Computers and Electronics in Agriculture 121 (2016) 141–148

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Evaluation of an inexpensive sensor to measure soil color

Roxanne Stiglitz [a], Elena Mikhailova [a,*], Christopher Post [a], Mark Schlautman [b], Julia Sharp [c]

[a] Department of Forestry and Environmental Conservation, Clemson University, Clemson, 29634 SC, USA
[b] Department of Environmental Engineering and Earth Sciences, Clemson University, Clemson, 29634 SC, USA
[c] Department of Mathematical Sciences, Clemson University, Clemson, 29634 SC, USA

ARTICLE INFO

Article history:
Received 31 July 2015
Received in revised form 28 November 2015
Accepted 30 November 2015
Available online 30 December 2015

Keywords:
Colorimetry
Iron
Munsell Color Chart
Soil color coordinates
Ultisols

ABSTRACT

Soil color determination can be subjective due to environmental conditions and human error. The objectives of this study were to examine the precision of a relatively inexpensive color sensor (Nix^{TM} Pro); to compare soil color measurements using this color sensor to human determination by soil science professionals using the standard Munsell Color Chart; and to compare the accuracy of this color sensor to a laboratory standard colorimeter (Konica Minolta CR-400). Sensor measurements were compared to the soil color chart by converting the Nix Pro values to Munsell soil color codes using BabelColor conversion software. Thirty-one Cecil (Fine, kaolinitic, thermic Typic Kanhapludults) soil samples were collected and tested for color. Munsell color codes were converted into cyan, magenta, yellow, and black (CMYK) color values, and the Nix sensor's scan results were tested against predetermined Munsell color values and colorimeter CMYK color values using correlation analysis for all treatments. Nix Pro Color Sensor was precise in soil color determination and it was more accurate than the Munsell Color Chart and comparable to the Konica Minolta CR-400 for both dry and moist soil. The Munsell Color Chart was accurate compared to the Konica Minolta CR-400 in dry soil, but it was less accurate in moist soil. The Nix Pro Color Sensor can be a successful tool to measure soil color in the standard Munsell color codes and this study presents a step-by-step method for converting sensor measurements to the standard Munsell color codes.

1. Introduction

Soil color is used in soil classification and the Munsell Color Chart is the standard method of color determination (Thompson et al., 2013). Munsell Color Charts allow users to identify soil colors ranging from reds to blues (Miller, 1958), and identify iron and humus content in the soil (Sugita and Marumo, 1996). However, limitations in using the Munsell Color Chart include: (1) user sensitivity (e.g. colorblindness, subjectivity) (Lusby et al., 2013; Mouazen et al., 2007), (2) environmental conditions (e.g. moisture content, lighting conditions) (Mouazen et al., 2007), and (3) difficult statistical analysis (e.g. limited color chips, cylindrical color coordinates) (Kirillova et al., 2014). These limitations have created a need for alternative methods of color analysis with fewer limitations, more precision and higher accuracy.

Sugita and Marumo (1996) tested how color alone can be used to differentiate between soils after each of the following treatments: air-drying, moistening, organic matter decomposition, iron oxide removal, and ashing. Removing organic matter and iron oxide produced the most distinguishable soil colors (97% of samples were distinguishable). The results showed that various treatments can help to distinguish the color between soil samples when using only the Munsell Color Chart making soil color analysis more accurate, and that color can be a robust indicator of organic matter and iron oxide levels in soil. However, because different regions have different soil properties, various other treatments may be necessary to accurately determine color. This method also eliminates the convenience of in-the-field color analysis that the Munsell Color Chart offers.

With the human eye being unreliable at color determinations (Thompson et al., 2013), other soil scientists have turned to spectrophotometers for determining soil color. In a study conducted by Shields et al. (1968), soil samples from Chernozemic and Podzolic soils in air-dried and field-capacity conditions were analyzed for color using the Munsell Color Chart and a Bausch and Lomb model Spectronic 600 laboratory spectrophotometer. The spectrophotometer results had low standard deviations showing that the spectrophotometer was more precise than the visual measurements using the Munsell Color Chart. Moisture also caused the Munsell color results to vary in hue more than expected. Spectrophotometers, therefore, do eliminate much of the human error

---

* Corresponding author at: Department of Forestry and Environmental Conservation, Clemson University, 261 Lehotsky Hall, Clemson, SC 29634, USA. Tel.: +1 864 656 3535; fax: +1 864 656 3304.

E-mail address: eleanam@clemson.edu (E. Mikhailova).

http://dx.doi.org/10.1016/j.compag.2015.11.014
0168-1699/

involved with color analysis of soil samples. The wide application of spectrophotometers to soil color determination has been limited because of their expensive cost and lack of portability making spectrophotometers an undesirable replacement for the Munsell Color Chart for quick analysis of a soil's color.

Aydemir et al. (2004) proposed a new method of soil analysis using color. In this method, a color image flatbed scanner was used to scan thin section soil samples. The results were then analyzed for soil micromorphology using the soil color processed by the Erdas Processing software. The researchers found that from 80% to 100% of the time, separation and identification of soil mineral, non-mineral, non-crystalline, and poorly crystalline components were successful. This method of color analysis to determine soil components shows promise for technologies in soil science. The flatbed scanner was successful in determining soil color and with analysis accompanied by software, it is possible to use color to determine many important soil qualities. However, this method of analysis is still limited to a laboratory setting in that scanners are not mobile and require a power source to function. Furthermore, it brings into question whether scanners of different types would perform just as well.

A recent study by Gomez-Robledo et al. (2013) tested the use of cell phone cameras to quantitatively determine soil color. A mobile app was developed for the experiment that would take photos of a soil sample and determine the red, green, and blue (RGB) color codes for the pixels that appeared the most in a cropped area of the photo. The resulting RGB color codes were converted to Munsell HVC and red, green, and blue coordinates (XYZ color codes) to compare to scans from a Konica Minolta 2600d spectrophotometer. The results showed that under controlled lighting conditions, the cell phone camera was more accurate at determining color than visual measurements with the Munsell Color Chart. A notable benefit to this method of color analysis is the convenience in mobility that it offers. With mobile devices becoming increasingly available to consumers, access to this technology would not be limited. Unfortunately, this type of analysis is camera specific and would require calibrations and testing on thousands of individual camera sensors which is not feasible. Furthermore, lighting conditions may not always be controlled during the use of the app creating more room for inconsistencies.

In a study by Meyer et al. (2004), unsupervised color indices and fuzzy clustering methods were observed to determine if accurate classification of plant, soil, and residue materials was possible using only digital images and the Image Processing and Fuzzy Logic Toolboxes in MATLAB®. Three different plant growth stages were recorded in 681 digital images taken with a Kodak Digital Science DC120 digital camera in automatic mode for best picture and red, green, and blue (RGB) separation. RGB color codes were chosen for this experiment because of the way the human eye perceives color through its 4% blue, 32% green, and 64% red cones, and because RGB can be mathematically converted to other color systems such as hue (H), saturation (S), and intensity (I). HSI could then be used to determine other color measurements such as excess green (ExG). The results showed that characterization accuracy increased with later growth stages of plants and with bare soils. More than 10% of an image needed to consist of plant pixel coverage for there to be enough color data for clustering. While the algorithms used during this experiment require further research to enable the software to more accurately characterize young growth plants and ground cover, there is promise in this new technology to advance soil and plant characterization through imaging software and the visible spectra.

O'Donnell et al. (2011) also took advantage of digital cameras and image analysis software in the hopes of characterizing soils redoximorphic features based on color. Under controlled conditions, a digital camera was used to capture images of exposed soil cores and the data was stored as RGB color values. The RGB values were then converted to 238 possible Munsell color notations using a minimum spectral distance algorithm. The standard methods of soil color analysis, Munsell Color Chart system, does not dictate how to incorporate Munsell notation into statistical analysis. Given that the Munsell notation does not bode well for statistical analysis, many scientists turn to converting color systems to, and from, Munsell notation which may introduce error. Others have previously noted the need for a statistical standard color system in soil science to accommodate analyses involving soil color (Kirillova et al., 2014).

The Munsell Color Chart has been widely applied to soil color determination because of its ease of use; however, color analysis should be precise and accurate as well. Ideally, a new method of color analysis would be easy to use, mobile, be relatively inexpensive, produce consistent and accurate results, and produce results that allow for easy statistical analysis. For these reasons, the objectives of this study were: (i) to examine the precision of a relatively inexpensive color sensor; (ii) to compare soil color measurements using this color sensor to human determination by soil science professionals using the standard Munsell Color Chart; and (iii) to compare the accuracy of this color sensor to a laboratory standard colorimeter.

2. Materials and methods

2.1. Study area

Soil samples for this study were collected at the Simpson Agricultural Experiment Station (Simpson Farm) near Pendleton, South Carolina. The Simpson Farm is used predominantly for research related to cattle operations (fescue in the spring and fall, Bermuda grass in the summer, and corn silage or winter annuals during winter) (http://www.clemson.edu/public/researchfarms/beef_cattle/). The soil series found on the study location include Cecil clay loam, Pacolet sandy loam, Cartecay–Chewacla complex, Hiwassee sandy loam, and Cecil sandy loam (websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx).

2.2. Sampling

Thirteen soil pits were excavated for the purpose of the 2014 Southeast Regional Collegiate Soils Contest, which was hosted by Clemson University at the Simpson Agricultural Station (Fig. 1; http://gis.clemson.edu/elena/SoutheastSoilContest.htm). These pits were also used to gather samples for the purpose of this experiment where thirty one samples from seven of the pits were chosen for analysis. Using the soil profiles described by Natural Resource Conservation Service (NRCS) staff for color before the competition, samples were collected from each horizon after the judging was completed. Soil samples were collected using a hand trowel to scoop soil from each horizon and the samples were then transferred to individual soil sample bags. After collection, the samples were analyzed at the Ag Service Lab using their standard operating procedures (http://www.clemson.edu/public/regulatory/ag_svc_lab/soil_testing/soil_procedures/index.html). The remaining soil from the samples was used for the color determinations associated with this study.

2.3. Laboratory analysis

Samples were characterized for texture (i.e., percent sand, silt, and clay) and classified based on the standard NRCS soil triangle (e.g., clay, clay loam, sandy loam, etc.). Each sample was oven dried, crumbled, and passed through a 2 mm sieve. The samples'