SENSORS – WHAT HAVE WE GOT AND WHERE ARE WE HEADING

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Abstract

There are now an increasing number of sensor platforms that may be available to farmers, regional councils, other land owners and rural professionals. Sensors to measure vegetation can be mounted on satellites, carried in aircraft, carried using unmanned aerial systems UAS or remote piloted aerial systems RPAS, vehicles have been used for some time and an increasing number of handheld sensors are on the market. As well as sensing platforms, end users now have a choice of sensor or imaging systems. Many of the remote sensors rely on light reflectance from the target, and there is a range of choice in terms of spectral and spatial resolution. This paper explores the range of sensors available.

Sensors have a range of abilities in terms of what they can sense, the more sophisticated hyperspectral imaging systems are capable of determining the nutrient (N, P, K, S) concentration as well as nutritional qualities. This is currently being employed in the PGP "Pioneering to Precision" project jointly funded by Ravensdown and the Ministry of Primary Industries (MPI). This sensor can also discriminate between plants and different varieties and cultivars of the same plant.

Other sensors have high spatial resolution, for example, UAS mounted systems such as the Trimble UX5 which generates 16 million points per hectare. Although this gives a very high quality image, it has a significant data processing and storage overhead. These very high quality images create an expectation in terms of presentation of results and put considerable demands on the rural digital infrastructure for delivery of service, as do other methods such as machine vision. Adoption by farmers has been slow in the past, there is the possibility that increasingly complex systems will put the information produced by these sensors out of reach for many farmers. These issues are also discussed.

Introduction

The choice of sensor for crop and pasture scouting is growing more complex with a number of sensing technologies and sensing platforms available. Most remote sensors rely on the reflectance from an object, they are low energy and so are only looking at the reflectance from the surface of an object and detect the differences in reflection between wavebands. Every living thing has a distinct spectral reflectance signature and it is that signature that is described in Figure 1, (red line). There are a range of statistical techniques that can be used to either discriminate one object from another or to quantify a property - how much chlorophyll is present for example.

Data resolution is improving both in terms of the spatial resolution, we are going down to a very small scale, and spectral resolution, we are increasing the number and range of wavebands that we can detect. The range of waveband detected is important in terms of what we can measure, and bandwidth is important in that the narrower the band width around individual measurement wavebands, the more likely it is to be effective. There is a lot of misrepresentation of what sensors can do. Figure 1 shows part of the electromagnetic spectrum we are currently using to make measurements of our agricultural productivity and wider environment. In order to measure the biochemical properties of plants we need an extended spectral range of measurement. This is well proven in scientific literature. The source of the picture: http://www.markelowitz.com/Hyperspectral.html is well worth visiting to read more about this whole technological area. The shortwave infrared is important in trying to determine bio-chemical properties of plants. Other parts of the spectrum can be used to compare leaf pigment or cell structure, a combination of all three increases the power and robustness of the sensor in terms of the information produced. There are a number of sensors used around the red edge area and these are often associated with detection of chlorophyll for example and other properties are estimated by association, the problem is that association does not always hold true and can be open to mis-interpretation. Using a wider spectral range with a greater number of wavebands producesmore robust results.

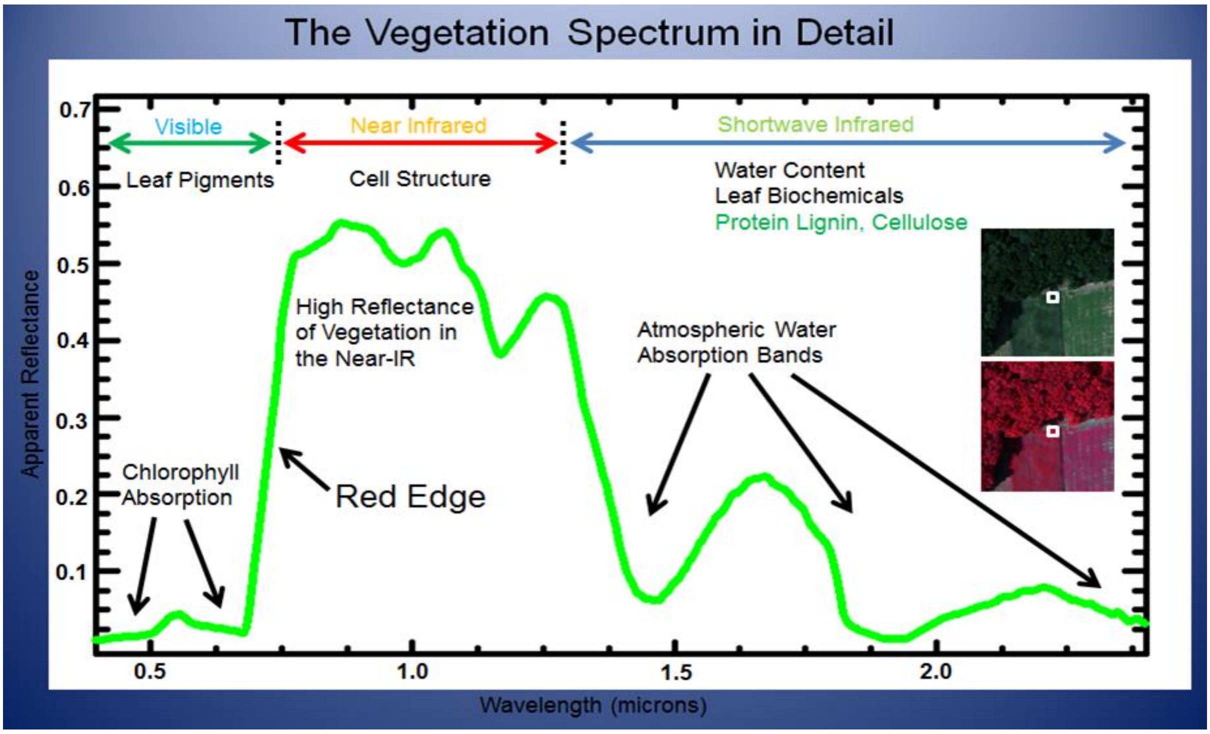

Figure 1. A vegetative reflectance signature within the VIS, NIR and SWIR region of the electromagnetic spectrum. From http://www.markelowitz.com/Hyperspectral.html

Sensing is where the sensor is pointed at a target and an averaged reading from the detector's field of view is used. Imaging is where the reflectance is developed into a line of pixels and then each line is mounted into an image, such as a push-broom sensor. Photography can be taken from the air and ortho-rectification used to allow a complete continuous image of a survey area to be completed.

There are basically five platforms available to carry sensors, pedestrian, vehicle, UAV, aircraft and satellite. Pedestrian sensors have been well documented at this workshop over the years with a number being demonstrated. They can range from a simple device that will calculate a vegetation index such as NDVI based on two wave bands around the red edge and chlorophyll absorption area, to more sophisticated instruments such as the ASD FieldSpec Pro which can be used to detect vegetation qualities and bio-chemical properties. An example of this is work described in Pullanagari et al (2012).

Simple two and three band sensors can also be carried by vehicles, these sensors, such as Greenseeker and Crop Circle have their own modulated light source which allows the sensor to be used in any lighting conditions, even after dark. They are more consistent than sensors which rely on ambient light because ambient light varies and so will reflectance, so if you are doing multiple surveys it is difficult to achieve consistent results. The main limitation is that they are carried on a vehicle such as a fertiliser spreader or sprayer and are used to decide the level of nitrogen application, for example or spot spraying of weeds. The size of area to be covered is limited to the area being treated, so it is important to consider it as part of the operation rather than a separate operation. These variable rate application systems are available to carry this out in real time.

Figure 2 illustrates three methods of pasture measurement. The first two use reflectance and the third is the C-Dax Pasturemeter ® similar trends exist in the data. The first two methods cost about 4 times the cost of the Pasturemeter and operate at similar speeds. Very few reflectance type sensors are used in New Zealand, around 3000 Pasturemeters are used in the New Zealand dairy industry.

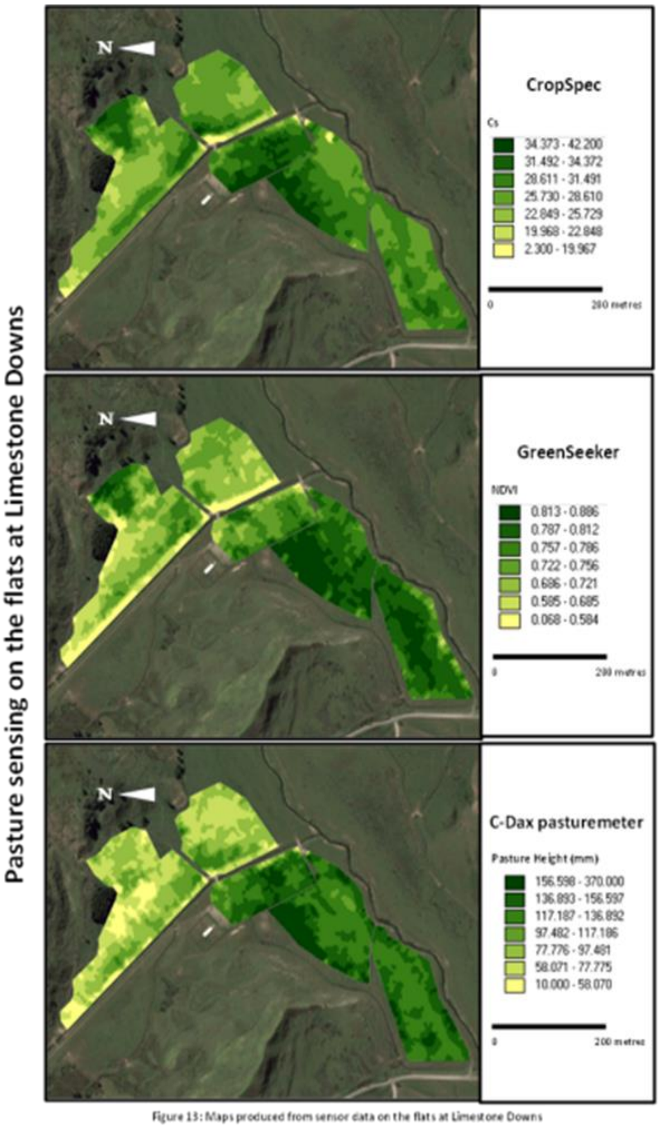

Figure 2. An illustration of three methods of pasture measurement.

UAVs have been put forward as the great new development and while they have huge potential they have limitations as well. The Civil Aviation Authority (CAA) are charged with keeping our airways safe and like all other air traffic, responsibility must be shown by the operator. UAVs need to be flown at 400ft above ground altitude or below, fixed wing models are required to have an observer as well as the remote pilot, the UAV must also stay within line of sight at all times. These conditions do restrict the operational capability and cost of running UAVs. There is a lot of interest in trying to get beyond line of sight to develop autonomous flight but in order for that to happen the CAA and other aviation authorities around the world must be completely satisfied that this is a safe thing to do. The main dangers are other air users, such as ag aviation pilots and people on the ground if something goes wrong. It is likely that these types of developments will have to be further researched and capabilities such as sense and avoid will have to be included. For example I might want to sample from 4m off the ground - infrastructure such as a centre pivot irrigator might be in the way and in a different place from the last flight. Lots of other hazards will need to be detected.

UAVs use in agriculture is at its early stages and new developments will come along which will make them much more automated, extend the time they can stay in the air, increase their flight time and battery life, increase their range. Most of this will be achieved through autonomous flight but under current rules we are using radio controlled flight, or at least we can intervene and take over control if things go wrong because we have line of sight. Radio controllers have a limited range, mainly line of sight, and to provide signal beyond that would require more infrastructure.

Currently UAVs are being used for developing accurate digital terrain models (DTM) through aerial ortho-photography. Crop scouting and weed detection, plant biomass estimation. The three examples in Figure 3 demonstrate how this can be done. This has been completed with a Trimble UX5 fixed wing UAV. The same system has also been used to investigate detection of urine spots under dairy farming, this is under an MBIE project Optimum – N which is being run by Lincoln Agritech and work is being completed by Lincoln University, AgResearch and Massey University. The main advantage of this system is that is spatially at a very fine resolution, when flown at 400ft (115 m approx.) the pixel size of the ground is 3.5 cm, meaning each hectare is represented by over 8 million pixels. We have to ask ourselves if we need this and the answer is probably not, but it does give very clear images which people like to see, it reinforces our view on accuracy, and is spatially accurate but we need to think of spectral accuracy in the same way. Fixed wing UAV are faster (travel at around 80km/h) than multi-rotor, 25 to 45km/h, and carry a much lighter payload.

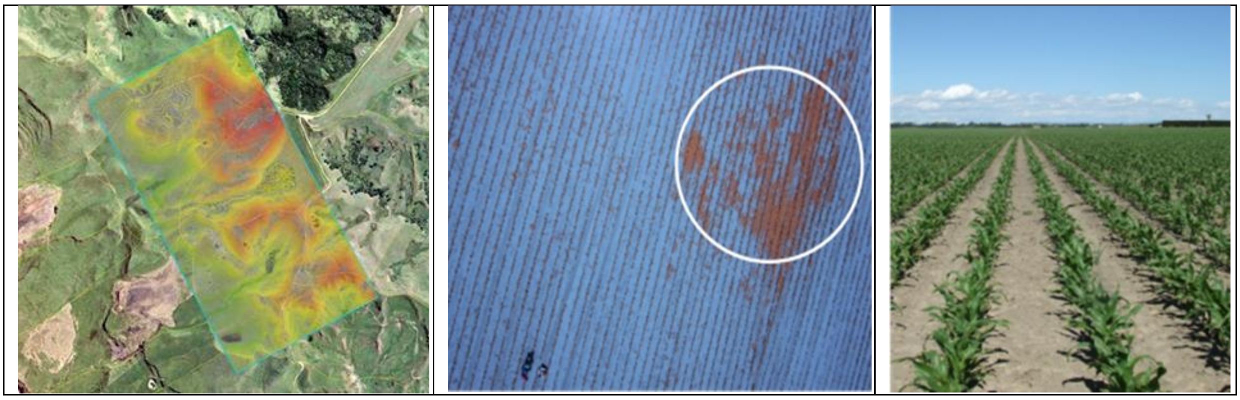

Figure 3. (a) DTM on hill country property, (b) weed detection using NIR camera, (c) Maize at ta stage where plant population can be counted from the air and bio-mass calculated.

Multi-rotor helicopter UAV's are capable of carrying more complex sensors because they can carry more weight however they are slower and making sure all data can be geo-rectified can be problematic at the moment. These are types of issues that are being worked on to make this technology more useful and there is considerable research effort going into this around the world.

Airborne sensors are a further area of interest which have been around for a long time but have continued to develop both in terms of spatial resolution, spectral range and resolution. Massey University has invested in a high end imaging system called an Aisa Fenix, produced by Finnish company Specim. Web Site http://www.specim.fi/index.php/products/airborne/aisafenix. The Fenix sensor has a spectral range similar to Figure 1. That differentiates it from other sensors in that both VIS/NIR and SWIR are available within one instrument. The catalyst for purchasing the sensor was work relating to a primary growth partnership (PGP) project jointly funded by Ministry for Primary Industries (MPI) and Ravensdown Fertiliser Cooperative, Pioneering to Precision: application of Fertiliser to Hill Country. One of the primary objectives was to identify the nutrient concentration within hill country pasture, using a technology that could achieve this accurately and quickly. This airborne sensor can be used to survey up to 1000 ha per hour. The sensor has been used using 448 spectral wavelengths imaged from the air, the data cube produced can then be interrogated to produce information on nutrient concentration within the sward. It is really like conducting a herbage test over every square meter of a farm or wider landscape. One of the main differences from using hyperspectral technology rather than conventional laboratory measurements is that one sample can be used for very many different tests, an N assessment can be completed and other parts of the data cube can be used for P, K, and S for example. The method is faster than chemical analysis, the information is reliable, the spatial variation can be understood and the whole farm can be sensed rather than attempt to extrapolate whole farm results out of a few sample points. The sensor effectively gives the user a wide ranging analysis tool with total coverage of every square meter of the landscape. As an example of the level of detail that can be achieved, Figure 4, illustrates the spatial distribution of pasture ME, this data has been validated and found to give a high level of agreement with laboratory measurements. This image was produced from the same survey as that which produced information on pasture nutrient concentration as part of the PGP project. The area of high ME is renewed pasture planted 1 year prior to the survey. The ME content of the un-improved pasture is generally very low as is typical of late autumn after a dry summer. (Image taken late April 2014). There are a number of processing steps required between downloading the survey data to producing the final result, but this can now be done with a high level of automation to make it a cost effective way of producing very detailed farm information, the current estimated cost is between $10 and $15 per ha.

Our ability to characterise our environment has improved enormously and the Fenix sensor represents a step change in what we can achieve. This gives us the opportunity to study our farmed environments to a far greater depth than ever before and rather than model what we think or hypothesise what is going on we can repeatedly collect data of every sq. meter of an environment. Our hill country environment is extremely variable and complex and it is extremely difficult to model what is going on with a degree of certainty that would provide farmers with improved knowledge on how to manage their properties. The same technology can be directed towards other forms of land use.

This situation represents the wider discussion of the technology transfer problems evident in New Zealand agriculture and around the world. Two diagrams help to illuminate the discussion. The first is an Agritech interpretation of the Gartner Hype cycle, (figure 5), and the second represents the idea of exponentialism, (figure 6). Figure 5 does not really cover all of Agritech but gives a representation of some technologies and their position in terms of moving from the technology trigger to being fully adopted. The amount of publicity and public notice something gets is not always in direct correlation with its usefulness. UAVs appear on Figure 5 but they are only one possible platform to mount sensors yet they receive an enormous amount of publicity compared to other methods of collecting remote sensed data. Their operational limitations are generally poorly understood by most people and costs of operation ill defined. However because they offer users control over the process they are perhaps seen as a low cost alternative compared to other forms of sensing.

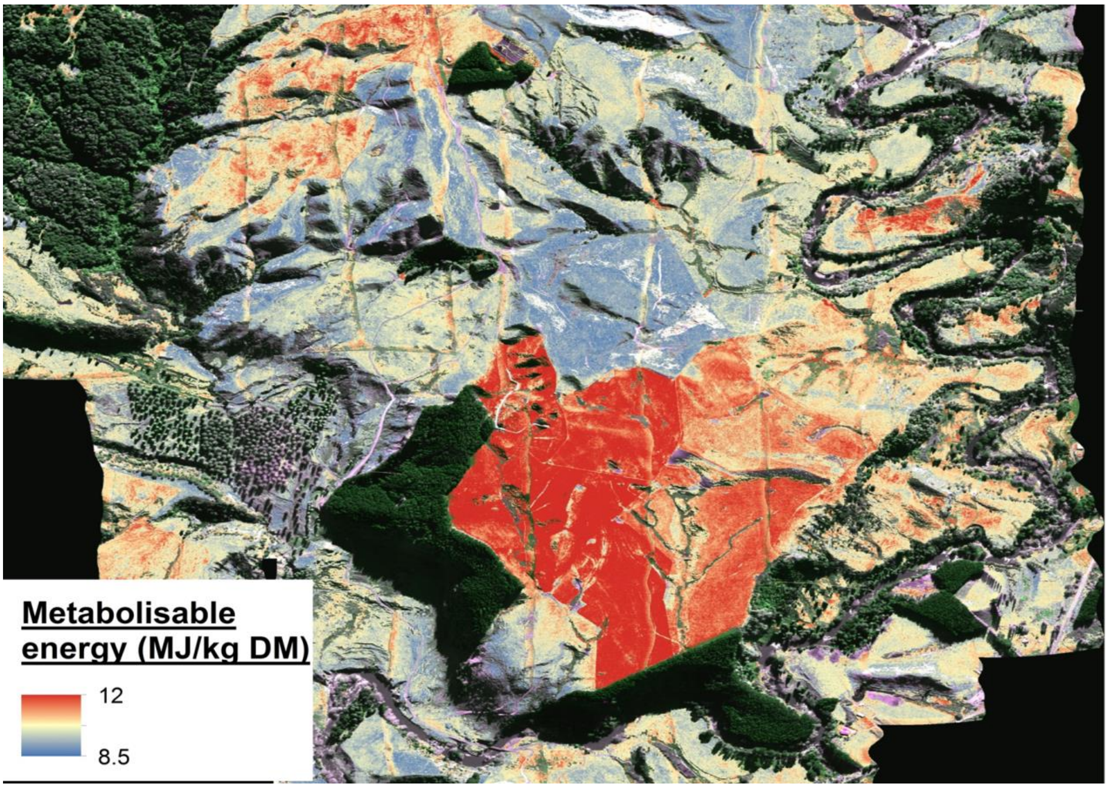

Figure 4. Farm map showing the Metabolisable Energy MJ/kg DM of pasture. April 2014. Lower North Island New Zealand.

Figure 6 comes from a presentation given by David Hunt of an Ireland based company Agrilarity to the 2015 Top Producers Seminar ProAg. David tried to demonstrate the ideal of exponentialism and the law of accelerating returns. He used the example of Kodak to illustrate the problem and describes two stages, deception and disruption. After the initial buzz around the technology trigger we often fall into the trough of disillusionment where we feel the technology may not be delivering on its initial potential, (as described in Figure 5). Many new technologies are disruptive, in that they will change the way we do things. Digital photography is a great example. Digital photography was first mooted in 1975 and the Kodak company, which had a very dominant position in the film photography market; for various reasons, thought that a number of limitations around picture file size and resolution requirements would limit the appeal of the technology. What they failed to realise was that the growth of computing or computational power was exponential (Moore's Law) compared to the linear growth and further incremental development of established film technology, at some point it had to become more attractive and then basically disrupt the old technology. Figure 6 attempts to illustrate this first; the deception stage where the new technology has not lived up to the initial hype and promise and the linear improvement in the old system appeared to offer the better progress. Once the point was reached where the rate of change was accelerating, the tipping point, or disruption occurred very rapidly. As the technology improved the obstacles to adoption were overcome, digital photography very quickly became the obvious choice. Part b of the figure illustrates the sales of film and digital cameras showing a very rapid change over. Since that time many of us have moved from using specific digital cameras to cameras mounted in our smart phones. Small digital cameras have now become commonplace in lots of everyday consumer products.

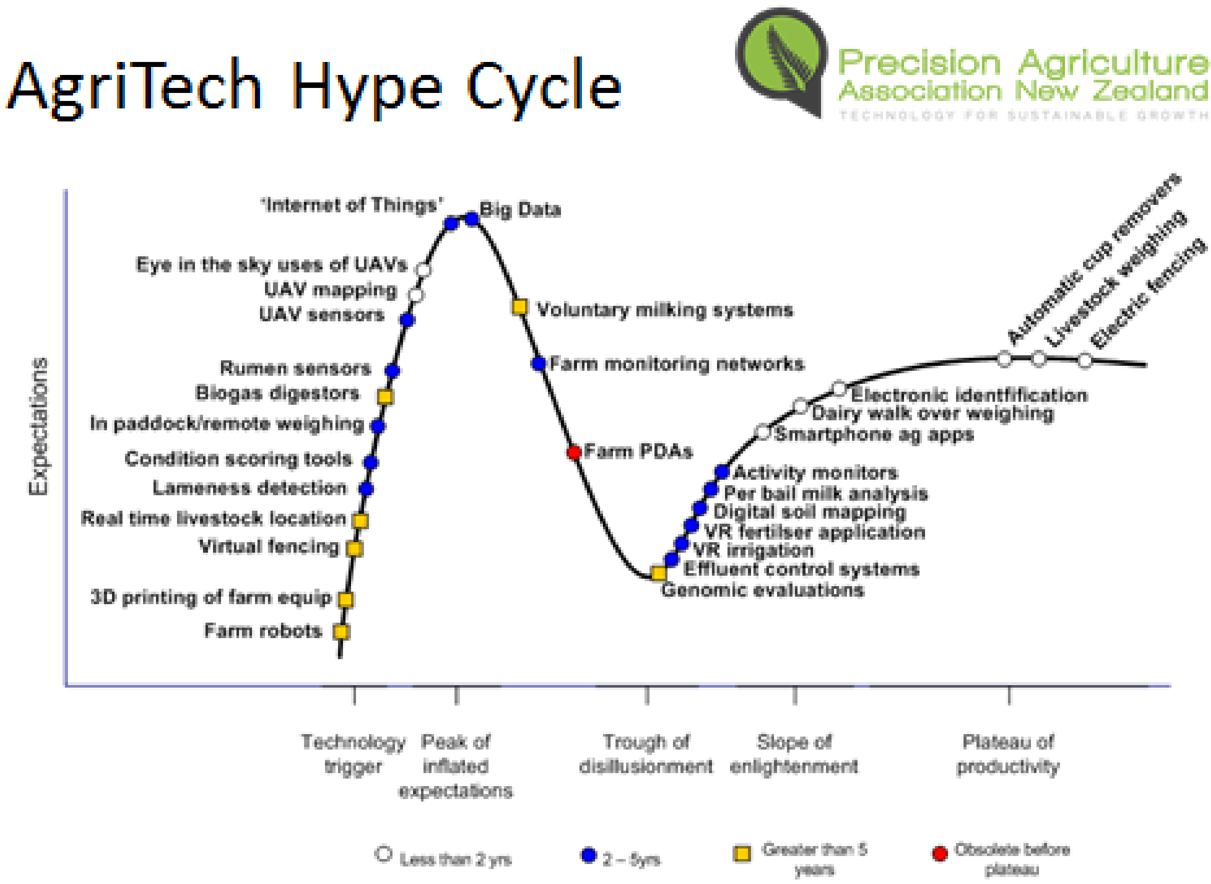

Figure 5. The Agritech Hype Cycle, as presented to the IPIM Conference August 2014, Brendan O'Connell, Precision Ag Association of New Zealand, (PAANZ).

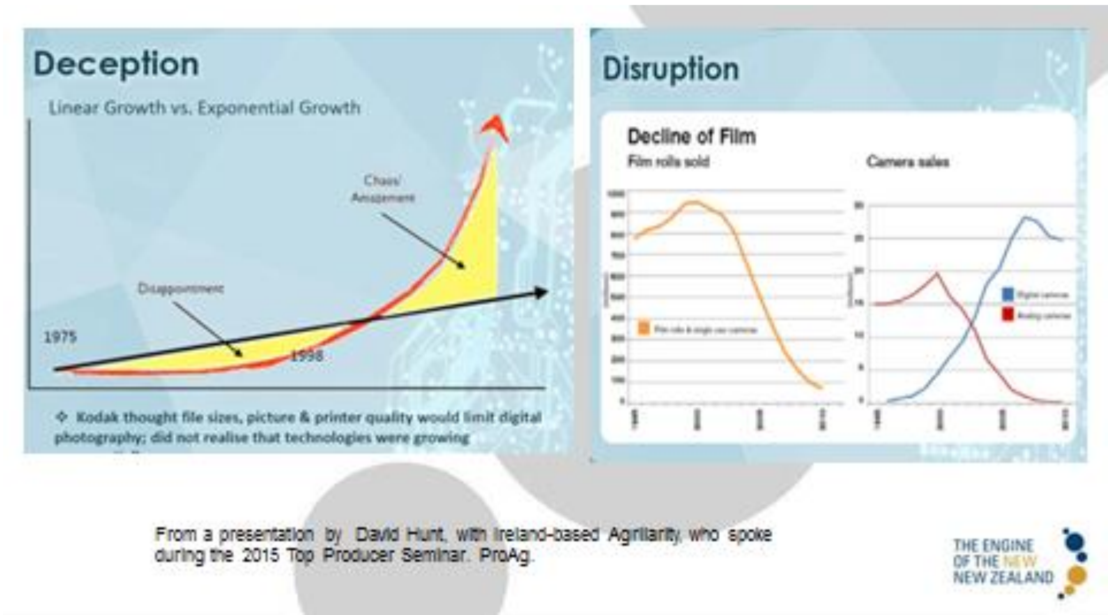

Figure 6. a), Illustrates the fact that the technology was causing disappointment, then as computational power increased it became clear the technology was viable, b), illustrate the sales of film versus digital cameras. http://www.agweb.com/assets/1/6/David_Hunt.pdf

Conclusions

We are now in a situation where we can accurately describe many characteristics of our environment in much greater spatial and spectral detail in an almost photorealistic way (figure 4). This should create many opportunities to improve our farm or land management . But, what it has effectively done for the moment is outstrip our ability to deal with this information in terms of how we interpret it and use it. In the hill country sector it has been really difficult to advance farm management due to a lack of information, this sensor will make a significant step change. The Fenix effectively completes a whole nutrient analysis for every square meter of a farm, with 12,000 readings per ha when flown at 2000ft above ground level. Each pixel in the image has 448 layers of information which can be used to represent the nutrient, energy and dry matter concentrations, as well as discriminate between varieties and cultivars, estimate yield and bio-chemical properties. This gets over many of the difficulties of measuring spatial variation and when combined with a GIS further enhances our ability to handle vast quantities of data in order to assist in decision making.

The use of UAVs is an exciting developing but it is likely that further flexibility in their operation will be required in order to make them more attractive to end users. Improved navigation and control will be required and reliability will have to be proved beyond any doubt before flight outside the line of sight will be allowed by the CAA. Because of payload limitations the range of sensors and or cameras will also be more limited. At the moment a simple eye in the sky seems a very legitimate use for this technology. Further systems which allow very accurate mapping have been used and proved to work well and provide useful utility. Further work is required to miniaturise sensors and more sophisticated camera and imaging equipment. Satellite systems are also becoming easier to access with increasing spatial and spectral resolution and also provide a legitimate alternative to the methods mentioned above. This makes the concept of interoperability important so that different sensing platform could be used within the same management information system.

The very visual nature of these technologies seems to provide a medium that is more readily understood by farmers and land managers, however the data has got to be reliable and meaningful in order for them to invest time, effort and money in interpreting the results and transforming the information into good management decisions. There are a number of stages that have to be negotiated, data acquisition, pre-processing and processing, interrogation and algorithm development for the parameters of interest. The use of hyperspectral imaging is an early example of big data being used within New Zealand agriculture, it will bring about many IT infrastructural issues in terms of service provision to farmers. It seems unlikely that we have quite reached the tipping point for this technology to take over from laboratory based herbage measurement but it certainly looks promising in terms of being able to over real assistance to farmers.

References

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