Soilytics, replacing chemistry with physics: hyperspectral infrared imaging replaces testing by loss on ignition organic matter method

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Soilytics: Replacing Chemistry with Physics: Hyperspectral Infrared Imaging Replaces Testing by Loss on Ignition Organic Matter Method

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1. Abstract

The relevance of understanding organic matter in agriculture includes its impact on soil texture, soil bulk density, water holding capacity, soil pH, cation exchange, and microbial biomass. . Currently organic matter is analyzed by the "Loss on Ignition" and "Walkley Black" methods. PDMI (Persistence Data Mining Inc.) is introducing the Soilytics™ solution, our hyperspectral soil nutrient mapping technology. Hyperspectral technology allows for quick and easy soil organic matter testing at a cost-effective rate. This will dramatically improve the efficiency of soil labs, while reducing cost and response times. Not only will this be a huge breakthrough for the soil testing industry, it will serve the precision agricultural market by improving fertilizer application and efficiency. Our technology will help farmers increase crop yields, optimize input costs, and improve environmental protection. Organic matter hyperspectral results are well within the standard margin of error of loss on ignition organic matter analysis between different laboratories and is a cost-effective method to test and make prescriptions for fertilizers application in agriculture fields. Through the use of advanced algorithms Soilytics™ is able to convert hyperspectral reflectance soil data into usable information to serve the agricultural industry. The Malvern Panalyticals ASD LabSpec is used to collect relevant data. Hyperspectral sensors allow us to visually see outside the range of human vision. Focussing on the SWIR (Short Wave Infrared), and VNIR (Visible-Near IR) spectrum have enabled a new advanced methodology to scan and collect data on nutrients and OM (organic matter) in soil. The data had to be analyzed for factors that could impact results based on texture, water content, and geology. The baselined data could then be processed into accurate information. Correlating these results to current lab methods resulted in the determination that the use of the full spectrum resulted in better results since limiting factors on confidence required additional spectral bands to properly baseline. LOI (Loss on Ignition) is the conventional method for organic matter analysis, cost constraints prevent more granular testing which impacts yields and costs. By remote sensing soil samples, we can take many more samples more

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quickly and efficiently. The sample data can then be uploaded directly to the laboratories, which eliminates the cost and delays of shipping samples.

2. Background Concepts and Principles for Organic Matter Detection in Soil

Field studies have shown that organic C (Carbon), total N (Nitrogen), and NO_3-N (Nitrate Nitrogen) have spatial dependence and variation (Cambardella et al., 1994). A spatial dependence between organic C, total N, and NO_3-N exists. Other studies have concluded that N uptake and crop response to N varies spatially within fields (Malzer, 1996; Dampney and Goodlass, 1997).

Soil carbon storage, as the third largest carbon pool in the Earth System, plays an important role in the global carbon cycle and climate change (Lal R, Kimble JM, 2000).

The relevance of understanding OM in agriculture includes its impact on:

- **Soil Texture**: Soil Texture influences the rate of organic matter decomposition. Soils with a high clay content generally have a higher organic matter content, due to slower decomposition of organic matter.
- **Soil Bulk Density**: Soil bulk density is correlated with soil organic matter levels. Soils with a high bulk density are likely to have low organic matter levels and are more prone to nutrient leaching.
- **Water Holding Capacity**: Soil water holding capacity is influenced by the organic matter level in the soil. Soils with a high level of organic matter will hold more plant available water than lower organic matter soils.
- **Soil pH**: Soil pH influences organic matter decomposition. Microbial activity at very low or very high soil pH will influence the rate of organic matter decomposition.
- **Cation Exchange Capacity** (CEC): The cation exchange capacity of a soil is greatly influenced by the organic matter level. A high organic matter soil will have a much higher cation exchange capacity than a low organic matter soil.
- **Microbial Biomass**: High levels of biological activity in a soil require a significant amount of organic matter. Soils with low levels of organic matter will have reduced biological activity.

3. PDMI is introducing the Soilytics™ solution.

Our hyperspectral soil nutrient mapping technology. By shooting the samples, we can take many more samples more quickly and efficiently. The sample data can then be uploaded directly to the Labs, which eliminates the cost and delays of shipping. This will dramatically improve the efficiency of the ASP's (Agronomic Service Providers) and the Labs, while reducing cost and response times. Not only will this be a huge breakthrough for the soil testing industry, it will serve the precision agricultural market by improving fertilizer application and efficiency. This technology will help farmers increase crop yields, optimize input costs, and improve environmental protection.

Methods for detecting OM in soil using hyperspectral sensors.

Though the use of advanced algorithms Soilytics™ can convert hyperspectral reflectance data into usable information to serve the agricultural industry. Malvern Panalyticals ASD LabSpec was used to collect relevant data. The data had to be reduced for factors that could impact results based on texture, water content, and geology. The baselined data could then be processed into useable information. Correlating these results to current methods resulting in the determination that the use of the full spectrum resulted in better results. Since limiting factors on confidence required additional spectral bands to properly baseline.

Hyperspectral technology allows for quick and easy data processing at a cost-effective rate. The sample data can then be uploaded directly to the labs or farm equipment for rapid decision making for proactive farming decisions while eliminating delays of shipping. It will serve the precision agricultural market by improving fertilizer application and efficiency. Our technology will help farmers increase crop yields, optimize input costs, and improve environmental protection.

4. Current methods for testing Organic Matter include:

Loss on Ignition (LOI) - Weigh, burn, weigh
Walkley-Black method (AKA color test)- Uses chromic acid to measure the oxidizable organic carbon. Best in samples below 2% OM
Combustion

The most generally accepted method of LOI has the following procedure:

(1) Determine and record the mass of an empty, clean, and dry porcelain dish ($\mathbf{M_P}$).

(2) Place a part of or the entire oven-dried test specimen from the moisture content experiment in the porcelain dish and determine and record the mass of the dish and soil specimen ($\mathbf{M_{PDS}}$).

(3) Place the dish in a muffle furnace. Gradually increase the temperature in the furnace to 440^0C. Leave the specimen in the furnace overnight.

(4) Remove carefully the porcelain dish using the tongs (the dish is very hot) and allow it to cool to room temperature. Determine and record the mass of the dish containing the ash (burned soil) (**M_{PA}**).

(5) Empty the dish and clean it.

DATA ANALYSIS:

(1) Determine the mass of the dry soil.

$M_D=M_{PDS}-M_P$

(2) Determine the mass of the ashed (burned) soil. **$M_A=M_{PA}-M_P$**

(3) Determine the mass of organic matter

$M_O = M_D – M_A$

(4) Determine the organic matter (content).

***OM* = $(M_O/M_D)*100$ (**Suryakanta, December 3, 2015)

Test method for Walkley-Black Method

(1) Determine the moisture content of the air-dry soil which has been ground to pass through a 0.42 mm sieve. (See Soil Moisture Content P1A/1.) Weigh accurately enough soil to contain between 10 mg and 20 mg of carbon into a dry, tared 250 mL conical flask (between 0.5 g and 1 g for topsoil and 2 g and 4 g for subsoil).

(2) Accurately add 10 mL 1 N $K_2Cr_2O_7$ and swirl the flask gently to disperse the soil in the solution. Add 20 mL concentrated H_2SO_4, directing the stream into the suspension. Immediately swirl the flask until the soil and the reagent are mixed. Insert a 200 °C thermometer and heat while swirling the flask and the contents on a hot plate or over a gas burner and gauze until the temperature reaches 135 °C (approximately ½ minute).

(3) Set aside to cool slowly on an asbestos sheet in a fume cupboard. Two blanks (without soil) must be run in the same way to standardize the $FeSO_4$ solution.

(4) When cool (20–30 minutes), dilute to 200 mL with deionized water and proceed with the $FeSO_4$ titration using either the "ferroin" indicator

or potentiometrically with an expanding scale pH/mV meter or auto titrator. (Department of Sustainable Natural Resources Soil Survey Standard Test Method Organic Carbon)

Test method for Hyperspectral Analysis involves:

The Hyperspectral sensor is a non-destructive measurement. Only homogenization of the 6 or 8-inch core sample is required, this allows for the reuse of the sample.

A contact probe is easily placed on sample or within close proximity (contact is best) and
data is acquired.

Figure 1. LabSpec 4 unit and sensor head (right)

The probe shown in Figure 1 contains 3 sensors that are sensitive in different wavelength ranges that we designate as SWIR1, SWIR2 and VNIR. See Table 1 below for details.

LabSpec 4 Hi-Res Sensor		**Signal-to-noise ratio**	
Spectral Range (Total)	350-2500 nm	**VNIR**	9,000:1 @ 700 nm
Resolution	3 nm @ 700 nm	**SWIR 1**	9,000:1 @ 1400 nm
	6 nm @ 1400/2100 nm	**SWIR 2**	4,000:1 @ 2100 nm
Dimensions (mm?) H x W x D	12.7 x 36.8 x 29.2	**Photometric noise**	
Weight	5.44 kg (12 lbs.)	**VNIR**	4.8 x 10-5 AU or 48 µAU@ 700 nm
Integrated light Source	Lamp 10 VDC, 50 W	**SWIR 1**	4.8 x 10-5 AU or 48 µAU@ 1400 nm

Resolution	3 nm @ 700 nm	**VNIR wavelength**	(350-1000 nm) 512 element silicon array
	6 nm @ 1400/2100 nm	**SWIR 1 wavelengh** **SWIR 2 wavelength**	(1001-1800 nm) InGaAs Photodiode^ (1801-2500 nm) InGaAs Photodiode*
Scanning time	100 milliseconds		*Graded Index InGaAs Photodiode, TE Cooled

Table 1: Specifications of the three sensors used in the LabSpec 4 Hi-Res instrument

PDMI's proprietary algorithm for Organic Matter is a key piece that allows us to isolate soil type, in addition to measuring moisture and a number of other variables. These measurements are critical to extracting the digital signatures of the other nutrients from the hyperspectral imaging data. Once we have these identified these signatures, we can isolate the digital signatures for organic matter to replace current destructive test methods.

5. Methods and Results of Hyperspectral Technology for Organic Matter Detection in Soil to Replace Loss on Ignition Testing (LOI)

Hyperspectral sensors allow us to visually see outside the range of human vision. Focussing on the SWIR and VNIR spectra has enabled a new advanced methodology of scanning nutrients and OM in soil. The use of nondestructive methods for rapid detection promotes environmental stewardship and advanced decision-making tools for profitability.

Testing History:

- Approximately 4000 samples have been tested
- ASD Spectral Reading in lab
- Samples were dried and sieved
- Chemical analysis at KSI labs
- Spectral Analysis post processed

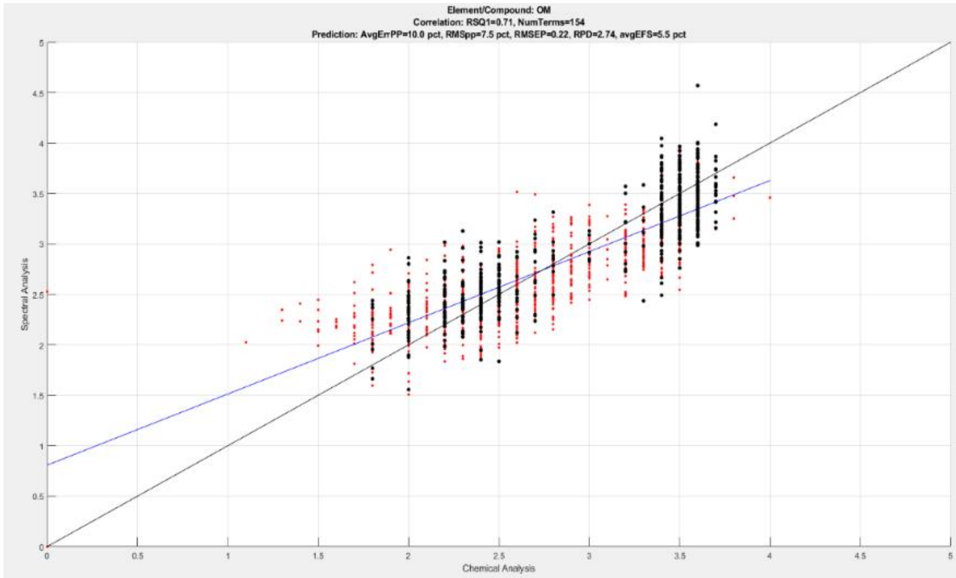
Test Methodology:

- Correlation and Predictions performed on OM, CEC, Spectral Wavelengths measured and used 425-2400 nm
- Correlation process using proprietary normalization and regression techniques
- Correlation performed Spectral vs. Chemical analysis
- Correlation analysis performed on 3500 samples
- Using derived regression model, predict values 500 samples
- Optimize prediction accuracy by adjusting model parameters such as wavelength averaging, selection of optimum terms

Figures of Merit:

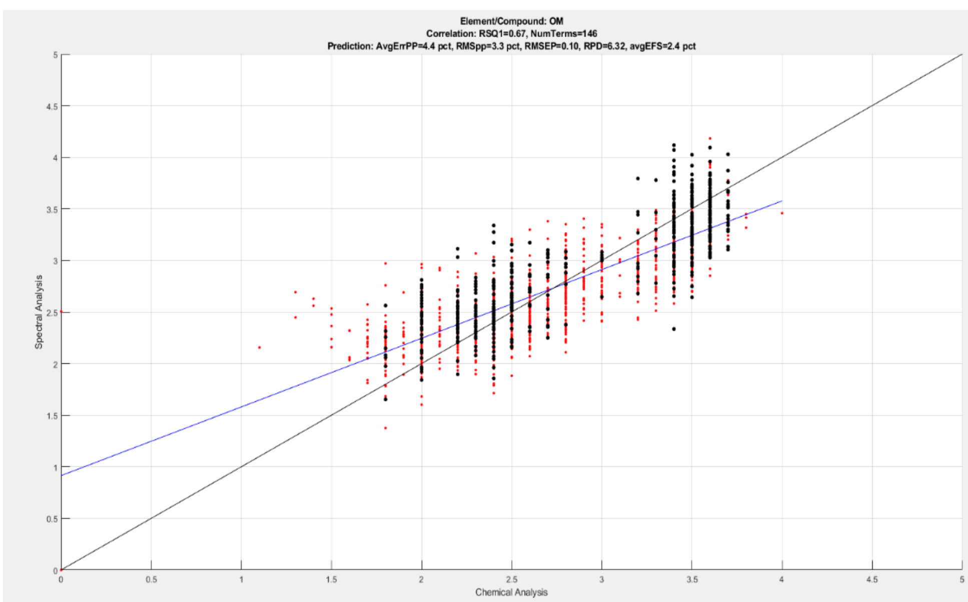
- RSQ — R squared average for model
- RMSEP PctMean — RMSEP as a percent of mean value of the parameter
- RMSEPavg — RMS error for all predictions, in units of the parameter
- RDP — Standard deviation of chemical / RMSEP

Spectral Results vs Walkley-Black Method 425-2400 N



Plots: Red shows model correlation, black shows 500 predictions at range of 425-2400 nm

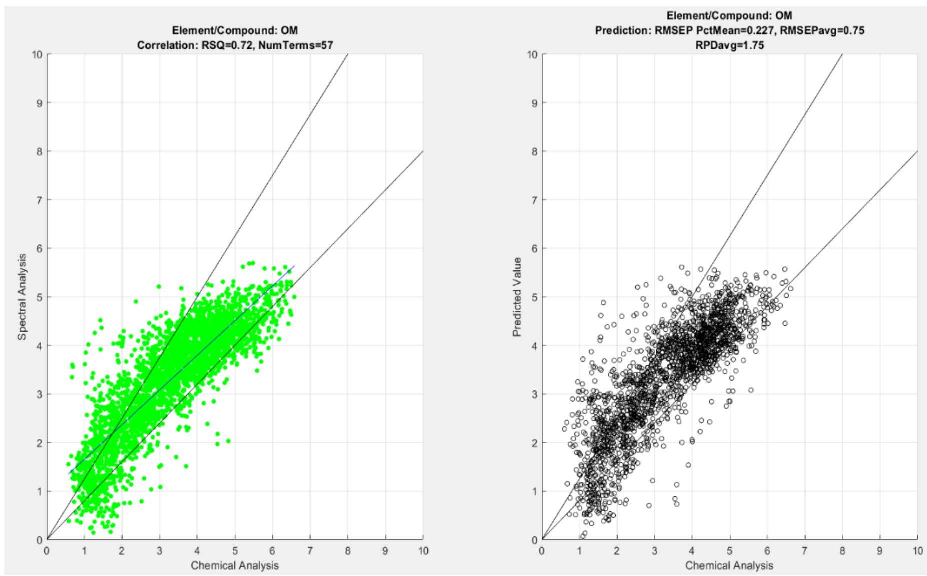
Spectral Results vs Loss on Ignition: 425-1600 nm



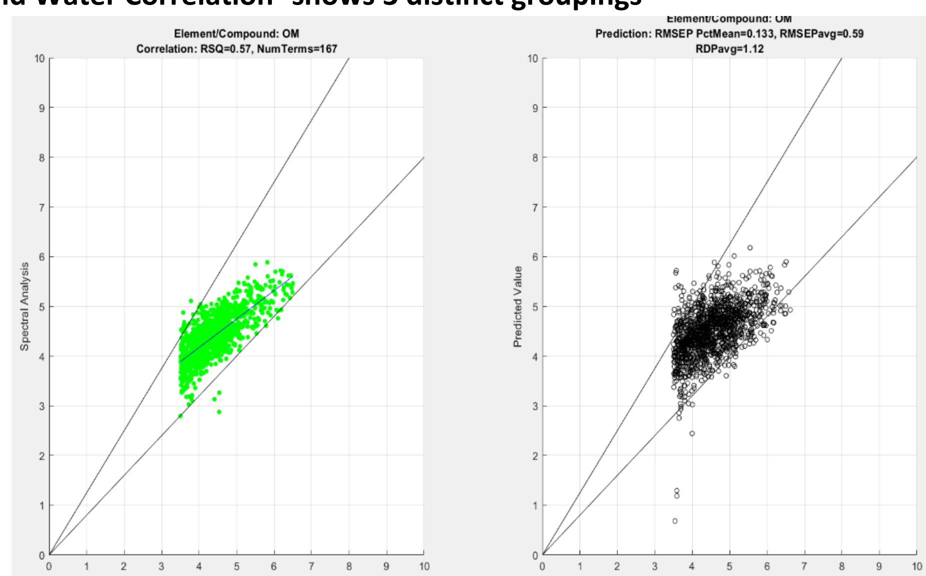
Test Methodology:

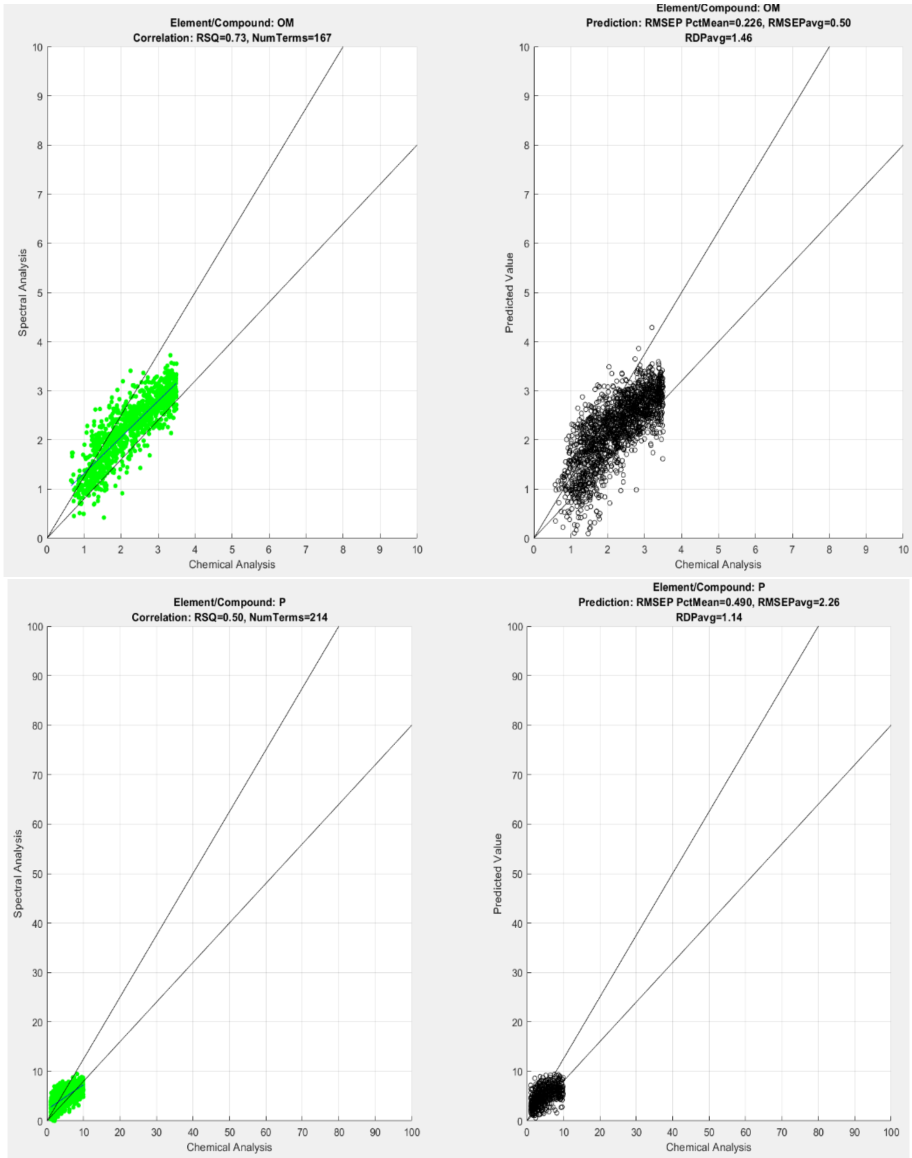
- Correlation and Predictions performed on OM,

- Spectral Wavelengths measured and used 450-2400 nm (VNIR-SWIR)
- Correlation process using proprietary normalization and regression techniques
- Correlation performed Spectral vs. Chemical analysis
- Correlation analysis performed on 3000 samples
- Using derived regression model, predict values 2000 samples
- Optimize prediction accuracy by adjusting model parameters such as wavelength averaging, selection of optimum terms

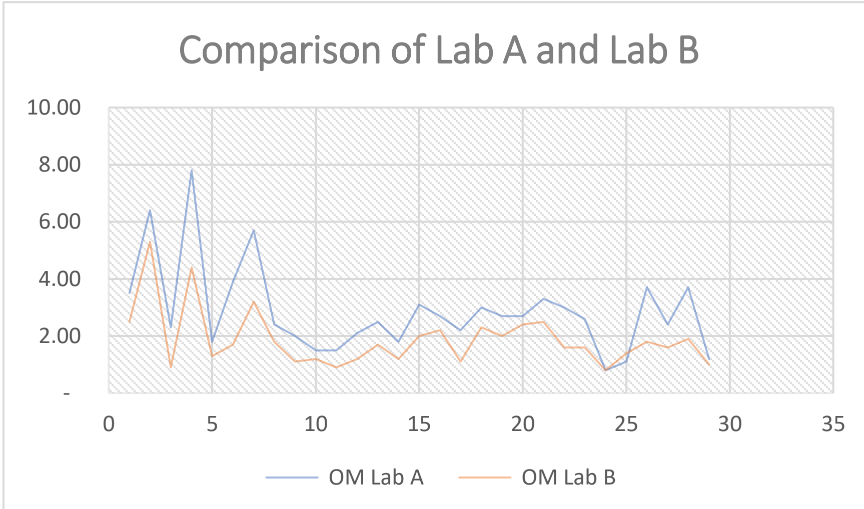


OM and Water Correlation- shows 3 distinct groupings



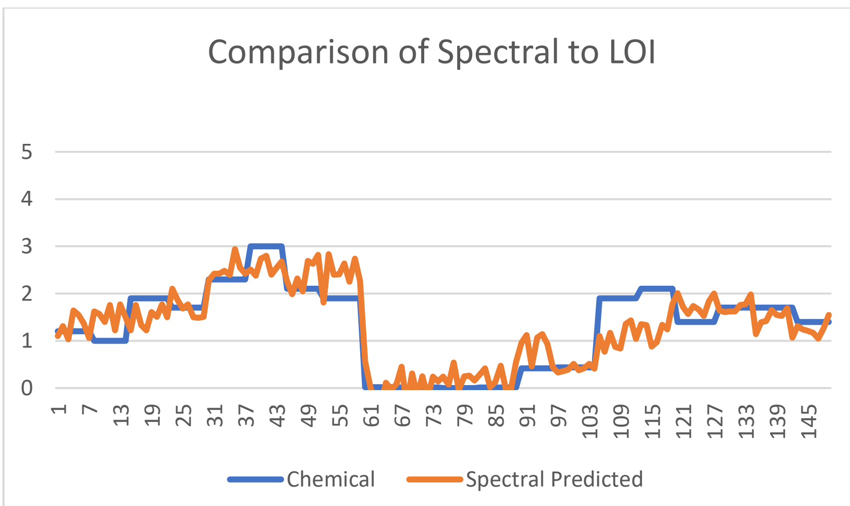

Element/Compound: OM
Correlation: RSQ=0.73, NumTerms=167
Spectral Analysis
Chemical Analysis
Element/Compound: OM
Prediction: RMSEP PctMean=0.226, RMSEPavg=0.50
RDPavg=1.46
Predicted Value
Chemical Analysis
Element/Compound: P
Correlation: RSQ=0.50, NumTerms=214
Spectral Analysis
Chemical Analysis
Element/Compound: P
Prediction: RMSEP PctMean=0.490, RMSEPavg=2.26
RDPavg=1.14
Predicted Value
Chemical Analysis

6. **Comparisons of "Lost on Ignition" test results from Two different Laboratories**



7.

8. **Comparisons of "Lost on Ignition" test results to Spectral Analysis**



9. **Summary and Conclusions:**

PDMI is introducing the Soilytics^{TM} solution, our hyperspectral soil nutrient mapping technology to replace Loss on Ignition and Walkley Black soil lab testing for soil organic matter. Through the use of advanced algorithms Soilytics^{TM} is able to convert hyperspectral reflectance data into usable information to serve the agricultural industry. The data had to be reduced for factors that could impact results based on texture, water content, and geology. The baseline data could then be processed into useable information. Correlating these results to current methods resulted in the determination that the use of the full spectrum resulted in better results since limiting factors on confidence required additional spectral bands to properly baseline. Not only will this be a huge breakthrough for the soil testing industry, it will serve the precision agricultural market by improving fertilizer application and efficiency. Our technology will help farmers increase crop yields, optimize input costs, and improve environmental protection.

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