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Identification and quantification of soil redoximorphic features by digital image processing

T. Kevin O'Donnell [a,*], Keith W. Goyne [a], Randall J. Miles [a], Claire Baffaut [b], Stephen H. Anderson [a], Kenneth A. Sudduth [b]

[a] Department of Soil, Environmental and Atmospheric Sciences, University of Missouri, Columbia, Missouri 65211, United States
[b] USDA – Agricultural Research Service, Cropping Systems and Water Quality Research Unit, Columbia, Missouri 65211, United States

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ABSTRACT

Soil redoximorphic features (SRFs) have provided scientists and land managers with insight into relative soil moisture for approximately 60 years. The overall objective of this study was to develop a new method of SRF identification and quantification from soil cores using a digital camera and image classification software. Additional objectives included a determination of soil moisture effects on quantified SRFs and image processing effects on interpretation of SRF metrics. Eighteen horizons from selected landscapes in the Central Claypan Area, northcentral Missouri, USA were photographed from exposed soil cores under controlled light conditions. A 20 cm^2 area was used for SRF quantification following a determination of the initial gravimetric water content of horizon faces. Overall color determination accuracy was 99.6% based on Munsell soil color groupings used for SRF identification. Rewetting of air-dry horizon faces by successive application of 1 mL of deionized water demonstrated little change in identified SRFs after seven applications. Mean change in identified Low Chroma and High Chroma SRFs between the seventh and tenth rewetting sequences was 2% (SD ± 4) and 0.03% (SD ± 0.3), respectively. However, ten of eighteen horizons contained a greater area of Low Chroma after ten rewetting sequences compared to the same horizon at the initial moisture state. Metrics characterizing SRF boundaries, shapes, number of SRFs, and mean area of SRFs were sensitive to post-classification image smoothing. Methods demonstrated by this study provide an opportunity to better integrate pedology with other related earth sciences by allowing standardized quantification of SRFs as well as a determination of human error associated with current visual estimates.

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1. Introduction

Color is the most cited attribute used for soil classification and land use decisions by people around the world (Barrera-Bassols and Zinck, 2003). Human perception of color is dependent on both a physical stimulus (e.g., reflected wavelengths striking receptors within the eye) and the processing of nerve impulses within the brain. The latter of these represents a subjective, psychological aspect of color perception that is dependent on an individual's color experiences and varies among multiple observers (Thompson, 1995). While color references have been adopted to aid in transfer of soil color knowledge (e.g., Munsell soil color charts), the lack of a standardized, objective color perception by humans remains a notable source of error when describing and classifying soils. Reliable land management decisions based on interpretations of soil color and color patterns (e.g., soil redoximorphic features) require accurate, concise measurements.

Soil redoximorphic features (SRFs) are micro- (surface and interiors of soil structural units) and macro-morphological (horizon and profile) features formed by oxidation-reduction chemical reactions mediated by microbes in association with saturated and anaerobic conditions within soil profiles and landscapes. Examples of SRFs include accumulations and depletions of Fe and/or Mn in soil profiles relative to the surrounding soil matrix (Schoeneberger et al., 2002). The identification of SRFs is typically performed in the field by color descriptions and has been relied upon by many hydrology and pedology investigations. Examples of SRF use include documenting wetland soil morphology (Blume and Schlicting, 1985), correlating soil water and oxygen content with soil color (Evans and Franzmeier, 1988), studying altered drainage effects on soil morphology (James and Fenton, 1993), correlating subsurface flow paths with soil color (Brouwer and Fitzpatrick, 2002), and documenting restrictive, subsurface horizon effects on hillslope hydrology (Calmon et al., 1998).

More recently, measured and predicted water table depths have been correlated with SRF estimates of presence and abundance made by human observers (Genthner et al., 1998; He et al., 2003; Morgan and Stolt, 2006). These findings suggest that SRF estimations made in the

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* Corresponding author. Tel.: +1 573 884 8533; fax: +1 573 884 5070.
E-mail address: tkot24@mail.mizzou.edu (T.K. O'Donnell).

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field by human observers can substitute for monitoring soil water regimes in legal designations of wetlands (Vepraskas and Caldwell, 2008a,b). However, imprecise measurements (e.g., lack of repeatable color recognition in the field by one or multiple observers), unknown accuracy (e.g., error associated with areal estimates), and undefined representative elementary areas (see VandenBygaart and Protz, 1999) remain. Increasing confidence in land management actions based on SRF interpretations requires more defendable methods for quantification.

Digital image processing techniques, often used in soil micromorphology, have provided useful tools for quantifying various soil attributes. A method for quantifying micromorphological features based on color was demonstrated by Protz et al. (1992). In this study, multi-channel images (e.g., red, green, and blue color values, hereafter RGB) of soil thin sections were used to quantify soil voids, organic material, mineralogy, and SRFs (Protz et al., 1992). Additional use of remote sensing software by Terribile and FitzPatrick (1992; 1995) demonstrated the usefulness of image classification algorithms for identifying and quantifying mineralogy from soil thin sections. Adderley et al. (2002) refined digital image processing of soil thin sections by converting RGB to Munsell colors to aid in feature interpretation. Aydemir et al. (2004) reexamined the use of remote sensing software and indicated that identification of mineralogy from soil thin sections by automated classification algorithms was very similar to manual, point-counting methods. Drawbacks to these methods include initial subjective decisions regarding color values that constitute particular morphologic/mineralogical features, time and equipment required to prepare soil thin sections, number of samples that can be processed, and limits on the areal size of samples analyzed.

Objective color determinations are possible and have been a focus of selected soil classification, mineralogy, and pedotransfer studies. Chromometers, spectrometers, and digital cameras have been used to accurately determine Munsell and RGB color values (Fernandez and Schulze, 1987), examine moisture effects on soil color (Shields et al., 1968), document accuracy of soil color descriptions (Cooper, 1990; Post et al., 1993; Shields et al., 1966), examine iron oxide contents of soils (Levin et al., 2005), and predict soil organic matter content (Kirshnan et al., 1980; Sudduth and Hummel, 1991; Viscarra Rossel et al., 2008). However, these studies have relied on disturbed (e.g., sieved) soil samples, prohibiting the quantification of color patterns formed *in situ*.

The use of digital cameras to objectively identify pedon color has been recently attempted. van Huyssteen et al. (2006b) demonstrated the use of digital camera and digital image analysis to quantify soil color from 10 excavated soil pits. The authors documented disagreement between visually interpreted colors and colors determined from digital image processing. Validation of this methodology showed only one Munsell Hue (i.e., 7.5YR) was accurately reproduced by digital image capture (van Huyssteen et al., 2006a), thus limiting the extension of this method to the continuum of soil colors often observed. Additionally, image analysis did not objectively discriminate SRFs from the matrix soil color during image processing and could not quantify potential error due to varying light conditions and camera setup among soil pits (van Huyssteen et al., 2006b).

Increased use of soil morphology for predicting hydrology at the soil profile and landscape scales, quantitative methods used in soil micromorphology, and various soil color measurement devices motivate the development of new SRF identification and quantification methods. Such a method can simultaneously advance emerging, interdisciplinary sciences relying on soil morphology. For example, Hydropedology seeks to better link pedology, soil physics, and hydrology through use of quantitative hydromorphological data (Lin, 2003; Lin et al., 2008). Moving from descriptive pedological studies and soil profile descriptions to a more quantitative science is needed, resulting in data more amenable to statistical testing and pedotransfer functions. This advance will promote more holistic studies of soil by integrating quantitative data already produced by the fields mentioned above and many other related earth sciences (e.g., ecology and geology).

This purpose of this study is to demonstrate the usefulness of readily available digital camera equipment and remote sensing software to the field of pedology. The overall objective of this research is to develop and document standardized SRF identification by color from soil cores under controlled light conditions through supervised image classification. The use of soil cores, as opposed to soil thin sections or soil pits, is highlighted to demonstrate a less destructive and more time efficient method of obtaining quantitative, morphological measurements of SRFs formed *in situ*. Additional objectives are to quantify accuracy of this image classification approach and the effects of moisture and post-classification image processing on selected SRF metrics.

2. Materials and methods

2.1. Study area and soil sampling

Two study sites were selected, Field 1 and 2, located within 2 km of Centralia, MO, USA (39° 13′ 58″ N, 92° 07′ 57″ W). Study sites and soil core locations were chosen to match locations with existing order one soil surveys and previous soil characterization data. Each field is managed for grain production and has been cropped using a corn–soybean rotation with minimum tillage (Field 1) and no-tillage (Field 2). Additional site history, management practices, conservation measures, and geomorphic setting is detailed by Kitchen et al. (2005), Lerch et al. (2005), and Myers et al. (2007).

Soil series described at these sites included Putnam and Adco (fine, smectitic, mesic Vertic Albaqualf) as well as Mexico and Leonard (fine, smectitic, mesic Vertic Epiaqualf). Cummulic Mollisols (Argialbolls) were also identified at each site. Soils described at the two study sites form a succession of summit (Putnam, Adco), shoulder (Mexico), backslope (Leonard), and footslope (Argialbolls) landscape positions. This soil catena is typical of the northcentral Missouri Claypan Region (Myers et al., 2007). Examples of SRFs identified for these soil series include Fe and Mn concentrations, depletions, and concretions (USDA-NRCS, 1995). Three soil series (Putnam, Mexico, and Leonard) meet criteria for designation as a likely hydric soil (USDA-NRCS, 2009). Seasonal perched water tables and lateral flow above a large clay content argillic horizon (i.e., claypan) have been observed for these soils (Blanco-Canqui et al., 2002; Jamison and Peters, 1967).

We extracted 8-cm diameter, 120-cm long soil cores on 31 Oct., 2008 and 1 Nov., 2008 from the two study sites. A total of six cores, three from each study site, were used in this study (Table 1). Soil cores were stored in capped polyethylene terepthalate glycol plastic tubing, transported to a controlled temperature room within 8 h of collection, and stored at 0 °C. Soil cores were removed from storage 24 h prior to core preparation and image capture.

2.2. Core preparation and image capture

A total of 18 horizons (3 horizons per core) were chosen for analysis to capture a range of horizon designations, depths, and textural classes (Table 1). Each horizon was prepared for digital photography separately. Soil cores were cut into 23-cm long segments and manually split lengthwise along structural voids, avoiding contact and smearing of exposed ped faces. This preparation produced two exposed horizon faces (Fig. 1). Prior horizon designations for the study sites were confirmed following splitting of cores. An initial gravimetric water content of one horizon face was determined for each core by collecting 1 to 2 g of soil, avoiding the central portion of the exposed face used for image capture (Fig. 1). The remaining horizon face was allowed to air-dry, followed by a determination of gravimetric water content using the methods specified above.

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