Trends in satellite remote sensing for precision agriculture

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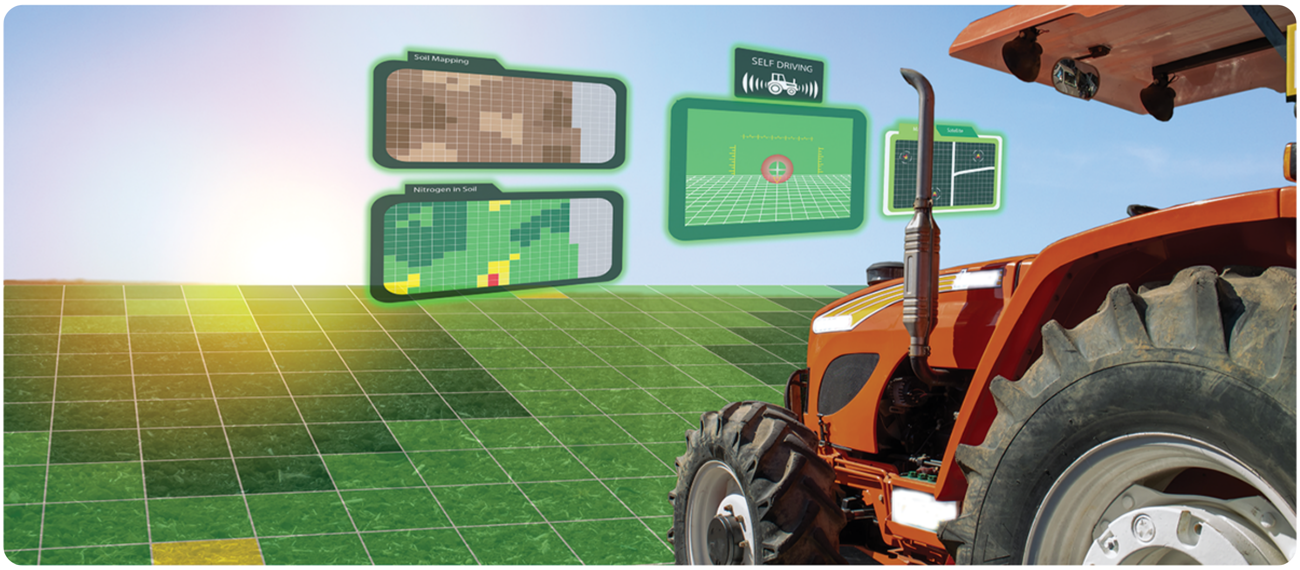

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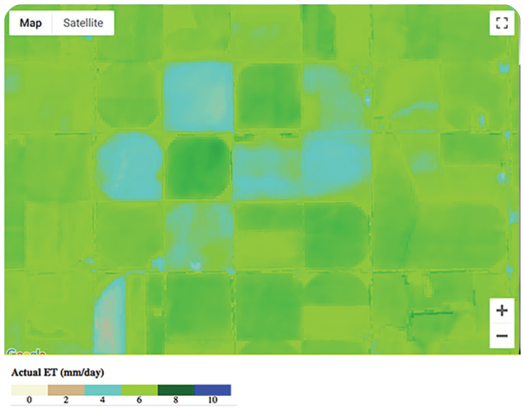
Remote sensing is an essential tool for precision agriculture, allowing producers and crop consultants to monitor spatial and temporal variability in soil properties, crop growth, and crop stress from nutrients, weeds, disease, insects, or water. During the last decade, the number and capabilities of multispectral satellite remote-sensing products have increased dramatically. This article provides an overview of some of the trends in satellite remote sensing for precision agriculture.

Remote sensing is an essential tool for precision agriculture, allowing producers and crop consultants to monitor spatial and temporal variability in soil properties, crop growth, and crop stress from nutrients, weeds, disease, insects, or water. This information is critical for decisions about when and how much to fertilize, spray, or irrigate crops.

In the early days of precision agriculture, Landsat 5 was the primary satellite provider for broad wavelength multispectral reflectance bands (blue = B, green = G, red = R, and near infrared = NIR). In the absence of cloud cover, Landsat imagery was available every 16 days at a spatial resolution of 90 ft (30 m), or six pixels per acre. A variety of vegetation indices, such as the normalized difference vegetation index [NDVI = (NIR – R)/(NIR + R)], were developed to track crop growth and crop stress at the scale of thousands of plants per pixel (for corn) using Landsat imagery.

Free and Fee-Based Products

During the last decade, the number and capabilities of multispectral satellite remote-sensing products have increased dramatically compared with historic Landsat 5. Direct successors to Landsat 5 include Landsat 7 and 8, which provide remote-sensing imagery (B, G, R, and NIR) every 16 days in 90-ft pixels at no cost. The European Space Agency (ESA) provides free multispectral imagery from the Sentinel 2 satellites. The Sentinel satellites have a revisit frequency of five days and collect multispectral imagery at B, G, R, and two NIR wavelengths. In addition, Sentinel 2 provides red-edge (RE) reflectance at three distinct narrow-band wavelengths. Red-edge reflectance occurs from 680-750 nm where reflectance increases dramatically as chlorophyll absorption decreases. This makes RE reflectance particularly sensitive to crop stress from nitrogen using a spectral index such as normalized difference red edge, where NDRE = (NIR – RE)/(NIR + RE). Spatial resolution of Sentinel 2 imagery is 30 ft (10 m) in the B, G, R, and NIR1 bands and 60 ft (20 m) in the RE1, RE2, RE3, and NIR2 bands.



Actual daily crop evapotranspiration from Google Earth Engine EEFlux for production fields located near Lexington, NE on July 11, 2019.

For a fee, satellite imagery is available at finer spatial resolution and quicker revisit times with the WorldView 2 or 3 and Planet Lab Flock CubeSats. WorldView provides multispectral imagery at a revisit frequency of about one day with a spatial resolution of 1.5–4.1 ft (0.46–1.24 m) so that each pixel represents reflectance from only a handful of individual plants. WorldView collects multispectral imagery across a wide range of wavelengths, including B, G, yellow (Y), R, RE, and two NIR bands. Imagery from Flock Dove CubeSats has a revisit frequency of one day with a spatial resolution of about

10–13 ft (3–4 m). Multispectral imagery is collected at B, G, R, and NIR wavelengths. Each Flock of Doves consists of multiple miniature CubeSats with successive CubeSats in a given launch following slightly different offset orbital tracks. Imagery from each CubeSat must be orthorectified and combined with images from all other CubeSat imagery in the same Flock to produce a scene. While the WorldView and Planet Lab Flock satellites have excellent spatial and temporal resolution, they are costly to access, unless the user hires a third-party provider such as Farmers Edge who can provide imagery for an acreage-based fee.

NDVI and Alternative Indices

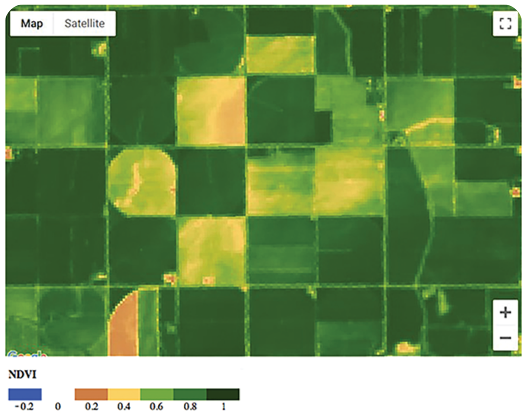
Normalized difference vegetation index is widely promoted as a tool for detecting a variety of crop traits, including biomass, crop planting density, nitrogen deficiency, insect damage, and disease and weed pressure. In reality, NDVI cannot by itself identify what factor causes poor crop growth, and crop scouting is needed to diagnose the cause of poor growth or yellow biomass. Furthermore, as NDVI values plateau in mature crops, they become relatively insensitive to changes in crop biomass or crop stress. Several spectral indices can be used as an alternative to NDVI. Crop nitrogen stress can be identified using NDRE, or green NDVI where GNDVI = (NIR – G)/(NIR + G). Typically, NDRE or GNDVI values are compared with a nitrogen-sufficient reference, and when they are 95% or lower compared with the reference, additional N fertilizer is needed.

Remote sensing can be used to manage irrigation applications in order to avoid crop water stress. Landsat 8 satellite-based estimates of actual crop evapotranspiration (ET) are available at no cost using the Google Earth Engine EEFlux method based on a surface energy balance calculation known as “Mapping Evapotranspiration at High Resolution with Internalized Calibration” (METRIC).

The EEFlux map (Fig. 1) shows actual daily ET for an agricultural region near Lexington, NE on July 11, 2019. Light blue regions are fields with an ET of 4 mm/day, whereas light green regions have an ET of 6 mm/day. A corresponding NDVI map from EEFlux below (Fig. 2) shows that fields with low ET are either fallow, recently harvested, or have low biomass.

Advantages and Disadvantages of Satellite-Based Imagery

Satellite-based imagery has advantages and disadvantages. Advantages include increasingly better spatial resolution and revisit frequencies. Other advantages include the ability to identify areas of a field with crop stress. This advantage enables precision agriculture management decisions so that problem areas are treated quickly.



Normalized difference vegetation index (NDVI) from Google Earth Engine EEFlux for production fields in Figure 1 located near Lexington, NE on July 11, 2019.

The primary disadvantage of multispectral satellite reflectance is interference from cloud cover. In the U.S. Cornbelt region, a satellite revisit frequency of one to three days is needed to have at least a 95% chance of weekly cloud-free images. This is more frequent than the revisit frequency of satellites such as Landsat 8 and Sentinel 2, whose imagery is available at no charge.

Other disadvantages of satellite imagery include the need for significant levels of data processing. Processing could include, for example, mosaicking, orthorectification, masking of clouds, atmospheric corrections for haze and dust, conversion of digital numbers to calibrated reflectance, and top-of-atmosphere or top-of-crop-canopy corrections for reflectance. Many of these steps are automated by data providers such as the ESA Copernicus Data Hub, Google Earth Engine EEFlux, or USGS Earth Explorer web sites.

Despite these disadvantages, the trend towards better public satellite platforms with more frequent revisit frequencies, higher spatial resolution, and availability of reflectance bands at wavelengths that indicate important crop stress symptoms means that producers and technical service providers should not discount satellite remote-sensing information for management decisions involving precision agriculture.

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