

# What do sensors tell us about crops?

**Crop sensors provide farmers with rapid, objective, quantitative and precise (repeatable) measurements difficult or impossible to obtain by other means.**

**Those data, usually acquired during the 1st stage of the PA cycle (see the first Precision Ag Corner in our November 2016 edition), need to be turned into information (2nd stage) to help them make optimal management decisions (3rd stage).**

**As our readers now well know, New Ag International has partnered with the Research Group on AgrolCT & Precision Agriculture (GRAP) of the University of Lleida-Agrotecnic Center in Catalonia, Spain. In every issue of the magazine José A. Martínez-Casasnovas, Jaume Arnó and Alexandre Escolà, with our Editorial Team, put together an editorial whose ambition is to help the various stakeholders bridge the gap between datanomics and commercial farming! In the previous Precision Ag Corner in September, we covered general aspects related to sensing. In this issue we review some of the most relevant sensing techniques, either remote or proximal, used to gather information on the crop.**

In the September Precision Ag Corner (PA) we described the basis of sensing techniques and reviewed some soil and yield sensors. However, one of the key aspects in PA is the use of sensors to provide farmers and advisors with reliable data of their crops. Which are the most used sensors in PA either boarded in remote or in proximal platforms? Although it is usually accepted that the trigger of PA were yield maps (obtained by proximal sensing), it is also true that the implementation of PA has been supported by the availability of remote sensing data.

## REMOTE SENSING IN PRECISION AG: MAINLY USED TO CALCULATE VEGETATION INDICES

No-one escapes that Remote Sensing is the acquisition of information about objects, land cover or phenomena without physical contact with them. Although these data acquisition can also be done with some proximal sensors (e.g. photographic cameras), the term Remote Sensing generally refers to the use of sensors boarded on satellites, aircrafts or Unmanned Aerial Vehicles (UAV, drones). Since the beginnings of digital multispectral remote sensing, back in 1972 with the launch of Landsat 1 (NASA), satellite images have been used in agricultural monitoring, crop status mapping, calculation of water needs and crop classification, among other. However, it was not until 2000 that the first publicly high-resolution images (1-4 m) were available with the launch of IKONOS. Afterwards, other satellites able to acquire even higher-resolution

imagery came, enabling full applications in precision agriculture (e.g. Quickbird-2, WorldView-2, 3, etc.). Today, technological advances have permitted the miniaturization of this type of sensors, allowing us to acquire images of up to 2-3 cm/pixel (when boarded on UAV), which expands the range of possible applications in agriculture and other disciplines.

In precision agriculture, remote sensing is mainly used in detailed crop monitoring through the calculation of the so called vegetation indices (VI). The most known VI is the Normalized Difference Vegetation Index (NDVI), which is a simple calculation using the vegetation reflectance on the red (R) and near infrared (NIR) bands of the electromagnetic spectrum:  $NDVI = (NIR - R) / (NIR + R)$ . Healthy plants absorb red light to carry out the photosynthetic process and mainly reflect NIR light. So the healthier the plant, the higher red light absorption (less reflectance), the higher NIR reflectance and, then, the higher NDVI. Alternatively, a plant affected by a disease, a pest or hydric stress tends to reflect more red light and less NIR light, decreasing the NDVI value. Since today there are large number of platforms and sensors, there are hundreds of possible combinations of bands to compute VIs. Then, scientists have to establish relationships between these indices and physiological characteristics of plants.

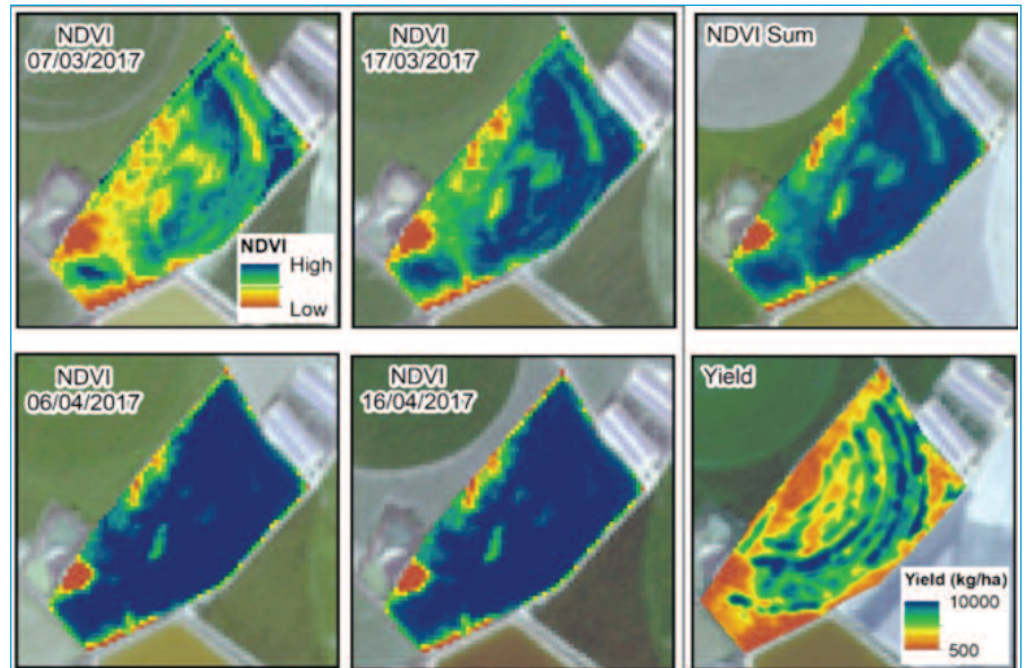
Vegetation indices from remote sensing images can be used for PA purposes in many ways and in different moments of the crop cycle.

Before the beginning of the season, and based on data from previous campaigns, VIs can be used to define site-specific management units for operations such as differential seeding (in grain crops), differential base fertilization, differential amendments with organic matter (e.g. compost) and differential irrigation, among other. For such purposes it could be better not base the decisions only on the VI of a specific date but on the integration of other possible previous images showing the variability of vegetation vigour in the target field/s. This will give a more realistic vision of the productive potential of the different zones of the field (Figure 1). In addition, and preferably, apparent electrical conductivity maps and previous yield maps (if available) should also be used in combination with VIs to define the different site-specific management units. However, many times these data will be not available and farmers will have to rely only in multispectral aerial images and VIs. What if we do not have a series of images to estimate the productive potential from VIs? In many cases farmers will only be able to afford one or two images to map the crop vigour. In those cases the best is to acquire images just before flowering (e.g. grain crops) (Figure 1), or at the beginning of maturation (e.g. grapevine). In other stages, crops (maybe) have not reached their maximum vegetative expression, or it is already declining. During flowering (e.g. maize), the colour of the flowers may interfere with the greenness of the vegetation and could alter the spectral

response in the bands used to compute the VIs, so images between the moment when the crop totally covers the soil and flowering will be preferred.

During the season, vegetation indices mainly serve to monitor the crop status and to decide about the management actions to carry out. These actions can be diverse. Following the crop cycle (e.g. in grain crops), one of the first actions to perform is the application of side dressing, mainly nitrogen (N). Aerial images are then of great interest to direct differential fertilization, since N is one of the main costs in crop production. The moment of image acquisition for this purpose is important (see also Figure 1). For example, in maize the right moment to acquire images to decide about differential side dressing is V6 (six leaves). In that moment the crop almost covers the ground and is still possible to enter in the field to apply the fertilizer. After side dressing, crop monitoring is also important, particularly in irrigated crops. It is not only to detect hydric stress and decide the moment of irrigation, but VIs can also be very useful to detect irrigation problems such as failure of sprinklers, different water pressure along pivot arms, failure of spray nozzles, etc. Complementary, monitoring through VIs can give a feedback to the farmer on how is the crop performing and on the consequences of management operations.

Another important issue for farmers is yield prediction prior to the harvest. Some VIs are well correlated with yield some weeks prior harvesting, without the inconven-



**Figure 1.** Vegetation index (NDVI) at different dates of a winter barley field (15 ha) mapped using Sentinel-2A images. The VI Sum indicates the sum of the VIs along the spring and the Yield image corresponds with the final yield mapped from data acquired by a yield monitor. The VI Sum represents the relative productive potential of each region of the field. The spatial variability of the yield match better with the stage of the crop before flowering (March VIs) than with VIs of later stages, when the NDVI is saturated because of the high absorbance of red light.

iences of yield monitors, or without the necessity to wait till the end of the campaign to have the yield map, either to organize logistics or to estimate the expected income. In grapevines, different studies have demonstrated that VIs derived from multispectral images acquired  $\pm 15$  days of the starting of grape maturity (about one month or more prior to the harvest) are useful to predict grape yield (see the Precision Ag Corner of June 2017, pg. 13). This prediction can improve if other vine load variables sampled during the campaign in reference vines (e.g. number of branches, number of bunches) are also taking into account, in addition to VIs. Some

research works have tried to go even further, trying to demonstrate if not only the grape yield is predictable from VIs but also the quality of the grapes and the quality of the final wine coming from specific selected blocks on the basis of VIs. In this respect, the studies have shown that crop variables related to the vegetative development have higher correlations with VIs, but not all grape quality variables are well correlated. For example, the probable alcoholic degree or total acidity of the grape juice do not usually present a clear differentiation in VI zones, or sometimes depending on the variety. Other properties such as total phenolics, colour, antho-

cyanins or tannins, present better performance in relation to VI zones. In those cases the relationships are inverse, which indicates that low vigour zones are the ones presenting the highest contents of phenolics and the highest values of absorbance units for colour, anthocyanins and tannins in the grape juice; and always the differentiation of those properties are in 2-VI zones than in 3-VI zones. Although VIs can be very useful to monitor spatial variability, before making decisions about differential management it will be important to understand whether there are sufficient and structured spatial variations of vigour. In this way the farmer/technician will see



**Created in 2004, FORCE-A started by developing and manufacturing fluorescence-based sensors dedicated to the university and R&D worlds. Then, it was decided to extend the activity to decision making, particularly in the vine area. J.L. Ayrat and Z.G. Cerovic are the founders of this company. J.L. Ayrat is acting as COO with Lionel Breton as CEO.**

**There are many crop sensors in the market but what do you think is the real use in research and in commercial farms? Is it wide enough? If not, what may be the reasons?**  
The real question is not the number of sensors around but the information they deliver. In both activities where FORCE-A is operating, the company aims to deliver adequate information for the users. In research, the versatility of DUALEX and MULTIPLEX allows researchers to develop their own model in line with their projects. In vine decision making, a highly complex world, the name of the game is to get the information (sensor) and to treat this information in order to deliver a recommendation and not only a characterization.

## Interview with Lionel Breton, CEO, Force-A

**What are the trends in crop sensing and what are the sensors Force-A is offering?**  
Basically, it could be said that three key elements are requested: yield improvement, disease prevention and input management. FORCE-A with its DUALEX and MULTIPLEX tools, offers a possibility to « reach » the signals related to these topics.

**Beyond sensors you also offer services related to decision making for management operations. What are the reasons behind such enlarged portfolio?**

It is obvious when you are a sensor manufacturer to move forward to decision making tools. If we look at the global wine industry, there is a trend worldwide towards better quality. Precision agriculture is a clear answer to "quality improvement".

**A focus group of the European Commission pointed out that Precision Agriculture (PA) usually means high initial costs and long return-on-investment periods. Are PA sensors "too expensive"? Are there independent trustworthy cost-benefit studies analysing the actual pay-back of PA implementation?**

As for all new technologies, there are different phases. The phase 1, we can call it the « native » one, is obviously expensive in terms of development, research and application. But when technology proves to answer a real market need, let's say in phase 2, cost saving through extensive usage of the technology is arising and brings as well profit to

the user. We have at FORCE-A, the clear evidence of this process.

**Are your fluorescence tools calibrated for early detection of nutrient deficiencies, in particular micronutrients deficiencies that are very often hidden in the early stages?**

In the nutrient management applications, our tools are dedicated to Nitrogen management, where several publications have shown our capability to assess early stage deficiencies (eg Multiplex on Maize).

**“In the nutrient management applications, our tools are dedicated to Nitrogen management, where we have a documented capability to assess early stage deficiencies, e.g. with Multiplex on Maize”**

**Over 20% of the wheat acreage in France access decision support services for third Nitrogen application mostly from satellite images and drones. How does Force A solutions differentiate from those integrated services with ready to use variable rate application maps?**  
One of the key features of

FORCE-A products is proximity non-destructive technology. This is very well understood by our clients and we developed for them proprietary indices such as NBI, the Nitrogen Balance Index.

**You have set up a number of partnerships around the world, mainly with research institutions. Very few indeed with the inputs industry. However one is noticeable, it is the partnership with French biostimulants company Goemar. What is the nature of the partnership?**

We have set up partnerships with both universities/R&D researchers and industrial partners; in this second case, especially with the world of vine and wine. We are operating on a worldwide basis on research with exclusive distributor arrangements from USA to China, from Brazil to India and we have a lot of partnerships with grape growers in key wine countries in order to deliver an in depth personalized recommendation; no two wines are equivalent!

**What are the principal challenges in crop sensing for PA in the coming years? How is Force-A positioned to address them? Where do you see the most important market growth for your products and services?**

As I was mentioning before, we have three key objectives quantity (yield), perenity of the crop (detection of disease) and safety (input management). We at FORCE-A get ready to answer challenges we could summarize as feeding an increasing number of people, protect raw material supply and respect the environment.





Figure 2. Example of image acquired by an UAV with a resolution of 2 cm/pixel. The figure shows the octocopter used to acquire the image and the level of detail (including two people sampling in the orchard during the flight!).



Figure 3. Different commercial radiometric sensors used for on-the-go crop vigour estimation and variable rate fertilizing.

whether site-specific management areas within the field are large enough to justify investing in the required equipment and devices for differential management. As one can see, remote sensing has played, and is playing, an important role in PA and it still has many things to say. Coinciding with the UAV boom, there is also a new revolution in the development of new satellites and sensors. The launch of new satellite missions with improved payloads and the appearance of nanosatellites, increasing both the spatial and temporal resolutions of image series, are opening new possibilities. For example, there are companies (e.g. Planet) that intend to provide daily coverage of the world with a detail of 3-4 m/pixel. For that there will be a constella-

tion of 120 satellites able to capture 150,000,000 km<sup>2</sup>/day in the RGB and NIR spectral bands. In addition to these private initiatives there are contributions of public administrations, as for example the Sentinel-2 mission of the European Commission. This mission provides free imagery with a revisit time of about 5 days and with a 10 / 20 m pixel resolution (visit <https://sentinel.esa.int/web/sentinel/missions/sentinel-2> for details). Although 10 m resolution can be a limit for PA purposes in small fields, it can be useful in applications in extensive crops or large horticultural fields. Despite these advances, aircrafts and UAVs go on in taking their part of the cake. Decreasing the altitude of sensors reduces the need for atmospheric corrections and

increases the spatial resolution of images (Figure 2). The latter is very important when working with row crops such as vineyards or fruit trees. This allows for the removal of ground pixels to only work with pure crop data. Additionally, such high spatial resolution imagery

could also be used to detect weed patches within fields and derive prescription maps to control them in a variable rate site-specific approach.

In conclusion, today farmers and technicians have a large number of possibilities to monitor their crops and to decide about differential management based on remote sensing imagery. New applications are expected to come in a near future and no platform or sensor should be discarded.

### PROXIMAL SENSING: HELPING TO ASSESS THE VIGOR OF THE CROP

Proximal crop sensing has evolved rapidly in the last years and many sensors and sensing techniques are either commercially available or at their last developing stages. Among the available techniques, there are applications based on machine vision, radiometry, ultrasounds, LiDAR and many other sensing principles. Such is the case of ground-based radiometric sensors to estimate crop vigour and to relate it to the N content or the N needs. Figure 3 shows several commercial sensors used for on-the-go vigour estimation for variable rate N application in grain crops.

In horticulture, crops are usually trained in 3D shapes. That makes it very important not only to sense them from above with aerial remote sensing solutions but also along their lateral sides. Additionally, measuring the fruits

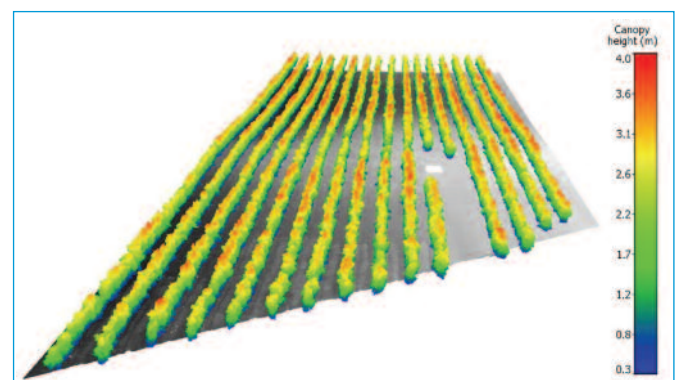


Figure 4. 3D point cloud (left) and canopy volume map (right) of a 1-ha olive orchard. Images adapted from the paper published by Escolà et al. at Precision Agriculture (2017) 18:111–132.

for geometric and quality characteristics in fruit crops may provide the farmers with important information on their final product. Machine vision, for instance, is used to detect and count fruits in orchard for crop load estimation. Radiometric sensors can be used for vigour and disease detection in fruit orchards. It is of interest the use of thermal radiometric sensors to detect water status and derived irrigation needs.

Other types of sensors and sensing techniques are still under development. Such is the case of LiDAR (light detection and ranging) sensors to get information on the canopy of arable crop as well as of tree crops. This kind of sensors is

being used airborne in forestry for many years in what is known as airborne laser scanners (ALS). However, cost reductions and technology improvements have turned them into a good ground-based alternative for agriculture, the terrestrial laser scanners (TLS), when stationary, or the mobile terrestrial laser scanners (MTLS). Putting it simple, LiDAR sensors use laser light to detect objects and estimate their distance. Usually, this kind of sensor provide with 2D or 3D distance measurements with the aid of rotating mirrors directing the laser beam to different angles around the sensor. The sensor output is usually a polar array providing with ranges

and angles for each of the measurements. When used together with a GNSS receiver, the position of the mobile antenna is transferred to the sensor and to each of the measurements resulting in a 3D point cloud of the scanned scene (Fig. 4, left). When scanning an orchard with a MTLS, information on tree heights, widths and canopy volume can be extracted and presented to the farmer as a spatial variability map of each of the parameters (Fig 4, right). Additionally, information on the leaf area index, canopy porosity and other geometrical and structural properties can also be derived. Moreover, scanning the fields or the orchards several times during the season provide with the temporal evolution of the crop. For instance, when subtracting canopy volume maps of different dates, the result is a growth map between the two dates.

Like other sensing techniques, the information provided is not a diagnosis of what is happening in the field but an overall picture of its variability. Then, it is turn for the farmer or the advisor to figure out what is going on in the field and to decide the best management strategy. These kind of systems and techniques are already in use in the industry but they are still under development in agriculture.

#### FLUORESCENCE SENSING: THE LIGHT THAT 'EXCITES' PLANTS

Apart from visible and infrared reflectance, chlorophyll concentration within leaves or the functioning of photosynthesis as a global process can be sensed by fluorescent light. Now, the light is not simply reflected but emitted at a wavelength greater than the initially absorbed which excites the plants to fluoresce. Thus, fluorescence in the blue to green region extends wavelengths from about 400 to 600 nm. Another common range for plant fluorescence is the red (650 nm) to far-red region (770 nm). As chlorophyll and pho-

tosynthesis are normally involved in this flux of radiation (from excitation to emitted fluorescence), signals detected by fluorescence sensors can be interpreted in terms of chlorophyll content and photosynthetic activity. Specifically, less photo-chemically active leaves (with lower chlorophyll content) increase fluorescence compared to healthy leaves with greater light absorbance. The reasoning is simple. Plants poorly equipped with chlorophyll due to being affected by water deficit, wrong supply of mineral nutrients, diseases or pest infestations cannot take advantage of much of the solar energy they receive. Thus, if photosynthesis cannot take place in the right conditions, plants use chlorophyll fluorescence as a way to dissipate all or part of the solar energy.

From the point of view of precision agriculture, crop site-specific information about the progress of photosynthesis may be of great interest when optimizing doses of water and phytochemicals. To give an example, detection of fluorescence is now possible using the proximal Multiplex sensor developed by Force-A (Paris, France). Making use of plant fluorescence, this sensor provides information on the physiological state of the crop and on the contents of chlorophyll and polyphenols in leaves and fruits. In this way, through discrete or on-the-go measurements, farmers can have additional information for decision-making in areas such as fertilization, early disease detection or monitoring of crop quality parameters. Moreover, the European Space Agency is preparing a mission for 2022 called Earth Explorer - Fluorescence Explorer (FLEX) that will allow mapping of vegetation fluorescence and, hence, quantify the photosynthetic activity. Such data is only possible with proximal sensors, currently (<https://earth.esa.int/web/guest/missions/esa-future-missions/flex>).

### Glossary of terms

**Remote sensing:** Technically, RS is the acquisition of information about objects or phenomena without physical contact. In Precision Agriculture, it generally refers to the use of satellite-, aircraft- or unmanned aerial vehicles-based sensing technologies to detect, analyse and classify vegetation based on reflected and/or emitted electromagnetic radiation from passive or active energy sources. Remote sensing is used in numerous fields, including agriculture, geography, land surveying hydrology, ecology, oceanography, geology, among others.

**Sentinel missions:** The European Space Agency (ESA) is deploying a new family of missions for Earth observation and monitoring called Sentinels within the Copernicus programme. Each Sentinel mission is based on a constellation of two satellites to fulfil revisit and coverage requirements, providing robust datasets for Copernicus Services. These missions carry a range of technologies, such as radar and multi-spectral imaging instruments for land, ocean and atmospheric monitoring. One of these missions is Sentinel-2, which is a multispectral high-resolution (10 or 20 m) imaging mission for land monitoring to provide, for example, imagery of vegetation, soil and water cover, inland waterways and coastal areas.

**Proximal sensing:** Term used as the opposite of Remote Sensing. But how proximal is Proximal sensing? To avoid establishing a threshold, in Precision Ag it is commonly accepted that proximal sensing techniques are those using sensors for ground-based measurements. Proximal sensing is very useful to get crop data with a higher detail than with RS or to get data from hidden areas, impossible to monitor using RS.

**On-the-go sensing:** Sensing technique consisting of one or several sensors providing readings in a nearly-continuous way so that measurements can be acquired either to be stored and subsequently processed or to be processed in real time. Once connected, some sensors are designed to provide reading at a given frequency so that the acquisition system only needs to capture the data. Some other sensors are designed to response after a trigger signal. Such signal has to be provided by the acquisition system, forcing it to include a microprocessor.