Mapping Conductivity-Depth Relationships by Combining Proximal and Penetrating EC_a Sensors

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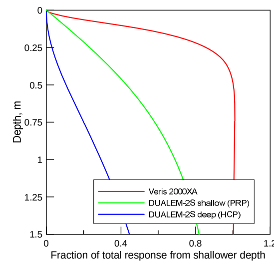
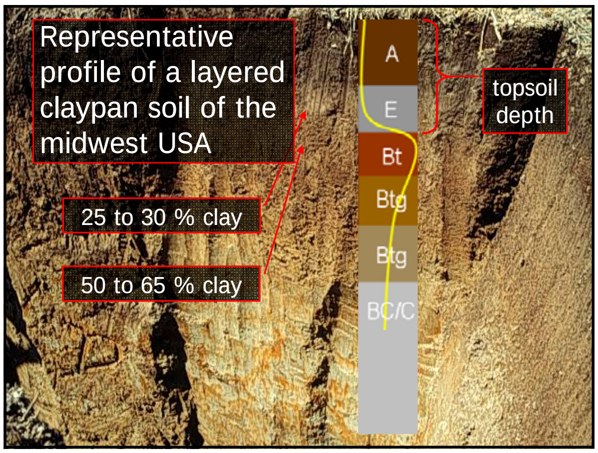
EC_a responds to soil layering



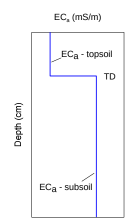
Because of variations in instrument response with depth, EC_a is affected not only by soil variables (salinity, clay, water content, etc.) but also how they are layered in the profile



Assumed model:
Two soil layers plus air gap

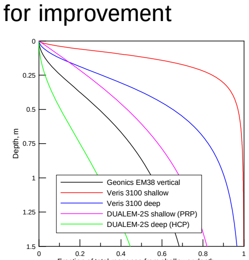
$$EC_{ax} = \int_0^{HI} EC_{air}\Phi_x(z)\,dz + \int_{HI}^{TD+HI} EC_{aT}\Phi_x(z)\,dz + \int_{TD+HI}^{\infty} EC_{aS}\Phi_x(z)\,dz$$

HI = instrument height above ground
TD = depth of topsoil
x = instrument ID (Veris, Dsh, Ddp)



Extracting layer information

- Previous two-layer model estimates obtained on claypan soils left room for improvement
  - RMSE in topsoil depth (TD) ~ 20 cm
  - Was two-layer assumption valid?
  - How to get additional, non-collinear information?



Objective

- Improve spatial estimates of layered-soil conductivity by combining:
  - Point measurements of layer conductivity obtained with an EC_a penetrometer, and
  - Mapped EC_a data from multiple proximal sensors

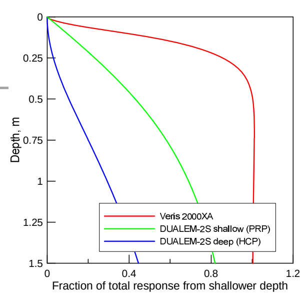
Study site

- Data collected on a set of research plots in central Missouri on highly layered claypan soils
- Because of historical erosion, TD varies from ~0 to over 100 cm
- Data collection was at summit, side, and footslope positions in each plot
  - Calibration dataset: 72 points
  - Validation dataset: 36 points

EC_a instruments used

- Veris Profiler 3000
  - Point measurements to ~90 cm depth
- Veris 2000XA
- DUALEM-2S

Cumulative responses



$R_{Ddp} = 1 - (z^2 + 1)^{-1/2}$

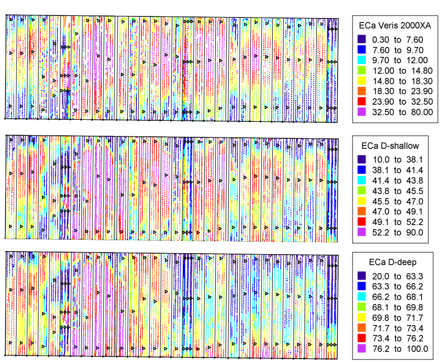
$R_{Dsh} = 0.952z\,(0.907z^2 + 1)^{-1/2}$

$R_{V2k} = 1 + 120\,((1/32)(64z^2 + 9)^{-1/2} - (1/64)(64z^2 + 1)^{-1/2} - (1/64)(64z^2 + 25)^{-1/2})$

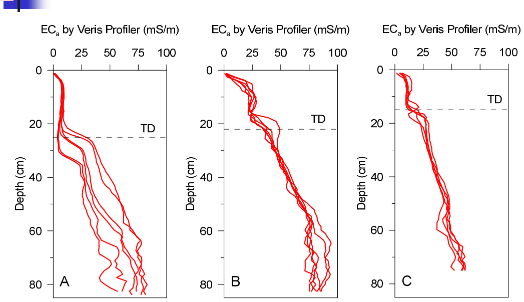
Data Collection

- At each sampling location, three soil cores were taken within a 3-m radius, and TD was determined by examination
- Two penetrometer EC_a datasets were collected at each core point
- Veris 2000XA and DUALEM-2S transects were on a 4.5 m spacing, and proximal sensor readings within 3m of each core point were kept for analysis

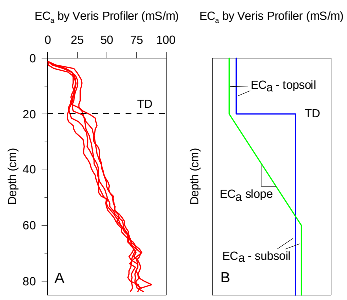
Mobile sensor data



EC_a penetrometer data



Alternative 3-layer model
Informed by penetrometer EC_a data



Model: three soil layers plus air gap

$$EC_{ax} = \int_{0}^{HI} EC_{air}\Phi_x(z)\,dz + \int_{HI}^{T1+HI} EC_{aT}\Phi_x(z)\,dz + \int_{T1+HI}^{T1+T2+HI} EC_{a2}(z)\Phi_x(z)\,dz + \int_{T1+T2+HI}^{\infty} EC_{aS}\Phi_x(z)\,dz$$

HI = instrument height above ground
T1 = depth (thickness) of topsoil
T2 = thickness of second layer
x = instrument ID (V, Dsh, Ddp)

Because EC_a is not constant in all layers, the integration gets a little "messy"

Solution

$$EC_{ax} = \int_{0}^{HI} EC_{air}\Phi_x(z)\,dz + \int_{HI}^{T1+HI} EC_{aT}\Phi_x(z)\,dz + \int_{T1+HI}^{T1+T2+HI} EC_{a2}(z)\Phi_x(z)\,dz + \int_{T1+T2+HI}^{\infty} EC_{aS}\Phi_x(z)\,dz$$

- Solve for T1+HI by inverting the cumulative response function
- Iteratively choose the other parameters to minimize RMSE between measured TD and modeled TD in the calibration set
- Solve for each of the three datasets independently and then combinations
  - V2k, Dsh, Ddp

Inversion solution results for TD

Model and EC_a source	Calibration set					Validation set	
	EC_{aT} (mS/m)	ΔEC_a (mS/m²)	EC_{aS} (mS/m)	RMSE (cm)	Bias (cm)	RMSE (cm)	Bias (cm)
2 layer - $EC_{a\text{-Dsh, Ddp}}$	12	--	66	9.0	-0.2	9.3	3.5
2 layer - $EC_{a\text{-Dsh}}$	12	--	63	8.2	0.0	7.6	3.8
3 layer - $EC_{a\text{-Dsh, Ddp}}$	7	45	72	11.6	-0.6	12.7	2.9
3 layer - $EC_{a\text{-Dsh}}$	14	46	56	7.8	-0.4	7.7	3.6

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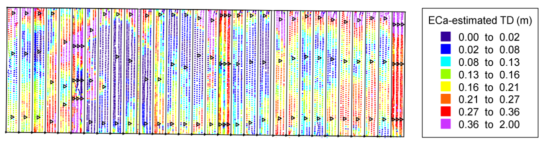
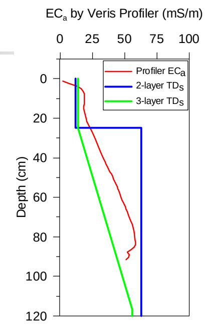
- No advantage to using multiple EC_a datasets
- Single-dataset results very similar for 2-layer and 3-layer model

Mapping TD from best 3-layer model



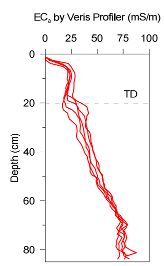
Modeling and mapping

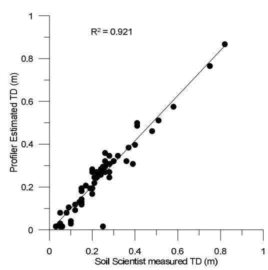
- Although RMSE was not improved, 3-layer model better represented true EC_a profile as shown by penetrometer
- We were unable to map other parameters in addition to TD, as these were not correlated to proximal EC_a datasets
- Need to more closely examine cropping systems effects



Other findings:

Penetrometer EC_a informs TD calibration data

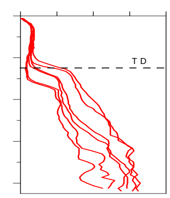


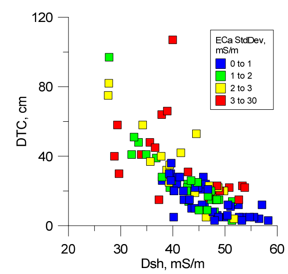


Other findings:

Effect of proximal EC_a variation at calibration points

- Screening calibration points with high spatial variability is a key to good calibrations





Summary

- Combining proximal and penetrometer EC_a data can lead to better modeling of subsurface conductivity variations
  - Visualization and parmeterization of a more physical model
  - Potential for automatically developing TD calibration datasets
- Although penetrometer EC_a traces showed variation in layer conductivities over the study area, only TD was related to proximal EC_a datasets collected here
- Further investigation is needed toward techniques for mapping layer conductivities