USDA Natural Resources Conservation Service
U.S. DEPARTMENT OF AGRICULTURE

SOIL AND PLANT SCIENCE DIVISION

Technical Soil Services

South Central Region

Bryan, Texas, Major Land Resource Area (MLRA) Soil Survey Office (SSO)

Soil and Plant Science Division (SPSD) Mid-Infrared (MIR) Spectroscopy Soil Analyses for the University of Wisconsin, Madison, MIR Study

Purpose

In January 2024, Natural Resources Conservation Service (NRCS) SPSD staff, Dr. Beyhan Amichev, MLRA SSO leader and soil scientist in the South Central Soil Survey Region (fig. 1), performed MIR spectroscopy analyses of 25 soil samples for University of Wisconsin, Madison, MIR study. These samples were selected from the Kellogg Soil Survey Laboratory's (KSSL) soils archive and the analyses will help develop an automated, user-friendly, web-based portal for estimating soil properties and soil health indicators from MIR spectral data.

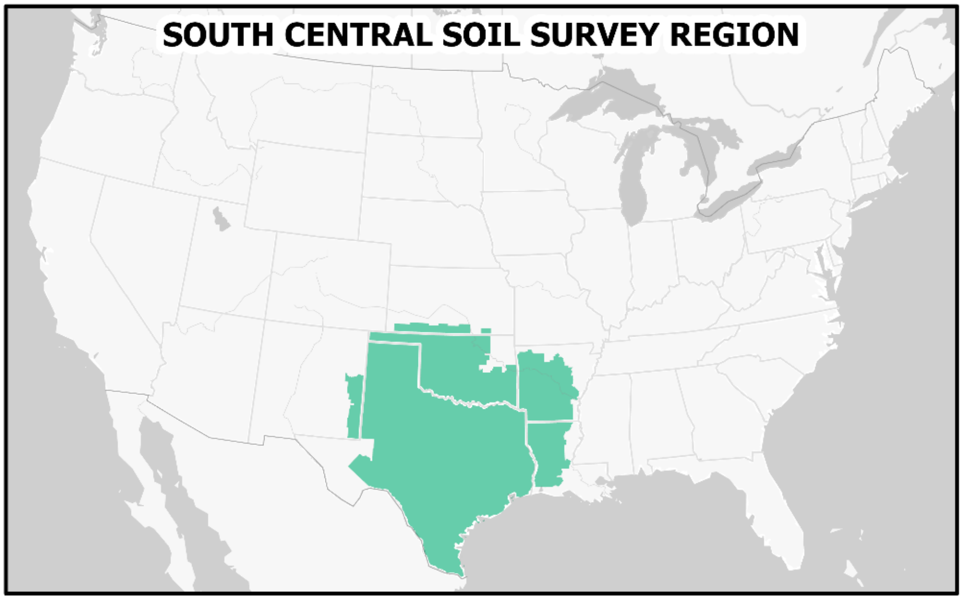

Figure 1.—Extent of the South Central Soil Survey Region.

Background

MIR spectroscopy has been the focus of soil analysis for more than a decade and has gained interest within SPSD leadership. The number of MIR-equipped SPSD offices in the nation has steadily increased in fiscal years 2022 and 2023, which has allowed for more SPSD field staff to train and gain experience in using MIR technology for soil survey projects. The current issue with traditional laboratory analyses is that they can be expensive and time-consuming. MIR technology provides an efficient and cost-effective alternative to traditional laboratory analyses for soil survey projects by obtaining soil spectral data from each sample that are used in MIR models for soil property estimations.

The MIR analyses require soil scientists to pre-process the soil samples (about 500 g) by oven drying them at 35-37 °C for four days with daily mixing and homogenization prior to MIR scanning. On the fifth day, the soil scientists finely grind the fine fraction of the soil (less than 2-mm particle size) to less than 180 μm particle size using a ball-mill and then scan four subsample replicates with an MIR spectrometer (fig. 2). After obtaining MIR spectral data from soil samples, soil scientists build MIR calibration models within the area of the soil survey project (e.g., Dynamic Soil Properties (DSP) project) by using Laboratory Information Management System (LIMS) data from the KSSL, which are MIR data paired with data from traditional laboratory analyses methods for archived soil samples. Soil scientists use these MIR models (one independent model per soil property and per study area) to estimate soil properties for all MIR scanned samples in a given study. Some examples of MIR estimated soil properties include percent of clay, silt, and sand, pH, electrical conductivity (EC, dS/m), bulk density (Db, oven-dry, fine earth fraction, g/cm^3), soil organic carbon (SOC, percent) and cation exchange capacity (CEC, cmol/kg) (fig. 3).

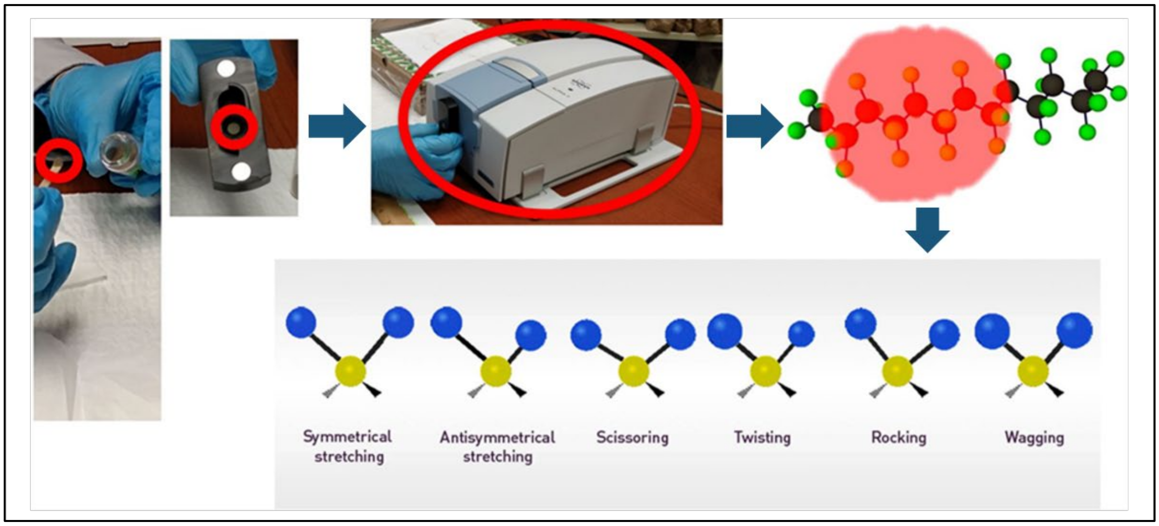

Figure 2.—MIR radiation and soil interaction.

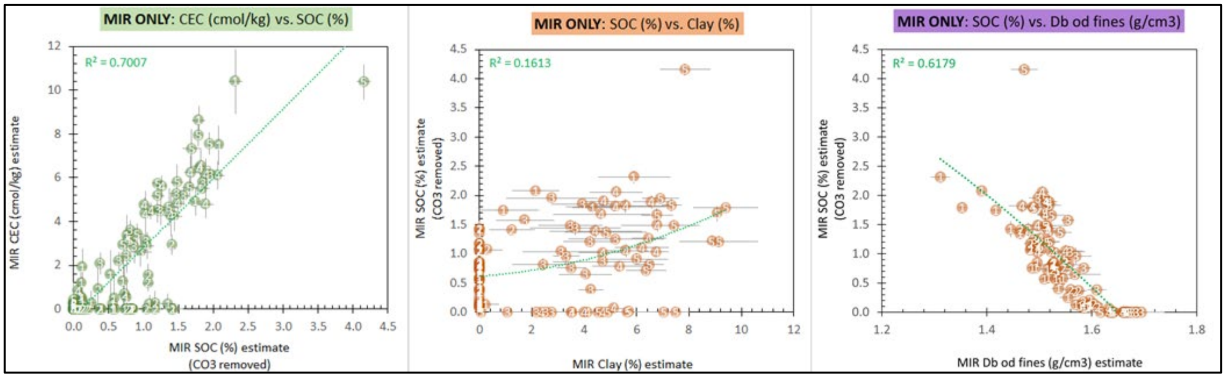

Figure 3.—MIR estimated data relationships for CEC, clay, SOC, and Db soil properties for 106 soil samples (0–50 cm depth) in 5 DSP projects in 2 Texas counties (Burleson and Rusk) for 5 soils (forested and pasture sites) from 3 taxonomic soil orders Alfisols (1-Padina), Entisols (2-Arenosa, 3-Tonkawa), and Ultisols (4-Darco, 5-Tenaha). MIR data shown are average (circle) and standard deviation (horizontal lines) of four replicates.

MIR radiation is the portion of the electromagnetic spectrum within which soil molecules, such as hydroxyl (-OH) molecules associated with clay and organic matter, calcium carbonate, and quartz, vibrate. Upon exposure to MIR radiation, depending on the soil's characteristics, such as mineral type and content, organic matter type and content, different portions of the MIR radiation are absorbed by soil molecules, while other portions remain unchanged. This interaction between MIR radiation and soil at a molecular level is what allows MIR technology to differentiate between the types of soil components within a soil sample, as well as to estimate their quantity for further soil interpretation (fig. 4). Some soil properties have direct absorption features regarding MIR radiation. These include SOC, clay, carbonates, and sand. Other soil properties, which include pH, EC, and CEC, do not have direct absorption features, but are related to the vibration of many different molecules in the soil matrix.

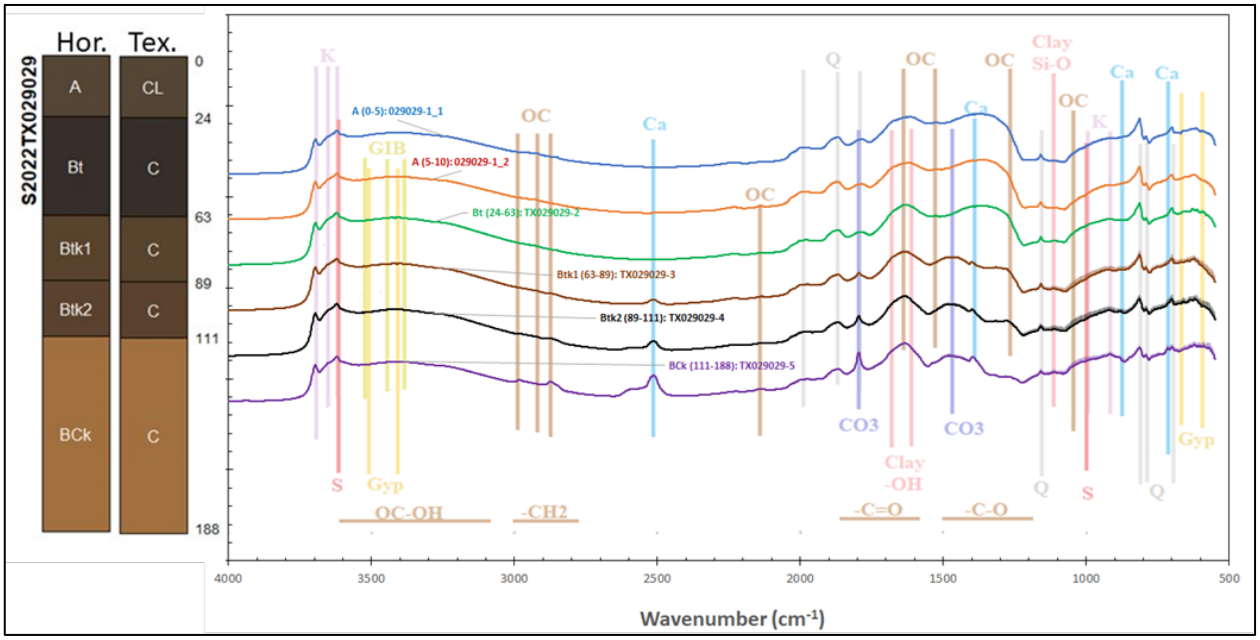

Figure 4.—Example of MIR radiation absorbance by different soil molecules in soil samples from five soil horizons in the same soil pedon from a carbon baseline project for the city of San Antonio, Texas. MIR wavenumber region indicators are as follows: K= kaolinite; S = smectite; GIB = gibbsite; Gyp = gypsum; OC = organic carbon; Ca = calcite; Q = quartz; CO3 = carbonates; Carbon functional groups: OC-OH, -CH2, -C=O, -C-O.

There are more than 80,000 archived samples in KSSL for which both MIR technology data and traditional soil analysis data are already available. These paired data sets allow the development of MIR prediction models for many soil properties and soil survey project sites across the nation. The University of Wisconsin, Madison, MIR study aims to address several potential issues, and these include MIR spectral calibration transfer, improving machine learning models, and making the soil property estimation more streamlined via an automated web-based application. The spectral calibration transfer potential issue exists because SPSD SSOs are using single sample MIR instruments relative to the multiple sample MIR instruments used at KSSL. The machine learning models that are needed to translate MIR spectral data into soil property estimates can also depend highly on SPSD staff experience with MIR technology, their understanding of the statistics behind MIR model building, and their experience and knowledge of local soil conditions. When spectral calibration transfer and machine learning models are optimized, many soil properties can be estimated for any MIR scanned soil sample, including both physical and chemical properties, regardless of time of sample collection.

Key Outcomes

The Bryan, Texas, MLRA SSO was one of several SPSD MIR-equipped SSOs to assist the University of Wisconsin, Madison, with the development of MIR spectral application tools focused on web-based soil property estimation. Upon successful completion of this MIR study, SPSD SSOs equipped with MIR technology can use these tools to automate soil property estimation and address any issues of model building, model validation, and model transfer due to differences in MIR instruments. The results from this study will also provide an opportunity for training and technology transfer to SPSD soil scientists and to use MIR web-based application tools for more efficient soil property estimation for MIR scanned soils.