12-2021

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Recommended Citation

Hill, Isabella, "Soil Moisture and Light Conditions Impact Digital and Visual Soil Color Assessments" (2021). *All Theses*. 3673.
https://tigerprints.clemson.edu/all_theses/3673

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Soil Moisture and Light Conditions Impact Digital and Visual Soil Color Assessments

Isabella Hill

SOIL MOISTURE AND LIGHT CONDITIONS IMPACT DIGITAL AND VISUAL SOIL COLOR ASSESSMENTS

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Plant and Environmental Science

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by
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December 2021

Accepted by:
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ABSTRACT

Determining soil color has traditionally been done visually, but inaccuracies with this method have been documented, including disagreement in evaluators, to differences in physical color books. Determining Munsell soil color in the field is also subject to environmental conditions, including soil water content (SWC) and light intensity. New digital spectral technology designed for determining soil color may offer accurate assessments regardless of human inaccuracies and environmental conditions. This research aimed to assess if visual observations differed from digital measurements of Munsell soil color as well as, the impacts of SWC and light on visual observations and digital measurements of soil color value and chroma, the two color components most important for soil use interpretations for siting and designing onsite wastewater systems. Munsell color was measured using the XRite Capsure and visually using Munsell Color Books on 111 soil horizons from three South Carolina regions. Distance between hues were similar among assessment methods although visual observations of value and chroma were significantly greater than digital measurements. Regardless, color values and chromas were less than one chip difference suggesting no practical difference in the two methods. While in general higher color values and lower chromas were determined from oven dried peds in comparison to field moist peds, the influence of SWC was region specific. Of most importance were higher color chromas documented from field moist peds compared to oven dried peds in the Coastal region. In this region gley chromas were determined in unsaturated soils emphasizing the importance to carefully evaluate other landscape features when interpreting the soil for onsite wastewater treatment. While

SWC affected the agreement between digital measurements and visual observations, in most regions the difference was less than one color chip and of no practical significance. Varying PAR did not affect digital measurements and had minimal influence on visual observations. Digital measurements of soil color value and chroma may offer validation of soil color under varying lighting conditions and could be a promising tool for training new soil evaluators in color assessment.

ACKNOWLEDGMENTS

I would like to sincerely thank my committee for their guidance throughout this project and everyone at SCDHEC who provided their expertise in the field. I am incredibly grateful to all my peers who helped in the lab and field and my friends who helped me stay motivated and inspired. Finally, I would like to thank my family for supporting me and my educational pursuits, even when they aren’t exactly sure what I’m doing.

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CHAPTER ONE

COMPARISON OF DIGITAL MEASUREMENTS AND HUMAN OBSERVATIONS OF SOUTH CAROLINA SOIL COLOR

Introduction

Soil color is one of the key components of field identification of soil properties and is used in many different fields including forensics to connect individuals to crime scenes (Sugita, 1996), to assess animal perception of foreign substances such as granular pesticides (Gionfriddo, 1996), is important for the siting and design of an onsite wastewater treatment system (Guertal, 1990), archeology (Ruck, 2015) (Milotta, 2018), dermatology (Reeder, 2014), horticulture (Thompson, 1996), and zoology (Lai, 2007). While other spaces are used, the Munsell color space is preferred because of its ease of use with color chips that are perceptually uniform (Chang, 2012)

While soil color is an extremely important aspect of soil assessments in different fields, limitations to the current method of determining soil colors have been found. For example, while new colors books of the same brand have been found to be uniform in color (Thompson, 2013), exposure to the outdoors can alter the chips (Figure 1), including lightening of value, intensification of chroma, and reddening of hues (Sáchez-Marañón, 2005).

The time of day has also been found to affect how the colors are perceived, with the difference between sunrise and sunset resulting in variation across as much as four hue pages (Sáchez-Marañón, 2011). Approximately 2% of color matches made by soil scientists are a perfect match (Soil Survey Staff, 1988) and soil scientists agree on the same color chip only 52% of the time (Post, 1993).

Digital measurements of soil color could offer a way to minimize these errors. The Munsell Color CAPSURE (XRite, Grand Rapids, Michigan) is a tristimulus colorimeter with an integrated system of calibration for Munsell soil colors. This research will determine how this device compares to the visual assessment of soil color.

Methods and Materials

Soil Locations

Soils in three major regions of South Carolina, Southern Piedmont (9), Midlands (14), and Coastal (7) of South Carolina were utilized due to their prevalence and locality of areas being developed (Table 1.1). For each location, multiple sites were visited in which the soil was being inspected for the suitability for a septic system.

Sample Collection

From each location, three individual soil peds were collected from each horizon (2-6 per profile) for a total of 160, 272, and 156 samples for the Southern Piedmont, Midlands, and Coastal Regions, respectively. A digital color measurement (CAPSURE, XRite, Grand Rapids, MI) was used to determine Munsell Soil Color with the hue, value, and chroma recorded as whole numbers. The aperture was set to Automatic/Large (8mm) for texture compensation (XRite, 2019). At the same time, Munsell color was determine visually (Munsell, 2010) by two of the authors and a South Carolina Department of Health and Environmental Control inspector.

Study Design and Statistical Analysis

This research is a survey and does not have a traditional experimental design, as no change to the environment were made.

The effects of region and color assessment (visual observation or digital measurement) on color components (hue, value, and chroma) were tested using an ANOVA. The ANOVA included the main effects and interaction of region and color assessment method. The ANOVA also included sites as replicates and peds at each site as sub-replicates. Specific mean comparisons were performed using Tukey's HSD test. Residuals were found to follow a normal distribution (Levene's test) and homogenous variances (Shapiro-Wilkes test). A significance of 0.10 was used for all comparisons as this study was conducted entirely in the field. All statistical calculations were performed using JMP Pro 14.3.0 (SAS Ins Inc 2018).

Results and Discussion

Region and color assessment method were determined significantly different factors for color value and chroma only. No interaction effect was determined for any color component (Table 1.2).

Region

With the exception of hue, soil color components were different based on region (Tables 1.2 and Figure 1.2). This may be explained by regional soils were very different in their composition. Southern Piedmont soils were typically Ultisols comprised of a thin sandy loam surface followed by a red clayey subsoil. Saprolite consisting of mottling of iron-oxides were often present. Soil profiles in the Midlands were mostly Ultisols that consisted of primarily sand that were either coasted or uncoated with iron oxides. Soil profiles on the coast included Ultisols and Entisols that varied from deep coarse sands to sandy loams with or without Fe oxides that were sometimes saturated in the subsoil (resulting in horizons with a gleyed matrix or depletions).

Commonly used hues were 7.5 YR, 10 YR, and 10YR for the Southern Piedmont, Midlands, and Coastal regions respectively. Color values were lowest in the Coastal region (ranging from 1 to 8, $\bar{x}$= 3.4), with color values similar Southern Piedmont (3 to 7, $\bar{x}$=4.3) and Midlands (1 to 8, $\bar{x}$= 4.6) soils (Figure 2a). Chromas were lowest in the Midlands (ranging from 1 to 8, $\bar{x}$= 3.7), with higher chromas in the Southern Piedmont (3 to 8, $\bar{x}$= 5) that were similar for Coastal region soils (2 to 7, $\bar{x}$= 4.7) (Figure 2b).

Comparison of Color Component Assessments

The same hue was determined (ΔHue $\leq$ 2.5) for 92 % of the 111 horizons regardless of color assessment method (Table 2). Visually observed color values ranged from 1 to 7.6, ($\bar{x}$= 4.5, SE =0.08) with 92% of which were within one color chip higher than digital color values (ranged from 1 to 7, $\bar{x}$=4.1, SE =0.07) (Table 2b). Chroma measurements followed a similar trend as color values, in which visually observed chromas ranged from 1 to 7.3 ($\bar{x}$=4.5, SE= 0.08), with 83 % within one color chip than digitally measured chromas (ranged from 1.5 to 7, $\bar{x}$=4.1, SE =0.07) (Table 2c). This agrees with the notion that humans are more likely to choose higher notations than appropriate (Post, 1993) and that color values observed using Munsell color charts are higher than the actual soil color by 0.5 unit (Fan, 2017). The 8% of the color values and

17% of chromas that were more than 1 color chip off were of various soils and did not follow any pattern in explaining the larger difference between the assessment techniques.

Conclusions

Statistically, there are significant differences between the digital and visual assessments of soil color value and chroma, however the two methods were less than 1 chip off meaning the difference is not of practical significance.

While not specific to soils, there are other technologies for measuring color, however this unit is specific for soil colors described by the Munsell color system. Other technologies for soil color analysis using smartphones are in development (Gómez-Robledo et al., 2013). In addition, other technologies including smartphone applications can be used to determine Munsell Color (Han, 2016), however there are issues to still overcome. For example, assessments of another digital device were found 64.5%accurate when converting Munsell color chip scans from lightness (L*), redness (a*), and yellowness (b*) back into Munsell notation, and 16% and 0% when all three components matched up between Munsell converted device measurements and visual observation Munsell color observations (Stiglitz, 2016).

This device can be useful in assisting in the assessment and validation of soil color. However, it should not be used as a single source of assessment. For example, in the present research, there were less than five occurrences (out of the ~300 digital measurements), in which the color determined by the digital unit was clearly inaccurate when compared to the Munsell color chart chip it measured the soil as, as well as the human observation. The XRite is the first digital technology marketed for soil color determination using the Munsell Color Chart. From a practical standpoint, the digital measurements can be used to help in training new soil evaluators and as additional information and validation of human observation of color assessment.

Tables and Figures

Table 1.1. Soil series (number of different profiles investigated) and orders of profiles utilized to determine digital measurements and visual observations of soil color components in South Carolina.

Region	Series	Order
Southern Piedmont	Cecil (4)	Ultisol
Southern Piedmont	Brevard (2)	Ultisol
Southern Piedmont	Chewacla	Inceptisol
Southern Piedmont	Appling (2)	Ultisol
Midlands	Pelion (5)	Ultisol
Midlands	Dothan	Ultisol
Midlands	Blaney (4)	Ultisol
Midlands	Lakeland (4)	Ultisol
Coastal	Wando	Entisol
Coastal	Seabrook	Entisol
Coastal	Kiawah (2)	Alfisol
Coastal	Rains	Ultisol
Coastal	Lynchberg (2)	Ultisol

Table 1.2. Degrees of freedom and significance for main factor and factor interactions.

Factor	**DF**	**P value**
(a)Δ Hue		
Region (R)	2	NS[†]
Assessment (A)	1	NS
R*A	2	NS
(b)Value		
Region (R)	2	***
Assessment (A)	1	*
R*A	2	NS
(c) Chroma		
Region (R)	2	***
Assessment (A)	1	NS
R*A	2	NS

*Significant at the .1 probability level. ***Significant at the .01 probability level. †NS, nonsignificant.

Figure 1.1. Weathered Munsell Color Pages. Page A has been used by undergraduates for soil judging for a few years and page B is a newer page that has been used fewer times.

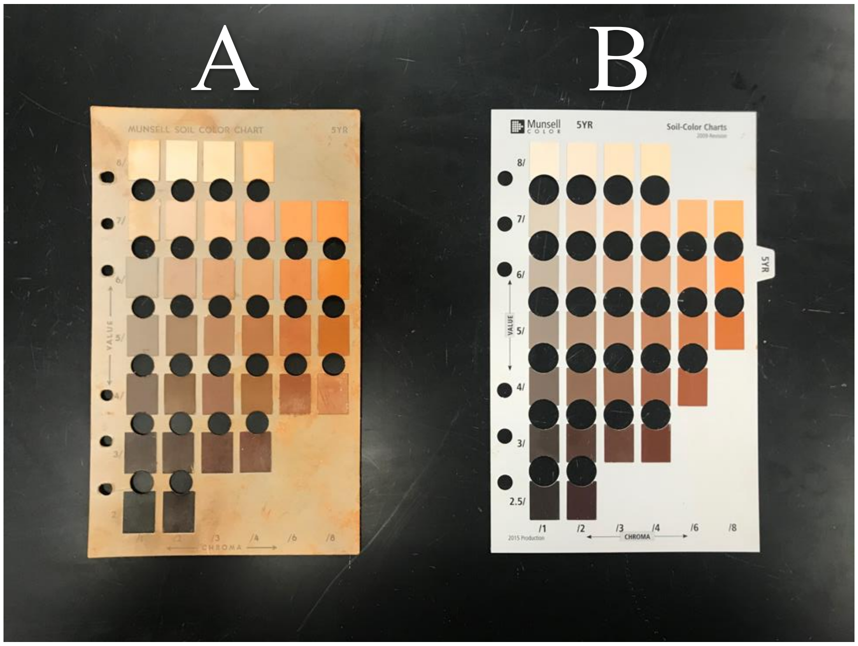
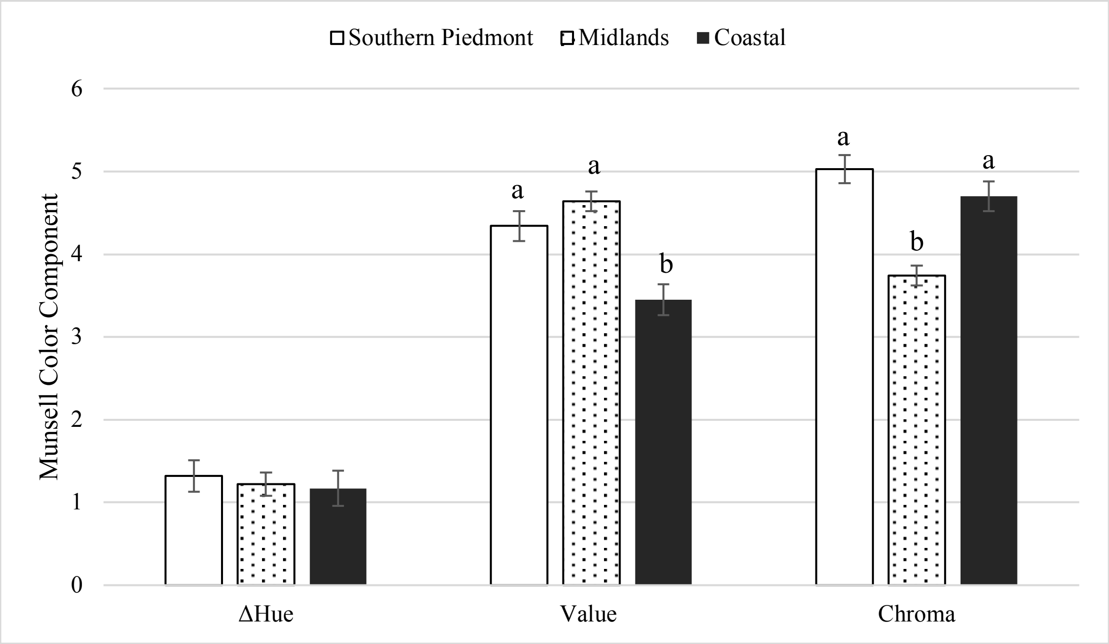


Figure 1.2. Mean and standard error for soil color components in the three different regions/soil orders of South Carolina. Means followed by the same letter are not significantly different according to HSD (0.10).



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CHAPTER TWO

SOIL WATER CONTENT AND PHOTOSYNTHETICALLY ACTIVE RADIATION INFLUENCES SOIL COLOR ASSESSMENT

Introduction

Soil color can be primarily contributed to organic matter, mineral composition, and water content (Viscarra Rossel 2006). Organic matter affects the value and chroma of the soil color (Franzmeier 1988; Konen 2003; Shields, 1968). Soil minerals, specifically those containing iron oxides, influence primarily the hue of the soil (Scheinost, 1999), but also impacts the value and chroma (Schwertmann 1993). Increases in water content lower color value (Post, 1993), attributed to changes in spectral reflectance (Viscarra Rossel 2006).

This visible property of soil is important to the classification of soils and for determining their potential use and management. Identification of soil saturation is important to safely design and install onsite wastewater treatment systems (Humphrey 2001), as soil saturation is a threat to properly functioning septic systems (Butler 1995). Soils that have been saturated for extended periods of time have very low chroma colors, meaning they lack brightness and are grayed (Franzmeier 1983). Iron reduction occurs under anaerobic conditions via soil saturation when bacterial respiration solubilize the iron oxides (Schwertmann 1993). The solubilized iron is leached through the soil profile exposing the remaining silicates which are a low chroma gray color (Schwertmann 1958; Verpraskas 2000).

The Munsell Color Space is utilized in soil science, among other fields, because it offers discreet colors that are perceptually uniform instead of a nearly infinite spectrum of color. This makes the visual assessment of soil color easier for the human eye. While Munsell soil colors are very prevalent in soil science, there are limitations to the human determination of soil color using physical color chips (Post 1993). Ideal conditions for color assessment are direct noon daylight overhead with little interference from the atmosphere, the pages of the color book should be unaltered by sunlight, water, or soil samples, and the sample should be rubbed to produce a single color (Cooper 1990). These conditions are often not available and, between sunrise and sunset, the hue determinations for moist soils can vary between as many as four color chips, especially with low chroma colors (Sanchez- Marañón 2011). This exposure to this direct sunlight can physically alter the chips and result in lighter values, more intense chromas, and redder hues (Sanchez- Marañón 2005).

Spectrophotometry has been used in the lab to determine soil color as early as the 1960s (Shields, 1966). Portable spectrophotometric devices are growing in popularity to due to improved accuracy in field soil color determination and comparability to visual observations (Dong 2020; Stiglitz 2016). With reproducible and accurate results from portable devices, systemic biases of soil classifiers toward higher notations may be negated (Barrett 2002; Marqués-Mateu 2018; Post 1993).

The advantage of the technology of the XRite CAPSURE (XRite, Grand Rapids Michigan) over other spectrophotometric devices is that it offers excludes ambient light and results in Munsell Color notation specific to soils. This allows users to avoid tricky conversions that are a source of inaccuracy (Stiglitz 2016) and limits the accessibility of other devices. This research will determine how light intensity and soil water content (SWC) affect the assessment of soil color value and chroma from visual observations and the XRite CAPSURE.

Methods and Materials

Location Determination and Sample Collections

South Carolina was divided into three regions, the Southern Piedmont, the Midlands, and the Coastal, all including areas of urbanization. Within each region, 1-3 profiles at each of 30 sites were used for the survey (Figure 1). Eighty-three percent of the profiles were Ultisols, 3% Inceptisols, 7% Entisols, and 7% Alfisols (representing 9, 1, 2, and 1 series, respectively).

For each profile, an auger collected three field moist peds from each horizon. Two of the authors and a South Carolina Department of Health and Environmental Control employee from the Onsite Wastewater Treatment Systems Division visually observed soil color using the Munsell Soil Color Book (Natural Resources Conservation Service Soil Survey Division 2017; XRite 2010). Digital Munsell soil color using tristimulus technology (XRite CAPSURE, XRite, Grand Rapids, MI) was also measured for each ped. The aperture was set to Automatic/Large (8mm) for texture compensation (CAPSURE Manual). To determine outdoor light intensity influence on color, photosynthetically active radiation (PAR) (FieldScout 6 Sensor Quantum Light Bar and Light Sensor Reader, Aurora, IL) was recorded at each profile.

For determining the influence of SWC on color, samples were oven dried (VWR Symphony, VWR, Radnor, PA) at 105 °C for two days (Schmugge 1980). Digital measurements and Munsell soil color was reassessed by three-four undergraduate soil science students and two authors.

Study Design and Statistical Analysis

This study is a survey and does not have a traditional experiential design, as no factors in the environment were changed.

Human observations of color value and chroma for each horizon for both field moist peds and oven dried peds were averaged. When evaluating the influence of light intensity on color determination, PAR values were organized into three groups: Low (0-1200µmol m-1 s-1,), Medium (1200-2100µmol m-1 s-1), and High (2100+ µmol m-1 s-1) based on PAR readings around the summer solstice (Nobel 1980) and time of day. Soil water contents fell into two groups, oven dried and field moist.

The effects of soil water content and color assessment method on color components (hue, value, and chroma) were tested with an ANOVA for within each region. The ANOVA included the main effects and interaction of soil water content and color assessment type (digital and visual). The ANOVA also included site as a random factor. The effects of light intensity and color assessment method (digital and visual) were tested with an ANOVA within each region. The ANOVA included the main effects and interaction of PAR and color assessment type (digital and visual). The ANOVA also included site as a random factor.

Data were assessed visually for ANOVA assumptions and no evidence was seen to suggest the assumptions were violated. Specific mean comparisons were performed using Tukey's HSD test. A significance of 0.05 was used for all comparisons. All statistical calculations were performed using JMP 14.3.0 (SAS Ins Inc 2018).

Results

Due to the random factor of region being significant, data is presented for each region.

Color Assessment at Contrasting Soil Water Contents

Color Value

The interaction effect in the Southern Piedmont identified that visual observations of color value were significantly higher than digital measurements for both SWCs (Tables 2.1 and Figure 2.2a). However, there was less than one color chip difference. There was no interaction effect in the Midlands, (Table 2.1, Figure 2.2c), but both factors were significant, and a similar pattern occurred as in the Southern Piedmont in which higher visual observations (5.1 ± 0.14) than digital measurements (4.6 ± 0.10), and oven dried color value assessments were one color chip higher (5.4 ± 0.12) than the field most peds (4.4 ± 0.08) (Table 1). In the Coastal region, the interaction effect identified that similar color values were determined regardless of color assessment on oven dried peds, but visual observations were significantly higher than digital measurements on field moist peds (Table 2.1, Figure 2.2e).

Color Chroma

In the Southern Piedmont, the interaction effect of color assessment and SWC identified that visual observations of color chroma were highest on field moist peds with all other color assessments similar regardless of SWC (Tables 2.1 and Figure 2.2b). In the Midlands, the interaction effect of color assessment and SWC identified there was no difference among color chroma assessment on field moist peds, both of which were higher than chromas determined on oven dried peds, and with lower color chroma determined on oven dried peds from visual observations compared to digitally measured chromas (Table 2.1, Figure 2.2d). Only SWC influenced color chroma in the Coastal region (Table 2.1) with field moist peds having higher chromas (3.44 ± 0.2) than oven dried peds (2.7 ± 0.18).

Influence of Light Intensity on Color Assessment

In the previous section when color assessment was partitioned by SWC, there were nearly equal sample sizes, but when the data was partitioned by light level, samples sizes were not equal. This was accounted for in the analysis. The differences in sample sizes lead to color assessment being a significant factor for both color value and chroma, but interaction effects were only minimally determined for color value in the Midlands (Table 2.2).

Light intensity was never measured strong enough to be in the “high” category at the Southern Piedmont and Midland sites.

Color Value

In the Southern Piedmont region, visual observations for color value were significantly higher than the digitally measured colors (Table 2.2, Figure 2.3a). Color values assessed under low PAR (3.6-6 and $\bar{x}$=4.5) were higher than when assessed under medium PAR (3-5 and $\bar{x}$=4.1) but were not significantly different (Table 2.1).

The Midlands region followed a similar trend as the Southern Piedmont for color assessment, with visual observations resulting in significantly higher values (Table 2.2, Figure 2.3c). Intensity of PAR did result in significantly higher values under low PAR (1-7.6 and $\bar{x}$=4.9) compared to medium PAR (1-7 and $\bar{x}$=3.3) (Table 2.1). No factor or interaction influenced color value in the Coastal Plain Region (Table 2.1).

Color Chroma

In the Southern Piedmont region, visual observations for color chroma were significantly higher than the digitally measured colors (Table 2.2, Figure 2.3b). Color chromas under different PAR intensities averaged the same for this region (5.4 and 4.7 for low and medium PAR intensities, respectively) (Table 2.2). The Midlands region followed a similar trend as the Southern Piedmont for color assessment, with visual observations resulting in significantly higher chromas than those digitally measured (Table 2.2, Figure 2.3d). In the Midlands too was color chromas similar under low and medium intensity PAR (Table 2.2, 3.6 and 4.3 for low and medium PAR intensities, respectively).

Color chroma did follow the same trend for color assessment as the other two regions, with visual observations being significantly higher than digitally measured chromas

(Table 2.2, Figure 2.3f). Intensity of PAR did not result in any significant differences in mean color chroma (4.9, 4.6, and 4.2 for low, medium and high PAR intensities, respectively) (Table 2.2).

Discussion

Soil Water Content

Both the value and chroma of the samples in the present study were significantly affected by the change in water content. This is consistent with other findings on both visual observations (Post 2000) and digital measurements (Stiglitz 2016) of soil color. The present research suggests that soil water affects agreement of the two assessment methods, with higher visual observations of soil color value and chroma, with agreement in oven dried samples, and with digitally measured values not affected by water content.

The highest means occurred in visually observed color values of oven dried samples and the lowest color values occurred in the digital assessments of field moist samples. This is in agreement with what is known about soil color, soil water increases light absorption (Jackson 2020), lowering the color value of the soil (Post 2000). The average difference in mean color value between digital and visual assessments on field moist peds was 0.4 and for oven-dried peds was 0.5. Both differences are small enough to indicate that the two assessment types are not practically different across SWC.

Although not statistically consistent across all regions, field moist chroma were generally higher than oven dried, with similar mean differences between assessment types in field moist peds (0.4) and oven dried peds (0.3). This difference in differences suggests little practical significance to favor one assessment method over another at different SWCs. The color value and chroma are not likely not to change if digitally assessed rather than visually observed. Thus, the digital assessment is a good tool to validate color values and chromas especially when there is visual uncertainty of meeting gleyed criteria. However, it should be understood that color value and chroma should never be the only factor considered when determining septic system placement and design (as confirmed by the Coastal region results).

Light

There was no interaction effect between color assessment and PAR intensity for color value or chroma in any region. This suggests that lighting does not affect the relationship between digital and visual observations. Perhaps differences in assessment type are associated with the digital unit blocking out exterior wavelengths and produces its own light to assess the soil color, while humans must rely on the environmental lighting, which other research suggests has an impact on the determination of soil color (Fan 2017; Turk 2019).

PAR has no significant impact on the determination of color chroma or value, except for in the Midlands region. While patterns of higher values at lower PAR were present across the state, it was only in the Midlands this pattern was significant. The fact that PAR was mostly an insignificant factor is not in agreement with what findings of other recent research that found varying light intensity to affect determination of soil color (Fan 2017). In cultural artifacts, colors at lower values were more difficult to distinguish than those at higher values (Milotta 2018), especially under varying lighting conditions (Milotta 2020). In addition, lighting throughout the day and year is considered a concern of soil professionals in determining soil color.

The average difference in color value between low and medium PAR for visual observations was 0.8 (closer to 1) and for digital measurements is 0.3 (closer to 0), indicating that color values determined visually may be practically impacted by lighting conditions while digitally determined are less impacted. This could be attributed to humans' tendency to select higher numerical notations (Post 1993). While color values indicate that lighting may impact visual observations of soil color more greatly than digital assessments, that same cannot be said for chroma, where the difference between low and medium PAR for both digital and visual assessments is 0.3.

Regional differences may be attributed to the mineralogy of the soil. Overall, soils in the Upstate and Midlands have redder hues than the soils of the Coastal region. The source of this redness is the iron rich parent material (Murphy 1995). Upstate soils were coated in darker and redder iron oxides in comparison to the lighter and less red iron oxides in Midland soils. Variations in the color of the soil and iron oxides is attributed to the mineral source of the iron (Schwertmann 1993) and variations in particle size, shape, aggregation, defects, and impurities (Scheinost 1999). The variations in the goethite crystal size may be responsible for the increase in redness and darkness in the Upstate soils (Journet 2013; Schwertmann 1993). Coastal soils were very sandy and often the natural color of the particles was darker (lower values) and sometimes fell within the criteria for a gley condition, though these soils have very different hydraulic conductivities than gleyed soils. The lower presence of iron oxide coatings in the soils of the Coastal region may be the reason why color chroma was not influenced by SWC. These soils were more susceptible to changes in SWC affecting the color value, but not to changes in environmental lighting.

Conclusions

The impact of SWC and light intensity on color assessment was documented for soils in three regions of South Carolina. Less differences in means of digital measurements for color value and chroma suggests that the digital method is more precise than visual observations when SWC is variable and by light intensity. Although of minimal significance, lower chromas and higher values were documented under lower PAR compared to those assessed under more intense PAR conditions. Soil evaluators often conduct field work in the early morning and late afternoon when temperatures are cooler. Soil color assessed under conditions that are less than ideal (early morning and late afternoon, cloudy skies, winter light) can impact soil use interpretations and should be considered with other information about the site and soil to make interpretations. The practical significance is from that visual and digital assessments were less than one color chip difference.

The digital unit can be a valuable tool under less than ideal lighting conditions, and in soil profiles with varying water contents (especially with soils with brighter and lighter goethite minerals) and for training purposes. However, further research on variations in natural lighting, including different wavelengths throughout the day and angles throughout the year is needed. The mineralogy of the soils within the regions likely influenced how much of an impact of light intensity and water content can have on soil color assessments, and thus assessment methods would need to be compared for soils of different mineralogy.

Tables and Figures

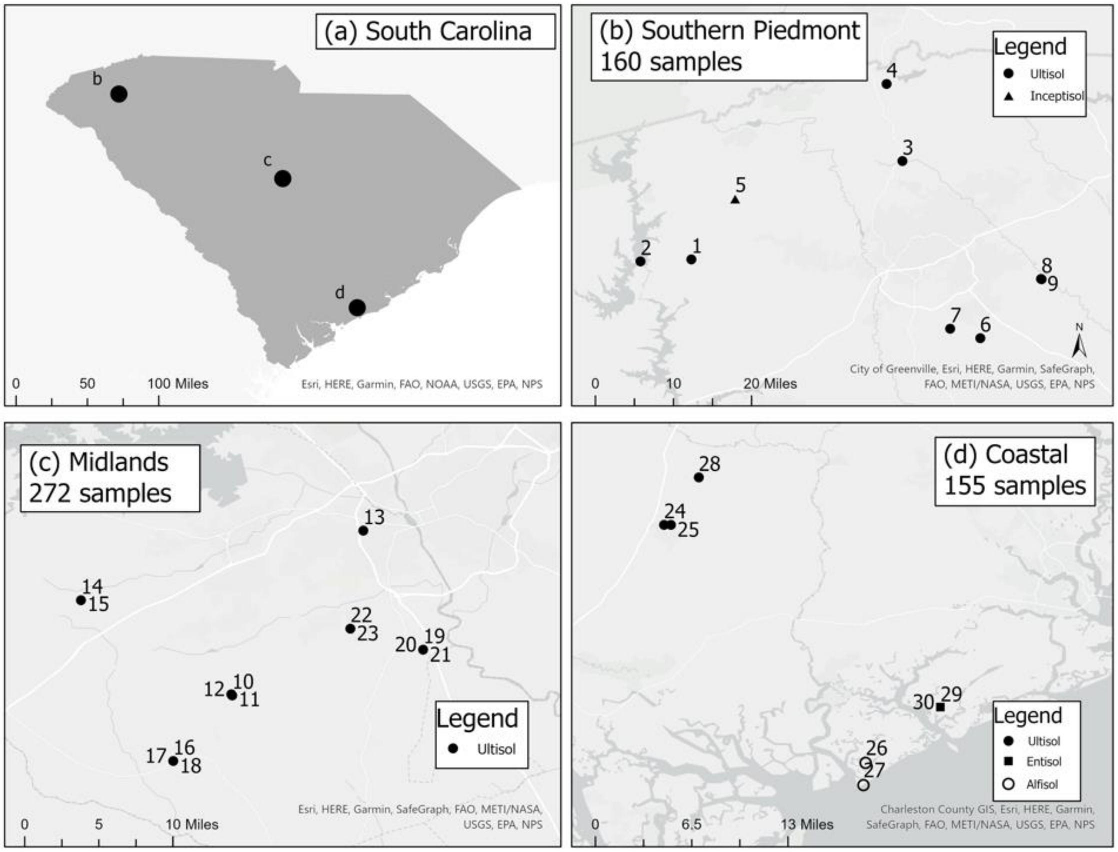
Table 2.1. Degrees of freedom (DF) and significance from Model source in ANOVA for color assessment and soil water content (SWC) and their interaction on Munsell color value and chroma.

Region		Value	Chroma
(a) Southern Piedmont	DF	Significance	
color assessment	1	<0.0001	0.1641
SWC	1	<0.0001	<0.0001
color assessment*SWC	1	0.0047	<0.0001
(b) Midlands			
color assessment	1	<0.0001	0.5355
SWC	1	<0.0001	<0.0001
color assessment*SWC	1	0.9511	0.0010
(c) Coastal Plain			
color assessment	1	<0.0001	0.9325
SWC	1	<0.0001	0.0063
color assessment*SWC	1	0.0145	0.3347

Table 2.2. Degrees of freedom (DF) and significance from Model source in ANOVA table for color assessment and PAR and their interaction for Munsell color value and chroma.

Region		Value	Chroma
(a) Southern Piedmont	DF	Significance	
Color assessment	1	0.0040	<0.0001
PAR	2	0.0548	0.9113
Color assessment* PAR	2	0.2560	0.8873
(b) Midlands			
Color assessment	1	<0.0001	0.0425
PAR	2	0.0007	0.0824
Color assessment* PAR	2	0.0970	0.2166
(c) Coastal			
Color assessment	1	0.0827	<0.0001
PAR	2	0.7844	0.5104
Color assessment* PAR	2	0.1914	0.1543

Figure 2.1. Site distribution of the three regions of South Carolina (in inlay map): (a) South Carolina (b) Southern Piedmont, (c) Midlands, and (d) Coastal. Within each region soil profiles (numbers) representing four soil orders were collected and soil color value and chroma were determined for each horizon.



Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS

City of Greenville, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS

Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS

Charleston County GIS, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS

Figure 2.2. Interaction effect of color assessment by soil water content for Munsell color value and chroma for samples collected in the Southern Piedmont (a and b), the Midlands (c and d), and the Coastal (e and f) regions of South Carolina. Bars are mean ± SE. Bars with the same letter are not significantly different within the region and Munsell color component.

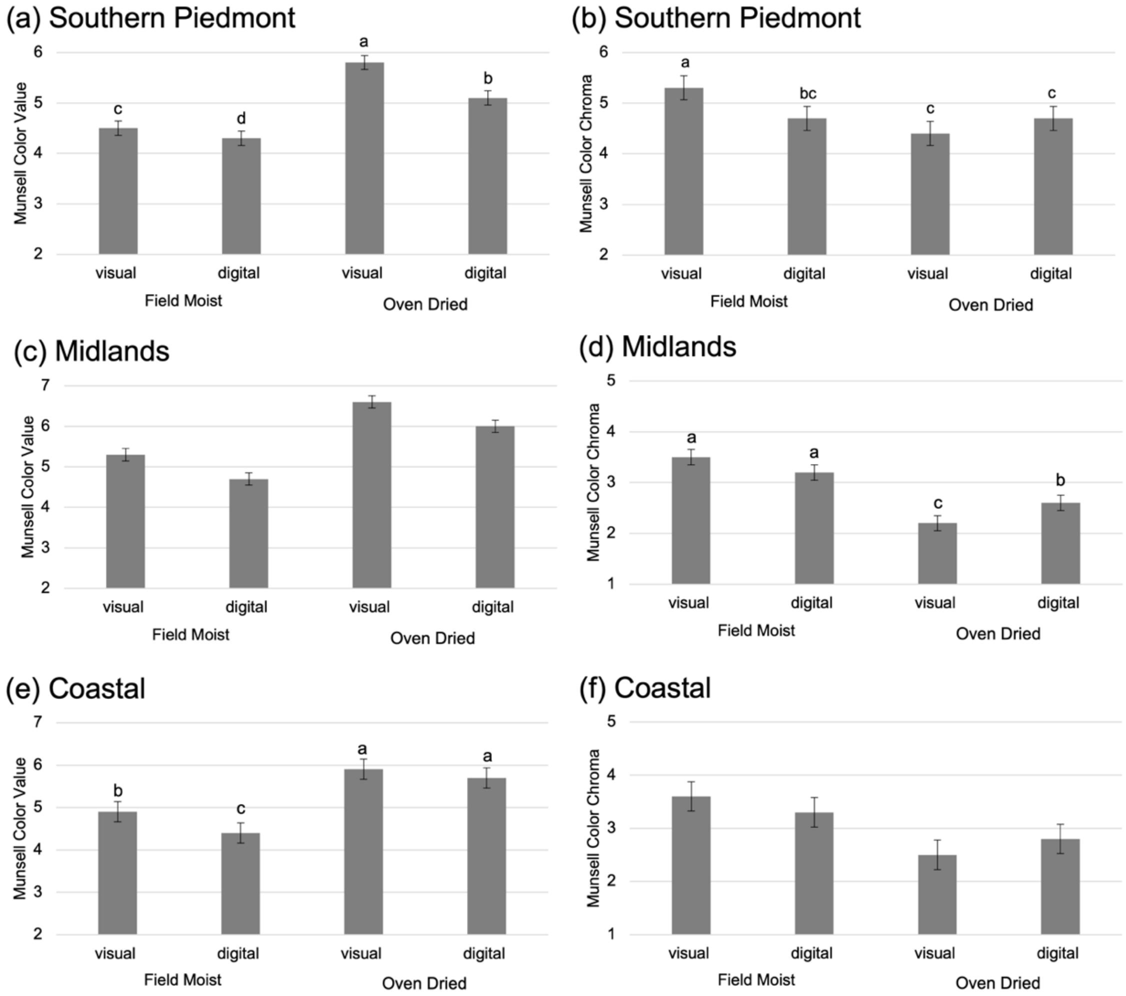
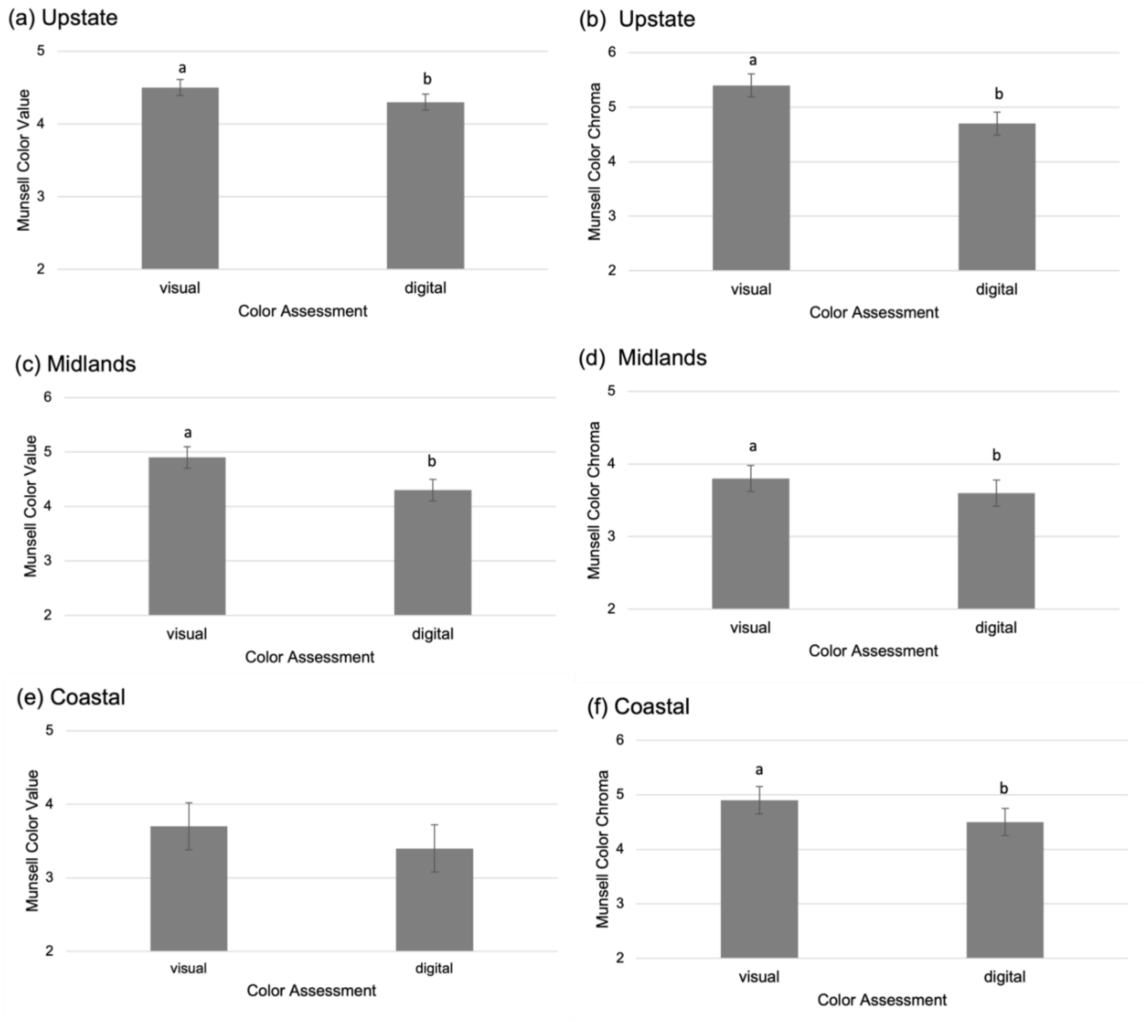


Figure 2.3 Bar charts for the effect of color assessment on Munsell color value (a, c, and e) and chroma (b, d, and f) for samples collected at the Southern Piedmont (a and b), the Midlands (c and d), and the Coastal (e and f) regions of South Carolina. Bars are mean ± SE. Bars with the same letter within region and color component are not significantly different.



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