A Simple Method for Estimating Cation Exchange Capacity from Water Vapor Sorption

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Introduction

- Knowledge of soil cation exchange capacity (CEC) is crucial for soil fertility considerations, sorption and release of polar and non-polar compounds, engineering applications, and other biogeochemical processes
- Standard procedures such as the ammonium acetate or the $BaCl_2$ compulsive exchange methods are expensive and laborious
- Previous modeling approaches estimate CEC from soil properties such as clay content (CL), organic matter (SOM), specific surface area (SSA), and pH
- Large scale studies and areas with no data on soil properties require rapid methodology to estimate CEC accurately

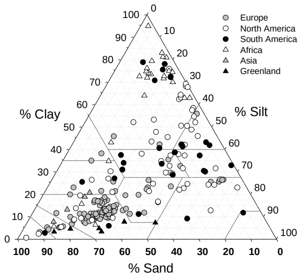
Objectives

- Develop prediction models to estimate CEC from soil water content at an arbitrary RH value considering hysteresis
- Validate the new models and compare their performance with existing models and methodologies based on other soil properties.

Methods

- **Investigated soils**

238 soils from 24 countries



Range

CEC [$cmol_{(+)}$ kg^{-1}]

1 to 83; mean = 21

Organic carbon [%]

0.1 to 8.4; mean = 1.9

- **Measurement methods**

CEC – ammonium acetate extraction at pH 7 or 8.2

Water vapor sorption isotherms – Vapor Sorption Analyzer [RH: 3 to 93% at 25°C (–10 to –460 MPa)]

pH – 1:2.5 in water

SOC – organic elemental analyzer

- **Model development (203 soils)**

Rationale: Water sorption/desorption is intimately linked to CEC

Format: $CEC\ [cmol_{(+)}kg^{-1}] = a + b \times w$

a, intercept; *b, coefficient; w,* water content (%) at specified RH and sorption direction

Nine regression relationships (10 to 90%) for both adsorption and desorption

- **Comparison with existing models (M)**

M1 $CEC = 42.8 - 5.36pH + 0.297SOM - 2.04CL + 0.363CLpH$

M2 $CEC = 2.24 + 0.774CL + 0.0807SOM$

M3 $CEC\ [mmol_{(+)}kg^{-1}] = -29.25 + 8.14CL + 0.25OC$

M4 $CEC = 0.1135SSA^{1.1371}$

UNITS

CEC [$cmol_{(+)}$ kg^{-1}]

SOM [g kg^{-1}]

CL [%]

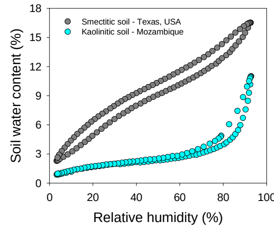
OC [%]

SSA [m^2 g^{-1}]

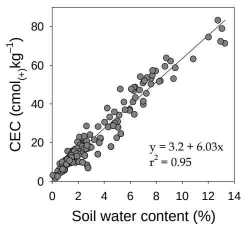
Results

- **Sorption isotherms**

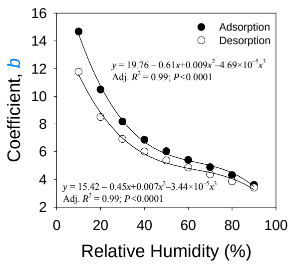
– different clay mineral-soils



CEC-soil water content (50%RH) relationship



- **Model** (*CEC* = *a*+*b*×*w*) **parameters**



Coefficient, b

Measure RH

Sorption direction

Derive *b* from figure

Intercept, *a*

Adsorption = 2.87 ±0.12

Desorption = 2.46 ±0.04

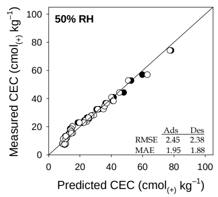
- **Model validation (35 soils)**

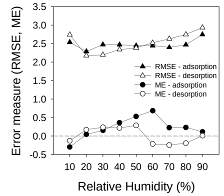
CL= 9 to 81%; SOM= 0.1 to 12.6%; CEC= 7.3 to 74.2 $cmol_{(+)}$ kg^{-1}

Variable clay mineralogy (kaolinite, smectite, illite)

Test of RH and sorption direction sensitivity

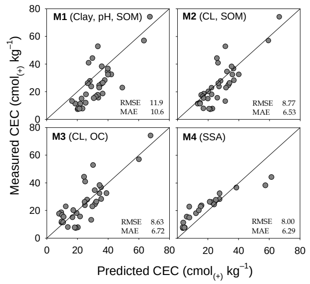
- **Model performance at 50%RH and sensitivity**





- **Performance comparison (M1-M4)**

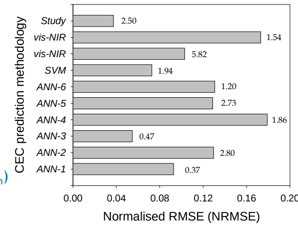
Regression models based on clay, OC, pH & SSA



- Accuracy lower than sorption-based models
- SSA-based CEC model more accurate than CL and SOM/OC-based ones
- Soil pH inclusion worsens CEC predictions

Other methodologies (soil properties)

- ANN, artificial neural networks; SVM, support vector machines; vis-NIR, visible near infrared spectroscopy
- Value on each bar is smallest RMSE
- NRMSE= smallest RMSE/(CEC_{max}–CEC_{min})
- Sorption method has smallest NRMSE



Conclusions

- Water sorption-based models accurately predicted CEC for a wide range of soils
- Models were not affected by organic matter content, sorption direction, or clay mineralogy
- Models proved superior to models/methodologies based on other soil properties

Acknowledgments

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References

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M3: McBratney et al. (2002) Geoderma 109, 41-73

M4: Yukuselen-Aksoy & Kaya (2006). Clay Min. 41, 827-837

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