Making more informed sensor decisions for better farm management

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Abstract
Given the plethora of sensors and platforms (including UAVs) available for detection and identification of crop characteristics, how does a user decide what to use, when to use it and whether it has value? Questions include, how do you choose the right sensor and platform?, what is an NDVI anyway?, are UAVs useful for farm management? The presentation will discuss some of the caveats of using remote sensing using the spectral NDVI as an example of some issues that need to be understood and considered when using sensing information with the intent of increasing understanding for better decision making. Growers, agronomists, scientists and other users will be able to ask more informed questions of their service providers and understand what questions to ask when they design projects to get better value from sensor technology.

Key Words
Remote sensing, NDVI, calibration, quantitative

Introduction
Remote sensing is the science of detecting and quantifying something of interest at a distance. This is done with sensors that are placed on different platforms, which allow the sensor to view the target of interest at the scale of interest. Sensing is a surrogate for measuring some physical, chemical or biological feature of the target, such as water or nutrient stress, plant architecture, soil property, disease, etc. Because light interacts with plants, canopies, soil and water differently depending on wavelength, selection of the correct wavebands of energy are crucial to measuring the features of interest. Over the past four decades many spectral 'indices' have been developed to measure features important in agriculture. These have been developed using multispectral, hyperspectral and thermal sensors among others (e.g, fluorescence, electromagnetic induction, gamma radiometrics, radar, etc.). The types of sensors (e.g., passive, active, point, imagers) and platforms (handheld, ground vehicle, UAV, plane, satellite) combine to provide information that can be used to improve decision making. However, how does a user of these technologies know what combination of platform, sensor and wavebands will provide the right information to improve crop management? In this paper, we will focus discussion on optical data for plant and canopy sensing.

The main types of sensors currently available commercially include those that can be classified into 'passive' and 'active' sensing. Passive sensors use sunlight for illumination and active sensors have an internal light source to illuminate the target. Passive sensors can be deployed at any distance from the target – from ground (proximal sensing) to UAV, plane and satellite. Active sensors generally are restricted to proximal sensing within a few meters of the target. The advantage of active sensors is that they can work independent of lighting conditions. Since the light source has known intensity and spectral characteristics they can be used under cloudy or clear sky conditions or even at night. Passive sensors, such as multispectral, hyperspectral and thermal sensors and digital cameras on UAVs and planes suffer from limitations of changing light during the day and across the season and therefore must be calibrated if features are to be quantified across time.

The use of different platforms and sensors is a means to an end, which is collection of the right kind of information to answer the desired questions. From commercially available sensors, data are usually provided as a type of 'index', which is often a ratio of wavebands from different parts of the spectrum selected to measure a feature of interest. Some indices are more suited to one type of measurement and understanding why, is important for assessing the utility of sensing in decision making. The principal criteria for selecting the right sensor/platform/wavelengths for the job are the questions asked.

Caveats and Cautions
There are hundreds of spectral indices that have been developed to measure specific physical, chemical or biological features. Commercially available multispectral indices include only a few of these, such as the NDVI. Other terms used include 'red edge', NDRE, CWSI, NIR and many others. By far the most

ubiquitous index is the NDVI, which will be used here to demonstrate some of the strengths and pitfalls of using sensing information for measuring canopy status and providing information for decision making.

NDVI stands for Normalised Difference Vegetation Index. It was developed in the early 1970s (Rouse et al., 1974) to differentiate vegetation from soil to allow quantifying and mapping of the Earth's surface from satellites. It is a normalised ratio of the near infrared (NIR) and red portions of the spectrum: (NIR-Red)/(NIR+Red). Plants absorb light in the red portion of the spectrum (~660-680 nm) due to photosynthesis and reflect light in the NIR portion (~780-880 nm), making plants appear bright (Fig. 1). When data or imagery is calibrated to reflectance, NDVI values range from 0 to 1, where higher values refer to more ground cover. Raw (uncalibrated) NIR and Red data give an NDVI range from -1 to 1.

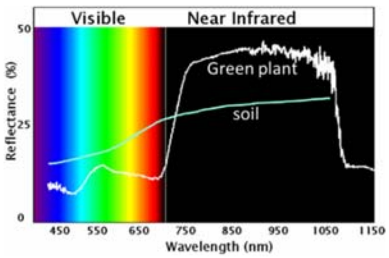

Figure 1. Spectrum of a typical crop canopy and soil.

Because the main strength of the NDVI is to detect vegetation, and amount of vegetation can be an indication of plant and canopy photosynthetic capacity, it has been used to measure many canopy characteristics. It is used to quantify biomass, 'vigour', 'health', 'stress', canopy nitrogen, pests and diseases and many other parameters. Fundamentally, the NDVI measures canopy cover (Fitzgerald et al. 2010, Perry et al. 2012). The amount of cover (from 0 to 100%) changes the spectral signature in the NIR and red portions of the spectrum such that the amount of plant cover can be quantified and mapped since it is distinct from that of soil (Fig. 1).

Calibration of sensor data
Reflectance is a physical measure of the amount of light bouncing off a surface. Because this is affected by the amount of incoming light and the features of the surface, it changes depending on the lighting environment. If the goal is to quantify a crop parameter spatially or temporally, it is important that changes in lighting are accounted for. This is done by calibrating the raw, digital numbers from sensors and imagers to reflectance using: (a) incident light sensors, (b) in-field calibration panels, (Fig. 2) (c) atmospheric correction models, or (d) pseudo-invariant targets to quantify changes across a paddock and through time so that they are comparable. Because different brands of sensor can give different values for the same index (e.g., NDVI), calibrating raw data to reflectance will also correct for differences due to sensor type.

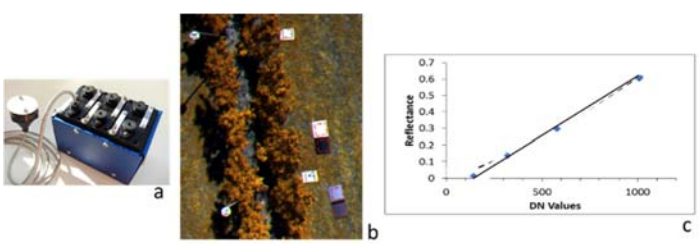

Figure 2. Two methods to calibrate remote sensing data. (a) Incident (upward looking) sensor, (b) calibration panels within the scene, (c) graph of raw digital numbers converted to reflectance using data from (b).

Placing calibration panels in the field of view is an accurate and straightforward way to convert data and imagery to reflectance. The difficulty is placing these across a large area. Measuring a canopy and returning often to a point where calibration panels are located is another option, but will require time and if sky conditions change, may not represent the entire area. Incident light sensors, which are upward looking sensors that measure sky conditions, are becoming available on airborne sensors. They can provide real-time correction to downward looking sensors but, currently, they do not appear to be highly accurate for image calibration. Atmospheric correction models are applied to satellite data. Pseudo-invariant targets include ground targets that are relatively stable across dates e.g., roads and water bodies, etc. These can be used to give a '1st order' approximation of reflectance if calibration data is collected from these objects. Data normalisation can be used to convert raw data to reflectance across different acquisition dates. An example was proposed in Mass and Rajan (2010) where image data scatter plots are matched to a base image of know locations of calibrated pseudo-invariant targets. This has the advantage of good calibration with fewer ground data points needed. A good recent review of sensors, data, geometric correction and potential workflows for remote sensing is provided in Aasen et al., (2018).

The biomass 'problem'

The NDVI (and other indices) represents a 2-dimensional representation of a surface. The NDVI is usually described as a measure of biomass, but accuracy breaks down as biomass increases because this is a measure of volume in three dimensions. This can be seen by the non-linear relationship of NDVI and biomass (Fig. 3b). Early in the season the relationship is generally linear when plants are expanding horizontally across the soil surface. Once they begin to grow vertically, the accuracy of NDVI to measure biomass decreases to the point where at values around 0.7-0.9, the index 'saturates', losing its sensitivity. Although a curve can be fit against the data (with high r^2 value), it is not useful as a measure of biomass (Fig. 3b). This effect is most prominent with passive sensors and there may be less 'saturation' using active sensors (Fig. 3c).

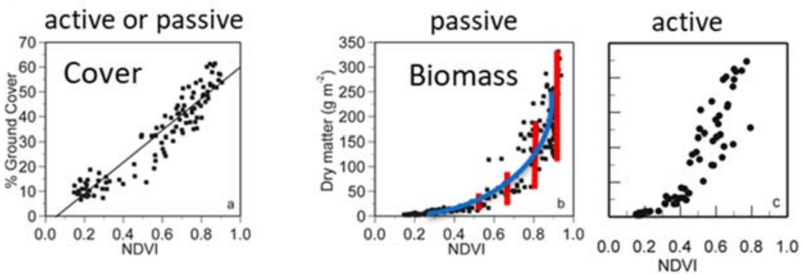

Figure 3. (a) NDVI is a direct measure of canopy cover. (b) Biomass relationship with non-linear curve fit and with vertical bars indicating variability at higher values of NDVI and biomass from a passive proximal sensor, (c) NDVI measured with an active proximal sensor.

The above describes the situation when biomass needs to be quantified (e.g., kg/ha). However, there are times when a relative measure of biomass or 'vigour' is sufficient to provide the information desired as long as the user is aware that above a certain threshold, NDVI is simply a measure of maximum cover. In this instance, a map of NDVI collected on a given date may give a measure of variability in canopy cover across a paddock or farm that provides a synoptic assessment of canopy conditions. Of course, the cause of the differences cannot be determined but it can be used to direct scouting for investigation.

Shades of NDVI

Although NDVI was designed to measure canopy and differentiate plant cover from soil, it measures both cover and changes in photosynthesis because as photosynthesis changes during the season, reflectance in the NIR and Red parts of the spectrum changes. Thus, a sparse but otherwise green, healthy canopy can have the same NDVI value as a denser, yellowing, senescent or unhealthy canopy (Fig. 4a). Tracking NDVI across a season results in a curve that can be separated into an early season growth phase and a senescent phase later in the season, representing different types of crop physiological processes (Fig. 4b). It should be noted however, this means when considering a time series of NDVI data, there are two interpretations to every NDVI value (e.g., horizontal dashed line in Fig 4b). Another aspect of the NDVI is that the values vary depending on the type of sensor (active vs passive) and the wavebands selected. Just as there are shades of green, red and blue, there are differences in NDVI, depending on the wavebands selected for the sensor.

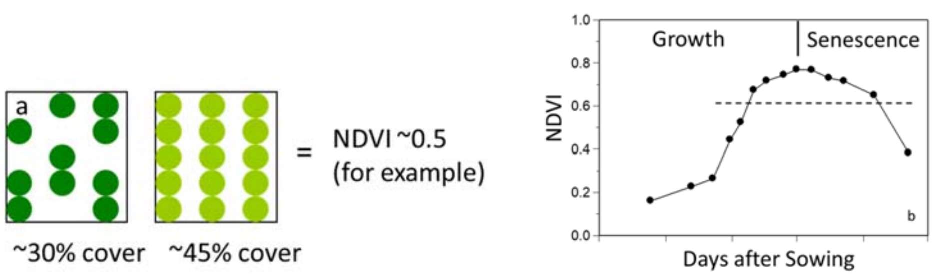

Figure 4. (a) Graphic of NDVI values for sparse, healthy canopy vs denser, less healthy or senescent canopy. (b) time course of NDVI showing plant growth and senescence patterns.

Linking indices to measuring the feature of interest
The main point for using sensors and imagers is to provide information on something that will help in decision making (e.g., biomass, canopy N, degree of pest damage). As noted, a qualitative, uncalibrated map, will provide a visual assessment of variation across a paddock that can be used for scouting. However, calibration is required for absolute measures and tracking changes across time (e.g., growth rates, development of disease, changes in N concentration). Service providers that deliver quantitative, validated data (e.g., kg/ha, %N) should also include a measure of variation (e.g., +/- kg/ha or % from mean).

Beyond NDVI

As noted, there are many other types of indices and technologies that can provide different types of information. Although NDVI is used commonly for estimating variable rate inputs for nitrogen fertiliser, there are other indices such as the NDRE (Normalised difference Red Edge) that use other parts of the spectrum (the 'red edge' – the sharp increase in plant reflectance in Fig. 1) that are better suited to measure N status of crops. In many instances it seems that NDVI has been selected because 'it was there'. Fortunately, there is increasing availability of other indices to match changes in crop physiology and morphology. However, the same caveats apply as discussed for NDVI.

Measuring temperature can allow water status of a plant or crop to be quantified because of changes in transpiration and conductance. Thermal sensing, therefore, can be used to infer water stress due to lack of soil available water, root damage or pests and diseases that affect the crop's ability to transpire, for example. Again, unless proper calibration procedures are put in place, quantifying water use, measuring acute vs chronic stress, etc. cannot be done. For thermal sensing and use of thermal indices (such as the Crop Water Stress Index – CWSI), calibration to temperature will also require measurements of air temperature, humidity and collection of data quickly to avoid changes to stomata that can occur within short periods of time, making calibration of thermal data more problematic than spectral.

Conclusion

The use of technology needs to be informed and placed in the context of the farming operation. The user needs to be clear what type of information is useful and ask informed questions. If sensing data is to be quantitatively compared with other types of data (e.g., yield or protein monitors, soil water) then there needs to be a clear path for calibration and comparing the data sets. Providing clients with an assessment of variation in the data, whether in terms of the index (e.g., NDVI, NDRE, CWSI) or the actual values for a calibrated data set would be a leap forward for the use of remotely sensed data in agriculture.

Suggestions when deciding to use sensing information in farming
- Be clear what you want to know: relative vs quantitative measures
- Collect timely data, at the right scale
- How are data calibrated and validated against actual measures (e.g., kg/ha)?
- Ask informed questions about platforms and information delivered
- How accurate is the information they deliver and how do they know?
- Do you need to integrate other data and how will this happen? (weather, yield, protein, EM)?

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