Spectral Reflectance Measurements for Soil Organic Matter Sensing

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Introduction

Successful implementation of site-specific field management is predicated on adequate knowledge of soil fertility levels within a field. Variable-rate application technology allows for changes in fertilizer and herbicide application in response to spatial variations in soil properties. Measurement of soil nutrient and organic matter levels has traditionally been accomplished through grid sampling and lab analyses. This process is both time-consuming and expensive for the producer. The cost of grid sampling, with one sample collected per 3 acres, is approximately U.S. $3 to $7 per acre (NRC, 1997). Accurate real-time soil fertility sensors have the potential to provide substantial savings over existing methods.

Optical sensors provide several distinct benefits over other means of soil-property sensing. Non-contact optical measurements reduce wear and power expenditure compared to soil-contact sensors, and are non-destructive to the sample material. Optical sensing systems can be implemented using ambient (sunlight) or artificial illumination. Spectral reflectance measurements represent one means of optical sensing.

Spectral Reflectance Measurements

Spectral reflectance is the ratio of reflected radiation to incident optical radiation for a surface. The optical waveband, from approximately 175 nm to 30,000 nm, can be segregated into the ultraviolet (UV) (175 nm to 350 nm), visible (350 nm to 780 nm), and infrared (IR) (780 nm to 30,000 rm) regions. Reflectance measurements generally span the visible and near-infrared (NIR) wavelengths, with a typical measurement range being from 250 nm to 2500 nm. The reflectance at each wavelength is given as the reflectance ratio (% R).

The instrument used for soil reflectance measurements in this research is a dual-beam UV-Vis-NIR spectrophotometer (Cary 5G, Varian Canada Ltd.). The spectrophotometer incorporates an integrating sphere, which allows for diffuse reflectance measurements while excluding the specular component. Reflectance spectra were taken at increments of one nanometer from 250 nm to 2500 nm, with each reflectance value averaged over three measurement cycles.

Agricultural Reflectance Sensing Applications

Spectral reflectance measurements have been applied in many areas of agriculture. Correlations between reflectance and soil nitrate levels (Ehsani et al., 1997) and soil organic matter (Krishnan et al., 1981; Sudduth and Hummel, 1992) have been investigated, with varying degrees of success. Other applications suggested in the literature include discrimination of plants from soil, discrimination of weeds from crop (in progress), defect detection in produce, assessment of cereal grain quality and measurement of meat quality and marbling.

The spectral reflectance of soils is influenced by a variety of factors. The most dominant effects, as discussed by Baumgardner et al. (1986) and Bowers and Hanks (1964), include soil moisture content, the presence of organic matter (OM), the soil particle size and surface roughness characteristics and the presence of mineral oxides. In general, increasing moisture content or organic matter decreases reflectance, while decreasing particle size increases reflectance. The effect of mineral oxides is mineral-specific, depending on the absorption characteristics of the minerals present.

Researchers have identified several reflectance wavebands that appear to be sensitive to soil organic matter levels. Reflectance in the visible region may correlate with existing color comparison techniques for OM estimation, but conclusions about the predictive power of NIR reflectance are often contradictory and require further investigation. Several patents for reflectance-based OM sensors exist, but no working system is currently commercially available. This provides the impetus for further investigations into the development of a real-time reflectance-based organic matter sensor.

Current Research Objectives

The objectives of the current research program are to:

1. review relevant literature and organic matter analysis techniques,
2. establish a spectral database for a variety of Saskatchewan soils,
3. investigate possible correlations between reflectance spectra and soil organic matter content and
4. determine reflectance wavebands with optimal predictive power for soil organic matter.

Materials and Methods

Soil samples have been generously provided by Enviro-Test Labs Ltd. and researchers in the Department of Soil Science, University of Saskatchewan. The samples have already been analyzed for soil nutrient and organic matter content. One set of samples comes from a variety of Saskatchewan fields and soil types, while the other group consists of subsets collected from specific fields. Initial efforts will focus on determining changes in the spectra for varying OM content within the soil from a single field, so that differences in other factors will be minimized. Later, the applicability of the technology to samples from a range of soil types will be investigated.

Several techniques for determining correlations between organic matter and spectra will be examined. Possible methods include statistical regression analysis and procedures such as Partial Least Squares (PLS) and Principle Component Analysis (PCA). The predictive ability and robustness of these methods will be evaluated to determine the technique most suitable for implementation in a working sensor.

Results

Two plots of reflectance spectra have been generated to illustrate the differences between soils. Figure 1 shows the difference between a black soil and a tan soil. As expected, the tan soil shows significantly higher reflectance across the visible range. Figure 2 shows the spectra of two separate samples from within the same field, but with different organic matter concentrations. Also as expected, the high OM (4 %) soil has a noticeably lower reflectance than the low OM (1 %) sample. Further investigation will attempt to determine the best wavebands for predicting organic matter variation.

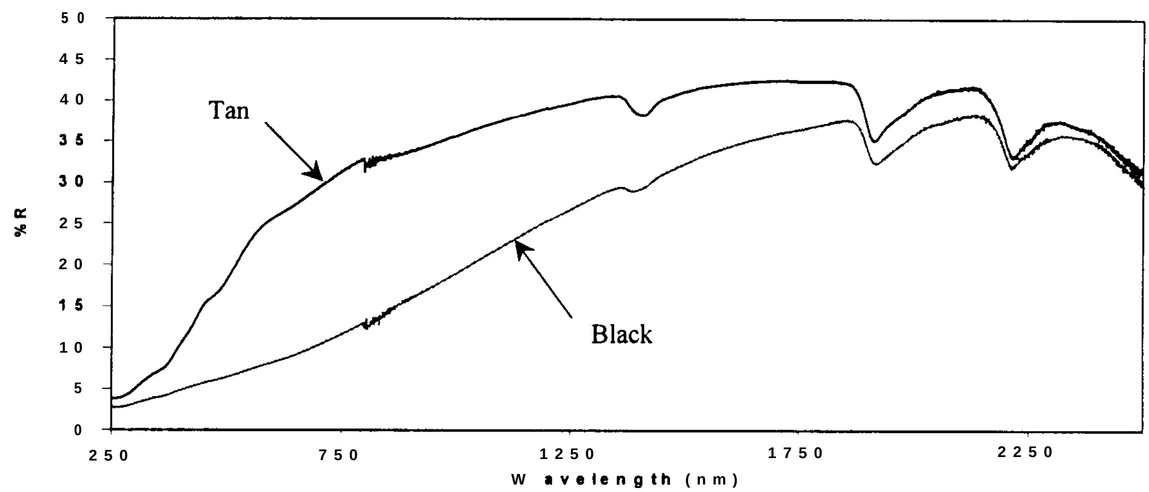

Fig. 1. Reflectance spectra for tan and black soils

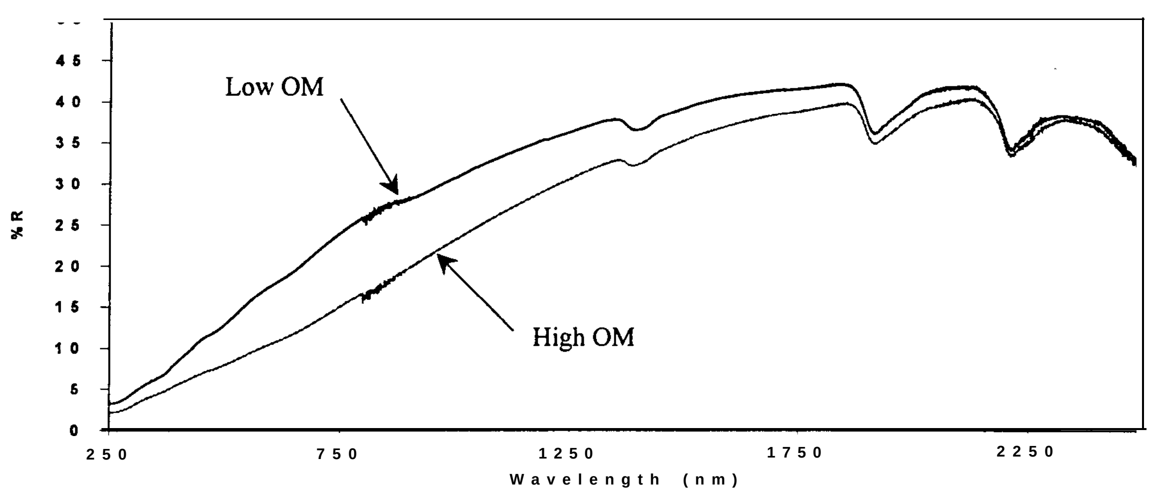

Fig. **2.** Reflectance spectra for high and low organic matter soils

Future Work

Short-term objectives for the research program are to:

1. collect reflectance spectra for a variety of Saskatchewan soils,
2. evaluate techniques for determining correlations between reflectance spectra and soil organic matter,
3. identify the wavelengths or wavebands which provide optimal predictive power and
4. develop a method for organic matter detection based on these wavelengths.

Future directions may be to:

1. investigate correlations between reflectance spectra and soil moisture content, soil nutrient levels (N,P,K) and other soil properties and
2. develop techniques for real-time sensing for these properties.

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