Using VNIR Spectroscopy to Rapidly Quantify the Coefficient of Linear Extensibility in Texas Soils

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INTRODUCTION

Shrinking and swelling soils cause extensive infrastructure and economic damage worldwide. Shrink-swell soils are of great concern in Texas for two reasons, 1) Texas has the most acreage of shrink-swell soils in the United States, and 2) yearly evapotranspiration rates exceed those of precipitation creating optimal conditions for soil wetting and drying cycles. This study was conducted to determine if visible near infrared diffuse reflectance spectroscopy (VNIR-DRS) can be used to predict the coefficient of linear extensibility (COLE) of soils. If successful, VNIR-DRS would provide a means to rapidly and inexpensively quantify a soil's shrink-swell potential real-time. Using soils that have been previously analyzed and archived in the Texas Agrilife Research Soil Characterization Laboratory, our objectives were to: 1) predict the coefficient of linear extractability (COLE) using spectroscopy, 2) predict COLE using measurements of total clay and cation exchange capacity (CEC), and 3) compare the two models.

MATERIALS AND METHODS

The Texas VNIR-DRS spectral library was created with 2454 oven dried, 2 mm ground soil samples, archived by the Texas Agrilife Research Soil Characterization Lab. The soils were scanned with a mug lamp connected to an AgSpec® Pro(Analytical Spectral Devices, Inc) with a spectral range of 350-2500 nm. Each soil sample was scanned twice with a 90° rotation between scans. The spectral data were pretreated by splicing, averaging, and taking the 1st and 2nd derivatives. Out of the 2454 soil samples, only 1236 had COLE, total clay content, and CEC values. These 1236 were divided into a calibration (70 % of the samples) and a validation set (30 % of the samples). Using only the calibration data set, models to predict COLE were made using soil spectra as predictors and lab measurements as predictors. Measured versus predicted values of the validation samples were compared using multiple regression. The regression equations were created using laboratory data and backward elimination in R. The primary elimination criterion was a p-value of 0.05 or less. Partial least squares (PLS) regression was used to create the COLE prediction model using soil spectra. For all validations comparisons, negative COLE values were changed to zero before comparison of predicted COLE values to measured COLE values. Diagnostics for comparing models included p-value, residuals plots, R^2 values, and simplicity.

RESULTS AND DISCUSSION

Texas has a wide range of geologies, annual temperatures and annual precipitation; therefore the soil data base that was scanned is extremely variable in its parent material, mineralogy, and other soil formation factors (Godfrey et al., 1973) The calibration and validation data had very similar ranges and averages of soil properties (Table 1).

Table 1: Summary statistics for calibration and validation datasets

Soil property	Units	Mean	Standard deviation
	calibration samples, n = 862		
COLE†	cm cm^{-1}	0.048	0.042
CEC‡	cmol(+) kg^{-1}	16.43	13.31
Clay	%	26.72	18.95
	validation samples, n= 374		
COLE	cm cm^{-1}	0.048	0.042
CEC	cmol(+) kg^{-1}	16.00	13.33
Clay	%	26.46	19.11

To meet regression assumptions of normal distribution COLE was transformed into the square root of COLE prior to model calibrations. Three soil properties and two models were chosen from backward elimination; the first model used total clay content and the second model used fine clay content and cation exchange capacity (CEC). Based on the literature clay content is highly correlated with COLE (Vaught et al, 2006). The total clay and fine clay plus CEC models resulted in R^2 values of 0.74 and 0.75, respectively. The residuals were homoscadastic, and no outliers were observed. Though clay content alone was not the best predictor of COLE, soil clay content is relatively easy to measure compared to CEC. Hence clay content alone is a less expensive alternative for estimating. While CEC alone had an R^2 of 0.69, adding total clay to the CEC regression improved residuals. Using the validation data (n=374), total clay plus CEC predicted COLE with an RMSD, R^2, and RPD value of 0.02 % clay, 0.74, 1.74 respectively. Total clay alone predicted COLE with an RMSD, R^2, and RPD value of 0.05 % clay, 0.65, 1.26 respectively (Figure 1). Total clay plus CEC predicted COLE better than total clay alone. Including CEC in the model probably improved the estimation of COLE because clay mineral type has been associated with soil shrink-swell potential and CEC is an indicator of clay type. Clay minerals with a higher CEC values, such as smectite, are known to be associated with soils of high shrink-swell potentials (Wilding, 1998), while kaolinite soils can have high shrink swell potential, they are more associated with low shrink-swell potential. Even though CEC and total clay content were able to predict COLE with an R^2 value of 0.74 there is much laboratory work which has to go into determining both the CEC and total clay content of a soil. Both procedures for predicting CEC and total clay content can be time consuming and expensive.

Spectroscopy was able to predict COLE with an R^2, RMSD, and RPD value of 0.67, 0.03, and 1.4 respectively. Spectroscopy predicted COLE better than predicting COLE with total clay content alone. However, clay content plus CEC predicted COLE better than spectroscopy (Figure 1).

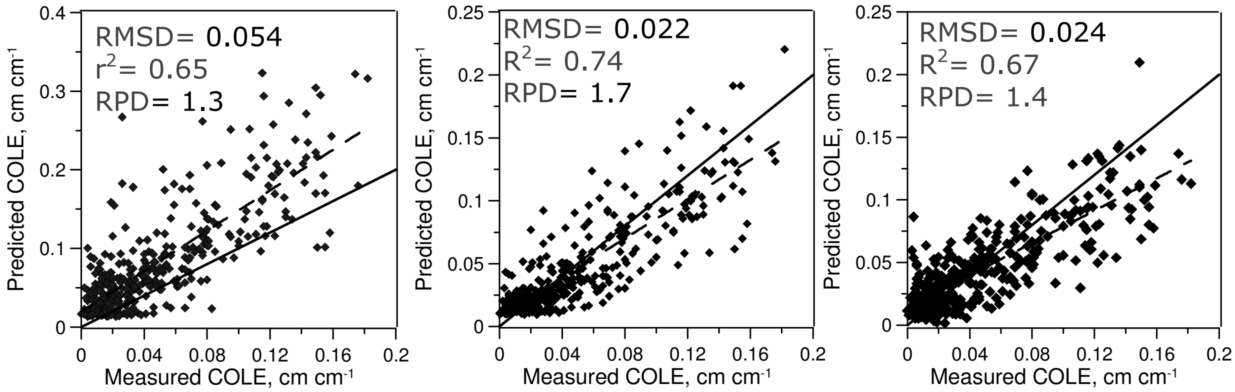

Figure 1. Predicted vs. measured COLE values of the validation set (n= 374) for (a) total clay content, (b) total clay content plus CEC, and (c) spectroscopy.

CONCLUSION

Though spectroscopy did not predict as well as the clay plus CEC prediction, scanning the soil with spectroscopy is fast, non-destructive, and has fixed costs compared to lab measurements of CEC and clay content. One useful way to interpret the spectroscopy prediction results is to look at how the prediction errors translate into predicting shrink-swell classes. According to the USDA NRCS, soils are classified into five shrink-swell classes, from very low to very high (Kariuki et. al. 2003). Given the prediction errors of spectroscopy, the results were still useful for classification purposes. The spectroscopy prediction error was an RMSD of 0.024 cm cm^{-1}. In other words, the spectroscopy predictions will be within 2.4% of the actual COLE value, 66% of the time. The separation between the moderate, high and very high shrink-swell classes is greater then 3%. Therefore spectroscopy can correctly classify soils into these three shrink-swell classes. Total clay content and CEC prediction of COLE had an RMSD of 0.022 cm cm^{-1}. The CEC and total clay content predictions can be used to predict COLE within 2.2% of the actual COLE value as compared to the 2.4% of the spectroscopy prediction. Taking into consideration the price and size of a project, this difference between the two predictions may not be practically significant. Our results indicate that VNIR-DRS may be useful in predicting a soils shrink-swell potential. We envision using spectroscopy for in situ characterization of soils for greater spatial and vertical densities than is practical with conventional soil characterization techniques. To make this vision a reality, continued research is needed on in situ VNIR-DRS applications. These in situ studies should be careful to include a wide range of soil diversity and field conditions.

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