DEPARTMENT OF SOIL SCIENCE
University of Wisconsin-Madison

FD Hole Soils Lab

digitalsoilmorphometrics

Spectra-informed soil profile characterization and soil classification

Yakun Zhang

October 21, 2021

Soil observation

- Fundamental in soil science
- Quantify soil properties and variation in soil profiles
- Understand soil genesis over time and biogeochemical processes
- Provide a guidance for land users

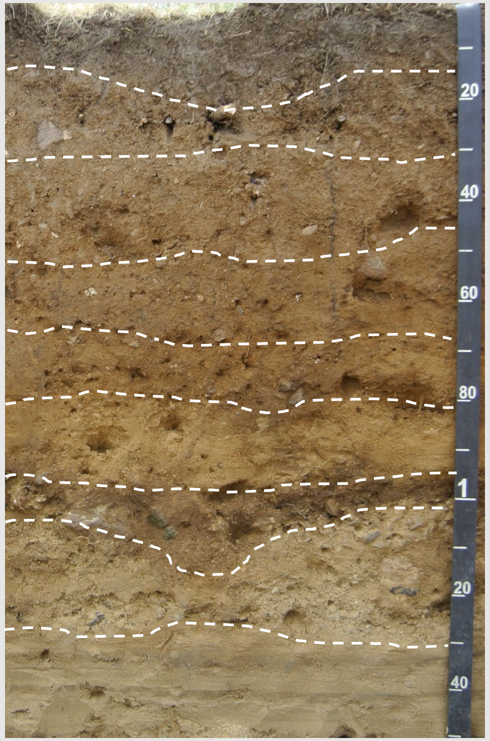
Soil profiles and soil horizons

Alfisol

Inceptisol

Alfisol

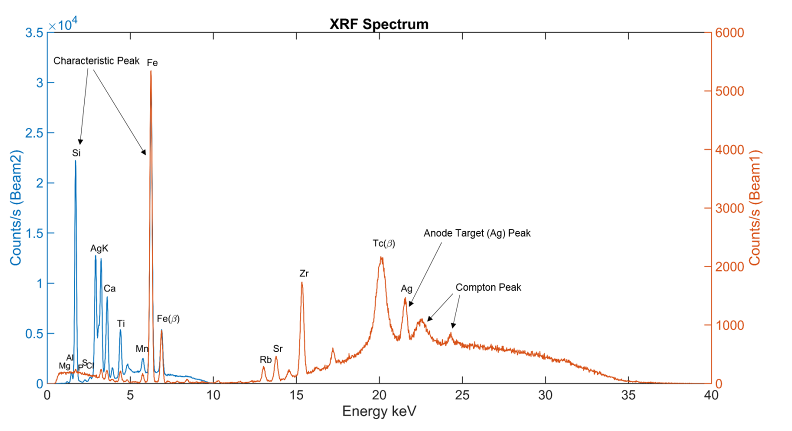
Alfisol

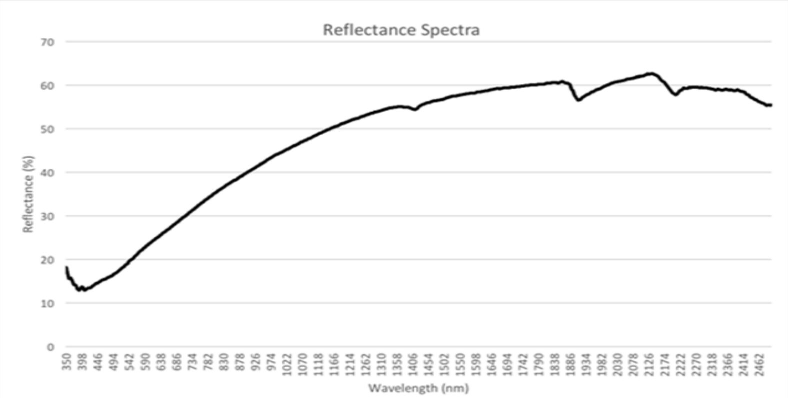


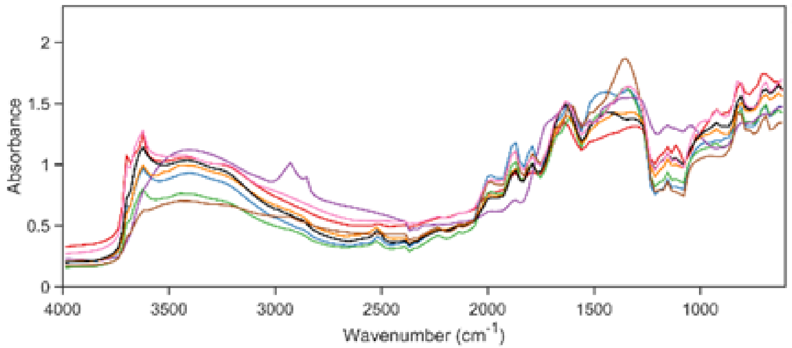
- Differences in color, texture, structure, mottles, coarse fragments, pores, roots
- Horizon delineation requires pedological experience and may vary among different observers
- Difference in splitters and lumpers

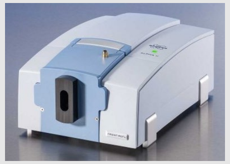
Spectroscopy techniques

- Portable X-ray fluorescence (pXRF) spectroscopy:
  - pXRF spectra
  - Elemental concentrations (Mg, Al, Si, Fe, Ca, Ti, Mn, Zn, Rb, Sr, and Zr)
- Visible near-infrared (vis-NIR) spectroscopy:
  - Spectral range: 350– 2,500 nm
- Mid infrared (MIR) spectroscopy:
  - Spectral range: 2,500 – 25,000 nm (4,000 – 400 cm^{-1})









Objective

- To evaluate the use of spectroscopic techniques to quantitatively and objectively delineate soil horizons

- Three case studies

Catena 180 (2019) 298–308

Contents lists available at ScienceDirect

Catena

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

ELSEVIER

CATENA

Soil horizon delineation using vis-NIR and pXRF data

Yakun Zhang, Alfred E. Hartemink*

University of Wisconsin-Madison, Department of Soil Science, FD Hole Soils lab, 1525 Observatory Drive, Madison, WI

Geoderma 343 (2019) 97–115

Contents lists available at ScienceDirect

Geoderma

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

ELSEVIER

GEODERMA

A method for automated soil horizon delineation using digital images

Yakun Zhang, Alfred E. Hartemink*

University of Wisconsin-Madison, Department of Soil Science, FD Hole Soils Lab, 1525 Observatory Drive, Madison, WI 53706, USA

Geoderma 389 (2021) 114961

Contents lists available at ScienceDirect

Geoderma

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

ELSEVIER

GEODERMA

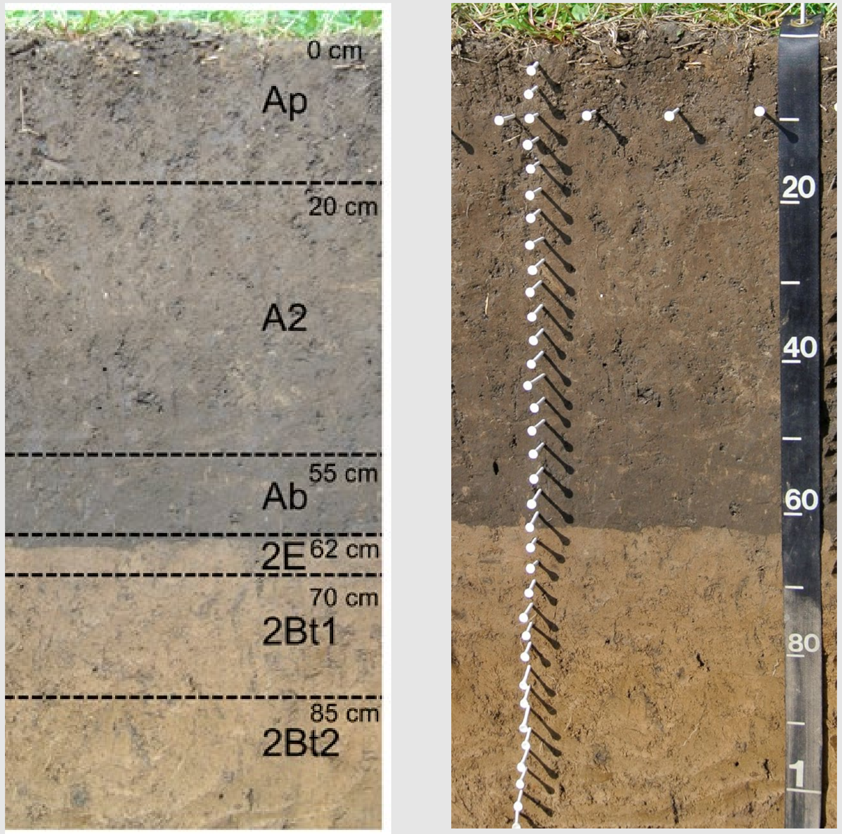
Spectral signatures of soil horizons and soil orders – An exploratory study of 270 soil profiles

Yakun Zhang*, Alfred E. Hartemink, Jingyi Huang

University of Wisconsin-Madison, Department of Soil Science, 1525 Observatory Drive, Madison, WI 53706, USA

1. Horizonation using pXRF + vis-NIR data

(a) (b)



- Mollisol profile in Wisconsin, USA
- Formed in Loess over glacial outwash

Mollisol
(A vertical transect)
↓
Scanning
(moist conditions, 3-cm depth interval)
↙ ↘
Vis-NIR spectra | XRF elements
↓ ↓
CIE $L^*a^*b^*$ color | Weathering indices

Interpolation

- 1 cm interval from 0 to 100 cm
- Equal-area quadratic spline with λ = 1

↓
Fuzzy clustering

- Cluster number: 4
- Membership exponent:1.5

↓
Digital gradient

- CIE $L^*a^*b^*$ color

  L^* – lightness

  a^* – red to green

  b^* – yellow to blue

- Weathering indices

  Ruxton index (R): $\frac{SiO_2}{Al_2O_3}$

  Sesquioxide ratio (Saf): $\frac{Si}{Al+Fe}$

  Calcium/Titanium ratio (CTR): $\frac{CaO}{TiO_2}$

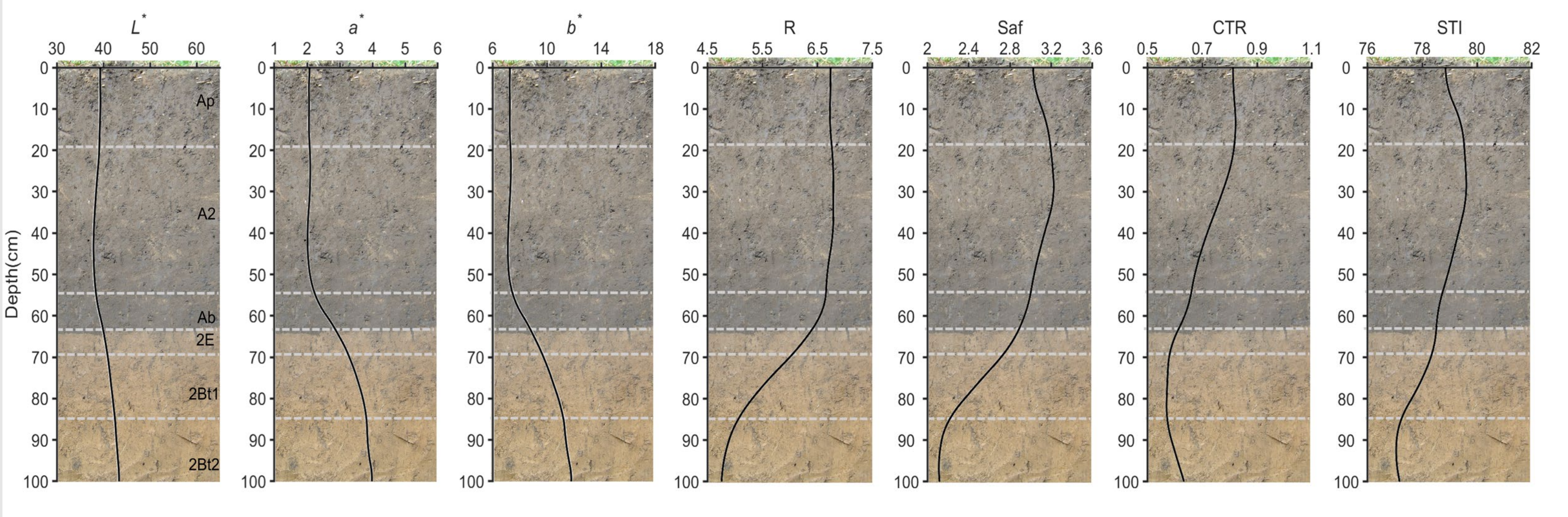
  Silica-Titanium index (STI): $\frac{\frac{SiO_2}{TiO_2}}{\frac{SiO_2}{TiO_2}+\frac{SiO_2}{Al_2O_3}+\frac{Al_2O_3}{TiO_2}} \times 100$

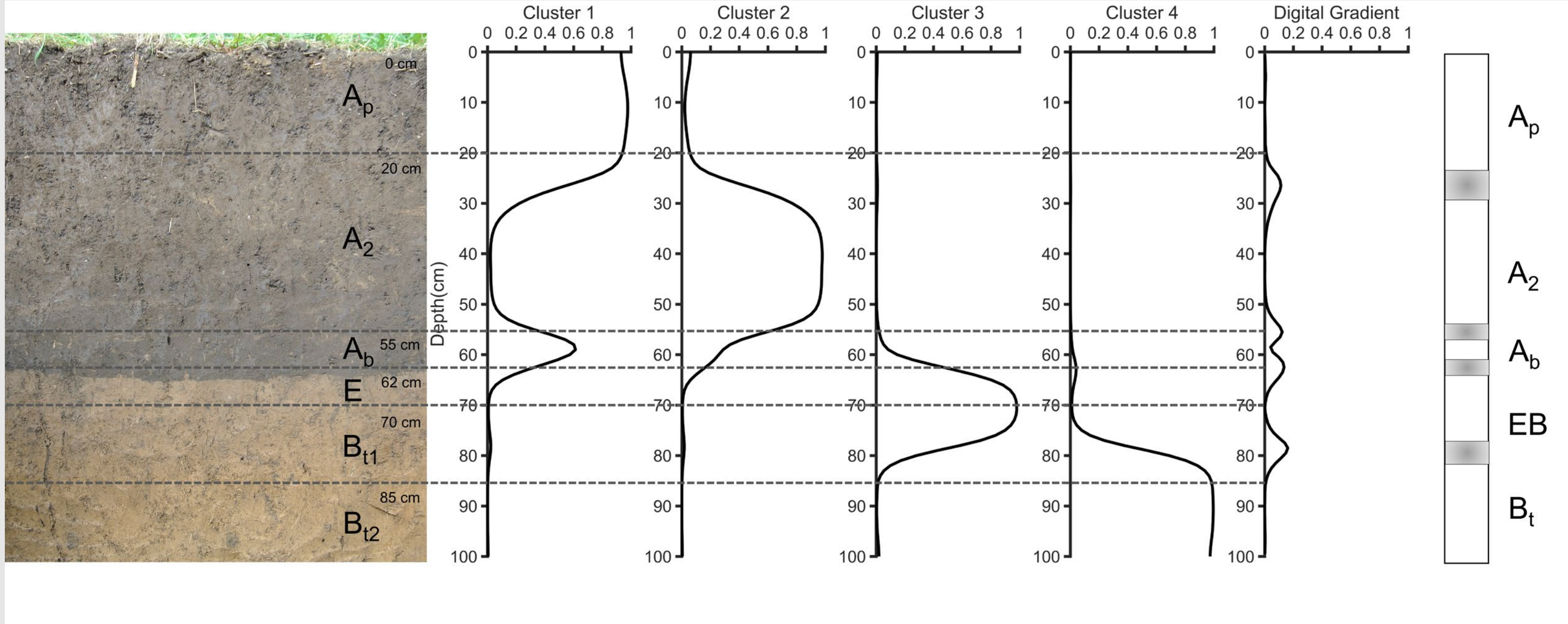
- Digital gradient

$$DG_{d+0.5} = \sqrt[2]{\frac{\sum_{v=1}^{k}(u_{v,d}-u_{v,d+1})^2}{2}}$$

$u_{v,d}$ – membership of cluster v at depth d

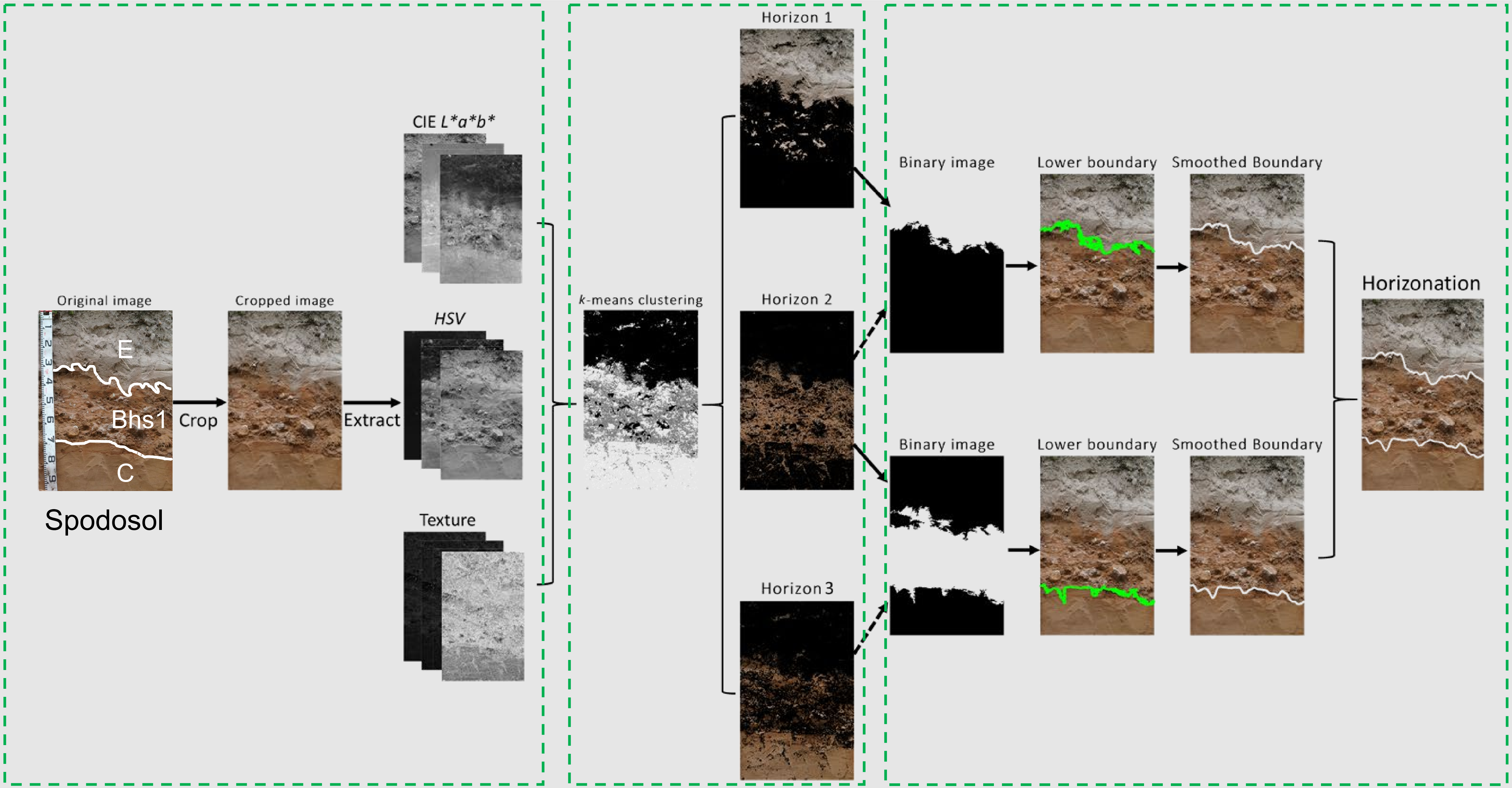
1. Horizonation using pXRF + vis-NIR data





- The CIE *L*a*b** color and weathering indices well distinguished A and B horizons.
- The A horizons (loess) were darker and less weathered than the B horizons (glacial outwash).
- The CIE *L*a*b** color and pXRF data were excellent variables for delineating soil horizons.

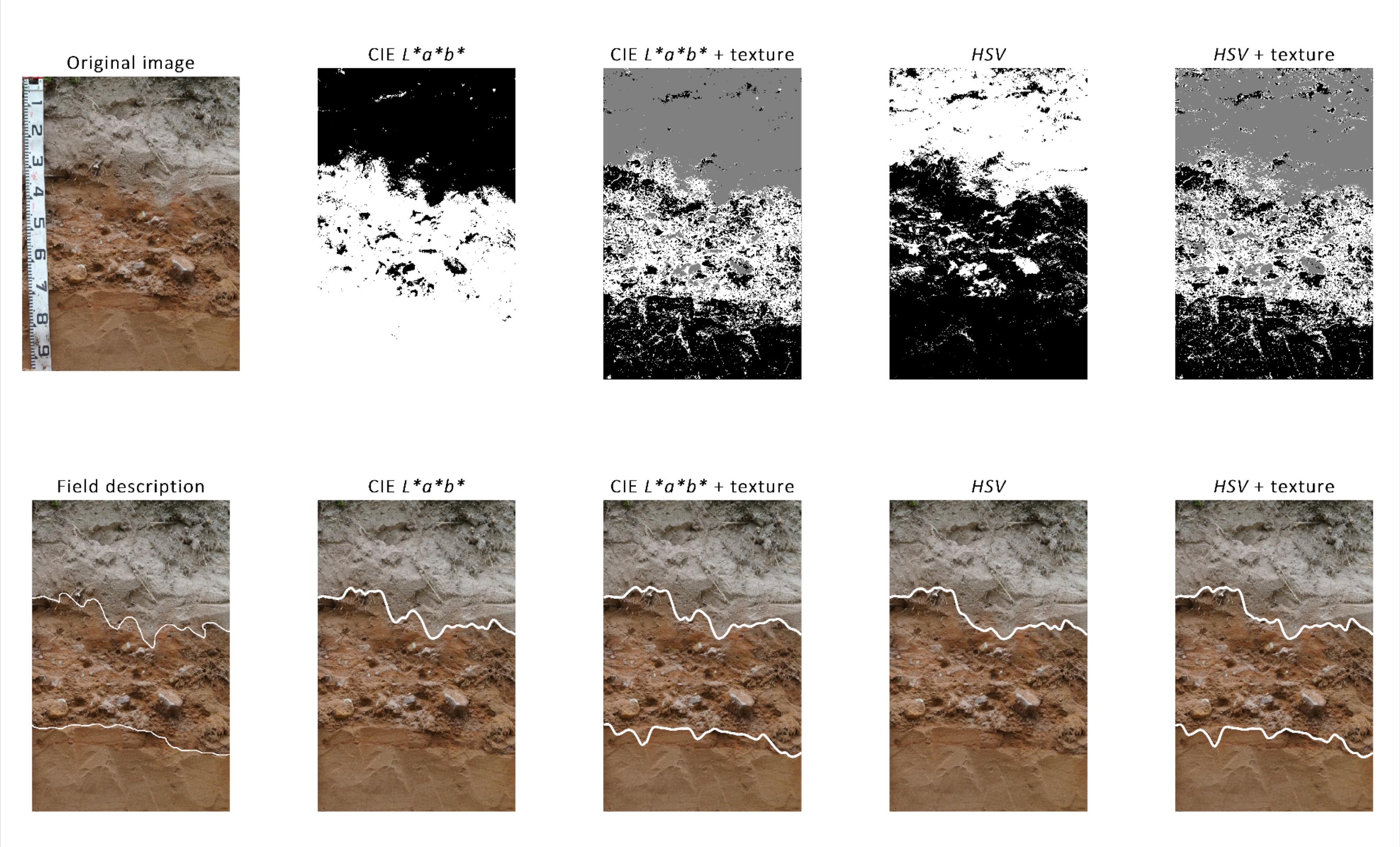
2. Automated soil horizonation on 2D images



Feature extraction Segmentation Boundary delineation

2. Automated soil horizonation on 2D images

Segmentation

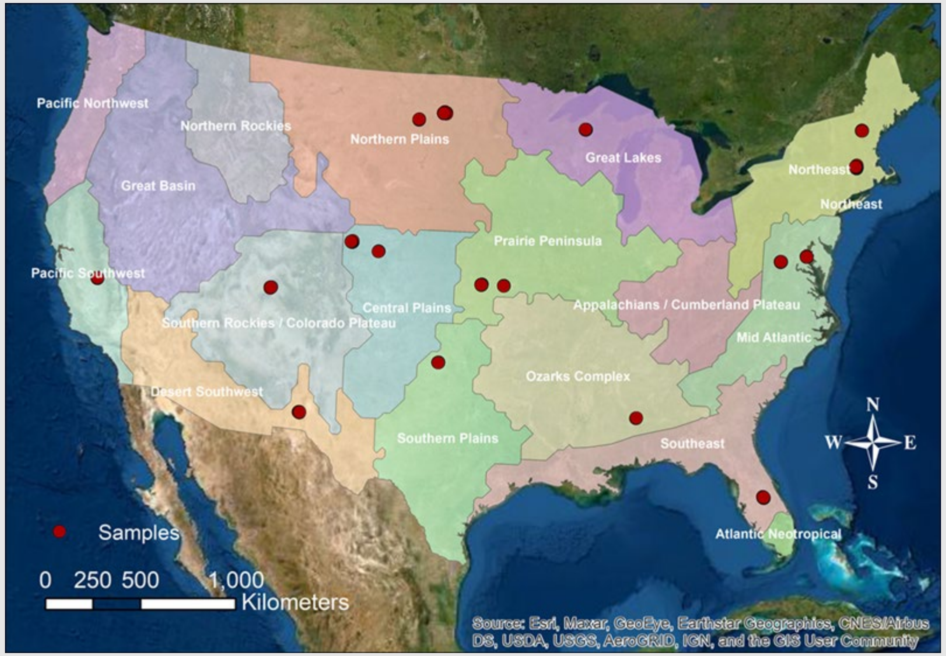


- The model performed well in profiles when the colors were distinct.
  - ➢ Reddish color ($a^* > 5$); Yellowish color ($b^* > 15$)
  - ➢ Darker color ($H > 0.20$); High saturation ($S > 0.25$)

- Image texture improved the horizonation when the horizon contained coarse fragments.

3. MIR spectra to classify soil horizons

- National Ecological Observatory Network (NEON) dataset

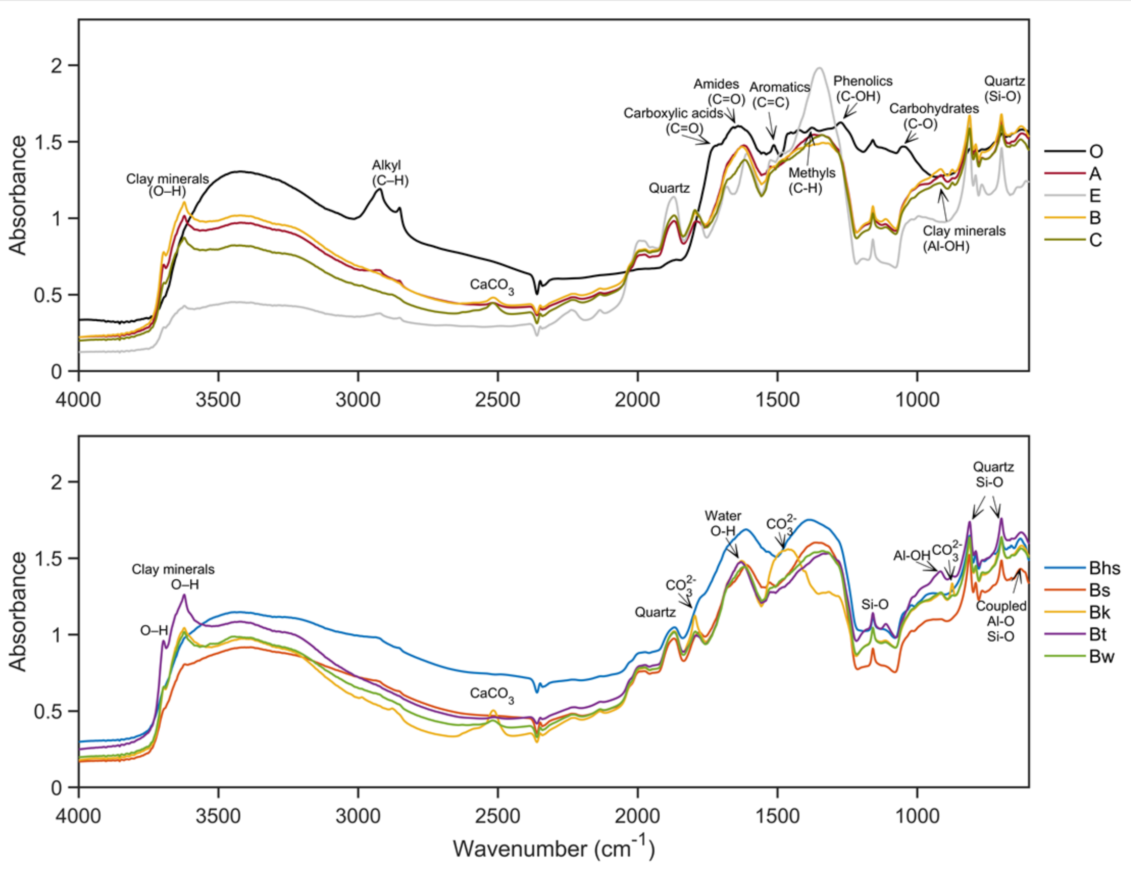


- Dataset: Soil MIR spectra of 1,167 soil samples at 270 profiles
- MIR spectral features: qualitatively explored on five **master horizons** (O, A, E, B, and C) and five **B horizons** (Bhs, Bs, Bk, Bt, and Bw).
- Random forest:
  - Calibration (189 profiles), validation (81 profiles)
  - Classify five master horizons, five B horizons

Horizon		Key features
O		Organic material
A		Mineral horizon with high organic matter
E		Pale color; loss of clay, Fe, Al; sand and silt particles
B	Bhs	Illuvial accumulation of organic matter, Al, Fe oxides
	Bs	Illuvial accumulation of Al and Fe oxides
	Bk	Accumulation of secondary carbonates
	Bt	Accumulation of silicate clays
	Bw	Little development of color and structure
C		Little soil development

3. MIR spectra to identify soil horizons

Averaged MIR spectra and identified features



Confusion matrix of random forest model

Prediction	Reference					
	O	A	E	B	C	Precision
O	17	0	0	0	0	1.00
A	3	58	0	18	2	0.72
E	0	1	10	5	3	0.53
B	0	34	0	162	13	0.78
C	0	0	1	9	8	0.44
Sensitivity	0.85	0.62	0.91	0.84	0.31	**0.74**
	Bhs	Bs	Bk	Bt	Bw	Precision
Bhs	1	0	0	0	0	1.00
Bs	7	7	0	0	0	0.50
Bk	0	0	16	4	5	0.64
Bt	0	0	1	53	7	0.87
Bw	0	2	3	9	23	0.62
Sensitivity	0.13	0.78	0.80	0.80	0.66	**0.72**

The Bold indicates overall accuracy

- Organic soils had different absorption features compared to mineral soils.
- MIR absorption features were related to organic functional groups, clay minerals, quartz, and carbonates.
- Soil MIR spectra can be used to characterize and classify soil horizons

Conclusions

- The spectroscopic information can improve the delineation of soil horizons quantitatively.
- Multiple sensors and methods can be used or combined to objectively and accurately identify soil horizons.
- It improves our understanding of soil.