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™ 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.

© 2015 Elsevier B.V. All rights reserved.

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/© 2015 Elsevier B.V. All rights reserved.

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'

Fig. 1. Example of soil profile (out of 7 total soil profiles used in the study) for practice soil pit 2 used during 2014 Southeast Regional Collegiate Soils Contest (October 5–9, 2014).

total carbon percentages were also determined by the Ag Service Lab (Agricultural Service Laboratory, 2014; Table 1). The moist samples were previously analyzed by NRCS staff using the Munsell Soil Color Charts by using the consensus among three professional soil scientists. Dry soil color determination using the Munsell Soil Color chart was completed under laboratory conditions by one individual.

2.4. Color analysis using the Nix Pro Color Sensor

Soil samples were tested for color using a Nix™ Pro Color Sensor. The sensor is controlled wirelessly by any Android or Apple phone or tablet through Bluetooth and has its own light-emitting diode (LED) light source located within the concave base of the sensor about 1 cm above the field of view. The sensor produces scan results in various color system codes, such as RGB, XYZ, lightness (L^*), redness (a^*), and yellowness (b^*) (CIE$L^*a^*b^*$), and cyan, magenta, yellow, and black (CMYK). The sensor is also rechargeable, easily accessible because of its small size, can be recalibrated easily, and costs $349 (http://www.nixsensor.com).

Thirty-one soil samples were tested by placing the sensor on a small amount of each soil, about an inch in diameter, which was poured onto a plate. The surface of the sample was leveled to give the sensor a flat area to rest directly on and the "scan" option was selected. The base of the sensor, 1.5 cm in diameter, was completely covered by the soil sample, allowing no outside light to enter the scan area. Previous testing showed that there was no significant difference in color results when scanned in indoor or outdoor lighting conditions because of the sensor's LED light source, therefore each sample was scanned three times under both dry and moist soil conditions and the CMYK, XYZ, and CIE$L^*a^*b^*$ results

Table 1
Selected soil properties for practice soil pit 2.

Horizon	Lower depth (cm)	Texture	Sand (%)	Silt (%)	Clay (%)	OC (%)	pH in water	BS (%)	CEC (meq/100 g)	P (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	B (mg/kg)	Na (mg/kg)
Ap	11	SL	70	14	16	1.3	5.0	42	4.8	10.0	23	299	107	2.5	14	0.25	0.15	4.5
Bt1	28	SCL	58	14	28	0.4	5.6	39	3.9	1.5	14	207	100	0.5	4	0.30	0.10	5.5
Bt2	59	SC/SCL	52	12	36	0.3	5.6	35	3.3	1.0	9	186	77	0.4	3	0.20	0.10	5.0
Bt3	90+	SC/C	46	8	46	0.2	5.5	30	4.0	1.0	9	217	111	0.4	1	0.25	0.15	6.5

were averaged and recorded. The samples were moistened using a water dropper. Each sample only received enough drops of water to dampen the entire surface of the sample to the point of no more color change in the soil. CMYK was chosen to use for analysis because the Nix Pro Color Sensor does not produce Munsell HVC results. Furthermore, preliminary work was conducted using CMYK color codes so further work was continued with this method for consistency. CMYK color codes are also measured on a scale of 0–100 (for each color, cyan, magenta, yellow, and black) making statistical analysis simple.

2.5. Converting Munsell notation to CMYK percentage values

The Munsell values of each soil sample (NRCS measured moist samples from the pits, the laboratory dried samples, and the researcher determined moist and dry Munsell values) were converted to CMYK percentages using color converter software. The codes were first converted to RGB values using the BabelColor software (http://www.babelcolor.com/). The RGB values were then converted to CMYK percentage values using the Pipette software (www.sttmedia.com/pipette).

2.6. Konica Minolta CR-400 analysis of soil samples

A Konica Minolta CR-400 laboratory-grade colorimeter was used as the baseline color measurement device and produced color results in a variety of color formats including CIEL*a*b*, XYZ, and Munsell HVC color codes. The colorimeter was calibrated by scanning a standard white plate and manually entering the CIEL*a*b* color values predetermined for the plate. When using the Konica Minolta, the clear base of the sensor was placed on the surface of the soil sample. The surface only needed to be large enough to cover the 8-mm aperture of the sensor. The cost of the CR-400 model used in this experiment was approximately $5000 (http://sensing.konicaminolta.us/).

The thirty-one soil samples previously analyzed for color were scanned using the Konica Minolta. Dry soil samples were placed on a plate and scanned using the colorimeter three times for each soil sample. The results were recorded and averaged. The soil samples were then moistened using a water dropper to dampen the soil surface. Each sample was again scanned three times and the results recorded and averaged. The results were recorded in XYZ percentage color values for statistical comparison to the Nix Pro Color Sensor because the colorimeter did not produce CMYK percentage color values. To accommodate for this difference, the XYZ percentage color values recorded using the Konica Minolta CR-400 were converted to CMYK percentage color values using the Pipette software (www.sttmedia.com/pipette). The CIEL*a*b* color codes were also recorded for the thirty-one soil samples.

2.7. Converting CIEL*a*b* values to Munsell notation

The CIEL*a*b* color codes produced by the Nix Pro Color Sensor and Konica Minolta CR-400 and recorded for the thirty-one soil samples under dry and moist soil conditions were converted to Munsell Color Chart notation using the BabelColor color converter software (http://www.babelcolor.com/). For this step, CIEL*a*b* was chosen to convert to Munsell because only one color converter needed to be used, thus eliminating a step and reducing possible error. Using the BabelColor converter, the checkbox for CIEL*a*b* color input was selected and the "Compare" option was changed to "Convert." Next, the "Deck 2" option was selected for the output color code to allow for conversion results to be displayed in Munsell notation. The CIEL*a*b* color coordinates were input manually and the resulting Munsell notations were displayed automatically.

2.8. Statistical analysis

Once all scan results for the Nix Pro sensor and Konica Minolta CR-400 were recorded, all data were compared to examine statistical relationships among the three methods of color determination in dry and moist soil sample conditions using correlation analyses. All cyan (C%) values were measured as zero, therefore no statistical analyses could be conducted for cyan. Additionally, pairwise t-tests were conducted for each of the 31 soil samples between each of the pairs of sensors to examine differences between Nix Pro Color Sensor and Konica Minolta for wet and dry samples. A significance level of 0.05 was used for all tests. A Bonferroni correction was applied to control the familywise error rate in the multiple pairwise t-tests (adjusted significance level = 0.0016).

3. Results and discussion

3.1. Precision of color sensor in dry and moist soil

Replicate scans or sets were completed (where one sample was scanned three times to examine the reproducibility of the measurement) for dry and moist soil samples using the Nix Pro Color Sensor. The results were nearly identical to each other with strong, positive correlations (Fig. 2a and b). Significant positive correlations exist between Nix Pro Color Sensor scans for magenta (M%), yellow (Y%), or black (K%) in dry soil with correlation values from 0.92 to 1 (p-values <0.001). Nix Pro Color Sensor scans in moist soil also show significant positive correlations among the scans for magenta (M%), yellow (Y%), and black (K%) with correlation values larger than 0.98 (p-values <0.001).

The graphs in Fig. 2 illustrate that moisture does not appear to be an important variable with the Nix Pro Color Sensor as seen by the overall strong, positive correlations between the color results of the dry and moist soil. Only minor differences were observed between the color codes of dry and moist soil samples, mostly appearing in the graph for yellow (Y%) (Fig. 2c). Table 2 shows that there are significant positive correlations for Nix Pro Color Sensor between dry and moist soil for magenta (M%), yellow (Y%), or black (K%) with correlations of 0.96, 0.84, and 0.89 respectively, (all p-values <0.001). Past studies have shown that moisture can make a soil appear noticeably darker, increasing the hue of the soil (Shields et al., 1968).

3.2. Accuracy of color sensor compared to Munsell Color Chart

Table 3 shows that there is a significant positive correlation between the Munsell Color Chart and Nix Pro Color Sensor in dry soil for magenta (M%) with a correlation of 0.89 (p-value <0.001), in dry soil for yellow (Y%) with a correlation of 0.78 (p-value <0.001), and in dry soil for black (B%) with a correlation of 0.59 (p-value <0.001). There is a significant positive correlation between the Munsell Color Chart and Nix Pro Color Sensor in moist soil for magenta (M%) with a correlation of 0.51 (p-value = 0.003), in moist soil for yellow (Y%) with a correlation of 0.59 (p-value <0.001), and in moist soil for black (K%) with a correlation of 0.58 (p-value <0.001). Fig. 3a suggests that the Nix Pro Color Sensor is more consistent with the Munsell Color Chart in dry soils for magenta (M%) and yellow (Y%) than it is for black (K%), although a significant correlation still exists between the two for black (K%). There is a consistent moderately strong, positive correlation between the two color determination methods for all three color values (Fig. 3b).

3.3. Accuracy of color sensor compared to laboratory colorimeter

There is a significant positive correlation between the Nix Pro Color Sensor and Konica Minolta CR-400 in dry soil for magenta

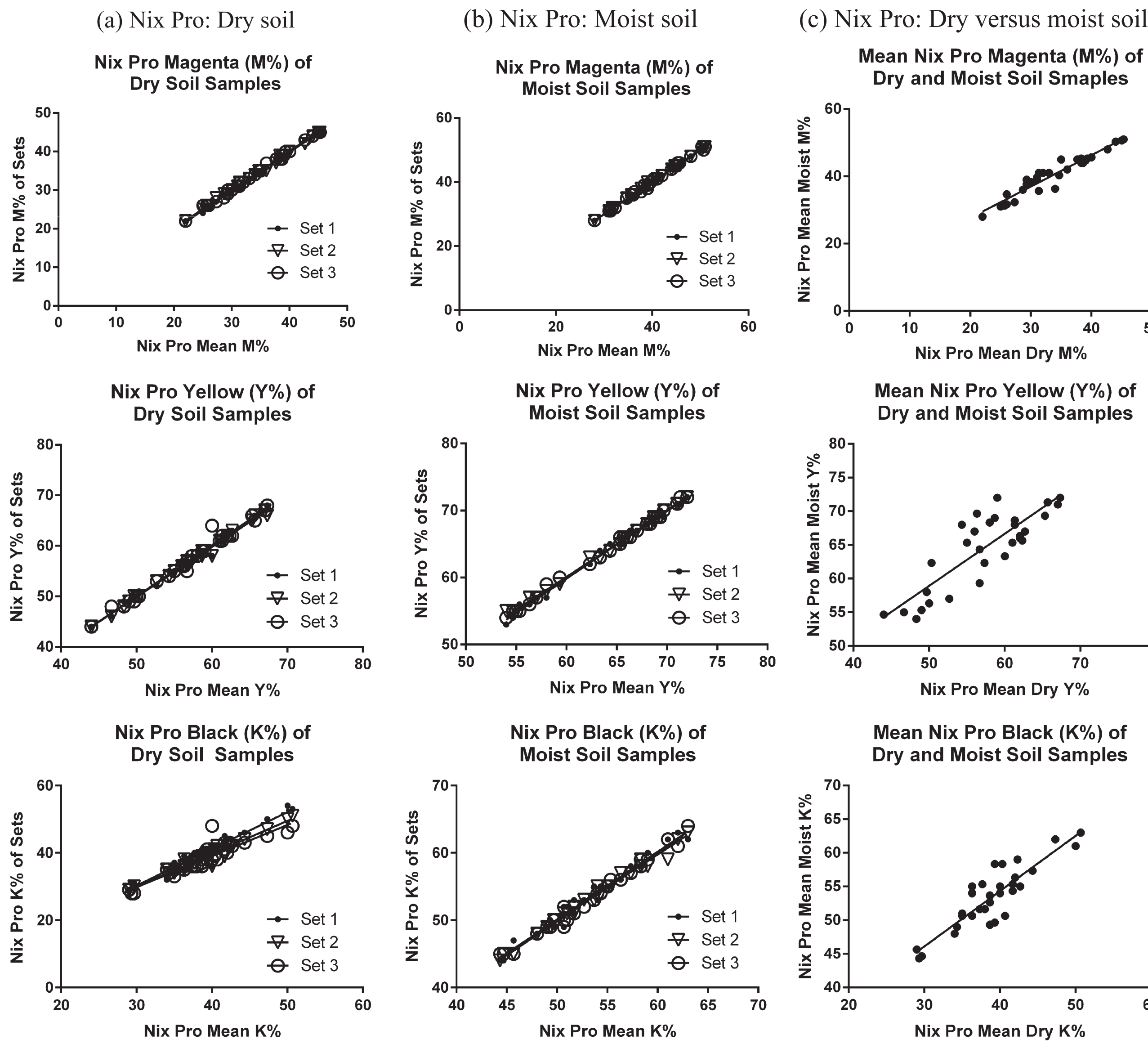

Fig. 2. Nix Pro Color Sensor CMYK color code means vs. Nix Pro Color Sensor CMYK scan sets in dry and moist soil and mean CMYK color codes in dry vs. moist soil (n = 31 soil samples for each set, corresponding correlation (r-value) and significance (p-value) data are reported in Tables 2 and 3).

Table 2
Correlation (r-value) between Nix Pro CMYK color codes: dry versus moist soil (n = 31 soil samples in each set, all p-values <0.001).

CMYK (color codes)	Mean moist magenta (M%)	Mean moist yellow (Y%)	Mean moist black (K%)
Mean dry magenta (M%)	0.96	–	–
Mean dry yellow (Y%)	–	0.84	–
Mean dry black (K%)	–	–	0.89

(M%) with a correlation of 0.93 (p-value <0.001), in dry soil for yellow (Y%) with a correlation of 0.97 (p-value <0.001), and in dry soil for black (K%) with a correlation of 0.45 (p-value = 0.011; Table 3). There is a significant positive correlation between the Nix Pro Color Sensor and Konica Minolta CR-400 in moist soil for magenta (M%) with a correlation of 0.96 (p-value <0.001), in moist soil for yellow (Y%) with a correlation of 0.71 (p-value <0.001), and in moist soil for black (K%) with a correlation of 0.8 (p-value <0.001).

The Nix Pro Color Sensor and Konica Minolta CR-400 are nearly identical in magenta (M%) and yellow (Y%) color values in dry and moist soil conditions and have a significant positive correlation for black (K%) in dry and moist soil conditions (Fig. 3a and b; Table 4). This suggests that the Nix Pro Color Sensor is accurate with respect to the laboratory standard colorimeter. These results were to be expected as sensors have proven to be accurate to other such devices in past studies (Gomez-Robledo et al., 2013).

A significant positive correlation between the Munsell Color Chart and Konica Minolta CR-400 in dry soil for magenta (M%) with a correlation of 0.8 (p-value <0.001), in dry soil for yellow (Y%) with a correlation of 0.72 (p-value <0.001), and in dry soil for black (K%) with a correlation of 0.36 (p-value = 0.047; Table 3). There is a significant positive correlation between the Munsell Color Chart and

Table 3
Correlation (*r*-value) between Munsell Color Chart, Nix Pro, and Konica Minolta CR-400: mean CMYK color codes in dry and moist soil ($n = 31$ soil samples in each set).

CMYK (color codes)	Munsell Chart	Nix Pro	Konica Minolta
Dry soil			
Magenta (M%)			
Munsell Chart	1	0.89*	0.8*
Nix Pro	0.89*	1	0.93*
Konica Minolta	0.8*	0.93*	1
Yellow (Y%)			
Munsell Chart	1	0.78*	0.72*
Nix Pro	0.78*	1	0.97*
Konica Minolta	0.72*	0.97*	1
Black (K%)			
Munsell Chart	1	0.52*	0.36**
Nix Pro	0.59*	1	0.45***
Konica Minolta	0.36**	0.45***	1
Moist soil			
Magenta (M%)			
Munsell Chart	1	0.51****	0.5*****
Nix Pro	0.51****	1	0.96*
Konica Minolta	0.5*****	0.96*	1
Yellow (Y%)			
Munsell Chart	1	0.59*	0.48******
Nix Pro	0.59*	1	0.71*
Konica Minolta	0.48******	0.71*	1
Black (K%)			
Munsell Chart	1	0.58*	0.48******
Nix Pro	0.58*	1	0.8*
Konica Minolta	0.48******	0.8*	1

* *p*-value <0.001.
** *p*-value = 0.047.
*** *p*-value = 0.011.
**** *p*-value = 0.003.
***** *p*-value = 0.004.
****** *p*-value = 0.006.

Konica Minolta CR-400 in moist soil for magenta (M%) with a correlation of 0.50 (*p*-value = 0.004), in moist soil for yellow (Y%) with a correlation of 0.48 (*p*-value = 0.006), and in moist soil for black (K %) with a correlation of 0.48 (*p*-value = 0.006).

The correlations between the Konica Minolta CR-400 and the Munsell Color Chart are similar to the correlations between the Nix Pro Color Sensor and Munsell Color Chart (Fig. 3a and b). This indicates that the Nix Pro Color Sensor has accuracy similar to the Konica Minolta CR-400 and would produce results more closely related to the Konica Minolta CR-400 than to those of the Munsell Color Chart. Given that the Munsell Color Chart is inaccurate (Kirillova et al., 2014), these results were also expected. However, it was expected that since the moist soil samples were analyzed for color by NRCS staff using the Munsell Color Chart that the moist soil color results would be more accurate to the colorimeter than the dry soil sample color results. The data suggest that the opposite is true, which may contribute to human error and user sensitivities when using the Munsell Color Chart for determining color (Kirillova et al., 2014).

A series of pairwise *t*-tests for sensor and colorimeter values in the CIE 1931 XYZ color space were conducted. Wet soil samples were compared for the average difference between the Nix Pro Color Sensor and the Konica Minolta for each of the 31 soil samples and found that 87% of *X* and *Y* soil samples had means that were not significantly different, while 90% of the *Z* channel soil sample means were not significantly different (i.e., 90% of the 31 null hypotheses were not rejected when comparing the means for the Nix Pro Color Sensor and the Konica Minolta). For dry samples, 87% of the *X*, 84% of the *Y*, and 87% of the *Z* channel samples means did not significantly differ between the Nix Pro Color Sensor and the Konica Minolta.

3.4. Converting CIEL*a*b* values to Munsell notation

Conversion results from the CIEL*a*b* color notation are demonstrated in Table 5. The results show that it is possible to convert Nix Pro and Konica Minolta CR-400 CIEL*a*b* color codes to Munsell HVC and produce similar results to those when using the Munsell Color Chart alone. For example, the Nix Pro sensor gave a complete match (i.e., same hue, value and chroma) for the dry Bt3 horizon, matched two of the three Munsell characteristics for the dry Ap and Bt1 horizons, and matched one of the three Munsell characteristics for the dry Bt2 horizon (Table 5). In general, conversion from the sensor measurements to Munsell color notation varied by only one or two chips in hue, value, or chroma. However, given that the Munsell Color Chart has a limited number of color chips, ideally the conversions should produce Munsell HVC codes more precisely.

Table 6 shows that when the Munsell color chips determined for moist soil samples were scanned using the Nix Pro color sensor and the subsequent color codes were converted back to Munsell, 64.5% of the results matched all three of the original Munsell color chips for hue, value and chroma. This complete match percentage dropped to 16.1% when comparing Munsell to Nix Pro scans of moist soil samples converted to Munsell notation and 0% complete match when comparing Munsell to Konica Minolta CR-400 scans of moist soil samples converted to Munsell notation. The Nix Pro scans of moist soil samples converted to Munsell matched two of the three Munsell characteristics 51.6% of the time. The Konica Minolta CR-400 scans of moist soil samples converted to Munsell notation values matched one Munsell characteristic 71% of the time.

Table 6 shows that when the Munsell color chips determined for dry soil samples were scanned using the Nix Pro color sensor and the subsequent color codes were converted back to Munsell, 64.5% of the results matched all three of the original Munsell color chips hue, value, and chroma. This complete match percentage dropped to 32.3% when comparing Munsell to Nix Pro scans of dry soil samples converted to Munsell notation and 0% complete match when comparing Munsell to Konica Minolta CR-400 scans of dry soil samples converted to Munsell notation. The Nix Pro scans of dry soil samples converted to Munsell matched one Munsell notation value for dry soil 41.9% of the time. The Konica Minolta CR-400 scans of dry soil samples converted to Munsell matched none of the Munsell notation values for dry soil 49.1% of the time.

4. Conclusions

The Nix Pro Color Sensor was repeatable based on significant positive correlations between scans when comparing sets of dry soil samples and for scans when comparing sets of moist samples. There were significant differences in color for scans for dry versus moist soil samples. Soil color is often measured at greater wavelengths when using spectrometers to account for the difference in soil color that can result from moisture in the soil (Alchanatis et al., 2006). Reported results show that the Nix Pro Color Sensor determined the true color of a soil sample regardless of moisture content based on significant positive correlations between Nix Pro Color Sensor scans for samples in dry and moist conditions.

Nix Pro Color Sensor observations were similar to the Konica Minolta CR-400 in both dry and moist soils based on strong positive correlations and statistical analysis between the two methods for both dry and moist soil. The Nix Pro Color Sensor may be a good alternative to the Munsell Color Chart in the color determination of a soil because its color values are more closely related to that of a

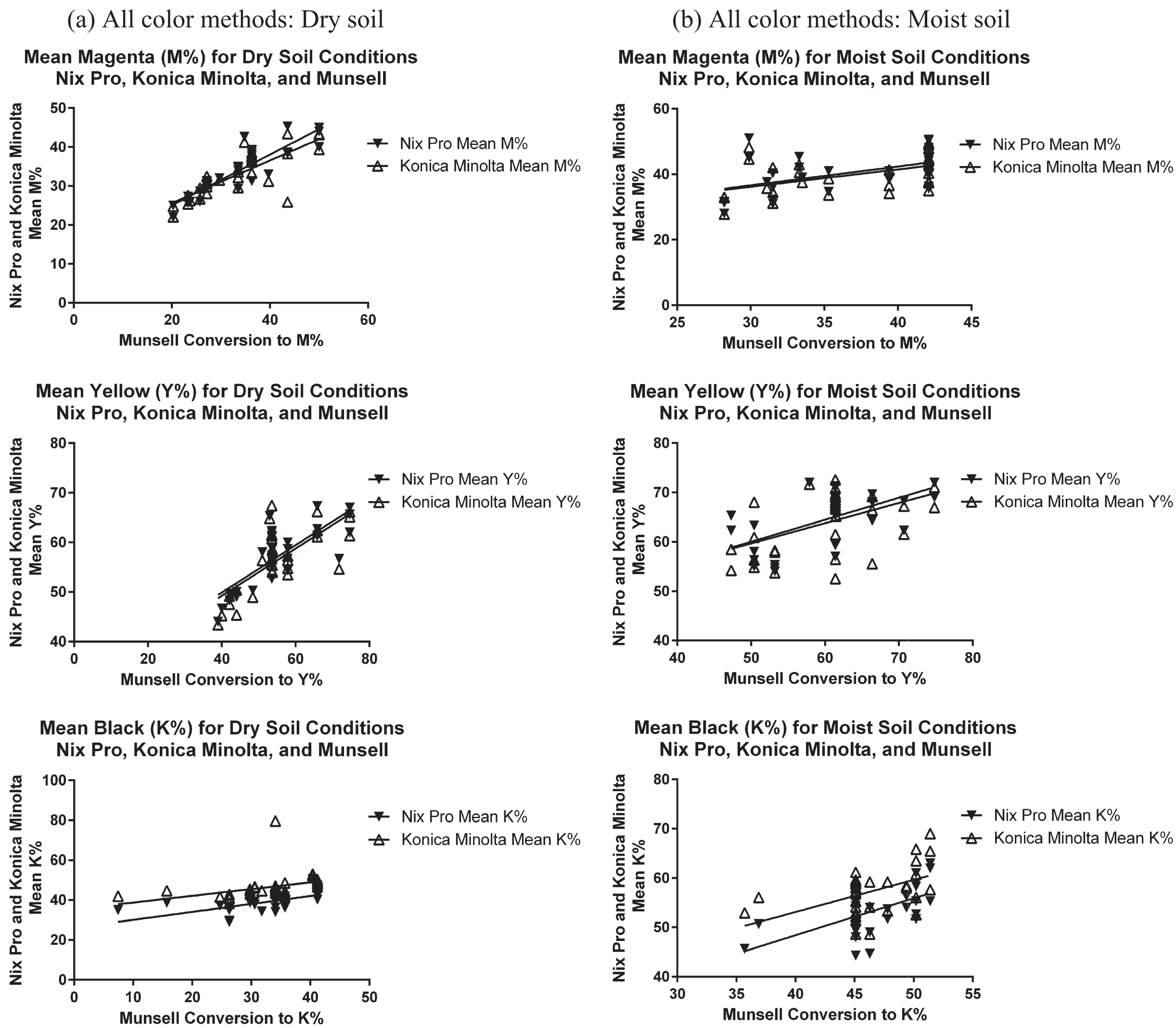

Fig. 3. Munsell Color Chart codes converted to CMYK color codes and compared to the Nix Pro Color Sensor CMYK color codes and Konica Minolta CR-400 conversion to CMYK color codes in dry and moist soil ($n = 31$ soil samples for each set; corresponding correlation (r-value) and significance (p-value) data are reported in Tables 2 and 3).

Table 4
Munsell Color Chart, Nix Pro Color Sensor, and Konica Minolta CR-400 color code mean (standard deviation) for each of the soil horizons of practice soil pit 2 in the CMYK (M = magenta, Y = yellow, K = black) codes.

Soil horizon	Lower depth (cm)	Munsell Color Chart (CMYK%) *n* = 3			Nix Pro Color Sensor (CMYK%) *n* = 3			Konica Minolta CR-400 (CMYK%) *n* = 3		
		M	Y	K	M	Y	K	M	Y	K
Dry soil										
Ap	11	24 (0)	43 (0.6)	33 (0)	25 (1)	47 (1.2)	39 (2.1)	25 (0.2)	45 (0.3)	46 (3.2)
Bt1	28	38 (0)	62 (0.6)	32 (0.6)	33 (0)	57 (0.6)	34 (0.6)	31 (1)	55 (0.2)	45 (0.4)
Bt2	59	29 (0.6)	55 (0)	28 (0.6)	31 (0)	55 (0)	35 (2)	31 (0.2)	54 (0.2)	41 (0.4)
Bt3	90+	32 (1.5)	50 (4.5)	35 (0.6)	35 (0)	59 (0.6)	38 (2)	34 (0.1)	56 (0.3)	42 (1.5)
Moist soil										
Ap	11	31 (0)	51 (0.6)	50 (0)	31 (0)	55 (0)	58 (0.6)	31 (0.6)	55 (0.8)	64 (0.2)
Bt1	28	36 (0)	60 (0.6)	46 (0)	41 (0)	64 (0.6)	49 (0)	41 (0.1)	69 (1.2)	59 (1)
Bt2	59	42 (0.6)	64 (0.6)	44 (0)	40 (0.6)	65 (0.6)	51 (1.5)	35 (0.3)	53 (0.9)	53 (0.4)
Bt3	90+	44 (0)	58 (0.6)	43 (0.6)	45 (0)	69 (0)	52 (1.2)	45 (0.6)	71 (1.3)	53 (0.2)

laboratory standard colorimeter, such as the Konica Minolta CR-400.

The various color systems available with the Nix Pro Color Sensor allow for a more convenient color comparisons than is available with the Munsell Color Chart. Many other areas of agricultural sciences are rapidly turning to portable sensors in the hopes of creating a practical and inexpensive method of on-site analysis for their crops and land (Sanchez et al., 2013). Other studies have

Table 5
Munsell Color Chart, Nix Pro Color Sensor, and Konica Minolta CR-400 color codes for each of the soil horizons of practice soil pit 2 in the Munsell Color Chart notation.

Soil horizon	Lower depth (cm)	Munsell Color Chart hue (H), value (V), chroma (C) $n = 1$			Nix Pro Color Sensor hue (H), value (V), chroma (C) $n = 3$			Konica Minolta CR-400 hue (H), value (V), chroma (C) $n = 3$		
		H	V	C	H	V	C	H	V	C
Dry soil										
Ap	11	7.5YR	6	4	7.5YR	5	4	10YR	5	4
Bt1	28	5YR	5	8	5YR	5	6	7.5YR	4	4
Bt2	59	7.5YR	6	6	5YR	5	6	10YR	5	4
Bt3	90+	5YR	5	6	5YR	5	6	5YR	5	6
Moist soil										
Ap	11	5YR	4	4	5YR	3	4	7.5YR	3	4
Bt1	28	5YR	4	6	2.5YR	4	6	5YR	3	6
Bt2	59	2.5YR	4	6	5YR	4	6	5YR	4	4
Bt3	90+	10YR	4	6	2.5YR	3	6	5YR	3	6

Note: Moist soil color was determined by NRCS soil scientists.

Table 6
Comparison of color matches (hue, value, chroma) between Munsell Color Chart, Nix Pro Color Sensor, and Konica Minolta CR-400 color.

Number of matches (hue, value, or chroma)	Munsell vs. Nix Pro Scans of Munsell chips (%)	Munsell vs. Nix Pro (%)	Munsell vs. Konica Minolta (%)
Moist soil			
Complete match	64.5	16.1	0
Two matched	29	51.6	16.1
One matched	0	25.8	71
No matches	6	6.5	12.9
Dry soil			
Complete match	64.5	32.3	0
Two matched	22.6	19.4	9.7
One matched	12.9	41.9	41.2
No matches	6	6.4	49.1

also shown that mobile devices are improving in analysis of soil morphology and that there is an increasing demand for "simple and inexpensive hardware" to be readily available (Aydemir et al., 2004).

Acknowledgments

Dr. Ksenija Gasic (Department of Plant and Environmental Sciences, Clemson University) provided access to the Konica Minolta CR-400 colorimeter. Clemson University – United States provided funding for this study; Technical Contribution No. 6304 of the Clemson University Experiment Station. This material is based upon work supported by NIFA/USDA, under Project number SC-1700452.

References

Agricultural Service Laboratory, 2014. Clemson University. <http://www.clemson.edu/public/regulatory/ag_svc_lab/index.html>.

Alchanatis, Victor, Ridel, Leonid, Hetzroni, Amots, Yaroslavsky, Leonid, 2006. Weed detection in multi-spectral images of cotton fields. Comput. Electron. Agric. 47 (June), 243–260.

Aydemir, S., Keskin, S., Drees, L.R., 2004. Quantification of soil features using digital image processing (DIP) techniques. Geoderma 119 (March), 1–8.

BabelColor, 2015. BabelColor: Color Measurement and Analysis. <http://www.babelcolor.com/>.

Gomez-Robledo, L., Lopez-Ruiz, N., Melgosa, M., Palma, A., Fermin Capitan-Vallvey, L., Sanchez-Maranon, M., 2013. Using the mobile phone as Munsell soil–colour sensor: an experiment under controlled illumination conditions. Comput. Electron. Agric. 99, 200–208.

Kirillova, N.P., Vodyanitskii, Yu.N., Sileva, T.M., 2014. Conversion of soil color parameters from the Munsell System to the CIE-L*a*b* System. Eurasian Soil Sci. 48 (5), 468–475.

Konica Minolta, 2015. Konica Minolta: Sensing Americas. <http://sensing.konicaminolta.us/>.

Lusby, F., Zieve, D., Black, B. (Eds.), 2013. May 7. Color Blindness. <http://www.ncbi.nlm.nih.gov/pubmedhealth/PMH0001997/>.

Meyer, George E., Neto, Joao Camargo, Jones, David D., Hindman, Timothy W., 2004. Intensified fuzzy clusters for classifying plant, soil, and residue regions of interest from color images. Comput. Electron. Agric. 42 (3), 161–180.

Miller, R., 1958. The Munsell System of color notation. Am. Soc. Mammal. 39, 278–286.

Mouazen, A., Karoui, R., Deckers, J., De Baerdemaeker, J., Ramon, H., 2007. Potential of visible and near-infrared spectroscopy to derive colour groups utilising the Munsell soil colour charts. Biosyst. Eng. 97, 131–143.

O'Donnell, T. Kevin, Goyne, Keith W., Miles, Randall J., Baffaut, Claire., Anderson, Stephen H., Sudduth, Kenneth A., 2011. Determination of representative elementary areas for soil redoximorphic features identified by digital image processing. Geoderma 161, 138–146.

Pipette, 2015. Stefan Trost Media: Software Solutions. <www.sttmedia.com/pipette>.

Sanchez, Maria-Teresa, De la Haba, Maria, Perez-Marin, Dolores, 2013. Internal and external quality assessment of mandarins on-tree and at harvest using a portable NIR spectrophotometer. Comput. Electron. Agric. 92 (March), 66–74.

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

Simpson Beef Cattle Farm, 2014. Clemson University. <http://www.clemson.edu/public/researchfarms/beef_cattle/>.

Southeast Soil Contest, 2014. Clemson University. <http://gis.clemson.edu/elena/SoutheastSoilContest.htm>.

Sugita, R., Marumo, Y., 1996. Validity of color examination for forensic soil identification. Forensic Sci. Int. 83, 201–210.

Thompson, J., Pollio, A., Turk, P., 2013. Comparison of Munsell Soil Color Charts and the GLOBE soil color book. Soil Sci. Soc. Am. 77 (March 25), 2089–2093.

Web Soil Survey, 2015. USDA. <websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx>.