Remote Sensing and Precision Agriculture: Ready for Harvest or Still Maturing?

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Introduction

With almost $90 billion a year in crop values, agriculture represents a commanding segment of the United States economy. In an era when large tracts of land are managed by agricultural conglomerates, small local farms still provide a cumulative total to the overall production picture. However, with many of the nation's lands being taken out of production, especially in rapidly developing regions, farmers are being asked to produce more on less acreage. In addition, farmers are also realizing reduced profits for many crops and an increased dependence on subsidies and price supports. These factors, combined with the constant variability of weather conditions, have growers constantly watching for technological solutions that may effectively enhance crop management without being cost prohibitive.

In recent years, the expanded use of the Global Positioning System (GPS) has given rise to agricultural advances in spatial data management that have revolutionized the way many growers manage their fields. It is not uncommon for a farmer to head to the field with a spreader or combine equipped with a GPS system that records positional information related to variable rate distribution or yield at harvest for his farm (figure 1). For many farmers, the ability to use this type of information to monitor yields and pinpoint areas for fertilizing using variable rate methods defines precision farming. Many growers use this information for trend and site-specific field analyses with the assistance of farm management systems. Farm management systems are essentially geographic information systems with sub-routines tailored to the activities of farming. As GPS and farm management information systems gain in popularity, it would seem logical that the intense management of agriculture also lends itself to remote sensing.

Remote Sensing and Agriculture

With the exception of monitoring on a global scale, remote sensing has not historically enjoyed extensive popularity as a major tool in farm management. Remote sensing, traditionally used in government and academic institutions for research and global monitoring, has done little to help the soybean farmer in eastern Virginia with a bad center pivot system. In fact, beyond the interesting images, most farmers do not begin to understand what remotely sensed data is telling them or how it can help them. Until very recently, the technology has not been available at either a price or a format acceptable to maintain a profit margin for the majority of growers. The word "profit" is important here. Anyone who has worked to bring remote sensing or any other technology to farmers knows that if it costs too much and appears too good to be true, you are wasting your time. As one farmer put it, " I can stand on my combine and see where my irrigation is failing." Money invested in a crop must break even or show a return for it to be of interest to the farmer. Once more, farmers must feel comfortable with their expertise and understanding of what exactly the data are conveying to them and how it will increase yields and profits.

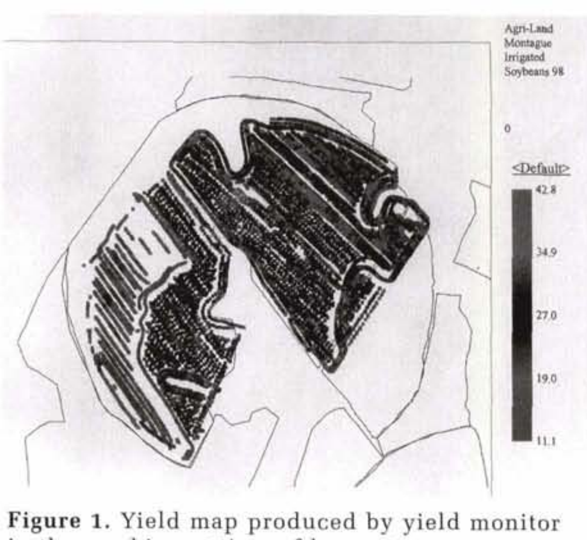

Figure 1. Yield map produced by yield monitor in the combine at time of harvest.

In all fairness, some farmers are not completely taken by surprise when shown a remotely sensed image of a field or series of fields. For years, the USDA's National Resource Conservation Service (formerly the Soil Conservation Service) has used color, black and white, and infrared photography in county soil surveys. However, the trend with regard to agriculture in both multispectral and emerging hyperspectral airborne and satellite remote sensing technologies is to demonstrate and oversell the capability while discounting the steep learning curve. This trend is unfortunate and must be discouraged if remote sensing is to be successful in the day-to-day management of agriculture. Remote sensing technology integrated into precision agriculture represents the most promising new frontier for the technology since applied environmental resource monitoring was initiated with Landsat in the early 1970s.

Remote Sensing – What Is Needed?

With almost 50 years of research in remote sensing devoted to plant stress and vegetation growth mechanisms, it would seem logical for the technology to have a ready-made role in precision agriculture. Important findings by researchers such as Gates (1965), Collins (1978), and Rock et al. (1988) into plant growth and detectable stress mechanisms have laid the groundwork for algorithm-based "products" that could be integrated into precision agriculture. Any grower will tell you that the earlier in the growing season he or she can get cues to a problem in a particular field, the better the chance for mitigating adverse circumstances. So, the first requirement for a marketable remote sensing technology is the delivery of data possessing high temporal fidelity. In many situations, this means that data and products must be acquired, corrected, processed, and shipped to the farmer within 24 hours of a mission.

For crops entering critical growth stages or under stressed conditions, the current suite of commercial satellites is inadequate. In fact, one recent survey found less than 25% of the critical parameters needed by growers could be derived using present commercial satellite data (Servilla 1998). The need for timely data at a regional scale may only be addressed by local companies using airborne technologies. For example, many of the problems associated with improving temporal fidelity have been addressed by groups such as the USDA's Remote Sensing Research Unit in Weslaco, Texas using small-format multispectral remote sensing on fixed-wing aircraft. These systems are inexpensive and effective in delivering data in a flexible and "on-demand" way. At Virginia Commonwealth University, flexible small-format sensing is being used to study and develop local models tied to yield and nutrient application (Anderson and Taliaferro 1998).

Flexibility in precision agriculture is important. For example, crops, such as winter wheat, have specific growth phases. Given the ever-present anomalies offered by the weather, information for timing fertilizer application is critical. Just as important is the examination of field uniformity once the nutrient application is made. In the timely delivery of these data, the Internet makes possible the mechanism for effective farm management using remote sensing. In fact, many companies are experimenting with, and taking advantage of, the World Wide Web to deliver many types of analytical products to farm customers.

The second requirement of a marketable remote sensing technology for agriculture is high spatial resolution. Many farmers already familiar with large-scale color infrared photography appear more comfortable with interpreting data that possesses pixel resolutions at least 2 meters ground sample distance for fields around 100 ha. (250 ac.). Even for large operations, resolutions should not exceed 5 meters for fields greater than 200 ha. For effective crop management, many spatial attributes involving the canopy (silking in corn and herbivory at the edge of a field for example) can be detected early and monitored at these high resolutions. Another benefit of higher resolution data is that it affords many growers the opportunity to integrate remote sensor data into farm management systems through geometric rectification. In situations where image data are un-rectified, higher spatial resolution permits the user to perform correction functions quickly when reference points associated with fields can be clearly identified. Exceptions for high spatial fidelity exist to an extent with crops such as tobacco where many small plots are cultivated over very large regional areas (Universal, 1999). In this case, satellite remote sensing has been proven highly effective and cost beneficial.

Finally, a third requirement of remote sensing integrated into precision agriculture is high spectral resolution. Spectral information about a field has the potential to deliver the grower the most valuable data obtainable, particularly if these data are acquired at scheduled, critical times during the growing season. It has been demonstrated in recent research that narrow bands (< 25 nm wide) harbor more information regarding the changing spectral attributes for vegetation than do wider spectral bands (see Carter 1994 and Chappell et al. 1992). In addition, correct band configurations are essential in monitoring both the chlorophyll (chemistry) side of the crop as well as the tissue morphological

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(biomass) side of the crop. The dramatic differences can be seen in figure 2 for soybeans growing in eastern Virginia. Each image presents information that the farmer needs to consider in decision making with regards to nutrients and irrigation.

Remote Sensing System Considerations in Precision Agriculture

Effective use of multi-temporal, multispectral information for precision farming requires modeling the radiometric effects of the imaging system. Where trend data will be used for predictive modeling, radiometric effects will become very important when data are generated by small format remote sensing systems. Any systematic or physical mechanism that alters the digital numbers within an image in a non-uniform way would be detrimental to results derived from that imagery. Three of the major sources of radiometric effects on multispectral digital camera systems are inadequate system calibration, bi-directional reflectance distribution function (BRDF), and short-term temporal change. Radiometric parameters such as detector linearity, uniformity, and stability should be determined periodically, ideally before and after each flight. Two radiometric effects related to instrument calibration are cosine field darkening and vignetting. Cosine field darkening is a radial effect that results in off-nadir CCD elements receiving less energy than if at nadir. For digital camera systems this effect is normally a function of $\cos^3$ of the view angle. Vignetting also radially reduces energy incident on the CCD, and is caused by the blockage of light by lens walls and mounts, particularly at large aperture settings. A comprehensive review of radiometric evaluation for multispectral systems can be found in King (1992).

The causes and effects BRDF have been studied for a vast number of systems and environments. BRDF is particularly important for precision farming applications where agricultural information such as yields, biomass, and turgidity are derived from spectral indices. A frequently cited example is that of stalk-type crops such as wheat or immature corn. These crops exhibit a reflectance minimum at nadir, with increasing reflectance as view angles become larger. This effect is especially prevalent with large field-of-view systems, and compensation becomes very important if the BRDF function is not constant over wavelength (see Deering 1989). If the BRDF effect is a function of wavelength, information derived from spectral ratios will be compromised (figure 3).

The last radiometric concern noted is brightness shifts between imagery frames caused by changing

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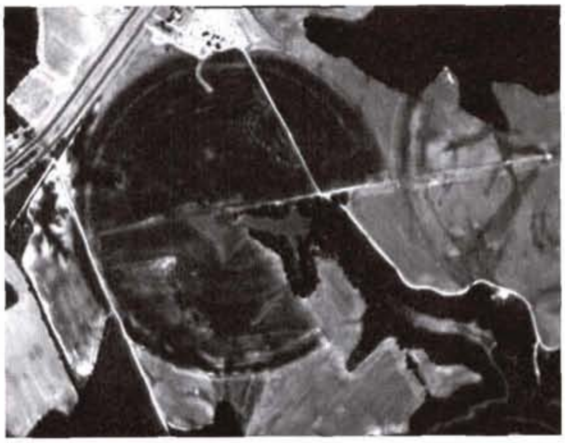
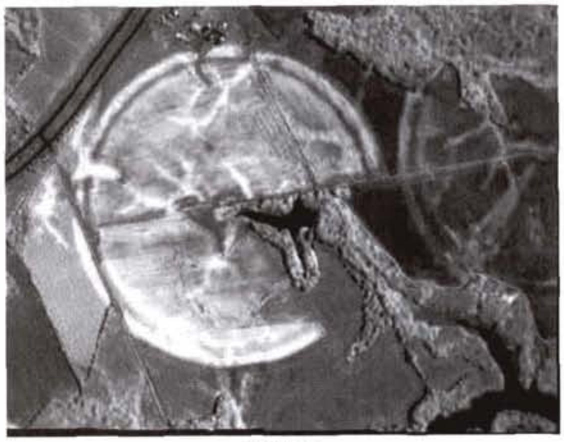
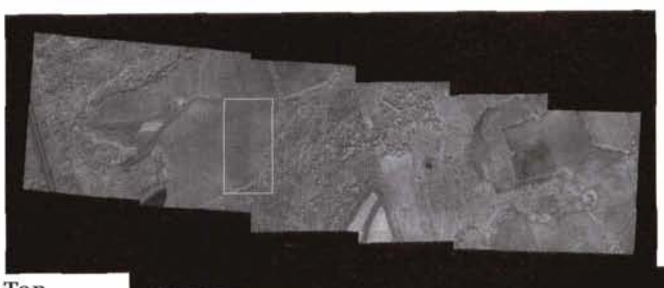


680nm



770nm

Figure 2. The left image, acquired at 680 nm (chlorophyll absorption) and the right image, acquired at 770nm (infrared reflectance of the plants) presents soybeans at the peak of the growing season. A region of stress is indicated by the box in both scenes. Image courtesy of Montague Farms Inc., Center Coss, Virginia.



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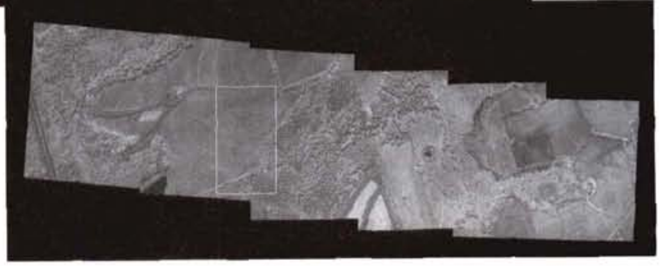

Bottom

Figure 3. The top image shows an uncorrected mosaic for cotton fields acquired at 770 nm. The bottom image presents the image after radiometric calibration. Note the area indicated by the white box where frames of imagery have been tied together.

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atmospheric conditions. This effect is normally negligible between frames from the same flightline, but can become significant between frames of different flightlines. Due to the relatively small footprint of most digital camera systems it may be necessary to collect several flightlines to cover a project area. If these flightlines are collected in a racetrack pattern (i.e., in the same direction), enough time may pass between flightlines that a noticeable brightness shift will occur. Two approaches that can be taken to compensate for temporal brightness shifts are atmospheric correction and statistical normalization. Atmospheric correction is normally undertaken for change detection studies using two or more images taken over the same area on different dates. The models to perform atmospheric correction can be complex, and the necessary data to populate them may be difficult or expensive to obtain. A more suitable approach for digital camera systems data is statistical normalization. With this technique, flightlines are "normalized" to each other using overlap pixels (see Morisette et al. 1996).

When applying radiometric correction algorithms, it must be remembered that the original DN values will be changed. In order to obtain "real" units (i.e. reflectance or radiance) it will be necessary to utilize within-scene ground-truth data. This can be accomplished by collecting background spectral signatures using a radiometer the day of the flight. A second approach would be to place control panels (having known spectral characteristics) within the region to be flown. These panels can also serve as geometric control.

Cultivating the Technology

To help straighten the learning curve, special analytical products derived from remote sensing data, using methods familiar to the remote sensing community, need to be tested and developed with the help of agronomists. Analytical products including specific band ratios, normalization methods, trend analyses, and band combinations as well as change analysis techniques must be derived and delivered to the farmer in an understandable format. These products will more likely than not represent regional models for crops managed by a large cooperative system. In addition, data standards should be developed and mandated in the use of production-level remote sensing for agriculture. Standards could also help provide government incentives for the use of remote sensing in precision farming. With the nation's food supply as the central issue, standards would foster a comfort margin with data being created by so many potential vendors.

The scheduled launch of a series of satellites possessing high spectral and spatial fidelity provides proof that remote sensing and precision agriculture are being taken very seriously by both the agricultural and remote sensing technology industry. It remains to be seen if these systems can deliver the goods to the grower at a price that is affordable with cost benefits being realized. Additionally, with many farmers still struggling to understand color infrared photography, how is hyperspectral imagery going to be explained? Again, the derivation of products that get at the basics of plant science coupled with the growers' familiarity with their fields is the answer. It may not be necessary to get deeply into the nuts and bolts of spectral understanding if we remember the "KISS" (keep it simple, stupid) rule. After all, a grower probably cares less about the four or fifty channel system acquiring the data than he or she does about the linear yield graph derived using the data (figure 4).

Reaping the Harvest

Ultimately, remote sensing technology and precision agriculture will be fused together or driven apart by the market. If useful data can be produced quickly and cheaply and demonstrate tangible cost benefits, then remote sensing will play a part in the ever-expanding role spatial data are having in farm management. However, if the technology is too complex, untimely, and a cost liability, it will fail. For many years remote sensing has demonstrated its utility in environmental monitoring. Much of this work has been funded under federal mandates and research. The new frontier in agriculture is to have a self-sustaining technology that creates information and helps increase productivity and ultimately, profits.

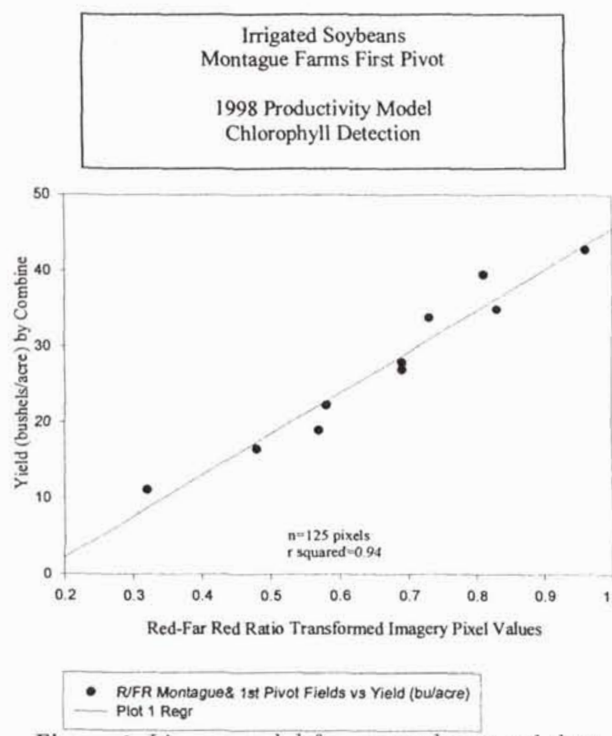

Figure 4. Linear model for remotely-sensed data and crop yield.

Literature Cited

Anderson, J. and D. Taliaferro. 1998. Preliminary relationships for yield forcasting comparing biomass and chlorophyll for irrigated and non-irrigated soybeans as derived using narrowband multispectral imagery.

Carter, G. 1994. Ratios of leaf reflectances in narrow wavebands as indicators of plant stress. *International Journal of Remote Sensing*. Vol.15, pp. 697-703.

Chappell, E., M. Kim, and J. McMurtrey III. 1992. Ratio analysis of reflectance spectra RARS: An algortihm for the remote estimation of the concentration of chlorophyll A, chlorophyll B, and carotenoids in soybean leaves. *Remote Sensing Environment*. Vol.39, pp. 239-247.

Collins, W. 1978. Remote sensing of crp type and maturity. *Photogrammetric Engineering & Remote Sensing*. Vol.44, pp. 43-55.

Deering, D. W., 1989. Field measurements of bidirectional reflectance. In: *Theory and Applications of Optical Remote Sensing* (ed Asrar, G.) *Wiley Series in Remote Sensing*, pp. 734, John Wiley & Sons, New York.

Gates, D., H. Keegan, J. SchleterV. Weidner. 1965. Spectral properties of plants. *Applied Optics*. Vol 4, pp. 11-20.

King, D., 1992. Evaluation of radiometric quality, statistical characteristics, and spatial resolution of multispectral videography. *Journal of Imaging Science and Technology*, Vol. 36(4), pp. 394-404.

Morisette, J. T., Dai, X., Cheshire, H. & Khorram, S., 1996. Comparing empirical normalization methods for a mosaic of Landsat Thematic Mapper Data. In: *ASPRS/ACSM Annual Convention & Exposition*, pp. 688, American Society for Photogrammetry and Remote Sensing, Baltimore, MD.

Rock, B., T. Hoshizaki, and J. Miller. 1988. Comparison of in situ and airborne spectral measurements of the blue shift associated with forest decline. *Remote Sensing Environment*. Vol 24, pp. 109-127.

Servilla, M. 1998. Agricultural remote sensing: Part two. *Modern Agriculture*. Vol. 1(7), pp. 18-21.

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