SATELLITE-BASED REMOTE SENSING FOR PA

FACT SHEET

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

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An overview of the different satellite imagery options available to Australian growers, and for use in precision agriculture

Introduction

Remote sensing in precision agriculture (PA) is mostly used to observe the spatial (over distance) and temporal (over time) variability in soil and crops by gathering optical reflectance information from the plant or soil surfaces. During the growing season, vegetative growth may be monitored for production variability resulting from nutrient deficiencies, water stress or pest infestation, which may all influence final yield. Imagery is also used to map farm boundaries, watercourses and terrain.

Optical imagery relies on areas with different soil and vegetation cover having distinguishing reflectance signatures in the visible and/or non-visible electromagnetic (EM) spectrum. The amount of energy reflected, transmitted or emitted in these areas of the EM spectrum provides information linked to many vegetation and soil characteristics. Optical remote sensing can provide a useful, low-cost means of assessing variability in these characteristics at a paddock, property and regional scale within and between seasons. In some situations, these images can provide a surrogate production map.

Satellite-based imagery has four properties that are important to their use in PA:

- spatial resolution: the size of the smallest object that can be identified in an image (loosely defined by the picture element (pixel) size of the image);
- spectral resolution: the number of segments (spectral bands) of the EM spectrum that can be measured;

Table 1: Basic specifications for the satellite-based remote sensing systems of potential use in PA: R = red band, G = green band, B = blue band, NIR = near infrared, MIR = mid-infrared, LIR = longwave infrared, SWIR = short wave infrared, TIR = thermal infra red

Satellite system	Spectral resolution (bands)	Spatial resolution (metres)	Temporal resolution
Sentinel-1	C-band radar at 5.404 gigahertz (GHz) 4 modes of polarisation (HH-HV-VH-VV)	10	6 days
MODIS	36 bands R, NIR B, G, MIR (0.4–14.4 micrometre (µm))	250 500 1000	1–2 days
ASTER	14 bands G, R, NIR 6 MIR bands 5 LIR bands	15 30 90	on request
Landsat 7 ETM+	Pancromatic B, G, R, NIR, MIR LIR	15 30 60	16 days
Landsat 8	Pancromatic B, G, R, NIR, MIR TIR	15 15 and 30 100	16 days
Landsat 9	Pancromatic B, G, R, NIR, SWIR TIR	15 30 100	8 days
WorldView-2	Pancromatic B, G, R, NIR Red edge Coastal Yellow NIR2	0.5 1.8 1.8 1.8 1.8 1.8	1 day
Sentinel-2	B, G, R, Red edge, SWIR	10 and 20	5 days
PlanetScope	B, G, R Red edge	5 5 5	1 day
DESIS	Hyperspectral 235 bands (2.5 nanometre (nm))	0.4 1.7	On demand

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- radiometric resolution: the number of data levels for each band that can be stored; and
- temporal resolution: the minimum time period between two images taken of the same area.

The main satellite systems used in agriculture and their operational characteristics are listed in Table 1. The data from most of these systems are archived, creating a potentially powerful historical resource.

Using remotely sensed imagery in PA

It is relatively common knowledge that scientists and growers can make use of satellite imagery. In fact, agriculture has been using satellite imagery for more than 30 years.

One of the most widely used and best-known satellites is Landsat 7, launched on 15 April 1999. This satellite is still in orbit and is planned to be decommissioned by the new Landsat 9 mission, which successfully launched on

Figure 1: Landsat 9 real colour image from cropland at 30m spatial resolution.

Table 2: Common indices used in remote crop sensing. Red edge NDVI is calculated from narrow band data with the wavelengths indicated in subscripts.

Index	Bands used	Physiological interpretations
Vegetation (or Simple) Index (VI)	$\frac{IR}{Red}$	Crop greenness, vigour, leaf area
Normalised Difference Vegetation Index (NDVI)	$\frac{IR - Red}{IR + Red}$	Crop greenness, vigour, leaf area
Soil Adjusted Vegetation Index (SAVI(0.5)) (0.5 = correction for soil reflectance)	$\left(\frac{IR - Red}{IR + Red + 0.5}\right) x (1 + 0.5)$	Crop greenness, vigour, leaf area when ground cover is sparse
Enhanced Vegetation Index (eNDVI)	$2.5x \frac{IR - Red}{IR + 6xRed - 7.5xBlue + 1}$	Crop greenness, vigour, leaf area in crops with high reflectance
Photosynthetic Vigour Ratio (PVR)	Red	Strong chlorophyll absorption (photosynthetic activity)
Plant Pigment Ratio (PPR)	$\frac{Green}{Blue}$	Strongly pigmented crops
Green Normalised Difference Vegetation Index (GNDVI)	$\frac{IR - Green}{IR + Green}$	Chlorophyll content, cell density and stress
Red edge NDVI	$\frac{IR_{750} - Red_{705}}{IR_{750} + Red_{705}}$	Crop greenness, chlorophyll content, water stress

27 September 2021 from Vandenberg Space Force Base in California.

Generally, this kind of imagery can be used like normal photography (Figure 1), where red, blue and green bands are combined to form a visual representation of reality. However, its power resides in the way the information is collected and stored: in individual bands. The bands can be combined in many different ways to produce new visual and physiological insights. Known as vegetative indices, the more common combinations of bands are shown in Table 2.

An example using the European Space Agency's Sentinel-2 satellite is shown in Figure 2. This imagery uses a combination of the red and the near infrared bands, commonly known as normalised difference vegetation index (NDVI). The NDVI takes advantage of the natural condition of plants to absorb more or less of the different 'colours' of light. Live green vegetation absorbs red and blue visible light as part of photosynthesis. At the same time, healthy plants refract (or scatter) near infrared light. NDVI is an index that measures this difference. It is influenced by the fractional cover of vegetation on the ground, the vegetation density and the vegetation greenness. The NDVI provides a measure of vegetation biomass and condition, and it indicates the photosynthetic capacity of the land surface cover.

In Figure 2, it is easy to differentiate those paddocks that have higher NDVI (dark green) from the paddocks with low NDVI. The higher the NDVI, the healthier the plants. These healthier plants refract less of the red visible band of light. NDVI decreases as leaves senesce, that is, deteriorate with age or other stress. Bare soil is close to zero on the NDVI, whereas bodies of water have negative values.

Spatial resolution

One of the mantras of precision agriculture is: 'Higher spatial resolution leads to a better targeted decision.' However, most of the satellite missions are designed for specific purposes, many of which are not primarily agricultural.

One of the most widely used satellites in natural sciences is NASA's MODIS Terra (Moderate Resolution Imaging Spectroradiometer). This satellite offers a spectral resolution of 36 discrete

Figure 2: NDVI of irrigated paddocks.

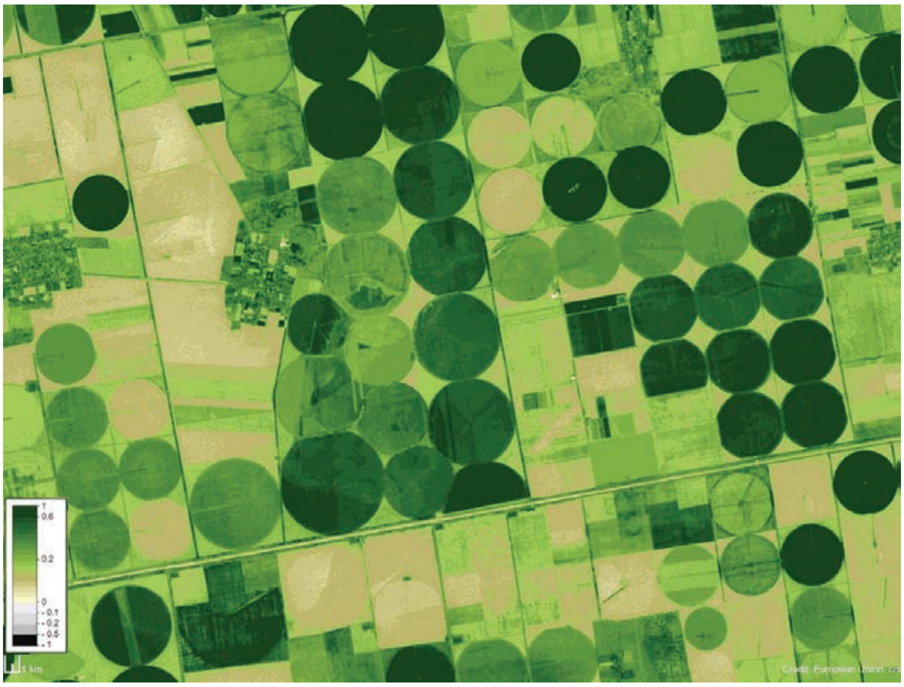


Figure 3: World MODIS LAI product for September 2013.

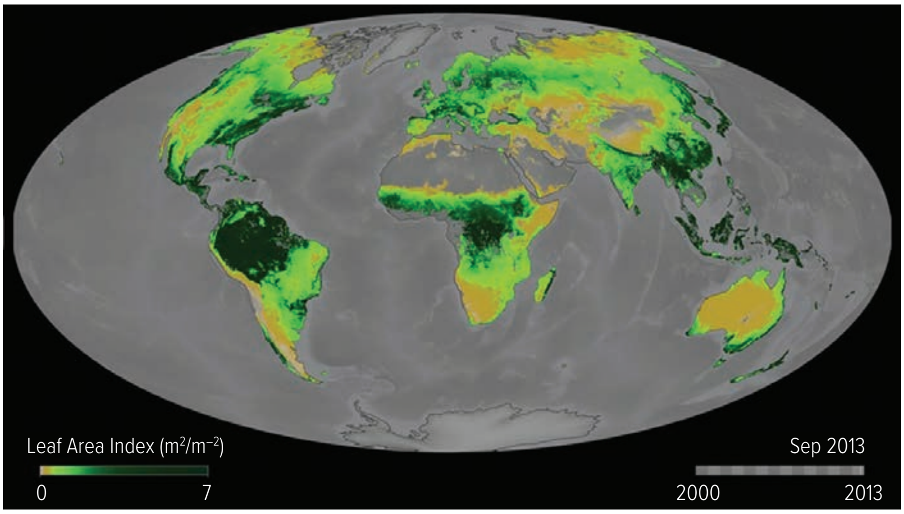
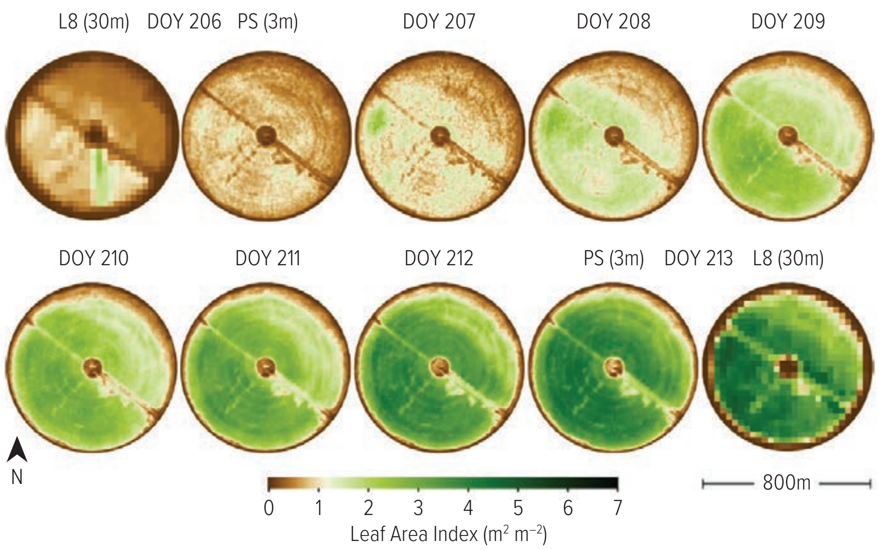


Figure 4: LAI using MODIS, Landsat 8 and Planet® at 3m resolution.



Source: Extracted from Houborg and McCabe, 2018 spectral bands that cover the visible (that is red, green and blue), shortwave, near infrared and longwave thermal ranges. This instrument's characteristics allow scientists to create algorithms to estimate more advanced indices than a simple NDVI. One of these indices is the Leaf Area Index (LAI), which is defined as the one-sided green leaf area per unit ground surface area. It is calculated with the following formula: LAI = leaf area (m^2)/ ground area (m^2). Such indices represent a physical phenomenon, in this case the size of leaf, which can be easily generalised to plant biomass and in other calculations, including yield per hectare. Figure 3 shows the world MODIS LAI product for September 2013.

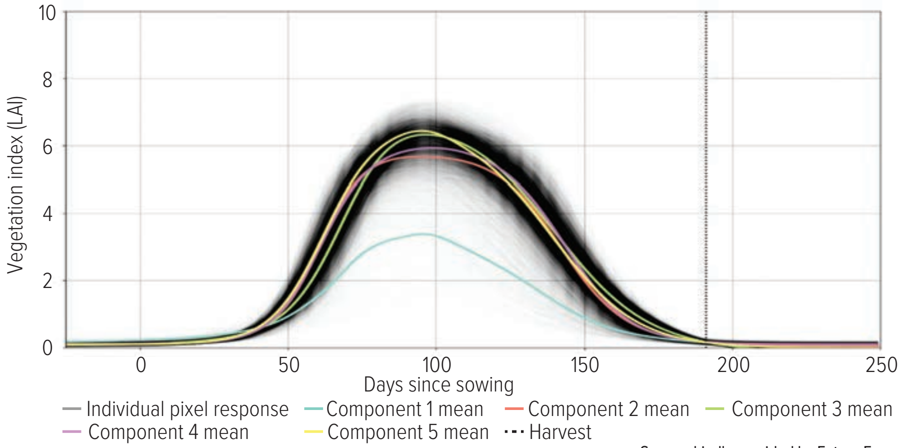
The trade-off with these kinds of satellites is their spatial resolution. Products from MODIS satellites are delivered in 250m to 1000m spatial resolution. This means the user will have one to 16 pixels per hectare, and this would lead to extreme generalisation if this information were to be used for yield estimation.

If higher resolution is needed, then other satellite constellations should be considered. One of the most popular options is Planet® imagery, which comes with a 3m to 4m resolution, a sub-daily revisiting time, and four bands including red, green, blue and near infrared bands. This has been expanded to eight bands in their latest release.

The Planet® products can be used in many ways in agriculture. Examples include being used to calculate the NDVI and to create a high-resolution picture of any farm, anywhere on any day (if cloud-free) worldwide. As the focus of these products is to cover as much landscape as possible in the shortest timeframe, their spectral resolution is limited and therefore cannot be used to directly calculate more sophisticated indices such as LAI.

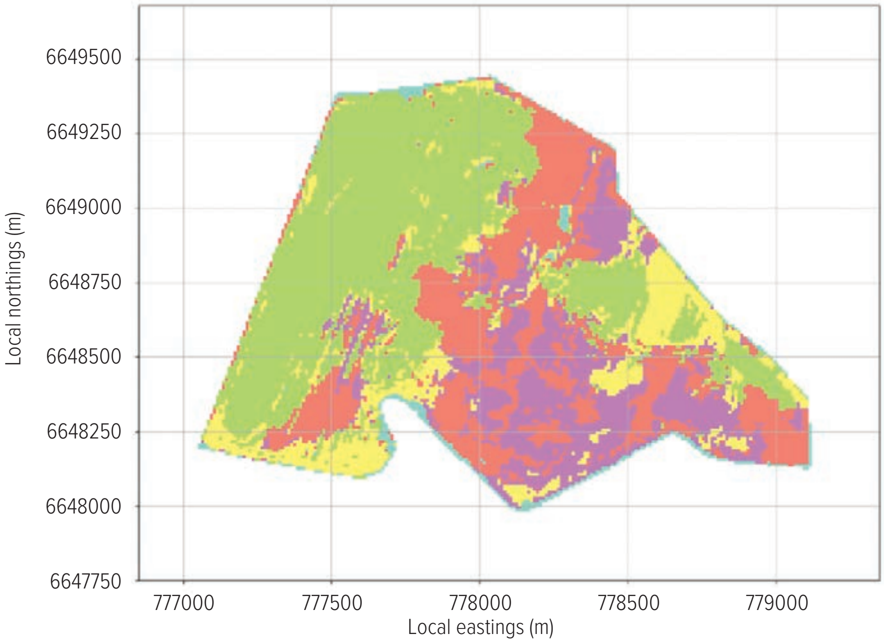
This trade-off has motivated the remote sensing community to create new algorithms, usually employing machine-learning techniques, to link the spectral power of free-to-use satellites, like MODIS or Landsat, and the better spatial and temporal resolution of other satellites, like Planet®. Figure 4 shows an example of a machine-learning fusion between Landsat 8 (11 bands at 15m, 30m and 100m resolution), MODIS

Figure 5: Time evolution of LAI in a wheat paddock, Narrabri, NSW.



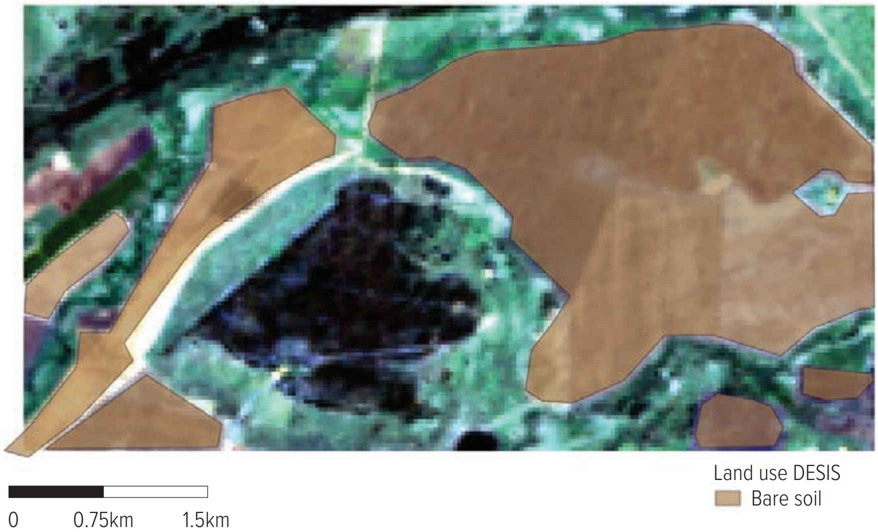
Source: kindly provided by Future Farm
Phase 2: Intelligent decisions – Improving farmer confidence in targeted N management through automated decisions

Figure 6: Clusters formed by different LAI time-patterns in a wheat paddock, Narrabri, NSW.



Source: kindly provided by Future Farm
Phase 2: Intelligent decisions – Improving farmer confidence in targeted N management through automated decisions

Figure 7: Hyperspectral imagery captured by DESIS.



Terra and Planet® CubeSat (four bands at 3m to 4m resolution). This is new research and it will be interesting to see how the technology is taken up.

Temporal (time) resolution

Growers, agronomists and researchers might ask, "What if we need to assess the plant response to a fertilising treatment over time?" For this kind of question, three things are required: high spatial resolution imagery, a good model that could translate information from more spectrally rich satellite imagery, and a high time resolution or revisiting time.

It could be argued that satellite constellations such as Sentinel-2 with a revisiting time of about five to six days are enough for most users. However, a cloud-free image is never guaranteed, and it is not unusual to end up with no imagery for a full month. This is where commercial constellations such as Planet® come into play.

Again, the remote sensing and modelling community has circumvented this issue by creating time-dependent models applied to satellite imagery. Figure 5 shows the evolution over time of LAI in a wheat paddock in Narrabri, NSW, for 2020. It uses Sentinel-2 imagery (10m resolution) plus a model for estimating LAI. Each of the black lines corresponds to a single pixel in Figure 6. With this kind of information, it is possible to model the LAI in time. Therefore, a complete picture of the evolution of plants in space and time can be produced and used to make informed agronomical decisions along the season.

Spectral resolution

There are also a number of satellites that have high spectral resolution. They may not possess super-high spatial resolution or have a short revisiting time, but they do capture an incredibly accurate spectral picture of the Earth. They are called 'imaging spectrometers' and one example is DESIS (DLR Earth Sensing Imaging Spectrometer).

This satellite has a spatial resolution of 30m and a spectral resolution of 235 bands (covering the visible and near infrared part of the spectra with a 2.5 nanometre spacing between each band. With this instrument, even more sophisticated agronomic

Figure 8: Spectra of different land uses measured by DESIS.

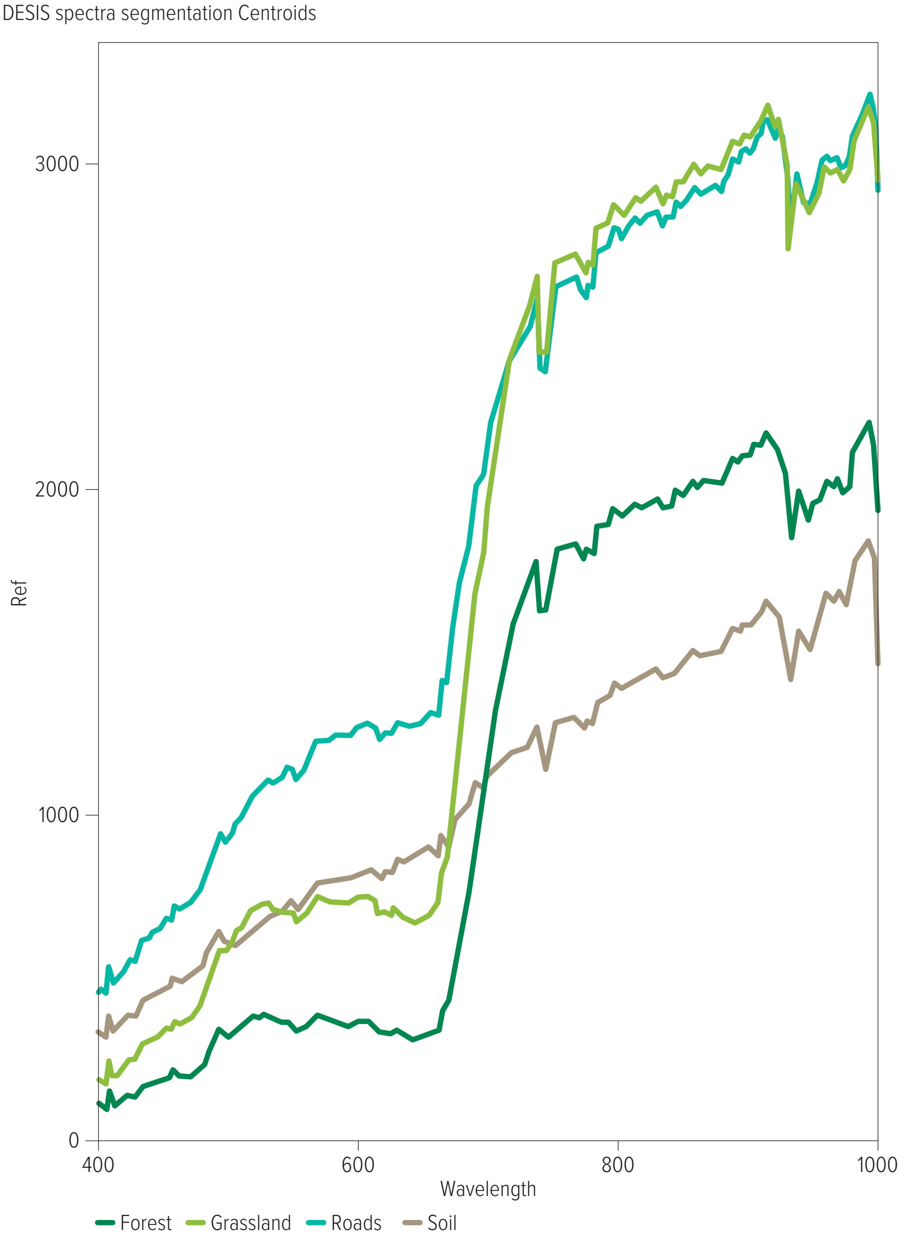
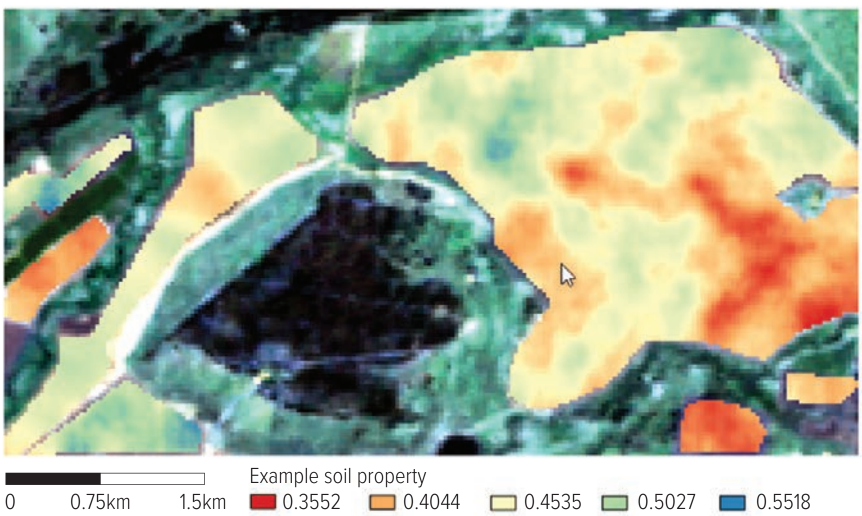


Figure 9: Fine-scale predictions of a soil property based on a multivariate spectral model.



algorithms can be calculated.

Figure 7 shows a hyperspectral image captured by DESIS of the wheat paddock shown in Figure 6 in Narrabri, NSW, this time for 2021. As so many bands are gathered at each pixel, it is possible to examine a full spectral response at each pixel and compile an average response for each type of land use in a region of interest. Figure 8 shows the average spectral responses across all 235 bands for the pixels in each land use type in Figure 7.

Figure 7 shows that the soil has a very characteristic spectral shape compared with the spectra of the forest or the roads. With this kind of instrument, the physical characteristics of the landscape can be captured with fine detail and subjected to further analysis. Figure 9 presents the results of a spectroscopic model created using DESIS imagery and the results of soil sample analysis taken the same day that the satellite passed. In this example, the higher spectral resolution of DESIS allowed for the calculation of valuable information at a fine scale that can be used to support decision making, for example in fertiliser application planning for the season.

Photo: ESA

European Space Agency's Sentinel-2 is providing high-resolution optical imagery of agriculture, forests, land-use change and land-cover change. It is mapping biophysical variables such as leaf chlorophyll content, leaf water content and leaf area index. It is also monitoring coastal and inland waters and helping with risk and disaster mapping.

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