REMOTE SENSING RESOURCES FOR AGRICULTURE IN THE NEXT DECADE

S.J. Maas
USDA-ARS
Shafter Research and Extension Center
Shafter, CA

Abstract

This article describes the characteristics of existing and planned satellite systems that support their use in providing remotely sensed information for agricultural applications, including precision farming, irrigation scheduling, and regional crop condition assessment. It also provides an assessment of the overall state of remote sensing resources for agriculture in the next decade.

Introduction

Recent evaluations by remote sensing technologists (Goldberg and Stoney, 1995; Stoney, 1997; Stoney and Bunin, 1997) have indicated that, by the first few years of the next century, there will have been a phenominal increase in the number of satellite earth observing systems. Many of the systems will carry imaging sensors with spatial resolutions hitherto only available to the military and intelligence community. The sheer number of systems (no less than 30 systems planned to be in operation by the year 2002) coupled with the capability for some of off-nadir pointing will allow imaging of most places on the earth's surface with a frequency of once every 2-3 days.

Image data provided by these systems will find application in many areas, including oceanography, mineral exploration, cartography, urban planning, environmental protection, and national security. Each area of interest makes particular demands on the quantity and quality of the remotely sensed data. This is particularly true in the area of agricultural applications, where earlier space-based imaging systems have often been shown to be less than adequate. Many of the new satellite systems will have characteristics that make them more appropriate for certain agricultural applications. The objectives of this article are to evaluate the characteristics of the new satellite systems with regard to agricultural applications and to provide an assessment of the overall state of remote sensing resources for agriculture in the next decade.

Discussion

Four factors determine the utility of remotely sensed image data for agricultural applications: spatial resolution, spectral resolution, overpass frequency, and timeliness of availability. An evaluation of these factors for some important agricultural applications (precision farming, irrigation scheduling, and regional crop condition assessment) follows, along with the identification of current and future satellite systems which appear to be appropriate for each application.

Precision Farming

Precision farming is a concept in which agricultural management practices are tailored to the known variability of growing conditions across a field. Thus, fertilizer may be applied at different rates across a field based on the known spatial variability in the texture of the soil and its ability to supply nutrients to the crop plants. Similarly, portions of a field may be selected for pesticide treatment based on the known distribution of pest species in the field. Inherent to the success of this concept is a capability to obtain information on the spatial variability of relevant field characteristics. Remote sensing is a powerful tool for this application, since remotely sensed imagery represents a geospatially distributed depiction of the state of the crop that, through proper interpretation, can be converted to a map for directing variable-rate management activities such as fertilizer and pesticide application.

Characteristics of remote sensing systems appropriate for precision farming applications have recently been reviewed by several authors (Hart et al., 1997; Bauer, 1997; Robert, 1997). A concensus of these findings suggests the following:

1.) Spatial resolution-- 3 to 4 m (10 to 13 ft) is optimum, with 10 m (33 ft) about the upper limit.
2.) Spectral resolution-- red (600-700 nm) and near-infrared (800-1100 nm) spectral bands necessary for crop biomass and ground cover determination, more bands useful for identifying pest, weed, and stress conditions.
3.) Overpass frequency-- Imagery obtained once a week is optimum, but some applications (such as pest management) might require more frequent observations during parts of the growing season.
4.) Timeliness of availability-- Imagery should be received by the user no later than 72 hours after its acquisition.

Existing space-based imaging systems have not been able to meet all of these requirements, and thus have not been important in the development of precision agriculture. In some geographical regions, aircraft-based sensor systems capable of meeting these requirements have been successfully used in commercial agricultural management applications.

New satellite systems scheduled to be launched in the next decade that potentially meet these requirements are listed in the accompanying figure. All five systems (IKONOS, QuickBird, OrbView, RESORS TK, and Resource21) include multispectral sensors with a spatial resolution of 10 m or less. These systems are a subset of a much larger

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 1:36-38 (1998)
National Cotton Council, Memphis TN

group to carry high-resolution panchromatic imagers, primarily useful in cartographic applications. Several of these new satellite systems can acquire images of a given location every 3-4 days by off-nadir pointing of the sensor or satellite, although the utility of this capability to precision farming is diminished by difficulties in interpreting crop status in off-nadir views of a field. As indicated in the figure, by the first few years of the next millenium, there will be a sufficient number of satellite systems aloft to insure a nadir view of a given location every 3-4 days (clouds permitting) by one of the systems. All five of these systems are intended for commercial (rather than strictly research) applications, and their developers have stated that imagery will be available within a short period of time (typically within 72 hours) after its acquisition.

Of these five systems, Resource21 is targeted primarily for agricultural applications. The developers intend to provide information products developed from imagery that are directly applicable to precision farming activities (Satterlee, 1997). The lower spatial resolution (10 m) of the Resounce21 system, however, may preclude its effective use in some precision farming applications, such as early pest and weed detection.

The OrbView 3-A satellite, to be launched in 1999, may be of particular interest to precision farming. In addition to a 4-band multispectral sensor with 4-m spatial resolution, this satellite is scheduled to carry the "Warfighter" package, a hyperspectral sensor with 280 discrete narrow spectral bands and 8-m spatial resolution. The high-resolution hyperspectral imagery provided by this sensor may be particularly useful in detecting pest and weed infestations and discriminating between different types of crop stress.

Irrigation Scheduling

Irrigation scheduling attempts to match water application to the transpiration demands of a growing crop. Scheduling irrigation application through measurements of plant and soil water status or estimates of crop water use is intended to prevent the occurrence of water stress during important phases of the growth of a crop, i.e., to keep the crop in a well-watered state. Techniques intended to schedule irrigation based on the detection of water stress may be ineffective, since economically important loss of yield potential may have already occurred by the time water stress has been detected.

Techniques have been developed for estimating the evapotranspiration of vegetated surfaces using remote sensing (Moran and Jackson, 1991; Moran et al., 1995). These techniques rely on measurements of plant canopy temperature obtained through remote sensing in the thermal infrared wavelengths (10-12 microns). Application of these techniques to irrigation sceduling is straightforward, provided an adequate source of thermal infrared image data is available.

There currently exists only one source of satellite-based thermal infrared imagery-- Landsat 5. The spatial resolution of this sensor (120 m), its overpass frequency (16 days), and the turnaround time for receiving data (typically greater than one week) preclude its use in operational irrigation scheduling. None of the five new satellite systems described in the previous section are currently scheduled to include thermal infrared sensors. Of all the new satellite systems scheduled to be in operation within a few years, only three (Landsat 7, EOS AM, and CBERS) will carry thermal infrared sensors. Spatial resolutions for these sensors range from 60 to 160 m (200 to 525 ft), making their use appropriate for only the largest fields. Overpass infrequency and problems with data availability (EOS AM is primarily a research platform) contribute to making these systems largely inappropriate for operational irrigation scheduling.

Many of the new satellites will carry sensors that operate in the "SWIR" band (1.5-1.75 microns). These sensors are intended to detect aspects of surface reflectance related to water stress in vegetation (Moran, 1997). Unlike thermal infrared, SWIR observations cannot be used directly to estimate crop evapotranspiration, and thus may not be effective in scheduling irrigation to prevent the occurrence of water stress in a crop.

Regional Crop Condition Assessment

Regional crop condition assessment is intended to look at field-to-field variability in crop growth and condition, and how this information can be aggregated to evaluate the general health and productivity of an agricultural region. Organizations like the Foreign Agricultural Service (FAS) of USDA have used medium- and low-resolution satellite sensors for many years in producing crop condition and yield estimates.

Interpreting crop condition from low-resolution satellite imagery, like that obtained from the AVHRR sensor aboard NOAA weather satellites (1 km spatial resolution), is complicated by the inability to resolve mixtures of fields with different crops and mixtures of fields and non-agricultural targets (roadways, buildings, water bodies, etc.). Existing satellites with medium-resolution imaging sensors (Landsat, SPOT, and IRS) are well suited for regional crop condition assessment, although the widespread use of their image products has been somewhat limited by the cost (on the order of $1000 to $3000 per scene) of the imagery for commercial users.

Sensor characteristics for regional crop condition assessment may be summarized as follows:

1.) Spatial resolution-- 20 to 60 m (66 to 200 ft) is optimum, with 100 m (330 ft) about the upper limit.

2.) Spectral resolution-- red (600-700 nm) and near-infrared (800-1100 nm) spectral bands necessary for crop biomass and ground cover determination, with more bands often needed for classifying fields into different crops. Thermal infrared and SWIR bands useful for assessing drought stress in crops.
3.) Overpass frequency-- Imagery obtained once every two weeks is optimum, but most applications could get by with one cloud-free scene per month.
4.) Timeliness of availability-- Imagery should be received by the user no later than 2 weeks after its acquisition.

The accompanying figure shows current and planned satellite systems likely to be appropriate for regional crop condition assessment. This agricultural application appears to be well served by existing and future systems. Announced reductions in the costs of imagery from existing and future systems should also promote increased use of these remote sensing products for this application.

The XSTAR satellites to be launched by MATRA MARCONI SPACE are somewhat of a special case. These systems have been proposed to be for precision farming applications, although the 20-m (66-ft) spatial resolution of the sensor would make it difficult to detect anything but the largest-scale variations within a typical field. This level of spatial resolution would also preclude the early detection of pest or weed problems in a field. The designers of the XSTAR system have attempted to compensate for the reduced spatial resolution with increased spectral resolution. The sensor aboard this satellite is described as "superspectral", acquiring imagery in at least 10 discrete narrow spectral bands. While limitations imposed by reduced spatial resolution may make XSTAR a questionable tool for precision farming, this satellite system may be an exceptional tool for regional crop condition assessment, particularly in the area of crop type and land surface classification.

Radar

Radar's unique capability of "seeing through" clouds makes it potentially a powerful tool for many remote sensing applications. Its use in agricultural applications is still a subject of research. Radar may be useful in estimating vegetation canopy height and roughness, bare soil wetness, and biomass. Unfortunately, radar imagery may contain artifacts that make its interpretation difficult. While several new radar satellites are scheduled for launch in the next decade, it is likely that radar will at most serve to complement data from optical sensors for agricultural applications.

Conclusions

By the first two years of the next millenium, satellite imagery of the necessary quality and frequency will be available from a variety of sources to support precision farming activities. The same cannot be said for the availability of satellite data to support operational irrigation scheduling. Few new satellite systems are planned to carry thermal infrared imaging sensors necessary for estimating the evapotranspiration data required to maintain well-watered crops. Existing and future satellite systems should be adequate for regional crop condition assessment applications. Except in the area of operational irrigation scheduling, satellites should replace aircraft during the next decade as the primary tools for acquiring remotely sensed information for agricultural applications.

Disclaimer

Mention of specific suppliers of remote sensing data in this manuscript is for informative purposes only and does not imply endorsement by the United States Department of Agriculture.

References

1. Bauer, M.E. 1997. Multispectral, thermal, and radar remote sensing: Potential for precision agriculture. Agronomy Abstracts, American Society of Agronomy.

2. Goldberg, A.M., and W. Stoney. 1995. Instrument data Sheets. Proc., Land Satellite Information in the Next Decade. September 25-28, 1995, Vienna, VA. ASPRS.

3. Hart, G.F., D.J. Major, C.S.T. Daughtry, and M.S. Moran. 1997. Remote sensing in precision agriculture: The basic elements. Agronomy Abstracts, American Society of Agronomy.

4. Moran, M.S. 1997. Spectral indices for detecting crop stress. Agronomy Abstracts, American Society of Agronomy.

5. Moran, M.S., and R.D. Jackson. 1991. Assessing the spatial distribution of evapotranspiration using remotely sensed inputs. *J. Env. Quality*. 20:725-737.

6. Moran, M.S., S.J. Maas, and P.J. Pinter, Jr. 1995. Combining remote sensing and modeling for estimating surface evaporation and biomass production. *Remote Sensing Rev*. 12:335-353.

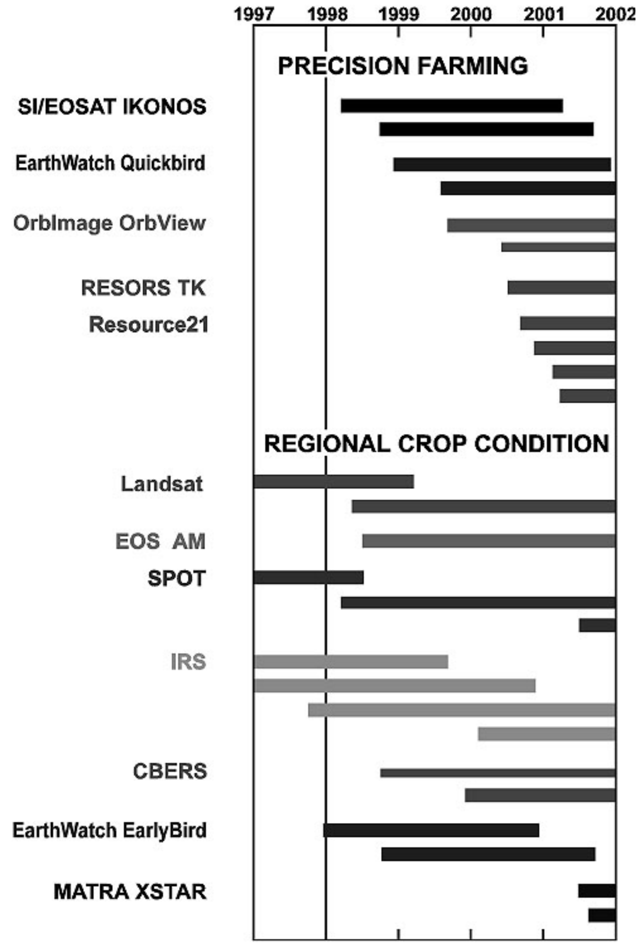
7. Robert, P.C. 1997. Remote sensing: A potentially powerful technique for precision agriculture. Proc., Land Satellite Information in the Next Decade II.

December 2-5, 1997, Washington, DC. ASPRS. (CD-ROM)

8. Satterlee, H. 1997. The information source for the 21st Century. Proc., Land Satellite Information in the Next Decade II. December 2-5, 1997, Washington, DC. ASPRS. (CD-ROM)

9. Stoney, W. 1997. Helping satellites from space, the satellites of the next decade. Agronomy Abstracts, American Society of Agronomy.

10. Stoney, W., and S.L. Bunin. 1997. Satellite and sensor data sheets. Proc., Land Satellite Information in the Next Decade II. December 2-5, 1997, Washington, DC. ASPRS. (CD-ROM)



Existing and planned satellite systems appropriate for precision farming (top) and crop condition assessment (bottom) applications.