Harnessing Mid-Infrared Spectroscopy for Soil Survey: A Cooperative Effort

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Mid-Infrared (MIR) spectroscopy provides rapid, non-destructive, and cost-effective predictions for a wide range of soil properties, from organic matter and mineral content to water retention and cation-exchange capacity (CEC). The NRCS Soil Plant and Science Division (SPSD) has over a decade of experience using MIR spectroscopy for soil survey applications. Beginning in 2011, the Kellogg Soil Survey Laboratory (KSSL) adopted MIR technology for internal quality control. The positive results from this initial use have since led to the broader adoption of MIR technology across 22 NRCS field offices, spanning locations from Alaska to Puerto Rico (see map in fig. 1 showcasing MIR-equipped field offices).

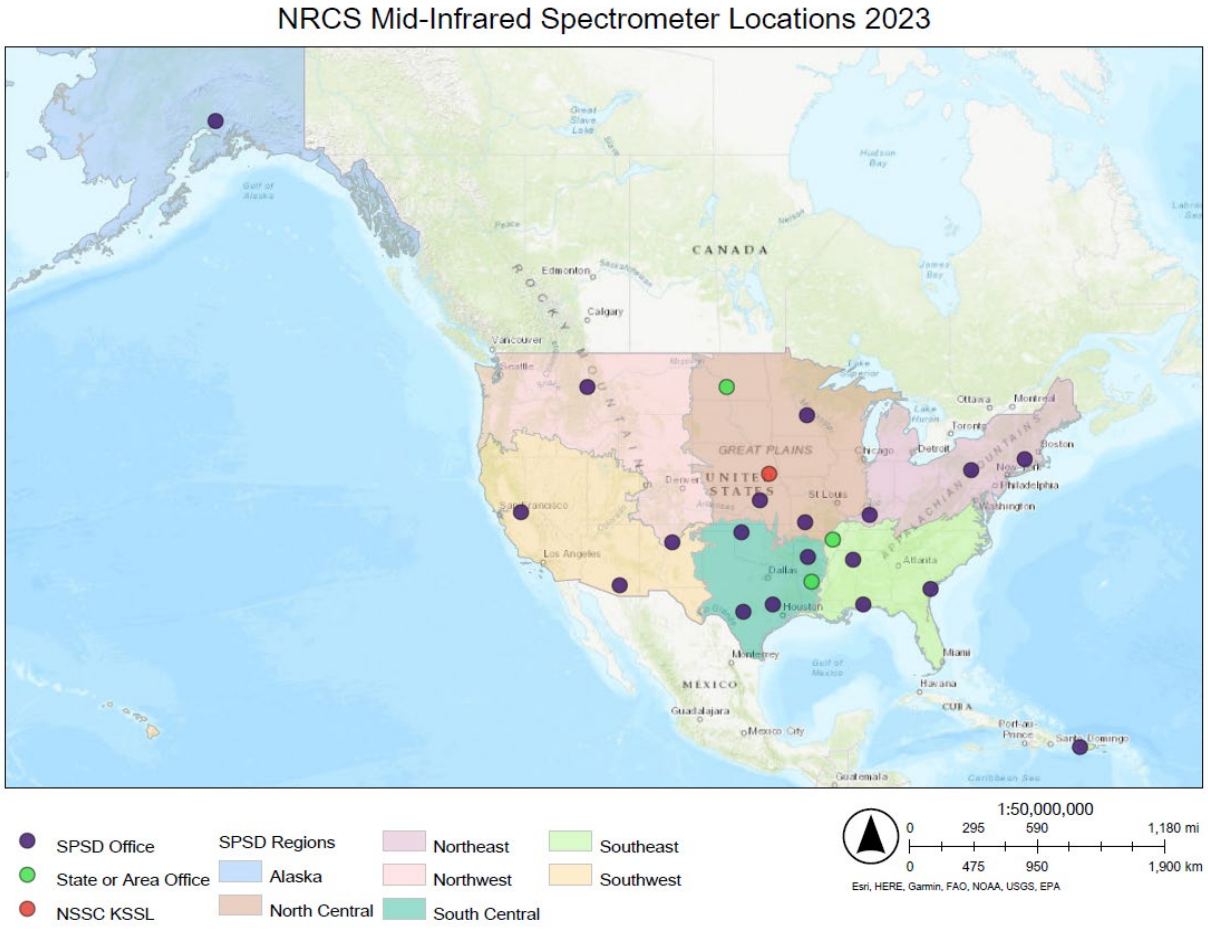

Figure 1.—Locations of MIR equipped NRCS field offices. The 19 purple dots represent SPSD offices, the 3 green dots represent state or area offices, and the red dot represents the National Soil Survey Center KSSL. Source: SPSD Technology Focus Team.

The widespread success of the SPSD's MIR program can be attributed to three parallel efforts. Foremost is the establishment and systematic expansion of an open-source MIR spectral library, which currently houses spectra of over 85,000 soil samples. In tandem with this resource, the SPSD has prioritized the deployment of spectrometers to NRCS field offices that are spectrally compatible, thereby ensuring that soil property predictions are consistent with the calibrations established by the KSSL. Complementing these developments is the continued dedication of the SPSD to MIR research, which includes both internal projects and synergistic collaborations fostered through cooperative research agreements.

One of the inherent challenges in the broader deployment of MIR spectroscopy has been the effective transfer of models across varied geographic domains, databases, and instrumentation. Such transfers often lead to a decrease in prediction accuracy due to factors such as inconsistencies in reference data, variances between instruments, and variation in soil property measurement protocols. In anticipation of these complexities, the SPSD commissioned a pilot study in Salina, Kansas, in 2017 and 2018. The data and findings gleaned from this investigation have been instrumental in refining the broader integration of MIR technology across NRCS field offices (Seybold et al. 2019).

The SPSD has continued to support MIR research over the years, most recently focusing on the development of MIR spectral application tools for assisting with the development and validation of spectral models. A recently funded cooperative agreement with University of Wisconsin (UW), Madison, led by Dr. Yakun Zhang, aims to address these challenges by developing a web-based soil property estimation tool that NRCS field offices can use to automate the development of machine learning models for soil property estimation. The project is actively seeking collaboration with NRCS MIR-equipped field offices to validate and refine the tool and, in particular, address the issue of model transfer between the KSSL and field office spectra (fig. 2).

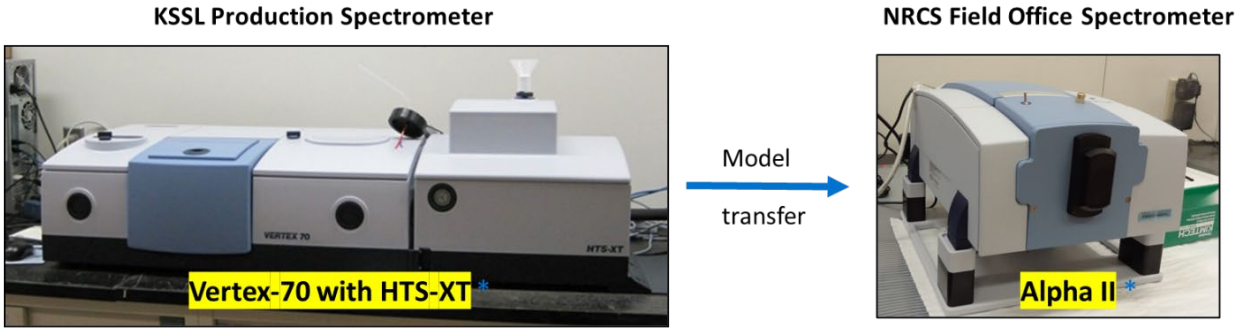

Figure 2.—Photos of the KSSL and field office spectrometers. Work from the Salina pilot study showed that the multi-sample KSSL unit and the single-sample field office unit were deemed sufficiently compatible for direct model transfer when following the same protocol (sample preparation, scanning, and partial least squares regression modeling). Direct transfer of other model types, like machine learning models, is an open area of research. Figure courtesy of Rich Ferguson.

In September 2023, Dr. Zhang hosted a project webinar for NRCS staff to provide a detailed overview of the project, including information on how NRCS MIR operators can collaborate on the project. The project will produce a public-access web portal where field scientists can effortlessly upload MIR spectra for accurate soil attribute estimations, streamlining field office workflows. To ensure its seamless integration, the project will provide user training, including resources like technical manuals and conducting annual training for NRCS staff. Ultimately, the initiative aims to strengthen the capabilities and efficiency of soil survey field offices. Additional information can be found on UW's project website (https://soilmir.wisc.edu).

The SPSD has funded other MIR-focused cooperative research agreements over the past several years, including the development a web-based MIR prediction tool for dynamic soil properties in Kentucky (University of Kentucky); MIR modeling of dynamic soil properties and the effects of wildfire on soil health in California (University of California, Davis); and MIR prediction of hydrologic soil properties in Mississippi and Texas (Mississippi State University).

The intricacies and challenges of soil survey are becoming more pronounced in the face of changing environmental dynamics and heightened demands on the soil resource. While traditional methods have served us well, evolving challenges necessitate innovative approaches. Technological advancements, such as MIR spectroscopy and web-based platforms, offer promising avenues to address these complexities, providing tools that optimize accuracy and efficiency in soil property assessments. Yet, the evolving nature of these challenges demands more than isolated technological interventions; it requires a cooperative research approach that fosters collaboration among experts, stakeholders, and field operators. By combining expertise, resources, and collaborative problem solving, we can better navigate the complex challenges facing soil survey and pave the way for a more informed and sustainable management of our planet's foundational resource.

Reference

Seybold, Cathy A., Rich Ferguson, Doug Wysocki, Scarlett Bailey, Joe Anderson, Brian Nester, Phil Schoeneberger, Skye Wills, Zamir Libohova, Dave Hoover, and Pam Thomas. 2019. "Application of Mid-Infrared Spectroscopy in Soil Survey." *Soil Science Society of America Journal* 83, no. 6: 1746–59. https://doi.org/10.2136/sssaj2019.06.0205.