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Raster sampling of soil profiles

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A R T I C L E I N F O

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A B S T R A C T

Three soil profiles in Wisconsin, USA, were sampled using a 10 × 10 cm raster: a Mollisol (1 × 1 m), Alfisol (1 × 1 m), and Entisol (1 × 0.5 m). The soils were described in the field, and samples were taken from the center of each cell. Soil organic carbon concentration, texture, and color were measured and used to revise field-delineated horizons and their boundaries. Using soil texture, an Eb horizon was identified on the raster maps in the upper part of the field-delineated Btb horizon of the Mollisol. Soil color, soil texture, and Ti showed little lateral variation. The pH tended to vary the most laterally. The raster method characterizes soil profiles in two dimensions and can be used to quantify lateral variation and improve field delineation of soil horizons.

1. Introduction

Soils are heterogeneous, complicating soil description. Soil scientists characterize a soil profile by dividing the profile into horizons based on properties observed in the field. These properties generally include color, texture, and structure. After horizon delineation, one soil sample is taken from each horizon for laboratory analysis. As a result, only the vertical variation of a soil profile is measured.

However, lateral variation of soil profiles and their three-dimensional counterparts, pedons, can occur within short distances. Various studies have found considerable lateral variation of soil chemical and physical properties within a single pedon (e.g. Raupach, 1951; Patterson and Wall, 1982; Stolt et al., 1993). In some cases, more than one soil order may be found within 2 m (e.g. Phillips, 1993).

The field delineation of soil horizons can be problematic. Field observations are generally qualitative or semi-quantitative, and horizon differentiation requires decisions that are based on pedological experience (e.g. Schelling, 1970; Arkley, 1976; Hartemink and Minasny, 2014). Discontinuous or thin horizons may be overlooked (Boone et al., 1999).

In this study, we used the raster method as a soil profile research tool. A raster contains equally spaced data points (Goodchild, 1992) and is commonly used in digital soil mapping (McBratney and Minasny, 2003). Few studies have used rasters to study spatial variation of soil properties in a soil profile (Davis et al., 1995; Schwen et al., 2014; Adhikari et al., 2016; Zhang and Hartemink, 2017). A raster of 10 × 10 cm squares was used to study three soil profiles: an Alfisol (1 × 1 m), Mollisol (1 × 1 m), and Entisol (1 × 0.5 m). Specifically, this research aimed to use raster data to: (i) evaluate the field-delineation of horizons, (ii) examine the spatial distribution of soil properties in two dimensions, and (iii) quantify soil property variation horizontally within 1 m.

2. Materials and methods

2.1. The sites

Three soils in Wisconsin, USA were studied: an Alfisol, Mollisol, and Entisol. These soils were described in detail by Grauer-Gray and Hartemink (2016). The Alfisol was a fine-silty over clayey, mixed, superactive, mesic Typic Hapludalfs (NewGlarus silt loam series) formed in loess over a mixture of sand, clay, and glauconite derived from the underlying bedrock. The Alfisol was located in the Driftless Area (latitude 43°2′0.71″ N, longitude 90°3′2.77″ W) at 320 m above sea level (m.a.s.l.). The soil occurred on a 6% slope in the shoulder position. The area has a mean annual temperature of 7.4 °C and a mean annual precipitation of 860 mm. Five horizons were delineated in the field with three occurring in the upper 100 cm (Table 1). The upper two (Ap, Bt) horizons formed in loess while the lower (2Bw, 2Bt, Cr) horizons formed in weathering products from the underlying bedrock.

The Mollisol was a fine-loamy, mixed, superactive, mesic Pachic Argiudolls formed in loess over outwash (Troxel silt loam series) and was located in Dane County (latitude 43°4′2.88″ N, longitude 89°32′8.10″ W) at 330 m.a.s.l. The area has a mean annual temperature of 7.8 °C and a mean annual precipitation of 840 mm. The soil occurred at the footslope position, and contained a buried A horizon at 59 cm due to sedimentation of soil eroded from upper parts of the soilscape. Redoximorphic features occurred at 77^+ cm. Five horizons were

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Table 1
Profile characteristics of the Alfisol (fine-silty over clayey, mixed, superactive, mesic Typic Hapludalfs), the Mollisol (fine-loamy, mixed superactive mesic Pachic Argiudolls), and the Entisol (a mixed, mesic Typic Udipsamments) in Wisconsin, USA.

Soil	Horizon	Depth (cm)	Moist color	Structure	Sand	Silt (g/kg)	Clay	Texture class
Alfisol	Ap	0–20	Very dark grayish brown (10YR 3/2)	Granular, subangular blocky	124	653	224	Silt loam
	Bt	20–68	Dark yellowish brown (10YR 4/4)	Subangular blocky	189	546	266	Silt loam
	2Bw	68–125	Strong brown (7.5YR 4.5/7)	Subangular blocky	691	68	241	Sandy clay loam
Mollisol	Ap1	0–18	Very dark brown (10YR 2/2)	Granular	129	665	206	Silt
	Ap2	18–39	Very dark brown (10YR 2/2)	Platy	114	665	221	Silt loam
	A2	39–59	Very dark brown (10YR 2/2)	Subangular blocky	91	657	252	Silt loam
	Ab	59–77	Black (10YR 2/1)	Subangular blocky	105	645	250	Silt loam
	Btb	77 +	Dark yellowish brown (10YR 3/4)	Angular blocky	101	625	274	Silty clay loam
Entisol	Ap	0–24	Very dark brown (10YR 2/2)	Granular	874	59	67	Loamy sand
	Bw1	24–55	Dark yellowish brown (10YR 4/6)	Structureless	930	27	43	Sand

distinguished to 100 cm depth.

The Entisol was a mixed, mesic Typic Udipsamments (Plainfield sand series) formed in sandy glacial outwash, mainly deposited by Glacial Lake Wisconsin. The Entisol was located in the Central Sands (latitude 43°54′30.6” N, longitude 89°40′47.0″ W) at 310 m.a.s.l. The area has a mean annual temperature of 7.3 °C and a mean annual precipitation of 870 mm. The soil occurred on a flat plain (0% slope). Four horizons were delineated in the field, with two occurring at 0–50 cm depth.

2.2. Soil sampling and analysis

The soil profile walls of the Alfisol and the Mollisol were divided into a 1 × 1 m raster of 10 × 10 cm squares to 1 m depth (Fig. 1). The soil profile wall of the Entisol was divided into a 1 × 0.5 m raster of 10 × 10 cm squares to 0.5 m depth. Soil samples were collected from the center of each raster square. Bulk density samples were taken from each depth interval, with a single (250 mL) sample taken in the Alfisol and multiple (100 mL) samples taken in the Mollisol ($n = 2$) and the Entisol ($n = 3$).

The soil samples (~200 g) were air-dried. Dry and moist color measurements were taken using Munsell soil color charts. Samples were finely ground to approximately 2 mm. Elemental metal content was measured using portable X-ray fluorescence (pXRF) with a Delta Professional pXRF Analyzer (Olympus Scientific Solutions Americas, Inc.) that was calibrated with a 316 stainless steel reference coin. Soil organic carbon (SOC) was measured with a Flash EA 1112 Series NC Soil Analyzer (Thermo Electron Corporation). Soil reaction (pH) was measured in 1:1 soil to water with an Oakton pH/CON 510 Series meter (Vernon Hills, IL, USA). Texture was determined using the hydrometer method (Bouyoucos, 1962). We digitally obtained the soil color of air-dried, ground samples using a flatbed scanner (Epson Perfection 4870 Photo) and image editing software (Adobe Photoshop CC). Our development of this method was motivated by literature on obtaining soil color digitally using smartphones (Gomez-Robledo et al., 2013) and digital cameras (Gregory et al., 2006; Viscarra Rossel et al., 2008; Hafizah and Khairunniza, 2011). We drew from the aforementioned articles and an article in which a flatbed scanner was used to digitally obtain the color of rock powders (Kemp, 2014) in order to develop the following method. Images of the soil samples were obtained using the flatbed scanner. The soil was placed in a ring on top of a clear transparency protecting the scanner bed and gently tamped to minimize microtopography. The soil was scanned in the dark without the scanner cover. The scans were done in 24-bit color at 600 dpi.

The RGB values of the scanned soil samples were obtained using Adobe Photoshop CC (Adobe Systems Incorporated). A circular sample of 1200 ± 5 px in the middle of the scanned soil sample was selected. An average color blur was implemented on the sample, a point sample was taken from within this blur, and the RGB values were recorded. The RGB color was converted to HSV color in the R statistical package (R Core Team, 2016). HSV color spaces are transformations of RGB color spaces, which describe color using three color coordinates: Hue (H), Saturation (S), and Value (V) (Smith, 1978).

2.3. Data analysis

Bulk densities were averaged to calculate the bulk density of the Mollisol and Entisol depth intervals. Statistics of properties by depth and by horizon were calculated using the *doBy* package (Højsgaard et al., 2014) within the R statistical package (R Core Team, 2016). Coefficients of variation (CVs) by depth were calculated by dividing the standard deviation (SD) by the mean. As CVs are only valid for ratio variables (Webster, 2001), pH was back-transformed to H^+ concentrations and CVs were calculated for the H^+ concentrations. CVs

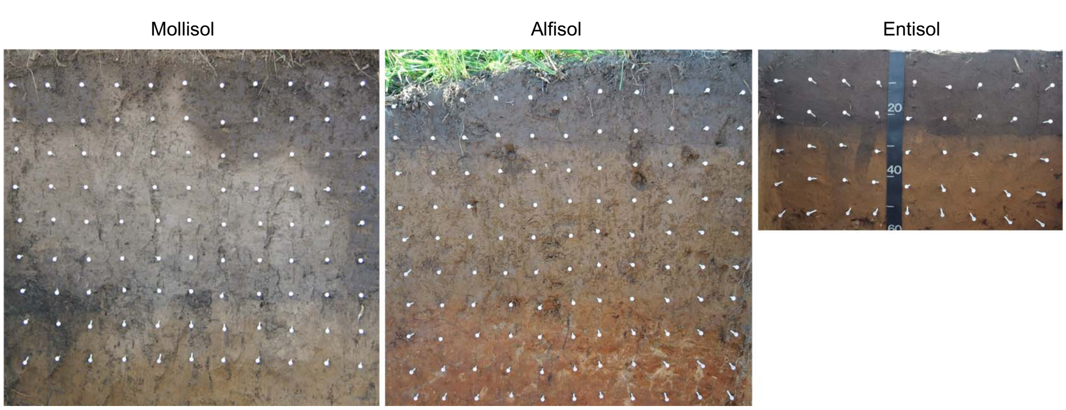

Fig. 1. Soil profiles rastered for field measurements and soil sampling (10 × 10 cm). The Mollisol and the Alfisol were sampled to 100 cm depth, and the Entisol was sampled to 50 cm depth.