaluation of sunny and cloudy conditions were based on the National Weather Service report for the Lincoln Airport. Ratings of "fair" or "a few clouds" were considered sunny, and ratings of "overcast" or "mostly cloudy" were considered cloudy. Other weather conditions were not included in the study. Morning was defined as the first hour after sunrise, and mid-day was defined as solar noon plus or minus 30 min. The shaded environment used was an awning on the west side of Hardin Hall on the University of Nebraska-Lincoln East Campus. All data for the shaded environment were collected at midday under sunny conditions.

2.3 | Study design

Fifteen individuals were assigned to analyze each of the five sample sets under a different lighting condition. The 15 individuals included undergraduate students with 0.5–3.5 yr of experience on the University of Nebraska-Lincoln Soil Judging Team and one professional with 15 yr of experience. The choice to use five different sample sets instead of analyzing the same set five times under different lighting conditions was made so that the individuals would not be biased by their memory of how they had assigned the colors under previous field conditions. However, we also considered that some sample sets may contain samples with colors that fall closer to the Munsell chips than others, leading to variability in the difficulty of evaluating colors using the Munsell book. To avoid covariance between lighting condition and any differences in proximity to the Munsell chips between the samples sets, the 15 individuals who evaluated soil color in the study were broken into five groups. Each group was assigned a different pairing between the sample sets and lighting conditions.

2.4 | Visual determination of color

The 15 individuals determined the dry and moist colors for soils in each of the sample sets under the designated field conditions using the Munsell Soil Color Book (X-rite, 2012).

For moist colors, water was added to the sample with a gentle mist from a spray bottle until color no longer changed with further addition of water (Soil Science Division Staff, 2017). Care was taken to avoid wetting the sample to the point of glistening. Each individual conducted the analysis independently and was responsible for determining the proper moisture state. All colors were estimated to the nearest whole chip, and each individual used the same copy of the Munsell Book for analysis of all samples. Under sunny conditions, the sample and Munsell book were held in direct sunlight during analysis unless they were part of the shaded-environment treatment group. All analyses were completed in late November to early December 2018.

2.5 | Chromameter analysis of color

After all visual analysis of color was complete, each sample was crushed and packed into the granular materials attachment for analysis with the chromameter (CR-400, Konica-Minolta). After dry color analysis was measured, the sample was moistened and re-packed into the attachment to obtain the moist color. The chromameter was calibrated with a standard white plate prior to analysis, and readings were taken using the Munsell color space setting.

Excellent precision and accuracy have been documented for Konica-Minolta chromameters, although a small correction has been recommended for better agreement with data collected by soil scientists (Post et al., 1993). Several possible reasons that explain the necessity of this correction were provided by the authors of that study, including variability in natural light conditions relative to the constant light source in the chromameter, which simulates standard sunlight. We did not make any adjustment to the chromameter readings in this study because we wished to preserve the readings taken under a constant light source as a point of comparison for the treatment groups measured under variable natural light scenarios.

2.6 | Data analysis

All Munsell colors were transformed to Cartesian coordinates using the following formulas:

$$x = \sin(\text{Hue}) \times \text{Chroma} \tag{1}$$

$$y = \cos(\text{Hue}) \times \text{Chroma} \tag{2}$$

$$z = \text{Value} \tag{3}$$

where hue represents the angle between the recorded hue and 10YR in a three-dimensional color space with 9° between each page of the Munsell Soil Color Book. This is a slight modification of conversions by previous authors, in which 5R is arbitrarily set as 0° (D'Andrade & Romney, 2003; Ruck & Brown, 2015). Here, 10YR is used as the 0° reference point because it is the most common hue for soil colors in the United States. This adjustment makes no difference in the calculation of distances between colors (Eq. [4]) but makes it easier to interpret the relationship between Munsell and Cartesian colors by aligning the most commonly used hue page with the y axis of the Cartesian plane, such that on the 10YR page y is equal to chroma.

With the colors in this format, it is possible to calculate the distance between each visually determined color and the chromameter-determined color of the sample. The distance (d) was calculated according the following equation (Ruck & Brown, 2015):

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \tag{4}$$

where (x_1, y_1, z_1) is the visually determined color, and (x_2, y_2, z_2) is the chromameter-determined color. A larger distance indicates lower accuracy in the visual determination of soil color. Although the Munsell color system is set up differently from the Cartesian coordinate system used here, the scale is similar (e.g., z = Value). Therefore, $d = 1$ is approximately similar to a one-chip difference in the Munsell book.

Differences in accuracy between the field conditions were analyzed by ANOVA comparing the average values of d for each condition. Finally, to make recommendations for improvement of Munsell colors recorded under suboptimal lighting conditions, regression analysis was used. To use the data in Munsell format, hue was transformed to a linear scale by assigning a number value to each page of the Munsell color book: 10R = 1, 2.5YR = 2, 5YR = 3, 7.5YR = 4, 10YR = 5, 2.5Y = 6, and 5Y = 7 (Post et al., 1993). One issue with this type of analysis is that the distance between hues in the Munsell color space varies depending on the chroma. One way to visualize the Munsell color space is as a cylindrical volume, with the binding of the book at the center of the cylinder and the pages creating a circle around the binding, each separated by an angle of 9° (Ruck & Brown, 2015). The hues of low chroma colors, closer to the center of the cylinder, have less distance between them than the hues of high chroma colors. Taking this into account, three separate regressions were created for analyzing hue: one for low chroma colors (1 or 2), one for mid-chroma colors (3), and one for high chroma colors (4–6). Regressions were used to compare the relationship between hue, value, and chroma evaluated with the Munsell charts and measurements taken with the chromameter under optimal and suboptimal field lighting conditions. The choice was made to conduct this analysis using the Munsell color space format so that it is easier to interpret and apply the results to field measurements recorded using the Munsell system.

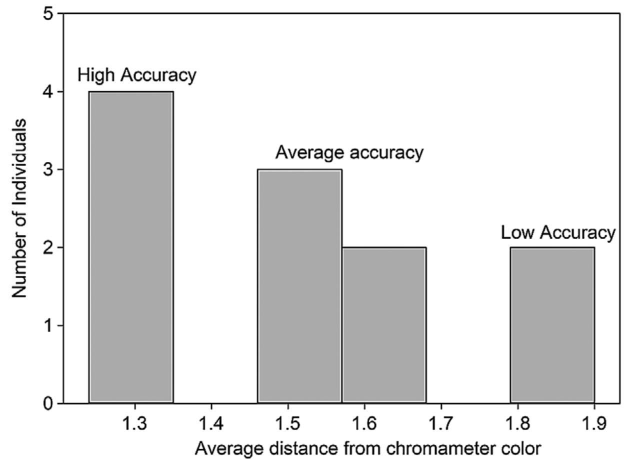

FIGURE 1 Distribution of the average distance between visually determined colors using the Munsell color charts and the chromameter color for each of the individuals who completed the analysis under all five lighting conditions. Based on this distribution, individuals were grouped into high-accuracy, average-accuracy, and low-accuracy categories

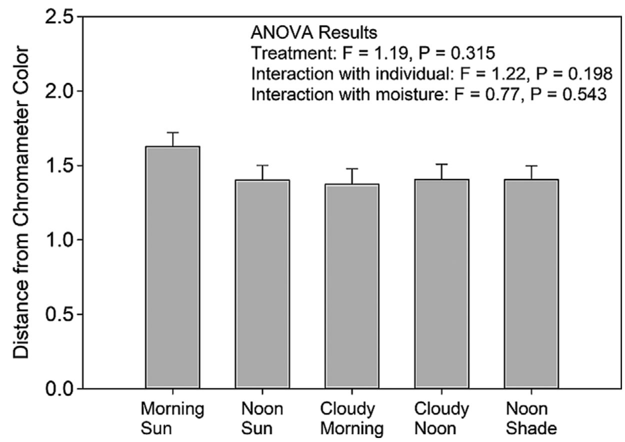

FIGURE 2 Average distance between chromameter-measured colors and visually interpreted colors analyzed under varying field conditions. Data are the averages for all nine individuals with high or average accuracy at determining soil color and include both moist and dry color. Error bars represent SE

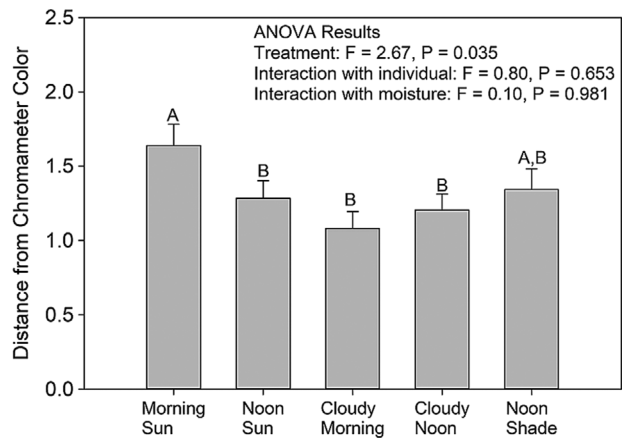

FIGURE 3 Average distance between chromameter-measured colors and visually interpreted colors analyzed under varying field conditions. Data are the averages for the four individuals in the high-accuracy group and include both moist and dry color. Error bars represent SE; letters above the error bars indicate the results of multiple comparisons statistical analysis using the Fisher test

3 | RESULTS AND DISCUSSION

Of the 15 individuals who participated in data collection, 11 completed the analysis under all five lighting conditions. For these 11 individuals, the average distance between the chromameter color and visual color determined by the individual varied (Figure 1). These individuals could be grouped into those with high accuracy, average accuracy, and low accuracy at determining soil color. Upon examining the data from the low-accuracy individuals, it appears likely that inaccuracies unrelated to the treatment variable were affecting the data, including errors such as mixing up “Y” and “YR” hues. Therefore, only the nine individuals with high or average accuracy were included in subsequent analysis.

Analysis of the data for all nine individuals with high or average overall accuracy showed that there was no significant impact of field lighting conditions on the accuracy of color determination using the Munsell color charts (Figure 2). Thus, for most individuals the ability to determine color is the same regardless of whether it is cloudy or sunny, whether it is morning or midday, or if they are standing in the shade. However, a second statistical analysis focusing only on the four individuals in the high-accuracy group found that there was a statistically significant effect of field lighting conditions on the accuracy of color determination (Figure 3). Namely, the accuracy of color determination suffers in morning light on sunny days, leading to a significantly higher distance between the visually determined colors and the chromameter colors (P = .035). Considering that individuals collecting the data in this study were mostly students with limited experience, the data for the four individuals with the highest accuracy may be more representative of the patterns expected for experienced professionals. It should be noted that these four individuals each had different pairings between sample sets and field conditions. For example, on sunny mornings each of the four individuals was assigned to analyze a different sample set. Thus, the results can be attributed to differences in the field conditions and are not an artifact of differences between the sample sets.

The results presented in Figure 3 suggest that clouds and shade do not affect the accuracy of visual color determination with the Munsell color charts but that time of day does affect accuracy on sunny days. Generally accepted knowledge suggests that clouds and shade are problematic for determining soil color. For example, Buol, Southard, Graham, and McDaniel (2011) state that, "Heavy overcast or deep shade under forest canopy makes soil color in the field difficult." Recent analysis of soil colors using smartphone cameras supports the conventional wisdom, revealing higher accuracy when colors are measured under sunny conditions (Fan et al., 2017). However, our results suggest that neither clouds nor shaded conditions produce measurable effects on the accuracy of visually determined colors measured using the Munsell color charts. In the morning, clouds actually increase the accuracy of soil color readings.

Further analysis of data from the four individuals with the highest accuracy at determining soil color shows that the light conditions on sunny mornings produce small inaccuracies in hue and chroma but have no influence on value. For the low-chroma colors (Figure 4a), there was no difference between the morning and noon-time regressions relating visually determined hue to chromameter hue. In both cases, the correlations were weak, with R^2 values of 0.32 (morning) and 0.22 (noon). This can be attributed to the close spacing between hue pages for the low-chroma colors at the center of the Munsell color space, which are difficult for the human eye to discern. The morning and noon-time regressions were also similar for the 3-chroma colors (Figure 4b), with a stronger correlation between the visual and chromameter colors at noon ($R^2 = 0.91$) compared with early morning ($R^2 = 0.69$). For the high-chroma colors, visually determined morning and noon-time hues were the same for 7.5YR and 10YR hues (Figure 4c). However, colors close to 5YR on the chromameter were read as 5YR at noon and 2.5YR in the morning.

There is no apparent difference between values determined in early morning compared with those determined at noon, with both regressions falling on nearly identical trend lines with similar R^2 values (Figure 5). Chroma tends to be overestimated in early-morning light, particularly in the high-chroma range, but this trend is never more than half a chip off from the trend for the noon-time colors (Figure 6). The R^2 value for chromas measured at noon (.930) is higher than for chromas measured in the morning (.754), suggesting that precision also suffers when chroma is determined in morning light. Previous work comparing soil colors determination by soil scientists with chromameter-determined colors suggests that chroma is the component of color that is the least precisely measured by soil scientists (Post et al., 1993). Our results suggest that chroma can be estimated with a high degree of precision if it is measured near solar noon.

Based on these data, some minor adjustments can be made for evaluating color in early-morning light on sunny days. When the color is determined to be between two chroma chips and both options are 3 or higher, it is recommended to choose the lower chroma chip due to the tendency to overestimate chroma in early morning light. Although the *Soil Survey Manual* suggests that, "the reading of sample color [when the sun

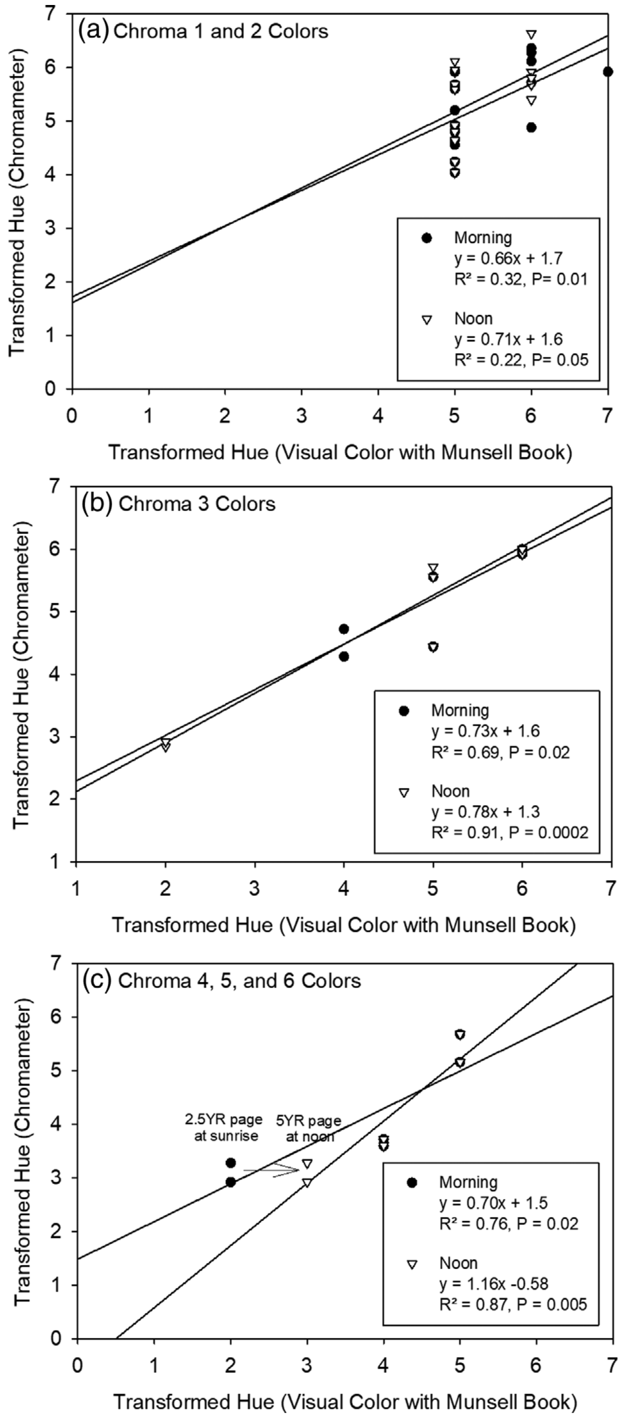

FIGURE 4 Relationship between hue measured with Munsell book and chromameter-measured hue for readings taken in the early morning and at noon under sunny conditions for (a) low-chroma colors (1 or 2), (b) mid-chroma colors (3), and (c) high-chroma colors (4–6). Hues are transformed to linear scale, such that a lower number corresponds to a redder hue (10R = 1, 2.5YR = 2, 5YR = 3, 7.5YR = 4, 10YR = 5, 2.5Y = 6, and 5Y = 7). Visual color data were collected by the four individuals with the highest overall accuracy in the study and include both moist and dry colors

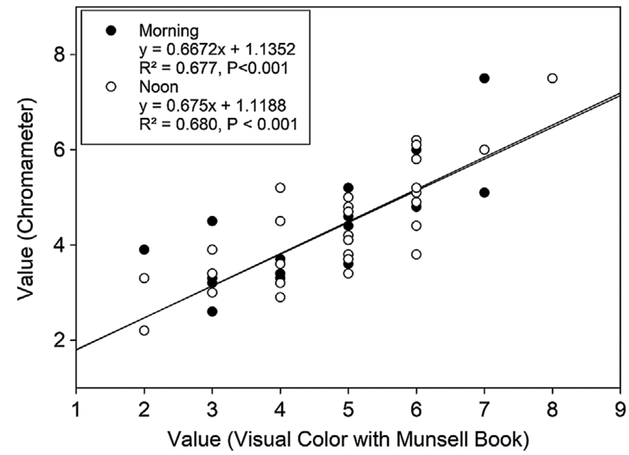

FIGURE 5 Relationship between value measured with Munsell book and chromameter-measured value for readings taken in the early morning and at noon under sunny conditions. Visual color data were collected by the four individuals with the highest overall accuracy in the study and include both moist and dry colors

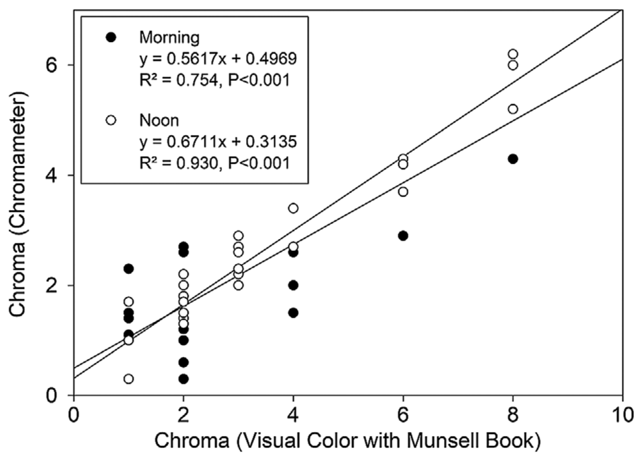

FIGURE 6 Relationship between chroma measured with Munsell book and chromameter-measured chroma for readings taken in the early morning and at noon under sunny conditions. Visual color data were collected by the four individuals with the highest overall accuracy in the study and include both moist and dry colors

is low in the sky] is commonly one or more intervals of hue redder than at midday" (Soil Science Division Staff, 2017), our results support a more modest adjustment regarding hue. Namely, high chroma colors read as 2.5YR in early-morning light might be better interpreted as 5YR. However, even this adjustment is offered tentatively, given the limited number of high-chroma red colors included in this study.

Considering the impact of early-morning light on chroma, it is further advisable that interpretations using soil color for the evaluation of hydric soil indicators use data collected near solar noon whenever possible. Such interpretations commonly require documentation of depletions or a depleted matrix with chroma 2 or less and/or the presence of redoximorphic features as evidence of saturation for long enough to produce reducing conditions (USDA-NRCS, 2018). This study reveals that chromas tend to be overestimated in early morning light, which may be problematic for hydric soil evaluation. However, this concern is minimized by the fact that the effect of early-morning light is mainly seen in the high chroma colors (Figure 6). A secondary concern arises from the steeper slope of the regression for chromas measured at noon compared with morning chromas. This suggests that differences in chroma are more visually apparent near solar noon, which would make it easier to see redoximorphic features.

Further study is needed to determine how soil scientists should use the information presented in this paper. First, the recommended adjustments for reading color in early morning sun, as presented in this paper, should be evaluated to determine if they are successful at improving soil scientists' accuracy at determining soil color. Recommended adjustments regarding hue might be improved through future studies focused on colors with high chroma and red hues, which are identified here as the most problematic soil colors for evaluation in early morning light. Alternatively, rather than attempting to adjust for known inaccuracies in early morning light, soil scientists might adjust their technique by seeking shade on sunny mornings to simulate cloud cover and to avoid inaccuracies caused by direct light in the early morning. Future studies could include early-morning shade as a treatment variable to test the effectiveness of this strategy. In addition, further study with a larger group of professional soil scientists is also recommended to verify whether the results of this small classroom study are applicable to more experienced professionals.

Many related questions might be posed that could be addressed using techniques similar to those used in this study. This study raises the question of how the accuracy of soil color changes during the interval between sunrise and noon as well as late in the afternoon. How long after sunrise should determinations of soil color be avoided? When is it too late in the day to determine soil color accurately? Does quality of light between seasons have an impact similar to those that we observed at different times of day? Future investigations should consider these questions.

Our hypothesis for this study was partially supported in that early-morning light led to less accurate determination of soil color, though only on sunny days and only for a subset of individuals who were able to achieve a high level of overall accuracy in soil color determination. Most field conditions that we thought would negatively affect the accuracy of color determination, including clouds and shade, had no significant effect. Furthermore, even in the early-morning sun, where we saw a significant effect, the average magnitude of the effect was less than the distance between two adjacent chips of the Munsell color book. Overall, these results suggest that field-determined soil colors are reliable despite variable natural lighting conditions.

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REFERENCES

Buol, S. W., Southard, R. J., Graham, R. C., & McDaniel, P. A. (2011). *Soil genesis and classification* (6th ed.) West Sussex: John Wiley & Sons. https://doi.org/10.1002/9780470960622

Cooper, T. H. (1990). Development of students' abilities to match soil color to Munsell color chips. *Journal of Agronomic Education*, *19*, 141–144.

D'Andrade, R. G., & Romney, A. K. (2003). A quantitative model for transforming reflectance spectra into the Munsell color space using cone sensitivity functions and opponent process weights. *Proceedings of the National Academy of Sciences of the United States of America*, *100*, 6281–6286. https://doi.org/10.1073/pnas.1031827100

Fan, Z. S., Herrick, J. E., Saltzman, R., Matteis, C., Yudina, A., Nocella, N., … Van Zee, J. (2017). Measurement of soil color: A comparison between smartphone camera and the Munsell color charts. *Soil Science Society of America Journal*, *81*, 1139–1146. https://doi.org/10.2136/sssaj2017.01.0009

Fitzpatrick, R. W., Raven, M. D., & Forrester, S. T. (2009). A systematic approach to soil forensics: Criminal case studies involving transference from crime scene to forensic evidence. In D. Miller & L. Dawson (Eds.), *Criminal and environmental soil forensics* (pp. 105–127). New York: Springer. https://doi.org/10.1007/978-1-4020-9204-6_8

Harden, J. W. (1982). A quantitative index of soil development from field descriptions: Examples from a chronosequence in Central California. *Geoderma*, *28*, 1–28. https://doi.org/10.1016/0016-7061(82)90037-4

IUSS Working Group WRB. (2015). *World reference base for soil resources 2014, update 2015 international soil classification system for naming soils and creating legends for soil maps*. World Soil Resources Reports No. 106. Rome: FAO.

Lee, B. D., Williamson, T. N., & Graham, R. C. (2002). Identification of stolen rare palm trees by soil morphological and mineralogical properties. *Journal of Forensic Sciences*, *47*, 190–194. https://doi.org/10.1520/JFS15223J

Lindbo, D. L., Rabenhorst, M. C., & Rhoton, F. E. (1998). Soil color, organic carbon, and hydromorphology relationships in sandy epipedons. In M. C. Rabenhorst, J. C. Bell, & P. A. McDaniel (Eds.), *Quantifying soil hydromorphology* (pp. 95–105). Madison, WI: SSSA.

Melville, M. D., & Atkinson, G. (1985). Soil color: Its measurement and its designation in models of uniform color space. *Journal of Soil Science*, *36*, 495–512. https://doi.org/10.1111/j.1365-2389.1985.tb00353.x

Post, D. F., Bryant, R. B., Batchily, A. K., Huete, A. R., Levine, S. J., Mays, M. D., & Escadafal, R. (1993). Correlations between field and laboratory measurements of soil color. In J. M. Bigham & E. J. Ciolkosz (Eds.), *Soil color* (pp. 35–49). SSSA Special Publication 31. Madison, WI: SSSA.

Rabenhorst, M. C., Matovich, M. M., Rossi, A. M., & Fenstermacher, D. E. (2014). Visual assessment and interpolation of low chroma soil colors. *Soil Science Society of America Journal*, *78*, 567–570. https://doi.org/10.2136/sssaj2013.08.0347

Richardson, R. L., & Daniels, R. B. (1993). Stratigraphic and hydraulic influences on soil color development. In J. M. Bigham & E. J. Ciolkosz (Eds.), *Soil color* (pp. 109–125). SSSA Special Publication 31. Madison, WI: SSSA.

Ruck, L., & Brown, C. T. (2015). Quantitative analysis of Munsell color data from archeological ceramics. *Journal of Archaeological Sciences: Reports*, *3*, 549–557. https://doi.org/10.1016/j.jasrep.2015.08.014

Schulze, D. G., Nagel, J. L., Van Scoyoc, G. E., Henderson, T. L., Baumgardner, M. F., & Stott, D. E. (1993). Significance of organic matter in determining soil colors. In J. M. Bigham & E. J. Ciolkosz (Eds.), *Soil color* (pp. 71–93). SSSA Special Publication 31. Madison, WI: SSSA.

Schwertmann, U. (1993). Relations between iron oxides, soil color, and soil formation. In J. M. Bigham & E. J. Ciolkosz (Eds.), *Soil color* (pp. 51–69). SSSA Special Publication 31. Madison, WI: SSSA.

Soil Science Division Staff. (2017). *Soil survey manual*. Washington, DC: USDA.

Soil Survey Staff. (2014). *Keys to soil taxonomy* (12th ed). Washington, DC: USDA-NRCS.

Turk, J. K., Goforth, B. R., Graham, R. C., & Kendrick, K. J. (2008). Soil morphology of a debris flow chronosequence in a coniferous forest, southern California, USA. *Geoderma*, *146*, 157–165. https://doi.org/10.1016/j.geoderma.2008.05.012

USDA-NRCS. (2018). *Field indicators of hydric soils in the United States* (Version 8.2). Washington, DC: USDA-NRCS.

X-rite. (2012). *Munsell soil-color charts with genuine Munsell color chips*. Grant Rapids, MI: Munsell Color.

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