Evaluation of the visible spectrum to measure plant and soil characteristics

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Introduction

Plant tissue analysis with VIS-NIR has been accepted for more than 25 years. The literature is full of the applications and information regarding the analysis of many constituents by the NIR measurement.

Soil analysis with NIR too has been around for quite a while. In one of the first papers, Bowers and Hanks[1] studied the potential for reflectance measurements to determine soil moisture, organic matter, and particle size of clay fractions. They concluded that soil moisture could be determined from the specific bands at 1400 and 1900. Al-Abbas et al.[2] studied the relationship between multispectral data and soil organic matter and clay content. They developed a regression model that could be utilized to map these soil properties from an airborne multispectral scanner. They used information in the visible as well as the NIR region. Ben-Dor and Bain[3], studying soil characterization of several soil properties concluded that the VIS-NIR spectral region could be used to characterize calcium carbonate, iron, aluminum, silica, potassium, loss on ignition, and free iron oxide. Even though these measurements were not as accurate as the laboratory reference measurements, they were accurate enough for rapid soil characterization. Couillard[4] concluded that VIS-NIR accuracy to predict several soil characteristics in undisturbed soil profiles gave better results than in dried and ground samples. She measured, among other constituents, organic matter, sand, silt, clay, P, and Mg, and total N.

The theory is simple as to why these measurements are successful in both plant and soil material. It is shown with the following two figures containing the spectra of a single wet and dry plant sample and a wet and dry soil sample. Figure 1 shows the spectra of wet and dry grass. Figure 2 shows the spectra of wet and dry soil. In general the plant spectra exhibit more character and peaks than the soil spectra. In the visible region, the grass's green color versus the soil's light brown color provides a major contrast. In the near infrared region, both the plant and soil spectra have major peaks at 1440 nm and 1930 nm for OH or moisture. The dry ground grass sample gives us the familiar spectrum that is used to measure protein, fat, fiber, ash, and moisture for the feed and food industry.

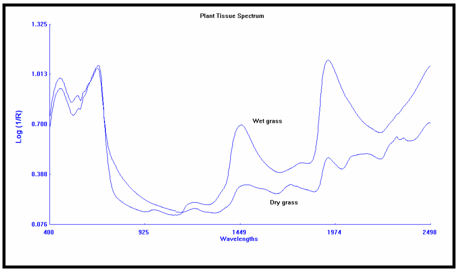

Figure 1. Wet and dry grass samples scanned from 400 to 2498 nm.

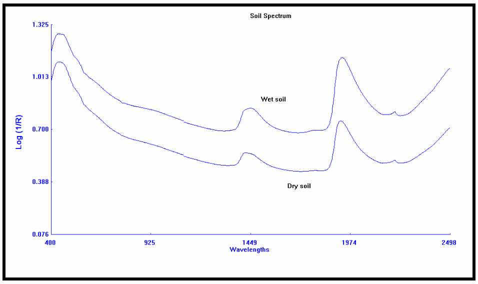

Figure 2. Wet and dry soil samples scanned from 400 to 2498 nm.

To obtain some insight as to what and how well important soil parameters can be measured with the VIS-NIR spectrum, I have included Table 1. from Andree Anne Couillard's thesis.[4] These samples were taken from the soil and thatch in turfgrass plots. The spectra was collected with an NIRSystems 6500 and the laboratory reference values were obtained by Andree Anne or the Pennsylvania Soil Testing Laboratory

Table 1. Accuracy for the undisturbed and dried-ground samples of soil

	Undisturbed			Dried-ground		
	N	SEC	R^2	N	SEC	R^2
Moisture	91	2.66	0.89	91	0.18	0.62
Organic matter90	0.64	0.88	91	0.85	0.74	
Density	94	0.11	0.80	95	0.10	0.84
Sand	50	2.43	0.79	46	1.39	0.92
Silt	50	2.23	0.76	48	1.56	0.87
Clay	49	0.42	0.76	49	0.44	0.76
pH	47	0.11	0.84	49	0.10	0.87
%P	46	17.46	0.81	46	20.05	0.74
%K	47	0.17	0.85	46	0.14	0.87
%Mg	48	0.36	0.44	48	0.38	0.36
%Ca	50	4.55	0.05	48	2.51	0.71
CEC 48	3.41	0.11	47	2.30	0.61	
Total N	48	0.04	0.29	48	0.05	0.16
Total C	47	0.90	0.34	48	1.06	0.29

Given this very general guide of what may be possible to analyze with the VIS-NIR spectrum, it would seem that there are a number of soil parameters that could be analyzed accurately enough to be useful. However, with a few exceptions, soil analysis with VIS-NIR has not caught on. Part of the reason is that soil scientists are not trained in VIS-NIR analysis. Second, to make the technology useful for precision farming or some other type of intensive agriculture production enterprise, the analysis needs to be taken on site where the decisions are to be made.

To explore this possibility, ISI has been conducting preliminary testing and evaluation of the visible region of the spectrum to make both plant and soil analysis for the turfgrass industry. The reason for using the visible region is that visible instruments cost less than NIR instruments. Below is a graph of the possible measuring capability of a low cost instrument that may be able to make acceptable measurements for parameters that are import to the golf course industry, Figure 3.

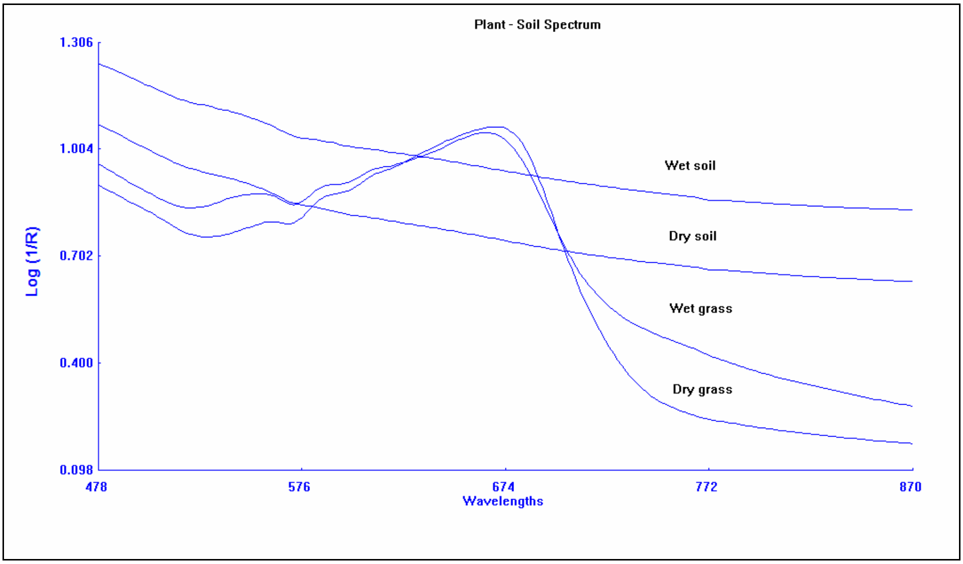

Figure 3. Displayed are the visible spectra of wet and dry samples of grass and soil. The plots extend beyond the visible but this entire region can be measured with a tungsten source and a silicon detector.

The devise we used was a S2000-TR instrument manufactured by Ocean Optics of Tampa, Florida. It uses a diode array that can measure this region of the spectrum in less than a second. By mounting the instrument on a platform with wheels, the system can be used to scan a golf course. An 18 hole golf course can be scanned in 2 hours. The procedure is to go from the tee to the hole in the center of the fairway and then around the green to the outside. This provides fairway and greens scans for each hole.

The instrument was calibrated with ISI software for moisture, nitrogen and appearance. The calibrations are very preliminary and their accuracy is now under investigation, Table 2. To give you some idea what the data looks like, Figure 4 shows the variation of moisture, N, green/brown, and yellow/blue over a 400 yard fairway.

Table 2. Calibration and cross validation statistics (SECV) for turfgrass.

Turfgrass	N	Mean	SECV	RSQ
Moisture	91	68.4	1.01	0.94
Nitrogen	34	5.6	0.33	0.84
Green\Brown	29	8.5	0.18	0.85
Yellow\blue	32	5.4	0.21	0.82

SECV = standard error of cross validation
RSQ= R squared.

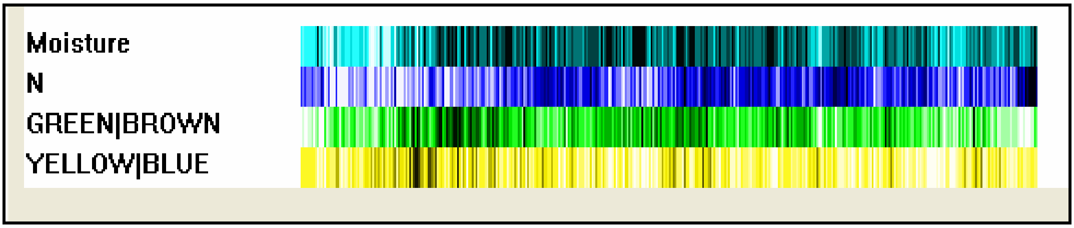

Figure 4. Display of the 4 parameters measured on a golf fairway by a VIS monochromator. The scanning distance was more than 400 meters. The dark areas are high values and the light areas are low values.

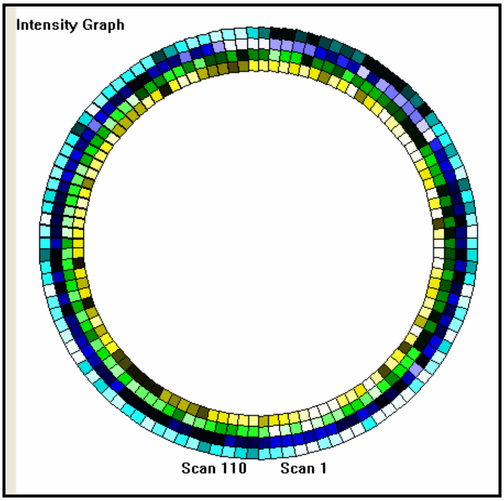

Figure 5. Display of the 4 parameters measured on a golf green. The distance around the green was more than 150 meters. The dark areas are high values and the light areas are low values.

This research and development effort on golf courses is only in the exploratory stages. Adding soil analysis with a fiber optic probe was used to study soil moisture, Table 3. If it is possible to make acceptable measurements of these parameters in the turf plants and soil, the savings to the golf course industry in water and nutrient management will be substantial.

Table 3. Calibration and cross validation statistics (SECV) for soil moisture.

Soil	N	Mean	SECV	RSQ
Moisture	57	15.8	0.78	0.98

SECV = standard error of cross validation
RSQ= R squared.

Turfgrass is not the only area where this type of equipment could be applied, and it provides a good example of how to obtain down-to-earth measurements of important constituents to aid in water and nutrient management. Other industries that could benefit would be small grain analysis in the early stages of plant growth, pasture management, and many more.

The use of plant and soil analysis with VIS-NIR spectroscopy with remote on-site devises has only just begun. This paper very briefly covers the theory of the measurement and some actual applications. The real value of the VIS-NIR analysis method will only reach its full potential when it leaves the laboratory and goes to the field. That is where the measurement and decision making need to be combined into smart systems to make practical use of this analytical method.

References:

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2. A. H. Al-Abbas, P. H. Swain, and M. F. Baumgardner. Relating organic matter and clay content to the multispectral radiance of soils. Soil Science **114**, 477-485 (1972).
3. E. Ben-Dor, and A. Banin. Visible and near-infrared (0.4-1.1) analysis of arid and semiarid soils. Remote Sens. Environ. **48**, 2612-274 (1995).
4. A-A. Couillard, Thatch biodegradation and characterization using Near Infrared Reflectance Spectroscopy. Thesis, The Pennsylvania State University, The Graduate School, College of Agriculture Sciences (1996).