PRACTICAL USES OF SMART TECHNOLOGIES

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Abstract

With the ever increasing pressure on agriculture to lower the economic and environmental cost of production of crops and livestock, combined with the growing availability and capability of smart technologies, there is a need to understand how best to practically combine these new computing and sensing capacities with agronomy to achieve the desired financial and environmental outcome. While this is a rapidly evolving area, the principles of good agronomic practice still hold, albeit at a smaller spatial scale, which provides us with a clear path to follow while trying to link smart technologies and agronomy together in the practice of Precision Agriculture.

This paper describes and reflects on the application of a number of smart technologies used on farm and within the company "Soilessentials".

Types of Spatial Variability

Although there are many forms of spatial variability, in practice they can be divided into 2 broad groups. These are firstly, spatial variability which can be corrected and secondly, spatial variability that cannot be corrected. In general, by farming the land over decades, we have caused much of the variation in crops and soils, however, as we have caused it, we can correct it. We call this type of variability Management Induced Variability. We are then left with variability that we cannot correct, but have to instead manage to improve crop profitability. This is called inherent variability. We have precision agriculture tools to detect , correct and manage both types of spatial variability, but in practice, the aim should be to correct management induced variability first, then change crop management in the areas where yield is limited by inherent variability.

Temporal variability can happen when changing weather patterns cause crops to respond differently to changes in the inherent spatial variability. This can be the major cause of changes in yield patterns from year to year in some fields and remote sensing, whether from satellite, unmanned aerial vehicles or tractor mounted sensors is the ideal tool to detect these temporal changes and create a variable rate application map for crop inputs tuned to that particular crop, soil and weather combination.

Tools to detect and solve Management Induced Variability

Management induced variability mainly comprises of soil fertility limitations; soil mineral N, compaction and field amalgamation. Current tools to detect and correct these are soil sampling conducted on either a grid or zone basis. In practice, the choice between them depends on the variability of the element to be sampled, the cost of analysis and the response of the crop to areas of high and low levels. We have found from experience that as pH varies relatively quickly in the soil, is inexpensive to measure, and has a large effect on the growing crop, the optimum sampling strategy is grid sampling at 50 meter spacing. However, P, K and Mg can vary less quickly in the soil, are much more expensive to analyse, and have a broader optimum range of levels so in many cases zone based sampling is adequate to define the different soil levels in the field. For zone sampling, the location of the samples are based upon factors such as field history, yield zones and soil textural areas which separates the field into zones rather than a grid pattern. One sample is taken from each zone.

pH Mapping and VRA Lime Application

Why does pH change within a field?

1. Field history. When you have several old fields amalgamated into 1 - even 40 years ago - then the lime application and cropping history will cause huge long lasting variations in pH across different soil types.

2. Spreader mistakes - years of spreading lime have caused some large variations in soil pH. Wrong calibration, dumping lime at gateways, stuck spreaders, spreading the last 3 tonnes in the hopper on the endrig.

3. Soil Texture - lighter soils tend to be lower in pH than heavier soils.

In general in the UK factors 1 and 2 are by far the most important, 3 comes a long way behind. However, because we can’t forecast where spreader mistakes have happened, zone sampling is inappropriate in our conditions when we are trying to detect and correct pH variability. In addition, as pH is highly variable, is low cost to analyse and has a large detrimental effect on growing crops (both low and high pH) we suggest that economically and practically, we need to take samples based on a grid at 50 meter intervals (4 per ha). Using this strategy we would normally expect to see a 50% saving in lime applications and a large reduction of the infield variability of pH.

Phosphate, Potassium and other Soil Elements.

The other main elements tend not to behave in quite the same way as pH. This is because they are normally applied as granular fertiliser, with is much easier than lime to spread evenly. There is still variability caused by field history and amalgamation, and some linkage to soil texture (potassium tends to be lower in sandy soils due to leaching, magnesium tends to be high in heavier soils) but the main causes of phosphate and potassium variation we see are due to:

1. Field history. When you have several old fields amalgamated into 1 - even 40 years ago - then cropping history will cause huge long lasting variations in P, K and Mg across different soil types.

2. Where yields have been variable within fields, and granular fertiliser has been uniformly applied to the average of the whole fields yield offtake, we tend to see an inverse relationship develop between soil phosphate and potassium and yield. In the

low yielding areas levels of nutrients tend to be high due to low offtake, and in high yielding areas tend to be low due to higher offtake.

3. Soil Texture - lighter soils tend to be lower in potassium than heavier soils.

4. Other factors come can come into play. For example fertility levels are often high near gateways where cows have lain waiting to come in to be milked. These factors are usually well known to the farmer and can be used in designing a zone sampling plan.

So our preferred strategy for P & K sampling is to create a zone sampling plan, the samples to be taken at the same time as the field is grid sampled for pH. As phosphate and potassium often tend not to be so variable with fields (due in part to the ease of spreading of granular fertiliser vs lime), as the cost of chemical analysis is higher, the optimum band of P and K levels is wider , and we can forecast more accurately where soil P and K levels are likely to be different, the economics of precision soil sampling swing to taking fewer soil samples than with pH alone. Our recommended method is to first split the field into old field boundaries, then within each old field boundary sub divide them into low and high yielding zones. Divide the yield zones into soil textural zones, then finally divide those if necessary into smaller zones using farmer or agronomist knowledge (where the cows lie). This method results in fewer soil samples, but with a high likelihood of capturing the variation of phosphate and potassium. Then to make an application map we suggest using a yield map for crop nutrient removal and modify the removal map based on the zone samples to either build or lower soil indexes in each zone by using variable rate application. This has proved to be a low cost, flexible and practical system for the spatial management of soil fertility.

Tools to Manage Inherent Variability.

Once management induced variability has been detected and corrected, inherent variability can be measured and mapped, the cause of the variability identified, and agronomic strategies put in place to minimise yield loss. If these areas cannot be brought back into profitability, then consideration can be made to reducing seed, fertiliser and agrochemical applications in those areas to bring them back into profitability.

Soil Conductivity Mapping.

Soil conductivity is an excellent surrogate measure of field variability and quickly and practically delineates areas of different soil texture. At the same time the conductivity survey is carried out it is often useful to use a high accuracy (RTK) GNSS receiver to create a digital elevation model of the changes in height across the field. This can then be used to create a slope and aspect map, which often correlates well to yield. We often see a 10% yield loss in slopes out of direct sunlight in cereals and potatoes. These maps are unlikely to change, and can be used as baseline information to manage the inherent spatial variation, using tools like variable seedrates and irrigation.

Yield Mapping

Yield mapping is a key component of precision farming, as it validates all other management decisions taken, and quantifies the cost of yield loss to determine if any corrective action is economically viable. Now yield monitors are available across a broad range of crops it's useful to normalize these maps and compare them across several years to delineate field zones in which the yield potential can be more accurately estimated rather than the current assumption of equal yield potential across the whole field. When multiple years of crop yield are normalized and integrated with soil texture, slope and aspect, soil fertility and other spatial attributes it is often possible to identify yield limited areas which are not performing as well as expected.

Tools to Manage Temporal Variability

In a commercial growing system crops and soils (and the biological, chemical and physical interface between them) are subject to changing weather conditions throughout the life of the crop. This then impacts on crop yield potential through drought stress or excess water, solar radiation levels and temperature differences. In order to practically manage crop inputs for the crop that is currently growing, we need a method of measuring the growing crop canopy and making management decisions on N applications, fungicides and growth regulators based on the current crop canopy. Repeated crop scans can be made and change maps calculated to highlight areas not responding to the current management regime and where the targeted intervention of an agronomist is needed. There are 3 main methods of acquiring this "real time" canopy information.

Satellite Imaging

Crop imaging from satellite is a mature technology and has been used for decades. Unfortunately even with the improved spatial, temporal and spectral resolution available now, it still suffers from cloud cover obscuring the target crop. Cost is also an issue, especially for higher resolution imagery, but lower resolution imagery like Landsat 8 is available free of charge.

UAV's

Unmanned Aerial Vehicles are early in their development lifespan, but are showing promise in some crop imaging situations. A combination of increased image reliability as the operator is in control of the acquisition, and very high resolution (1 to 3 cm is easily possible) makes it possible for growers to get detailed crop imagery on demand for crop scouting and variable rate map production.

Tractor Mounted Sensors

A range of tractor mounted sensors (e.g. Yara, GreenSeeker, TopCon, CropCircle) have been available for several years, and have been shown to quantify within field crop variability in growing crops. Their chief advantage is a low cost per field (as it's a one off payment for the sensor), crop imaging whatever the weather or in the dark and they can be configured for real time application of nitrogen and crop protection products.

Variable Rate Nitrogen

Variable rate nitrogen is a powerful tool to manipulate crop canopies and as much can be achieved by manipulating N timings as by changing total N application rates. Care must be taken before using VRA N as, if the procedure above is not followed, then crop areas that are limited by management induced variability (i.e. low pH areas) will be interpreted by the sensor as needing more nitrogen, although the yield limiting factor there is not nitrogen. This will immediately lower nitrogen use efficiency and therefore reduce profitability and increase N leaching.

Data Management

Data management is one of the biggest problems facing users when trying to practice precision agriculture. Now machines are connected to the internet through the mobile and WIFI networks data can be sent and received from the farm office to the tractor with minimal input from the operator. Work jobs, VRA maps and yield maps can all be synchronized from the tractor or agronomist to the farm office or cloud based farm management system. Tractor performance can be monitored and recorded to allow comparison of tractor performance. This allows tractors to become part of “The Connected Farm” and solves data transfer problems. However, as data volumes grow from connected tractors and users, the main limitation in delivering precision agricultural crop recommendations is data volume and analysis. However the development of cloud computing has the potential to remove these limitations in a cost effective manner, making it practical to agronomically benefit from the huge data volumes that are now available.

Cloud Computing

One of the main limitations to the mass uptake of precision agriculture was the ability to cheaply and effectively deal with huge volumes of data. Satellite imagery, UAV mosaics and telematics data all create potentially huge spatial and temporal databases. Fortunately the rise of elastic cloud computing makes handling rapidly growing data sets relatively straightforward with computing frameworks that allow for the distributed processing of large data sets across clusters of computers.. They are designed to scale up from single servers to thousands of machines, each offering local computation and storage. Rather than rely on hardware to deliver high-availability, the framework itself is designed to detect and handle failures so delivering a highly-available service.

New Options in Remote Sensing

Several advanced new satellite systems are in development which aims to improve on the existing high cost, low availability models.

ESA - Sentinel Series

The Sentinel series of earth observation satellites is planned by the European Space Agency (ESA) to be delivered over the next few years. See the ESA website for an overview of the Sentinel missions. In agriculture, Sentinel 2 is a 2 satellite system specifically designed for vegetation monitoring. Sentinel-2 will carry an optical payload with visible, near infrared and shortwave infrared sensors comprising 13 spectral bands: 4 bands at 10 m, 6 bands at 20 m and 3 bands at 60 m spatial resolution (the latter is dedicated to atmospheric corrections and cloud screening). The 13 spectral bands guarantee consistent time series, showing variability in land surface conditions and minimising any artefacts introduced by atmospheric variability. When the pair of satellites is in operation, they have a revisit time of five days at the equator (under cloud-free conditions) and 2–3 days at mid-latitudes. The increased swath width along with the short revisit time allows rapid changes to be monitored, such as vegetation during the growing season. ESA are planning to make the Sentinel imagery available at very low cost.

Planet Labs

Planet Labs is a commercial company in the vanguard of a revolution in earth observation (EO), where, as a disruptive technology, they are launching "flocking" satellites 29 at a time from the international space station. Their aim is to offer 3 to 5 meter resolution imagery of the whole Earth, updated daily. These are a fraction of the size of a traditional EO satellite, which makes them low cost to build and deploy. This system has the potential to revolutionise agricultural earth observation with high spatial and spectral resolution and daily revisit times.

Sky Box

Sky Box (recently acquired by Google) uses a similar concept to Planet Labs, in that multiple, small, low cost imaging satellites replace one or two large, expensive imagers. They aim to offer high resolution (sub meter), daily imagery, but are also offering HD video from space and allow users to task each satellite live so they can get real time video of their target. They offer up to 90 seconds of HD video from space on demand, of any point in the world.

Agriculture plays a part in the business model of these new, disruptive earth observation companies, but their main, high value markets are in retail, transport, logistics and environmental monitoring. Also the key disruptive technology is not the satellites themselves, but the elastic cloud based image analysis and processing systems that make it possible to process the enormous data volume these EO systems gather daily.

KORE - Remote Sensing Imagery Fusion

The KORE project (http://artes-apps.esa.int/projects/kore) brings together a number of complementary services offering information to support precision agriculture to farmers and agronomists. In particular, it aims to fuse imagery from many different sources (satellite, UAV and tractor mounted) in order to offer reliable crop imagery for crop scouting and spatial crop modelling at least weekly. This weekly imagery, supplied via a web browser and mobile app, promises to lower the burden of crop scouting, and provide early warning of developing crop problems.

Spatial Crop Modelling

Traditional crop models can predict yields and crop quality characteristics by field. However with the computing power and easy availability supplied by elastic cloud computing, and the higher resolution and better reliability of EO data (for spatial model validation and information) it's now possible to run and validate spatial crop models daily to predict likely crop yield and quality variation, based on a particular set of weather data, soil assumptions and yield potential. This allows the production of near real time crop canopy and yield estimates. When compared to recent EO imagery the spatial crop model can highlight where there is a disagreement between the expected and actual crop value. These areas are likely to harbor previously undetected yield limiting factors, which need to be investigated by the farm agronomist. Examples of current projects working on spatial crop modelling are:

Potato Yield and Tuber Size Distribution – Tuberzone.

The potato industry has witnessed a 10-year long yield stagnation; coupled with increasingly stringent demands on potato quality, there is a compelling need for farmers to increase marketable yield. This project aims to develop an innovative spatial crop model & integrated decision support system for improved variable rate seed planting, fertiliser use & irrigation scheduling to increase productivity of the potato value chain. Converging the multi-disciplinary expertise of Soil Essentials (SE), Newcastle University (NU), Mylnefield Research Services (MRS), Grimme (GR), & McCain (MC), we will build upon the MAPP point model (Management Advisory Package for Potatoes) by taking a holistic approach & considering the spatial variability of tuber size distribution to inform a new & improved adaptive spatial meta-model. The resulting spatial decision support system is cross-sectorial & has the potential to transform in-field decision-making, not just for potato farming but also for other root & arable crops.

Potato Late Blight – Blightsense

Potato late blight is one of the world's most destructive crop diseases, with £3.5Bn annual losses globally in an industry suffering stagnant yields for the last decade. This project will develop a rapid acoustic biosensor device for in-field identification of air-borne sporangia of Phytophthora Infestans (causal agent of late blight), to meet the compelling need for improved disease management & control. Soil Essentials (SE), a precision-farming SME, together with University of Cambridge (UC), the James Hutton Institute (JHI), Mylnefield Research Services (MRS) & Syngenta (SG), will develop an integrated diagnostic tool for early pathogen detection, by coupling low-cost, antibody-coated acoustic sensing consumables with a proven spore-trap. The proposed innovation, enabled only by the interdisciplinary convergence of state-of-the art acousto-electronics, smart materials, biochemistry, late blight epidemiology, advanced ICT & precision agriculture, will enable optimised disease control, reducing potato crop waste & fungicide costs, improving marketable yield & quality. As a platform technology, it can be easily adapted to detect other crop & livestock pathogens for wider agricultural impact.

Conclusions

Many of the principles of precision agriculture have remained the same in terms of improved use of targetted inputs and maximising nutrient use efficiency for example. The tools to complete the job have matured and new opportunities are emerging which make the application of PA easier and potentially more profitable for farmers and growers. The new opportunities to collect remote sensed data for example has lead to the emergence of cloud computing which can be more readily accessed by farmers for farm management purposes than could have been thought possible in the past. Improvements in computing can also mean that higher resolution (both time and space) crop models can be developed to assist in PA based management systems. Clearly there are many new opportunities emerging where access to advanced computing resources has made a significant difference to what is both possible and practical.