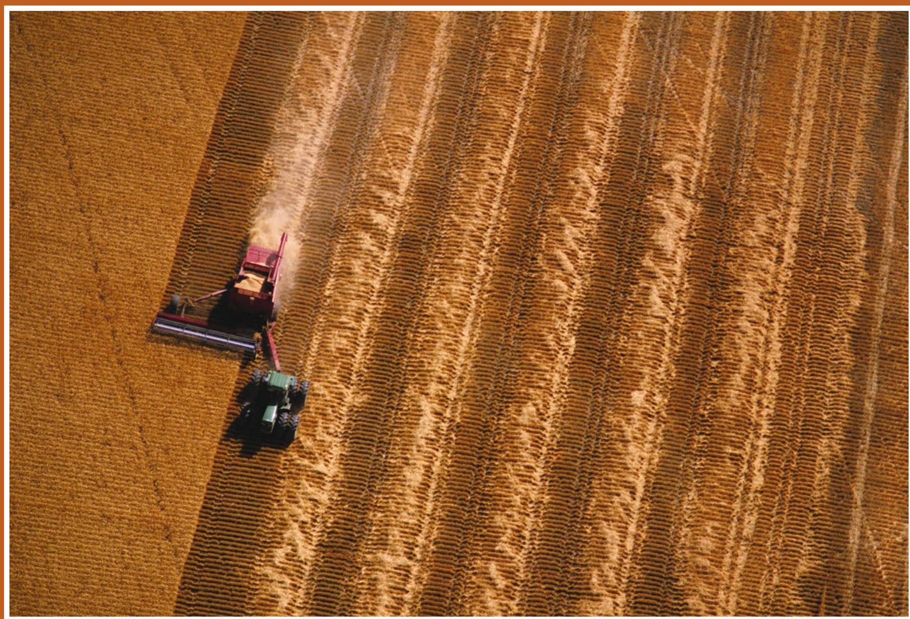
Spectral Imaging
Finds a Place on the Farm

With the lower cost of components — and the increased pressures of globalism — remote spectral imaging is becoming a viable agricultural tool.

by Brent D. Johnson, Senior News Editor

It has been said that astronomy is the surest proof of human mind because we can never expect to benefit materially from it. On the contrary, the spectrophotometric devices that reckon the atmospheric chemistry of distant planets and stars are finding applications here on Earth. Sophisticated airborne and space-based imagers from NASA, such as Aviris, Hyperion and Advanced Land Imager, are enabling precision agriculture.



Remote spectral imaging enables farmers to target specific areas that are experiencing stress, potentially boosting yields while lowering costs.

"Precision agriculture is farming by the foot and not by the field," said Rodney McKellip, Ag20/20 manager in NASA's Earth Science Applications Directorate at Stennis Space Center in Mississippi. Using hyperspectral, multispectral and infrared imaging, he explained, farmers can identify areas that are experiencing water, nitrogen or micronutrient stress, and can target their relief.

Different techniques

The terms "multispectral imaging" and "hyperspectral imaging" sometimes are used interchangeably, but the techniques are quite different. A multispectral imager produces an image for each of a number of discrete and relatively wide bands, and a hyperspectral imager is more like a laboratory spectrometer. It produces images over a contiguous range of narrow spectral bands and enables the spectroscopic analysis of data.

For example, the SAMRSS airborne multispectral imager from Opto-Knowledge Systems Inc. of Torrance, Calif., covers the 550-, 660- and 850-nm, and 7- to 14-µm bands, simulating Landsat bands 2, 3 and 4. This system sports three 1k × 1k-pixel cameras from Dalsa of Waterloo, Ontario, Canada, and two frame grabbers from BitFlow Inc. of Woburn, Mass.

The trick, said Opto-Knowledge's president, Nahum Gat, is to synchronize the cameras and the frame grabbers down to ±0.5 of a pixel so that the fields of view overlap. Without synchronization, one camera could be in the middle of exposing a frame while another is finishing, resulting in three unregistered pictures of the same target area because of aircraft motion.

Software corrects any remaining misregistration due to alignment of the optical axes of the camera. A mid-IR camera from Indigo Systems Corp. of Santa Barbara, Calif., also has been registered to the multispectral images, using software that accounts for the different pixel size of the thermal imager.

Opto-Knowledge's Avnir hyperspectral imager measures 60 bands in 10-nm increments between 430 and 1012 nm. It essentially is a high-speed, thermoelectrically cooled, back-illuminated CCD camera with an imaging spectrograph mounted on the front. Apochromatic optics,

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corrected for the full visible and near-IR spectral range, eliminate chromatic aberration.

Gat said that the hyperspectral system is critical because it can provide information about plant physiology. When coupled with radiative transfer models, Avnir allows the user to characterize the spectral signature of plants and to determine whether they are healthy or under stress. The company also has developed a 900- to 1700-nm sensor, but it has not yet been used in precision agriculture.

SAMRSS and Avnir fly together on a Cessna at 5000 to 9500 feet. The airborne approach gives them the flexibility to image at specific times when a crop is at key growth stages. "Timing is everything," McKellip said. The spatial resolution for the airborne system is 1 meter, and the results of the flight screening are available within 24 to 48 hours, enabling nearly real time decisions about growing conditions.

Extracting plant signatures from a signal poses a significant challenge. The sensors receive both reflected and emitted light from the ground. Signal processing is required to extract the desired signature, including sensor calibration, atmospheric compensation and aircraft attitude corrections.

Sensor calibration converts the raw signal into engineering radiance units. Atmospheric compensation accounts for the solar spectrum, solar slant angle, atmospheric constituents, such as CO_2, humidity, aerosols and other species that affect light passing through the atmosphere. Aircraft attitude correction registers the imagery with the geographical coordinate system. Finally, the data are converted into a form that the farmer or the crop adviser can use to make decisions on crop management.

Many of these steps currently require manual intervention, but the trend at Opto-Knowledge is toward full automation of the process. "From an engineering standpoint," Gat said, "there is a tremendous amount of effort that goes into this."

The hyperspectral images obtained give growers a tool that allows them to manage field conditions. The information can be fed into a digital controller and, using the global positioning system for navigation, tractors can be guided to problem areas — where they can distribute nutrients or pesticides within 3/4 in. of where they are needed.

Precision on Sheely farm

The Sheely farm in California's San Joaquin Valley, the largest and most intensively used agricultural land in the country, is one of a number of test sites for the Ag20/20 program, supported by NASA, the US Department of Agriculture and the National Cotton Council. Several precision agriculture applications — geared mainly to cotton — are being explored on the farm, including irrigation scheduling, nutrient application, soil remediation, insect detection, growth control and yield predictions.

The Sheely farm is one of several sites testing precision agriculture techniques as part of the Ag20/20 program. Here, Gordon Scriven of Opto-Knowledge Systems Inc. collects hyperspectral data on the ground that will be used to validate airborne measurements of the cotton fields.

Ted Sheely has been using the Opto-Knowledge hyperspectral/multispectral system for two growing seasons to farm a seven-acre plot of cotton, tomatoes, garlic, wheat and pistachios. Multispectral, thermal and hyperspectral systems image the fields weekly during the growth season. Flight planning affords the flexibility to reschedule if cloud cover is a concern on a particular day.

One problem in California is an increased level of soil salinity because of irrigation practices, eventually causing the soil to become barren. The application of gypsum compensates for salinity, preventing damage. On Sheely's farm, remote sensing detects specific areas of high salinity in the field, enabling the targeted distribution of gypsum. Without this information, he would have to apply the mineral uniformly over the field — depositing too little where it is most needed

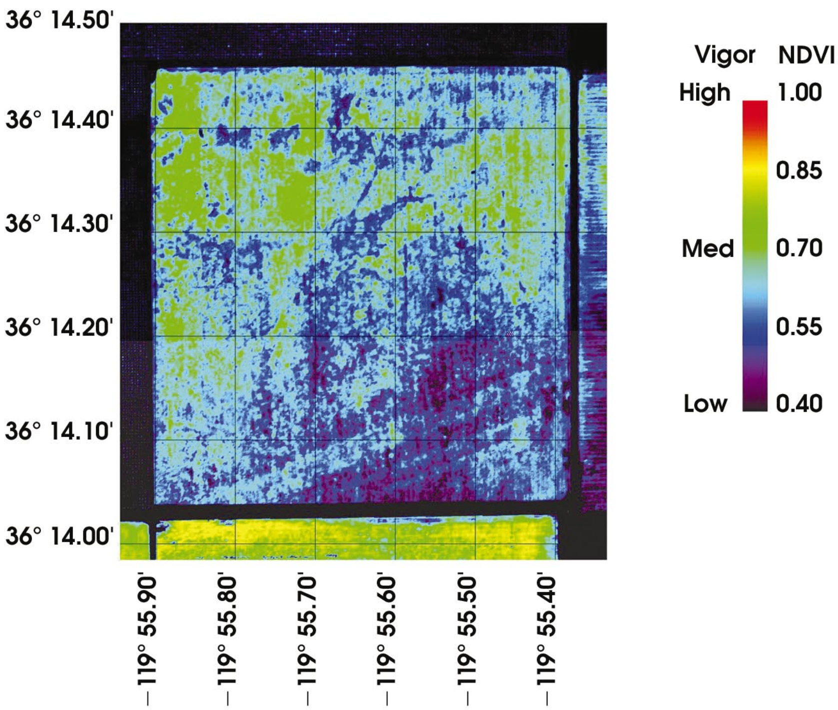
and too much where it is not.

The technique has also allowed the farmer to cut back on the use of nitrogen fertilizer and growth regulators. For example, he used to apply 8 oz of plant growth regulator per acre. Based on the remote sensing data, he now uses 1 lb in some places and none in others, producing higher crop yields at a lower cost.

Pest control

Researchers hope that remote sensing also will help them to identify the conditions that make crops susceptible to insect infestation. In California, spider mites turn plant leaves a bronze color. The spectra of the afflicted plants should indicate these "hot spots."

But experiments have successfully predicted even the potential danger of spider mites, identifying where cotton is most likely to produce an infestation before it does. Dust catching in the mites' webs, for example, causes a minute change in the spectral reflectance of a plant.



A hyperspectral image of a field indicates the relative health, or vigor, of the plants, based on their normalized difference vegetation index (NDVI). Healthy plants absorb more visible light and reflect more infrared than do unhealthy plants.

Early indications show that remote sensing — hyperspectral imaging in particular — can distinguish the signatures of healthy and infested plants to allow intervention before there is significant damage, promising a savings of up to 20 percent in labor and pesticides.

A Mississippi team supported by NASA uses remote sensing to detect lygus bugs. These pests also feed on cotton, causing damage to the buds and the bulbs of developing flowers. Airborne or satellite imagery can identify the lush areas in a field that are preferred by lygus bugs to predict where the pests may be. The team hopes to use the technique to identify aphids, white flies and thrips, which damage seedlings.

Water conservation

Irrigation management has been a major focus of the program. The entire San Joaquin Valley relies heavily on irrigation. Because one or two cycles of irrigation can cost tens of thousands of dollars, farmers and agrobusinesses are keen on a different approach. "If you can time irrigation to optimize water use, that has tremendous implications," McKellip said.

Steve Maas of Texas Tech University in Lubbock was involved with Opto-Knowledge as a project leader at the Sheely farm. An aerospace engineer who has found a home in agricultural and environmental studies, he is building a multispectral imager for thermal wavelengths that will indicate the water status of the plant canopy by measuring the temperature of the field. The bands between 1500 and 1900 nm are good for detecting water absorption, which would help determine the status of the vegetable canopy.

Maas said that the price of high-performance CCDs and research-grade digital cameras has fallen significantly, making them suitable for this multispectral work. Faster computers with PCI buses can now handle the throughput from these devices, which is typically in the gigabyte range for a single scan.

Competitive edge

As improvements in software, automation and sensor technology continue to make remote sensing more accessible, multispectral and hyperspectral remote imaging will play a greater role in agriculture. This is significant for a farmer seeking to compete in today's global markets, Sheely said.

"I do not have cheap land or cheap labor, and I have the strictest environmental regulations in the world. The only edge that the American farmer has against the world economy is technology." □

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Variable Rate (VR) application of chemicals based on remote sensing data reduces production costs and limits environmental hazards

OKSI's overall goal is to help growers reduce production costs, increase yield and produce quality, and improve compliance with environmental regulations. OKSI's technology was demonstrated under NASA's Ag.20/20 project in California's San Joaquin Valley

OKSI provides technology and consulting services in the use and development of remote sensing programs for precision farming and spatially variable crop management.

OKSI designs, develops, and operates the sensors and instrumentation required for the implementation of precision farming programs and plant health monitoring.

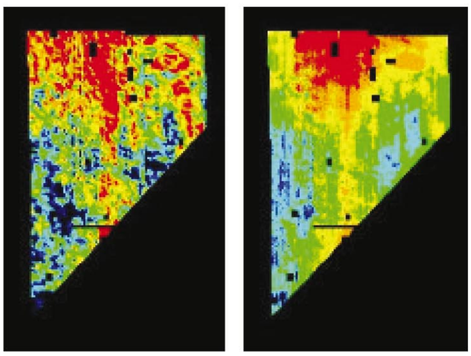
The capabilities cover the range from

- Airborne sensors and instrumentation
- Ground support instrumentation
- Spaceborne imagery analysis
- Software tools
- Prescription maps for use in ground and aerial spray controllers
- Instrumentation for instantaneous fruit monitoring before and during harvesting.

Airborne Sensors provide a georeferenced image map of a field allowing very accurate mapping of crop health stress conditions

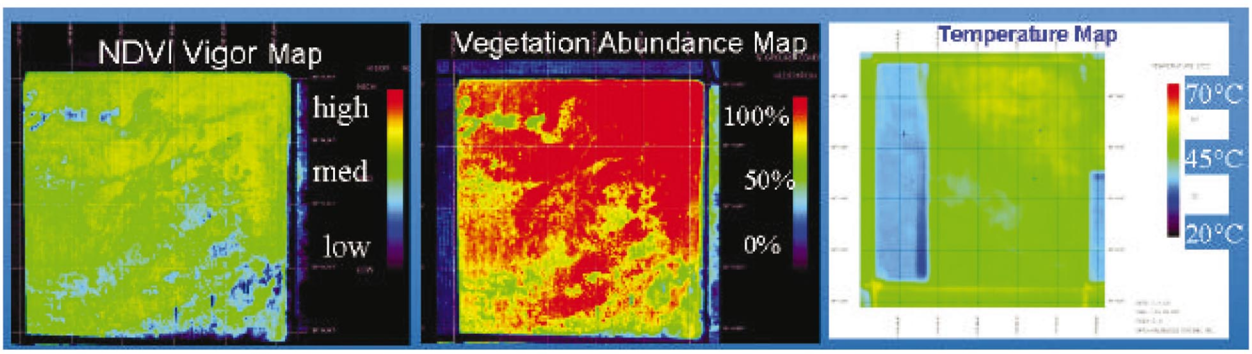
Ground Truthing Activities
Infield research has used to calibrate & validate air- and space-borne remote sensing data

YIELD PREDICTIONS



Actual yield map (October 2001) | Predicted yield map (July 2001)

Rapid Data Delivery to Growers
Web based data delivery within 24 hours of flight. Examples of full farm management data archiving at **www.ag2020.net**



Irrigation scheduling by crop health mapping. A suite of data products allow growers to optimize irrigation scheduling to reduce costs and increase plant health